Proceedings of the Fourth and Fifth Dr. Scholl Conferences on the Nutrition of Captive Wild Animals

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Proceedings of the Fourth and Fifth Annual

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ON THE NUTRITION OF CAPTIVE WILD ANIMALS

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Fourth Annual Dr. Scholl Nutrition Conference
on the Nutrition of Captive Wild Animals

MILK REPLACERS: COMPOSITION AND PRODUCTION

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Introduction

The assignment given me today was to review the basis on which our milk replacers are formulated and to discuss the production and controls used in manufacturing these milk replacers. The history of Borden and milk dates back to the middle nineteenth century when our founder, Gail Borden, discovered how to condense and preserve milk. Condensed milk was used for infant feeding for many years. So it is not surprising that Borden developed a milk replacer for dogs about 40 years ago.

Formulation Philosophy

The dam's milk is the perfect food in the best delivery system available for each species. In the absence of the dam's milk, we believe the best approach to feeding is to provide a milk replacer that approximates the composition of the milk of the target species. Although some detail is available concerning micro-ingredients such as vitamins and minerals, in the domestic dog and cat, we concern ourselves primarily with protein, fat, and carbohydrate. These are of primary importance because they relate to the natural digestive systems of the target species and their ability to handle the quantity of these components presented to them through the milk replacer.

We evaluate the composition on a dry basis because we believe that the actual relationship of the 3 major components is the most critical guide. Water is certainly of extreme importance, and the amount used to reconstitute a powdered formula will affect the volume of nutrients that can be fed. However, from a practical standpoint the liquid, ready-to-feed forms present manufacturing problems with the higher solid levels. The use of powder allows more flexibility in making milk with higher solids. The liquid forms, where available, can be more convenient and, since they are sterile, find a place in germ free or gnotobiotic research.

Table 1 shows the composition of the milk of several species for which we have developed specific milk replacers, and these are compared to cow's milk. There are obvious differences among the species. It becomes apparent why cow's milk is not suitable for many species. Even using condensed milk does not change the composition on a dry % energy

provided by the three energy yielding components of the milk as shown in Table II.

Table III shows typical analyses for our four milk replacers, Esbilac, KMR, SPF-Lac, and Foal-Lac for dogs, cats, pigs, and horses respectively. Esbilac and KMR analyses are for the powder forms but are also available in liquid, ready-to-feed forms. SPF-Lac is only available in liquid and Foal-Lac is only available in powder form. Our Foal-Lac pellets have a different formulation for dry feeding.

Now we need to discuss the way these formulas are put together to achieve the desired composition.

<u>Production of Milk Replacers</u>

It is our opinion that even though the proportions aren't correct, the protein and sugar (lactose) from milk are the most desirable sources. Therefore we must, in part, use the components of cow's milk to add back to skimmed milk to achieve the desired composition. In Esbilac and KMR we add additional casein to build up the protein. In Foal-Lac we add additional whey to build up the lactose.

The fat component presents a problem. We must remember that these commercial formulas must be maintained at a cost that is compatible with the economics of saving the lives of these species. Consequently the use of butter becomes prohibitive especially when you must provide 40% fat in some cases. Our selection of a combination of soybean oil and coconut oil as the fat sources is based on the necessity of processing all but one of our milk replacers in food grade plants, economics, and quality. We do not use hydrogenated oil because we want to minimize the occurrence of trans forms of the fatty acid and still provide the essential fatty acids in adequate quantities. In the case of Foal-Lac, we do use an animal fat since it is not necessary to manufacture this product in a food plant.

There are some data on some vitamins and minerals in some species. Calcium and phosphorus levels are adjusted with appropriate compounds to achieve a desired ration and a total level that corresponds either to known values or extrapolated from the known values of other species. All the trace minerals and vitamins are added to provide levels that appear to be in excess. Extra vitamin E is used particularly because of the use of higher levels of unsaturated fat which increases the requirement of this vitamin. Vitamin A and D are particularly important and are always monitored.

The insoluble components such as casein are solubilized, mixed with the other components at the proper pH, homogenized and in the case of the powder, spray dried to achieve a uniform powder of the proper density. In the case of liquids, the batch is adjusted to the proper solids level, canned and sterilized. The liquids are very difficult because some additives must be added to maintain the components in soluble or suspended form while trying to minimize gelling with age.

Quality Control

The spray dried powders are analyzed for protein, fat, ash, and moisture as well as vitamin A and vitamin D before canning. In addition we check the peroxide number to make sure the fat has not deteriorated and analyze for total bacteria concentration, salmonella and coliforms. When this information plus other vitamin and mineral analyses have been completed, and passed, the powder is released for canning under inert gas to preserve the fat and vitamins, and to retard browning of the milk components. The final canned product is again checked for peroxide level and a second complete bacteriological check.

The liquid products are monitored in process to assure the proximate composition. After the product has been canned and retorted, a statistically representative number of cases is incubated at 78°F for ten days. A smaller number of cases is incubated at 100°F to make sure there are no thermophylic (heat loving) bacteria present. Even one bulged can, requires a can by can inspection of the sublot before the product is released. The high temperature incubated samples are destroyed while the 78°F incubated samples are sold. During this period of time we analyze the finished product for vitamin A, vitamin D, calcium, phosphorus and other selected vitamins and minerals. The selection varies from production to production so that over a period of time we get a complete picture of the composition.

Summary

It is well understood that milk is very complex. The way that milk components are put together in the mammary gland is complex and uniquely wonderful. There are certainly special compounds provided for the well being of the young that we are not considering. The very fact that the natural milk is raw and unprocessed is of importance. So when we are presented with an orphan we can only attempt to nourish it with a milk replacer until it can develop to the extent that it can use other foodstuffs. A tough assignment.

We have discussed the formulation philosophy, production, and quality control we use to try and accomplish this task. This has apparently met with success as judged by the fact that we still provide these products for owners of animals as well as many zoos around the world. I believe there is room for improvement and we are dedicated to this end.

TABLE I

COMPOSITION OF SELECTED MILKS - DRY MATTER BASIS (OFTEDAL)

NUTRIENT	DOG	CAT # A	CAT # B	PIG	HORSE	COW
Solids%	22.7	17.6	26.1	20.1	10.5	12.4
% of Solids						
Protein	33	40	41	23	18	26
Fat	41	28	41	41	12	30
Sugar	17	27	14	25	66	37
Ash	5	6	4	4	4	6

*Solids calculated from composition by Monson
A reported by Jenness & Sloan from Abderhalden
B reported by Oftedal from Folin et al.

TABLE II

COMPOSITION OF SELECTED MILKS - ENERGY BASIS (OFTEDAL)

NUTRIENT	DOG	CAT	PIG	HORSE	COW
Gross Energy (kcal/g)	1.46	1.74	1.24	0.51	0.71
Fat Energy %	59	57	61	23	48
Protein Energy %	31	35	22	22	26
Sugar (Lactose) Energy %	11	8	16	54	26

TABLE III

COMPOSITION OF MILK REPLACERS-TYPICAL ANALYSIS, SOLIDS BASIS

NUTRIENT	ESBILAC	KMR	SPF-LAC	FOAL-LAC
Water %	2.1	2.6	85.0	5.1
Protein % Solids	34.4	43.0	30.7	20.0
Fat % Solids	43.0	28.5	34.7	14.4
Lactose % * Solids	15.1	18.5	29.7	54.0
Ash % Solids	5.4	6.4	5.0	6.5
Gross Energy (Kcal/g)**	5.85	5.12	5.5	4.3

*Lactose by difference

**Gross Energy calculated on the basis of 4, 9, 4 calories per gram of protein, fat, and lactose respectively.

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COLOSTRUM, ITS FUNCTION AND USES

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Colostrum is the first milk secreted at the termination of pregnancy. It differs from milk secreted later in lactation since it contains more lactalbumin and lactoprotein. (12) Colostrum serves several functions. It provides the first nourishment a newborn animal receives, and it is ideally suited to do this. In addition, it contains high numbers of circulation. The antibodies are often life-saving for a neonatal animal and can make the critical difference between a healthy animal and a dead one.

When newborn animals must be hand raised, they often have not received colostrum. This is more critical in some species than others. Some neonates receive passive maternal immunity from the placenta, but others rely on the colostrum to provide this protection.(5) Primates, guinea pigs, and rabbits receive their passive immunity utero via the placenta. Those domestic animals that receive their passive maternal immunity through both the placenta and colostrum are dogs, cats, rats, and mice.(8) Finally, those animals receiving their passive maternal immunity solely through he colostrum are cattle, sheep, goats, pigs, and horses.(8) Antibody transfer from the dam to the offspring is related to the type of placentation in each species. Essentially, the fewer cellular layers between the dam and fetal blood circulations, the more in utero antibody transfer takes place.(8) Exotic animals appear to follow the same taxonomic lines as their domestic counterparts in relation to transfer of maternal immunity. For those neonates that receive their passive maternal immunity via the colostrum, whether they have nursed can be of vital importance to the survival of the animal.(5)

The neonatal intestine can absorb antibodies for approximately 24 to 36 hours post partum.(5) In domestic animals, the concentration of antibodies in the colostrum and in the serum of three to seven day old neonates that have nursed nearly equals or exceeds that of the dam's serum.(7,8) Maternal antibodies are gradually broken down by the neonate and replaced by antibodies made from the neonate's own lymphoid system. This usually takes several months.(7) For those neonates that receive their passive maternal immunity from the colostrum, whether they have nursed can greatly affect their ability to withstand the disease challenges which face all new born animals. The maternal immunity passed in the colostrum or by the placenta provides the young animal with antibodies to most of the pathogens the dam has contacted. The neonate then has defenses against these organisms prior to its own exposure. If the newborn does not receive this protection, it will be immunodeficient for several weeks to months until its own immune system begins to provide this protection.(5) This can be particularly critical for exotic neonatal animals requiring hand rearing since the neonate is exposed to many pathogens at birth and rearing techniques and formula compositions are often only educated guesses.

There are four basic types of immunity: humoral or antibody production; cellular; phagocytosis; and non-specific mediators i.e., interferon and complement.(6) These all function as part of the lymphoid system. Antibody or immunoglobulin production occurs in the lymphoid follicles and in the medullary cords of the lymph nodes, spleen, and diffuse lymphoid aggregates.(6) Fetuses are usually incapable of producing antibodies much before the third trimester, and the ability to make a specific antibody develops sequentially over several weeks to several months. Fetuses can respond to some antigens prepartum, other antigens at birth, and still others several weeks post partum. The neonate should be able to respond to all antigens when it is at least several weeks old.(6,8)

The initial antigen stimulation causes active proliferation and recruitment of small lymphocytes or B cells from the blood. The B lymphocytes have specific immunoglobulin receptors that recognize antigenic determinants on foreign material.(6) The B cells come in contact with the antigen. This stimulates cellular division into either lymphoblasts which enter the circulation and produce antibodies, or plasma cells which remain in the lymph nodes and produce antibodies. There is a large number of cells produced from a single cell that was stimulated by an antigen.(6) There are five classes of antibodies or immunoglobulins: IgG; IgA; IgM; IgD; and IgE. IgG is the major circulating antibody which helps prevent illness when the animal is exposed to a pathogen. IgE is localized in tissue and is also significant in disease reduction. IgG is the basic structure of the others. Immunoglobulins or antibodies are proteins which bind to the antigen when they come in contact with it. The immunoglobulin in turn binds itself to either complement or cell surfaces. The destruction of the antigen then proceeds by either cell mediated cytotoxicity, phagocytosis, or complement cytolysis.(6,7)

Passive transfer of colostral immunoglobulins appears to have a major influence on neonatal mortality rates in domestic artiodactyls and perissodactyls. In lambs, 14% of clinically normal animals had some failure of antibody transfer. In contrast, failure of passive transfer was found in 46% of lambs dying of natural causes between one day and five weeks of age. (10) In newborn calves, deaths due to infectious causes were directly related to low concentrations of serum immunoglobulins. In calves less than three weeks of age dying form infectious diseases, serum IgG concentrations were significantly lower than those of clinically normal calves. Fifty percent of the dead calves have serum IgG concentrations more than two standard deviations below the normal mean. Low IgG concentrations were attributed to failures in passive transfer of colostral antibodies. This is one of the most important factors influencing neonatal calf mortality rates.(3)

Failure of colostral antibody transfer had been linked to high prevalence of infections and deaths in neonatal foals.(4,90) Similar problems have also been documented in puppies and kittens even though they receive some maternal immunity through the placenta.(11) These kinds of problems are only beginning to be documented in exotic neonatal animals. It seems reasonable that lack of transfer of colostral immunoglobulins can play a major role in neonatal deaths especially in exotic animals receiving passive maternal antibodies through the colostrum.(5) The major causes of neonatal deaths at the San Diego Zoo between 1965 and 1977 were trauma, malnutrition, and infections. The neonatal mortality rate in artiodactyla was 13.1%; in carnivora it was 24.6%; and in perissodactyla it was 11.8%. The overall neonatal mortality rate was 14.7% with 562 neonatal deaths out of 3835 pregnancies at risk.(5)

In one study, severe, sometimes fatal diarrhea has been a major problem in hand raised neonatal exotic ruminants. A number of different organisms have been implicated including: Salmonella sp; Cryptosporidium sp; Eimeria sp; enterotoxigenic Escherichia coli; Campylobacter fetus jejuni; bovine viral diarrhea virus; and rotavirus. More than 14 different animal species were involved. Overcrowding and deprivation of colostrum were determined to be the major contributing management factors.(2)

There are several different tests which may be done on neonatal serum to determine if a neonatal animal has received colostrum. The most accurate is serum electrophoresis which actually quantifies the amounts of different immunoglobulins in the circulation. Refractometry for total serum proteins can be a crude measure of the presence of maternal antibodies. Neonates with very low total serum proteins with normal packed cell volumes may be immunodeficient. The zinc sulfate turbidity test and the sodium sulfite precipitation test are also used.(9)

There are several alternatives available for providing increased immunologic protection when a neonatal exotic animal must be hand raised. Although it is frequently not feasible, a milk sample may be collected from the dam which is then fed to the neonate or frozen for future use. Anytime a newly lactating female is handled, colostrum should be collected and frozen. If maternal colostrum is unavailable, colostrum from a closely related species may be given. Cow and goat colostrum may be obtained from local dairies, and frequently local horse breeders will cooperate in supplying equine colostrum.(5) In addition, serum or plasma may be collected from adult animals. This may be administered to the neonate orally or by injection. IgG may also be fractionated from the plasma of adult animals, and this may be stored frozen for future use.(5)

Extreme care should be taken when colostrum is collected from either domestic or exotic animals. If the milk is not collected and stored in a clean, sanitary manner, it can become contaminated. Colostrum is an ideal culture medium. Feeding neonatal animals colostrum which has been inadvertently inoculated with pathogenic organisms has produced serious illness and death especially in immunodeficient neonates. The transmission of disease from the female through the milk can cause serious problems. If the female has mastitis, she may shed large numbers of organisms in the milk. Some systemic diseases may also be transmitted via colostrum or milk. Domestic goat colostrum was fed to several neonatal ibex, Capra ibex nubiana. A disease resembling caprine arthritis-encephalitis, a retrovirus infection, was introduced into these animals, and it resulted in numerous deaths. The domestic goat colostrum is the most likely source of the viral infection.(1)

Several things can be done to reduce the potential risks involved in feeding colostrum to immunodeficient neonates without compromising the positive effects. The colostrum should be collected in a clean, sanitary manner. It should be sealed in 90 ml to 120 ml units and pasteurized in a 56 degree centigrade water bath for 30 minutes. This is comparable to slow time and temperature pasteurization at 140 degrees Fahrenheit. It kills most pathogenic bacterial and viruses while maintaining the integrity of the immunoglobulins in the colostrum.(2) The colostrum is then stored frozen for no more than six months. Whenever possible, colostrum alone should be fed for the first 24 hours of a neonate's life. Then colostrum is used as 10% of the daily ration for the first three weeks of life in those animals judged to be at risk.(2) The local effect of the IgE helps protect the gut mucosa even thought the neonate does not absorb the immunoglobulins after the first several days. The colostrum should always be pasteurized prior to use regardless of the source.

Mortality rates in domestic animals receiving colostral immunity are much reduced. Preliminary information indicates the same may be true for exotic neonatal animals. Proper handling and storage of colostrum can reduce the risks of colostrum use while protecting the positive factors. Since many exotic animals are rare or endangered animals, any method which may increase survival rates is important. The use of domestic or exotic animal colostrum may well be a major factor in reducing neonatal mortality in hand raised exotic animals.

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INFANT DIET/CARE NOTEBOOK

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INTRODUCTION

Let me start today's presentation with a few quotes from correspondence I have in my file between myself and several consecutive American Association of Zoological Parks and Aquariums presidents.

May 26, 1982 - To: Peter Karsten, Calgary Zoo
Dear Peter:
"It appears that interest has dwindled over the last couple years...I feel we should delete the Infant Diet/Care Advisors from the AAZPA committee structure."

August 6, 1982 - To: Steve H. Taylor, Sacramento Zoo
Dear Steve:
"Please accept this letter as notification that I have re-assigned you as Infant Diet/Care advisor."

April 28, 1983 - To: Charles Bieler, San Diego Zoo
Dear Chuck:
"For my own part, I think a new chair is needed to bring new ideas and goals to this project. Five years is enough."

August 25, 1983 - To: Steve H. Taylor, Sacramento Zoo
Dear Steve:
"This will serve to advise you that President-Elect Bieler has reappointed you to serve as one of the Infant Diet/Care Advisors."

April 27, 1984 - To: Elvie Turner, Fort Worth Zoo
Dear Elvie:
"As you are most likely aware, I have been an Infant Diet/Care Advisor since 1977... I have enjoyed this project very much, but feel someone else should continue this work."

August 6, 1984 - To: Steve H. Taylor, Sacramento Zoo
Dear Steve:
"Please accept this letter as notification that I have appointed you as Infant Diet/Care Advisor..."

Now please do not get the wrong idea. The Infant Diet/Care Notebook is a viable tool for our industry and I am proud that I was given an opportunity to be involved with its formation. But (as a word of warning), I am not a nutritionist or a veterinarian, but a zoo director. And by and large, we all know, that zoo directors are those members of our profession who have chosen not to specialize and therefore have absolutely no area of expertise.

Background

Briefly let me relate to you the history behind this publication. Prior to 1977 the Infant Diet/Care Committee collected articles, letters, weight gain charts and anything submitted to them regarding hand-raising zoo animals. This was all kept in a file and could be referred to by the committee if necessary to answer phone inquiries. In 1977 a new committee was formed and it was decided that a notebook containing many different fact sheets on hand-raising would be the most advantageous approach to providing a basic hand-raising guide. Our main objective was to obtain as many infant diets as possible for any and all species kept in zoos. We have never attempted to analyze the different diets or techniques we have received, but simply maintain an index of hand-raising diets and care techniques. The AAZPA Infant Diet/Care Notebook was first made available to institutional members free of charge in the fall of 1978. After the initial distribution, the notebook was sold to cover the expense of its printing.

Supplement #2 was published in 1980 and added 143 diets to the notebook, bringing the total to over 250 infant diets. Most of the mammals commonly found in zoos were represented by at least one diet, but only four bird diets were submitted. Committee members continually tried to fill in the gaps of missing species and arrive at a more complete notebook. If we would read of a new and unusual birth and subsequent hand-rearing, we would attempt to get that zoo to report their findings. We would also include any articles concerning hand-raising in our bibliography. I, personally, have found the bibliography section as helpful as the fact sheets themselves. Unfortunately the bibliography is now dated, fragmented, and in need of updating.

The notebook is divided into several sections and was designed to contain more than just the completed fact sheets. The first section contains instructions and blank fact sheets. From our experience this is the section last read! We have had to send back a large portion of the completed fact sheets because they did not meet our guidelines. These guidelines were developed to ensure consistency throughout the notebook, and thus make it easier to read and understand.

The second section of the notebook was designed to be a section of short and original articles or comments, especially for those who could not fit their information on a fact sheet. This section has not been well developed as of this date.

Thirdly, we have the fact sheets themselves. At first, the committee was collecting only mammal diets, but after the initial notebook's publication birds were added.

Today we have a total of 344 mammal diets and 35 bird diets, although 117 of these are to be included in supplement #2 and have not yet been published. These 379 diets were submitted to me by 122 different individuals from 59 different zoos and related organizations.

The last part of our notebook is the bibliography section. We had hoped that this section would contain references to all articles concerning hand-raising zoo animals.

The notebook was designed only as an index and we never proposed it to be a complete reference answering all questions on hand-raising. It does give us names and whereabouts of colleagues who have either successfully or unsuccessfully hand-raised animals we may be attempting to raise ourselves.

DISCUSSION

The topic of hand-raising is enigmatic at best and is a subject which has not properly been evaluated. Few, if any, studies exist that follow a hand-raised animal through adulthood. It is most likely that all of us in the zoo business have had at least one bad and one good hand-raising experience.

As we have heard this morning there are many nutritional considerations when attempting to hand-raise a young exotic animal. Also, (and just as important) there are many behavioral problems associated with hand-raised animals. The following considerations should probably be examined prior to attempting to hand-raise a rejected neonate captive animal:

1. Is there any available information on hand-raising successes with this species?

2. Do you have facilities, time, and staff for this project? Can you provide a stimulating environment?

3. Do you have conspecifics which may be raised together or do you have other plans to prevent imprinting?

4. Is the animal rejected a biological weakling which in nature would not have lived?

5. And lastly, does the necessity of maintaining adequate gene pools of rare and endangered species negate all of the above?

This last statement reflects some of our work as Infant Diet/Care Advisors. We have managed to obtain at least one artificial diet for all those species designated as Species Survival Plan animals. We feel this is very important as certain single specimens may be important to a survival plan with precious few founders.

If we believe (and I think many of us do) that zoos may be a last resort and may significantly contribute in saving certain endangered animals from extinction, then hand-raising may be a "last, last" resort in saving those species. For extremely small populations, such as the California Condor, the Gorilla, the Indian Rhino, the Speke's Gazelle, the Whooping Crane, and others, hand raising techniques must at least be available. It is my hope that the Infant Diet/Care Notebook provide baseline data for these types of projects.

The current notebook is in an important state of transition. We have accomplished our first goal of establishing an indexing system to give zoo workers some initial information on a hand-raising situation. From reading the notebook zoo workers can get initial ideas for formulas, amounts, temperatures, housing, etc. More importantly they can get the names of people that have had similar experiences.

The notebook will never be finished and there are many areas which need to be improved.

1. The bibliography needs to be kept current and complete.

2. The diet sheets have their real value in initial treatment of a particular animal, i.e., as in the middle of the night when a night keeper discovers a "hairy-nosed skitoo" rejected by its mother. Therefore the diet sheets should be made to better reflect this need.

3. There is a need for analysis and recommendation. Our committee or the publisher (AAZPA) has never attempted to make recommendations on formulas or treatments, but only provide ideas and resources. People have always wanted more from the notebook than our fact sheets permit, but we have been firm in our belief that an indexing system was our primary goal.

4. Several common mammal species and many bird species are still unrepresented in the notebook. Notably we have not a single diet for howler or woolly monkeys, langurs, anteaters, arctic foxes, spectacled bears, monotremes, skunks, or elephants

to name a few. As stated previously we only have 35 individual bird diets. Certainly the notebook has voids.

5. Of immediate concern, the present three-inch notebook is full and we must decide if we wish to continue to a volume two.

6. Finally, there has always been a certain amount of criticism concerning the fact sheets themselves and in particular that they do not contain enough information. This needs to be examined closely and see if changes can be made within the reasonable guidelines of the goals of the notebook.

SUMMARY

The Infant Diet/Care Notebook published by the American Association of Zoological Parks and Aquariums provides a bibliography and index systems on hand-raising of exotic animal species. The real need for hand-raising information may now be in saving endangered species from extinction. The notebooks will never be complete, and we welcome input from everyone in the form of additional diets and comments and suggestions on format changes.

Paper received May, 1985

WEIGHT GAIN AND INTAKE REQUIREMENTS IN NURSERY REARED MACAQUES

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INTRODUCTION

Rearing nonhuman primates in a nursery setting, rather than in the neonate's natal group, is certainly not a goal to be pursued for effective and efficient operations in a zoological setting. High cost, difficulties in providing adequate socialization opportunities to ensure species-typical behavioral profiles, and difficulties in reintroduction into established groups all point to the desirability of allowing infants to remain with their mothers rather than rearing them in the more restricted confines of a nursery. Nevertheless, nursery facilities (whether in a research laboratory or zoo) are a "necessary evil" from which much can be learned to ensure survival of neonates that, for whatever reason, must be reared by humans. Having sufficient numbers of animals reared under various protocols to make meaningful comparisons of their impact on development can provide valuable information for facilities having to rear only occasional animals in a nursery setting.

There is no experimental evidence available to dictate the "best" protocol to follow concerning nursery rearing of nonhuman primates. High survival of "normal" animals has been shown by various laboratories using a variety of rearing techniques and diets (Ruppenthal, 1979). However, survival of "high risk" animals has been shown to be influenced dramatically by various feeding techniques, schedules, and interventions. While our laboratory (IPRL) has put considerable effort into saving as many high risk subjects as possible for research and conservation interests, much of the information below remains untested experimentally and is offered as information only.

PERINATAL CARE

Temperature Requirements

Acute hypothermia has been shown to be a normal phenomenon at birth and for the first several hours after birth in macaques and great apes and is an inappropriate measure in determining whether to remove perinates from their mothers (Ruppenthal, Goodlin, and Sackett, 1983). However, chronic hypothermia must be closely guarded against. Neonates in our facility spend at least the first four days of life in an isolette equipped with a humidifier to avoid drying of mucous membranes. Initial temperature is maintained at 93-94° F. Temperature is gradually reduced in 1-2° F decrements over the four day period until reaching nursery temperature of 84° F. If the animal shows signs of hypothermia 4-8 hours after temperature reduction (-97°), the isolette is increased to the previous day's level and reduced again the following day. This protocol is maintained until the neonate is able to maintain temperature (98.5° F or greater) with heating pad support when removed from the isolette. A word of warning: never turn heating pads above the lowest setting to combat hypothermia. Use of a heating pad when animals are inactive or immobile (usually seen associated with hypothermia) can lead to shock from heating the ventrum with concomitant shunting of blood to the ventral surface. Urine scalding or burning can also result if high heat is used. If an animal is lethargic or comatose, use of an isolette is dictated.

Our main rearing room after animals emerge from the nursery is maintained at 78-80° F. Lower temperatures led to frequent bouts with upper respiratory infections in *M. nemestrina* although *M. mulatta* and *M. fascicularis* seemed unaffected. Raising the temperature alleviated the problem in the pigtailed monkeys.

Feeding Techniques

Infants are normally fed from a small 2-oz. bottle (Borden Small Animal Nurser) commonly supplied in pet supply houses from birth until training to self-feed. A 22 gauge syringe needle-sized hole in the nipple is used for normal birthweight animals and a 24-27 gauge hole is used for premature and/or low-birth-weight infants.

Neonates less than 150 days gestation (mean gestation for *M. nemestrina* is approximately 170 days; SD=7) are at extreme risk for aspiration pneumonia due to uncoordinated sucking and swallowing. A 3.5-5.0 French infant-feeding tube inserted nasally or orally is used for these infants. The residual fluid in the stomach is withdrawn and measured with a syringe and replaced. Initial feeding of 3-5 ml. of 10% dextrose solution, increased by 1-2 ml. increments as tolerated (indicated by residual fluid) are fed every 2 hours. After 1-2 days, dextrose-formula (up to 50:50 solution) is offered. Bottle feeding is initiated by offering a bottle of 10% dextrose (3-5 ml.) at 5-10 days. If no problems are observed, formula concentration and amount is gradually increased.

Most infants can be trained to self-feed by 7-14 days of age. An inclined ramp or "surrogate" leading to the food source assists in training due to the fact that the infant's ventrum is securely positioned and the body is supported. The feeding reservoir used in our facility is shown in Figure 1. It has several advantages that an inverted bottle does not have. The large surface area reduces the change in intensity of sucking that must be employed to draw up a feeding tube. When the animal stops sucking, remaining formula flows back into the reservoir, rather than dripping until pressure is equalized in the container. This allows for accurate measurement of intake and assists in keeping the side of the cage free of dripping formula.

Formula Types and Concentrations

There are several commercial formulas for human neonates that are acceptable for use with nonhuman primates. We presently use SMA with iron (Wyeth Labs) but constituted to 18.29 Kcal/oz (35 oz. water per measure rather than 32 oz.) rather than 20 Kcal as called for on the product. This dilution was chosen following experience at the Wisconsin Primate Research Laboratory using Similac (Ross Laboratories) for rhesus monkeys. It was their impression that full-strength formula created constipation in their animals that was relieved with the slightly less concentrated formula. A series of clinical trials in our laboratory indicated that the SMA formula is more palatable to pigtailed monkeys and better assimilated as indicated by stool firmness. This information remains untested experimentally. The 10% dextrose formula provides 11.54 Kcal/oz. and the 50:50 dextrose/SMA formula provides 14.92 Kcal/oz.

Socialization

There are several well known experimental studies that have documented the critical need for peer-peer socialization early in life to promote normal species-typical behavior in most nonhuman primate species. However, animals develop more species-typical social behavior if socialization time is limited on a daily basis, rather than if neonates are housed together 24 hours per day. This rearing condition has been termed the "together-together" condition (Harlow, 1959). When reared under this condition, mutual clinging overrides development of normal social behaviors such as play. This would indicate that nursery reared animals should spend considerable time in a single care situation and be placed together for "play" sessions rather than being housed in pairs or groups.

Effects of Feeding Schedules on Intake:
Rhesus vs. Pigtailed Monkeys

Various feeding schedules are followed by different laboratories and are dictated, at least in part, by available staff, experimental considerations, and research emphasis. The IRPL maintains a 24-hour nursery facility while the University of Wisconsin Primate Laboratory does not. The IPRL rears M. nemestrina primarily while the species of choice at Wisconsin is M. mulatta. Comparisons of birthweights for the two species is shown in Figure 2.

As can be seen, there is virtually no difference in the cumulative birthweight distribution between the species in males, while rhesus females are somewhat heavier than pigtailed females. Animals born below the 10th percentile are at extreme risk if left with their mothers. At the IPRL infants born in the lowest 10% of the population are routinely removed from their mothers and nursery reared. While in excess of 90% of these infants die if left with their mothers, approximately 85% survive when nursery reared (Ruppenthal, 1979).

Figure 3 depicts average weight gain for the first 30 days of life for male pigtailed and rhesus neonates and includes average Kcal intakes. Figure 4 shows the same information for females of the two species. As can be seen, pigtailed neonates consume far fewer calories than do rhesus during the first several days of life. This is due to the fact that feedings in our facility are restricted while the rhesus neonates are fed ad libitum at each bottle feeding.

Pigtailed infants reared under this regimen do not regain birth weight until approximately one week while rhesus infants; calorie consumption increases almost linearly, due to the fact the staff is available to feed 24 hours per day, the rhesus intakes decline at day 7, and especially at day 13, when the nighttime feedings are eliminated. Even though the pigtailed infants are fed significantly less during the first two weeks, males catch up to rhesus males in weight by 14 days of age and females catch up by 30 days of age. Restricting intakes during this time period reduces the incidence of diarrhea for all weight classes (Zimmerman, 1969) and significantly reduces mortality and morbidity in infants born in the lowest 10% of the birthweight distribution due to fewer problems from vomiting and aspiration pneumonia.

If infants are fed on an interrupted schedule (many facilities do not feed from 8-10 pm until 8 am) infants often gorge themselves during the first feeding in the morning. When faced with this schedule it is strongly recommended that the initial feeding be interrupted frequently by formula removal to allow the infant to reacclimate without overeating. Gradual feeding (by allowing only small amounts to be consumed over the first several minutes) greatly reduces the incidence of vomiting and gastrointestinal problems.

Early feeding of greater amounts of calories evidently has no lasting impact on weight gain later in life. Figures 5 and 6 show weight gains over the first four months of life (until weaning) for male and female rhesus vs. pigtailed monkeys. If anything, pigtailed males achieve heavier weights than do rhesus males. Furthermore, animals born lighter in birthweight do not show "catchup" during this time period.

Weight Gain and Intake During the First Month for M. Nemestrina

Prior to 1978, animals in our facility were fed ad libitum formula from the first day of self feeding until weaning at approximately 3.5-4 months of age. Formula dispensers were measured, sanitized, and placed back on the animal's cages every eight hours. At that time we ran a series of bacterial cultures on the formula from hour-one to hour-eight in one hour increments. Prior to four hours bacterial growth was negligible but after four hours bacterial growth increased dramatically. After a series of clinical trials with a four-hour-on, four-hour-off feeding regimen indicated no differences in weight gain between the two schedules it was decided to follow the latter schedule after the animals reached three weeks of age. Prior to three weeks of age animals remain on the ad lib schedule but formula is changed every four hours. The three week time period was chosen to insure that virtually all animals would be self feeding.

Figure 7 shows average weight gain and calorie intake for male (N = 227-277) and female (N = 170-206) pigtailed monkeys for the first month of life combining both new and old feeding protocols. Both sexes lose weight for the first few days and require as much as 6-10 days to regain birthweight. Low-birthweight infants regain birthweight more rapidly than do higher birthweight animals, probably because they are less active and remain in isolettes (warmer environment) for a longer time. Highly significant correlations are shown for each two day block for both sexes for weight vs. calorie intake (Female = .435-.705; Male = .427-.682: all p's < .001). Males gain weight somewhat faster during this time period than do females (Male average = 5.1 g/day; Female average = 4.0 g/day). Evidently, males utilize calories slightly more efficiently than do females (Male weight gain = 53.6 g/1,000C; Female weight gain = 49.4 g/1,000C).

Considerable difference was observed between the two feeding regimens in their effects on weight gain per calorie consumed. Table 1 shows weight gain per 1,000 Kcal for both males and females for four birthweight classifications. As can be seen, males gained more weight per calorie than did females (with the exception of ad lib lowest 10%) and smaller animals gained more weight per calorie consumed than did larger animals. Overall, the four-hour-on, four-hour-off feeding regimen was more beneficial as far as calorie utilization. This difference was probably due to the fact that fewer diarrhea problems were observed with this feeding schedule. It appears that having food ad libitum simply promotes overeating with resultant gastrointestinal problems. It is also probable that the dramatic bacterial growth observed with eight-hour feeder changes contributes to the diarrhea and should be avoided.

Weight Gain and Intake from Birth Through Weaning

Figures 8 and 9 demonstrate weight gain and caloric intake for males and females for the first 14 weeks of life by rearing protocol. It should be pointed out that, although the animals had access to solid food (commercial monkey biscuits) from 2-3 weeks of age, they do not begin to consume it until weeks 11-12 for most animals. The chow is simply placed in their cages to acclimate them to its presence. Prior experience demonstrated that delaying introduction to solids until weaning caused considerable fear reactions and make it far more difficult for the animals to accept it. The only other food available to the animals prior to weaning was apple bits (used in learning assessments) and 1/4 piece of orange or apple offered from three weeks of age every other day. All animals readily ate this addition and, of course, gained some caloric value from it. Thus, caloric values represented in the figures are quite close, but not exact. After 11-12 weeks of age, the consumption of solid food reduces the animals' caloric needs from formula so a gradual "flattening" of the intake curve is observed. The reduction in caloric values observed during weeks 13-14 is due to weaning protocols. It has been our experience that animals accept weaning more readily if a gradual procedure is followed rather than simply changing abruptly to water at any given age. Our weaning procedure begins at 91 days of age and proceeds as follows:

Days 91-98	60% formula available 4 on - 4 off.
98-112	40% formula available 4 on - 4 off.
112-114	40% apple juice available ad lib. Intake recorded every 8 hours.
114-119	20% apple juice available ad lib. Intake recorded every 8 hours.
119-126	100% water ad lib. Intake recorded every 8 hours.

Recording of intake throughout weaning insures being able to follow the individual's progress through the procedure. If an animal balks at any step, it is simply regressed to the previous step and the weaning procedure is prolonged.

As can be seen in Figures 8 and 9, intake of formula is dramatically reduced beginning with the onset of the 4 on - 4 off schedule and stays significantly lower throughout onset of weaning.

Paper received May, 1985

TABLE I

WEIGHT GAIN PER 1,000 CALORIES FOR 0-30 DAYS OF AGE

	MALES		FEMALES	
Birthweight Centile	ad lib.	4on-4off	ad lib.	4on-4off
1-10	54.8	72.7	58.4	66.3
11-50	49.7	58.8	47.8	50.8
51-90	44.2	56.3	35.5	45.9
91-100	36.9	55.7	**	41.3

** Insufficient N

TABLE II

WEIGHT GAIN PER 1,000 CALORIES - BIRTH THROUGH 10 WEEKS

	MALES		FEMALES	
Birthweight Centile	ad lib.	4on-4off	ad lib.	4on-4off
1-10	46.8	52.6	39.9	47.2
11-50	37.2	45.5	37.0	40.3
51-90	36.6	43.8	28.8	39.8
91-100	29.9	42.4	**	41.3

** Insufficient N

FIGURE 1

Infant Primate Research Laboratory - Feeding Apparatus & Mounting Bracket

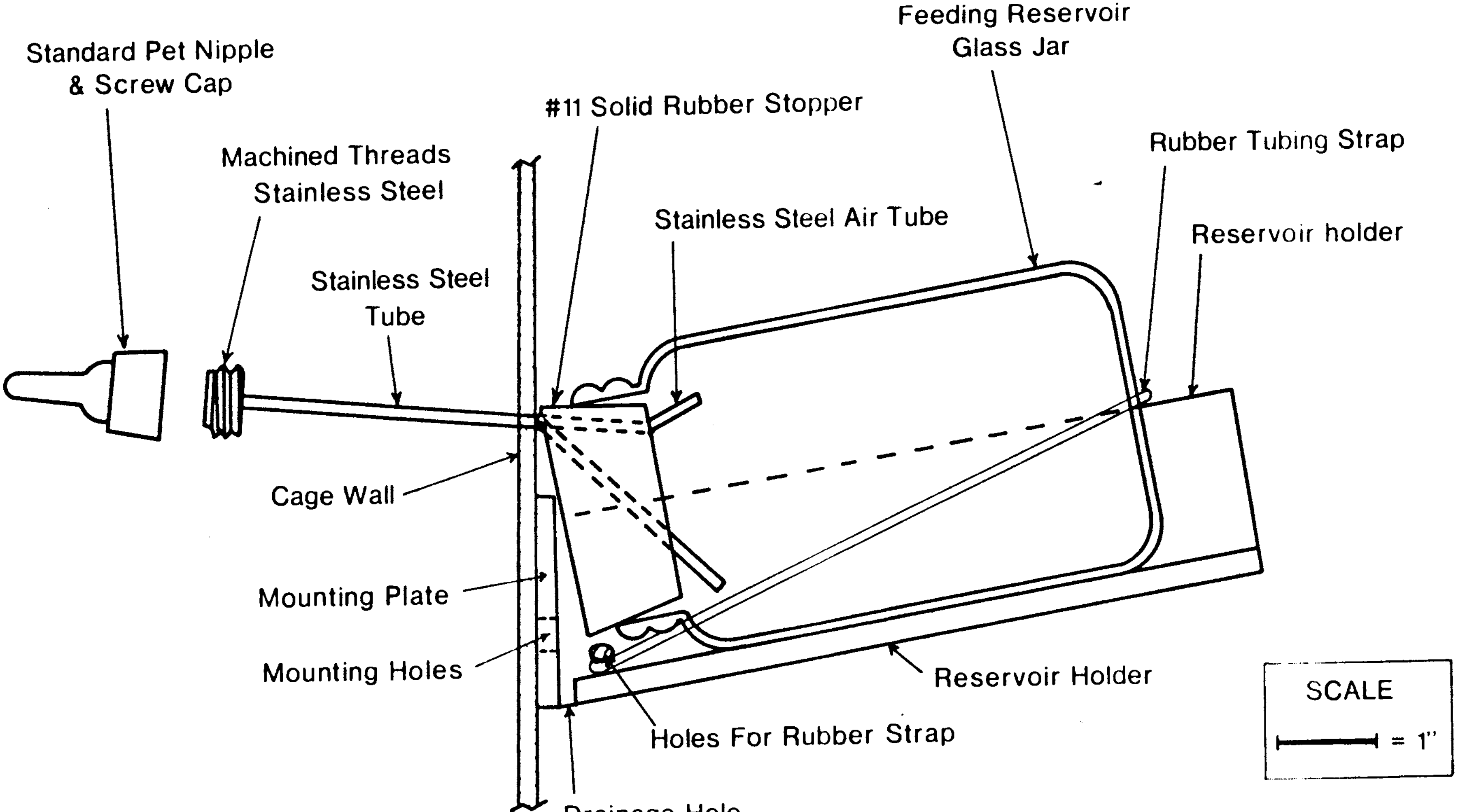


FIGURE 2

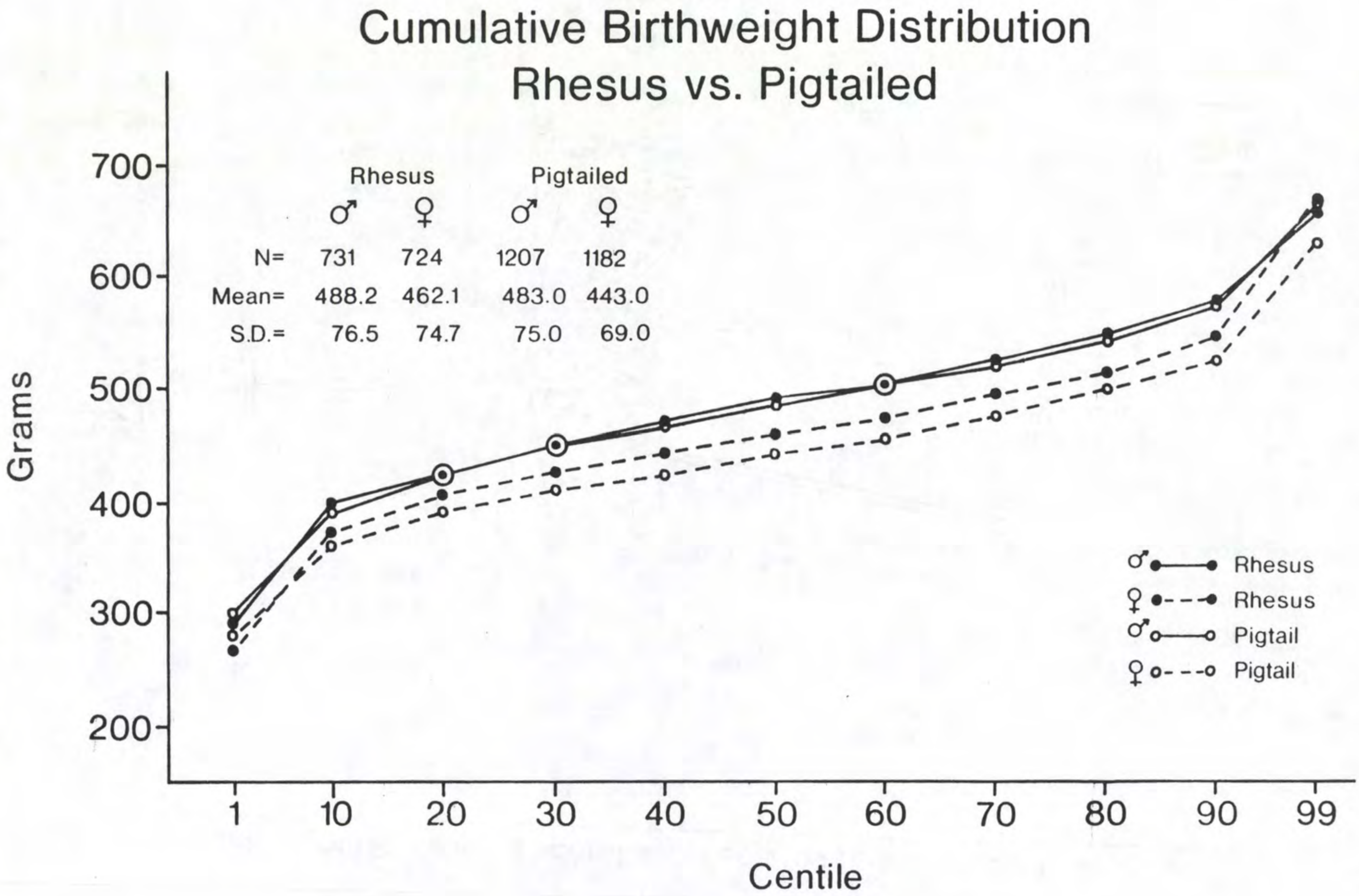

Cumulative Birthweight Distribution
Rhesus vs. Pigtailed
Rhesus
Pigtailed
♂
♀
♂
♀
N= 731 724 1207 1182
Mean= 488.2 462.1 483.0 443.0
S.D.= 76.5 74.7 75.0 69.0
Grams
700
600
500
400
300
200
Centile
1
10
20
30
40
50
60
70
80
90
99
♂ Rhesus
♀ Rhesus
♂ Pigtail
♀ Pigtail

FIGURE 3

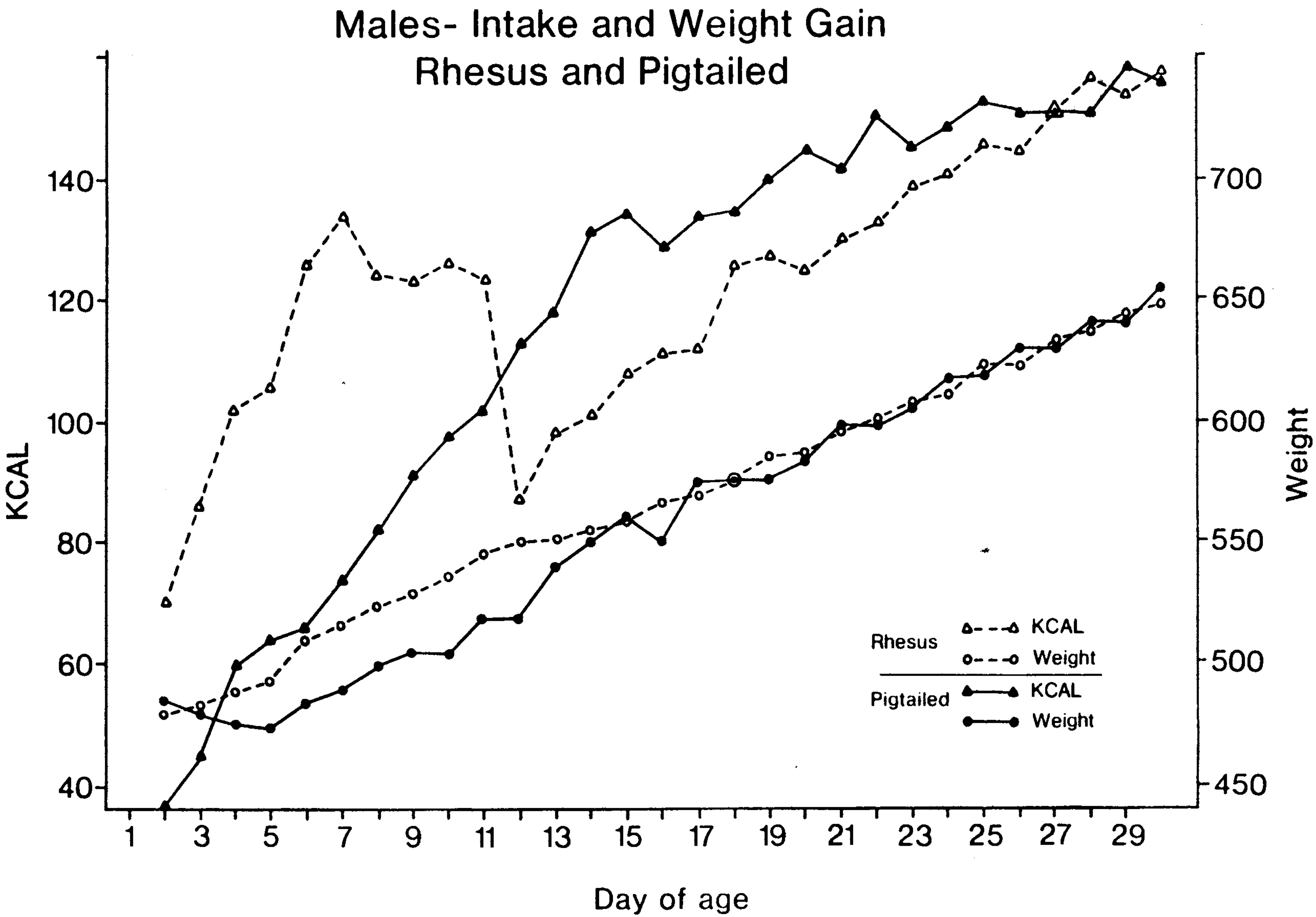

Males- Intake and Weight Gain
Rhesus and Pigtailed
KCAL
Weight
Day of age
140
120
100
80
60
40
700
650
600
550
500
450
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
Rhesus
KCAL
Weight
Pigtailed
KCAL
Weight

FIGURE 4

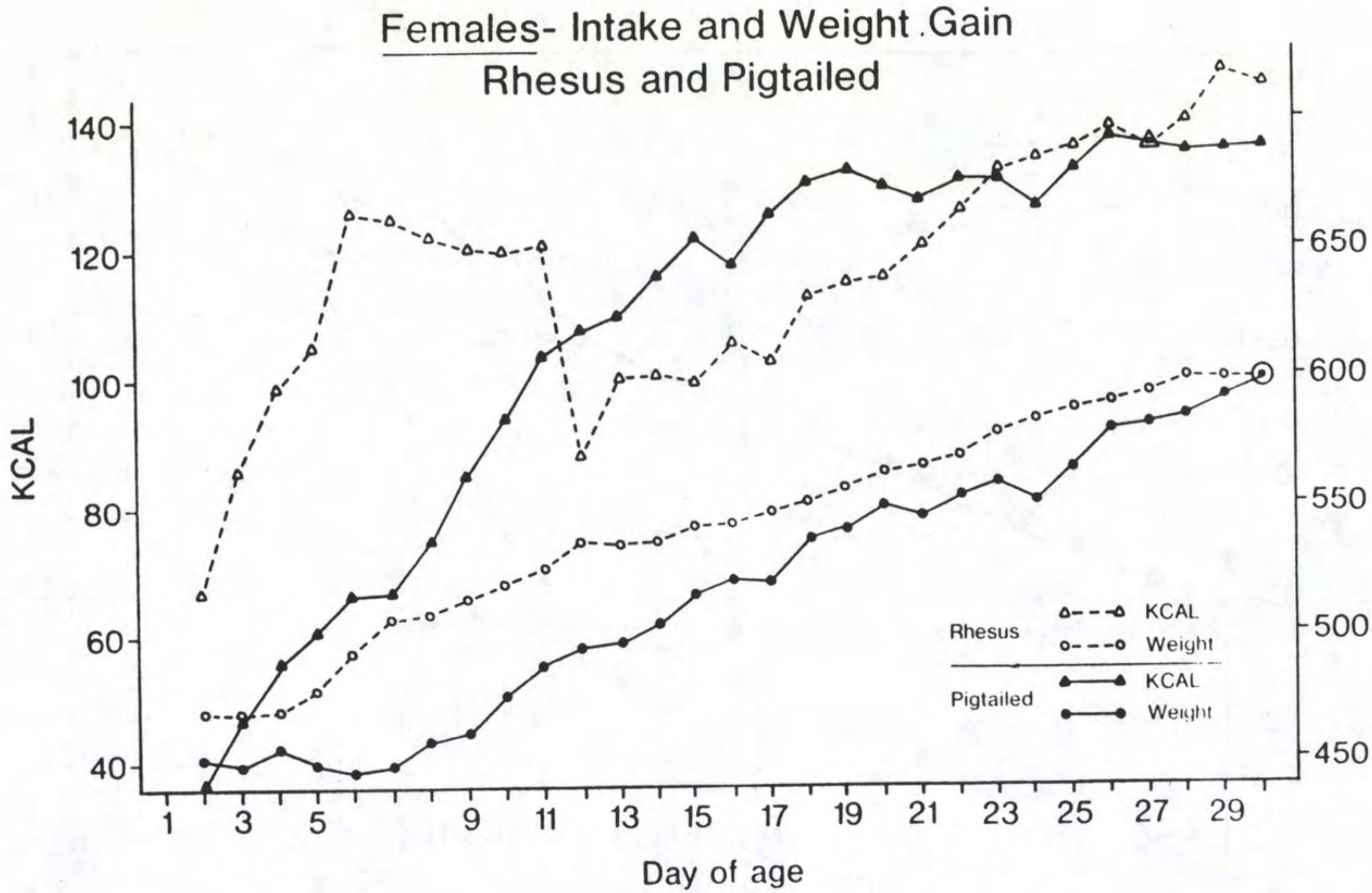

Females- Intake and Weight Gain
Rhesus and Pigtailed
140
120
100
80
60
40
KCAL
650
600
550
500
450
Weight
1
3
5
9
11
13
15
17
19
21
23
25
27
29
Day of age
Rhesus
KCAL
Weight
Pigtailed
KCAL
Weight

FIGURE 5

Rhesus and Pigtailed Males Weight Gain for Four Months

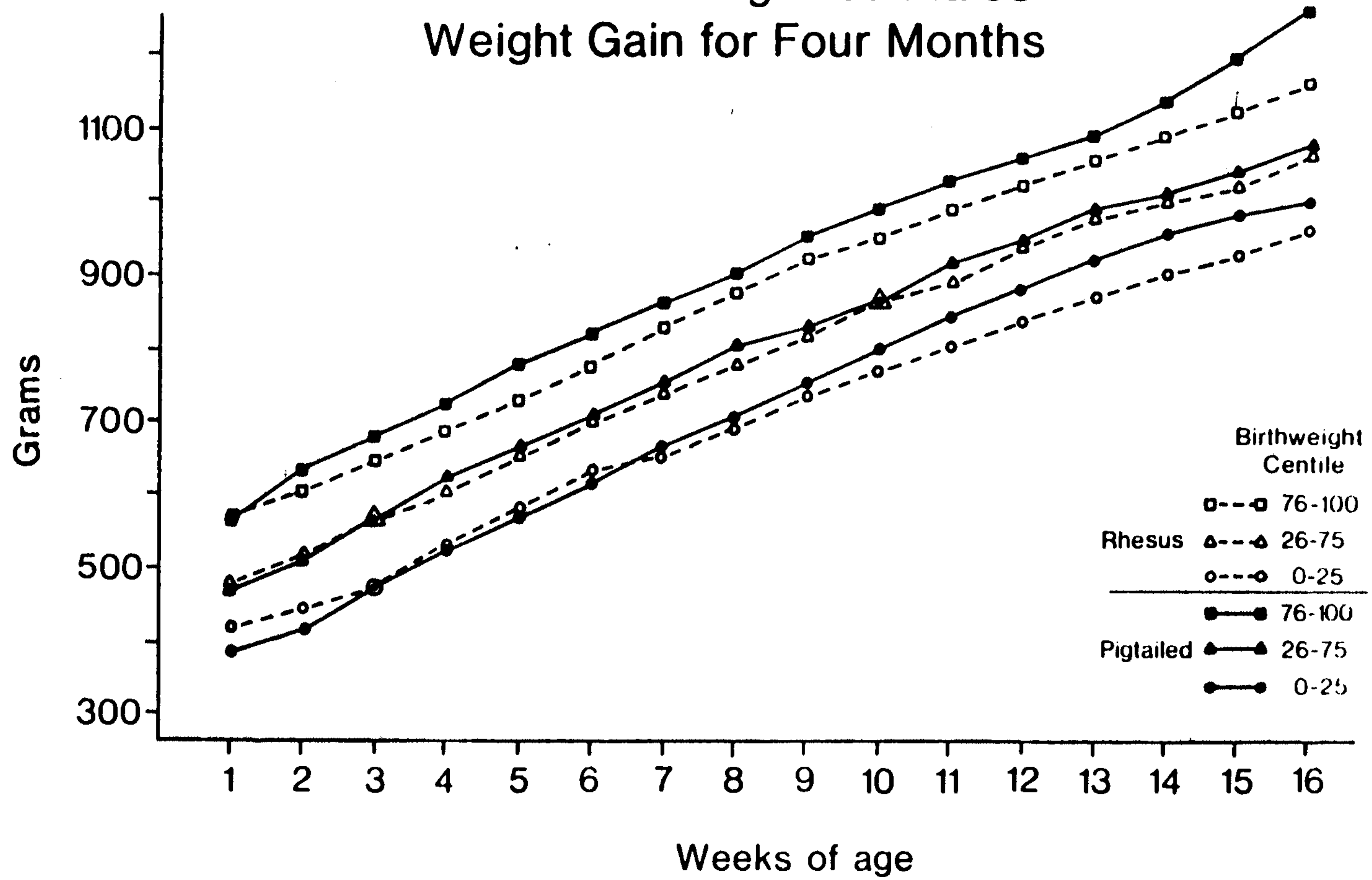
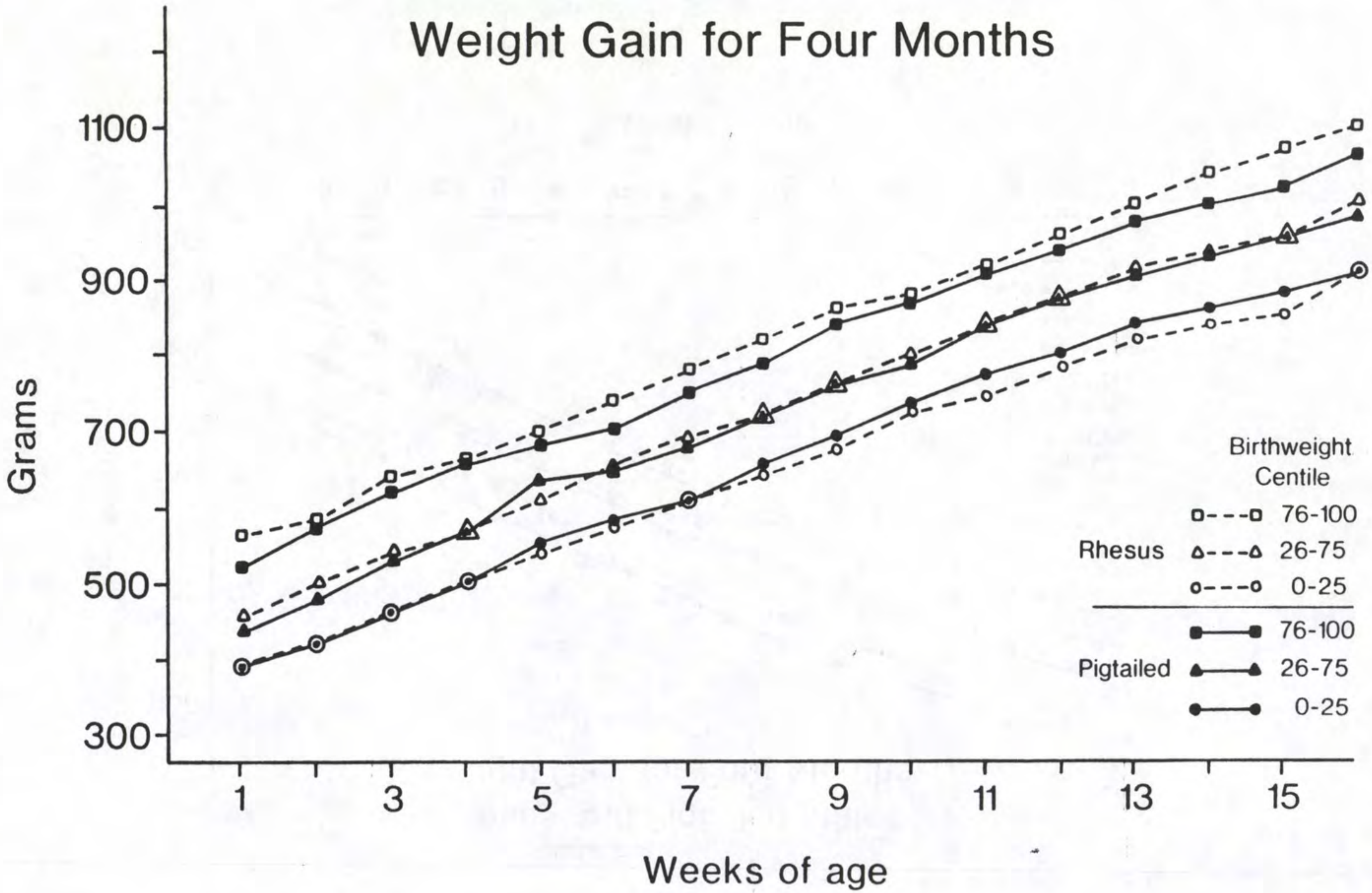
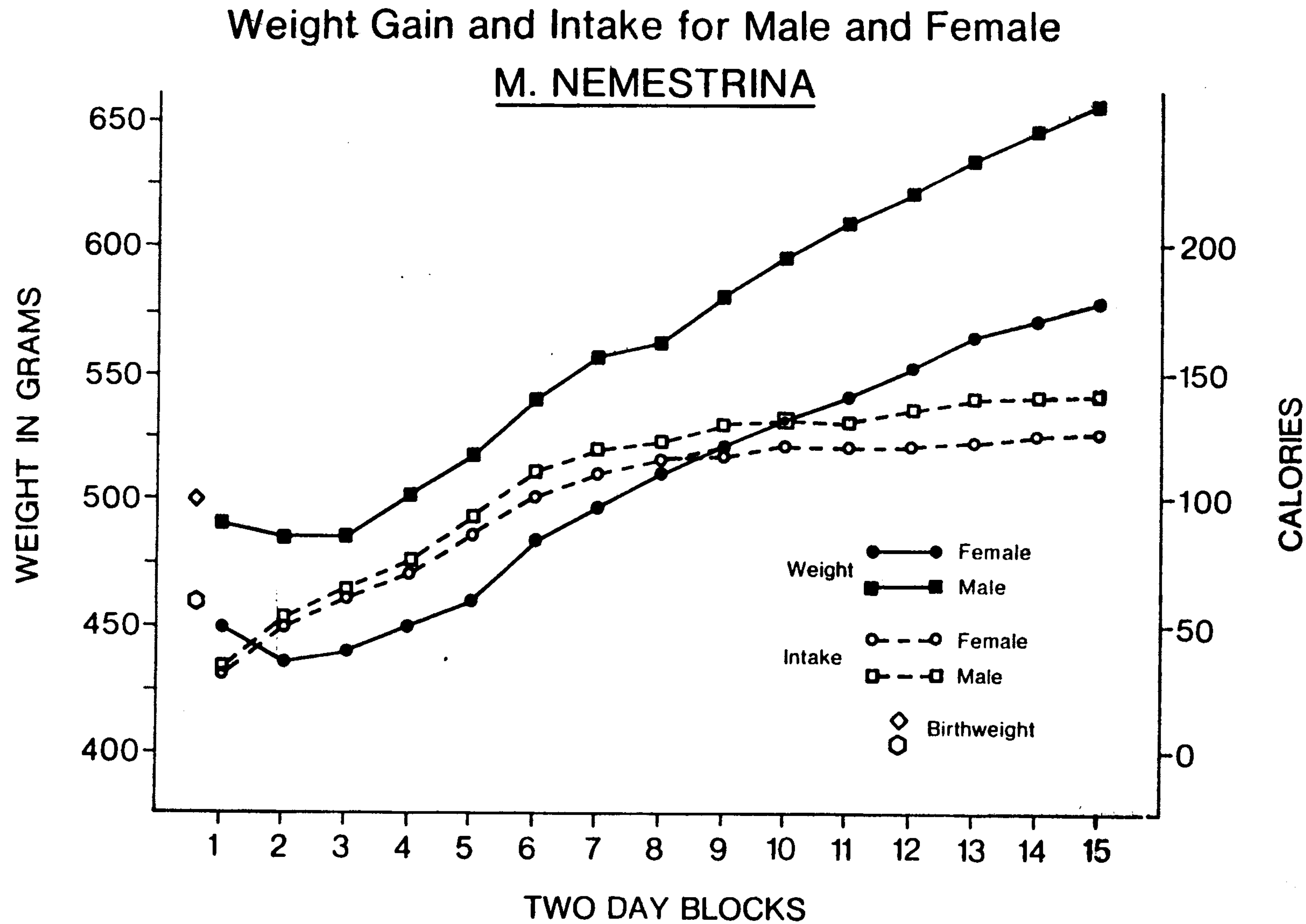


FIGURE 6

Rhesus and Pigtailed Females Weight Gain for Four Months





Weight Gain and Intake for Male and Female
M. NEMESTRINA
650
600
550
500
450
400
WEIGHT IN GRAMS
200
150
100
50
0
CALORIES
Weight
Female
Male
Intake
Female
Male
Birthweight
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
TWO DAY BLOCKS

FIGURE 7

FIGURE 8

Male Caloric Intake and Weight Gain

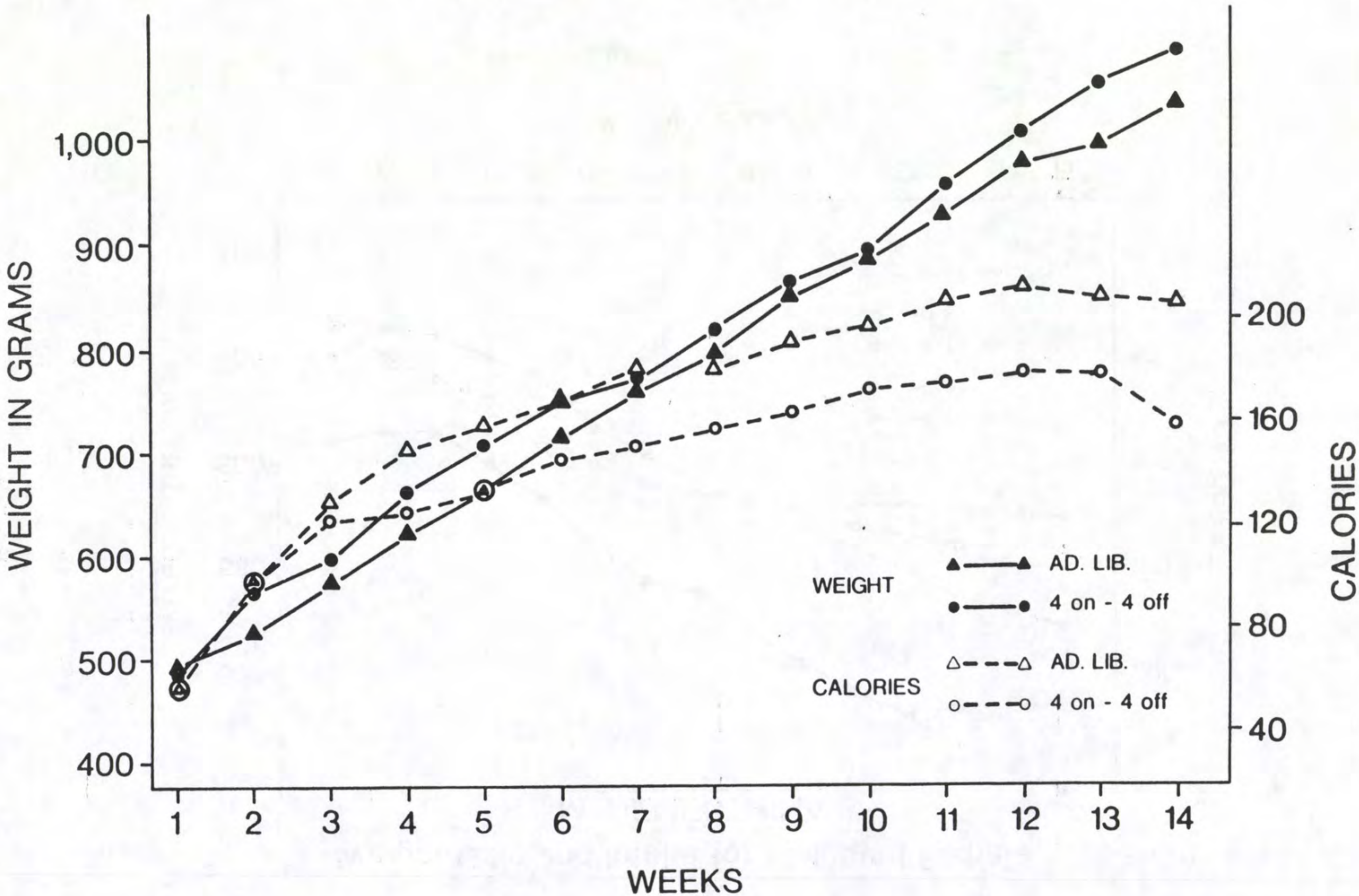
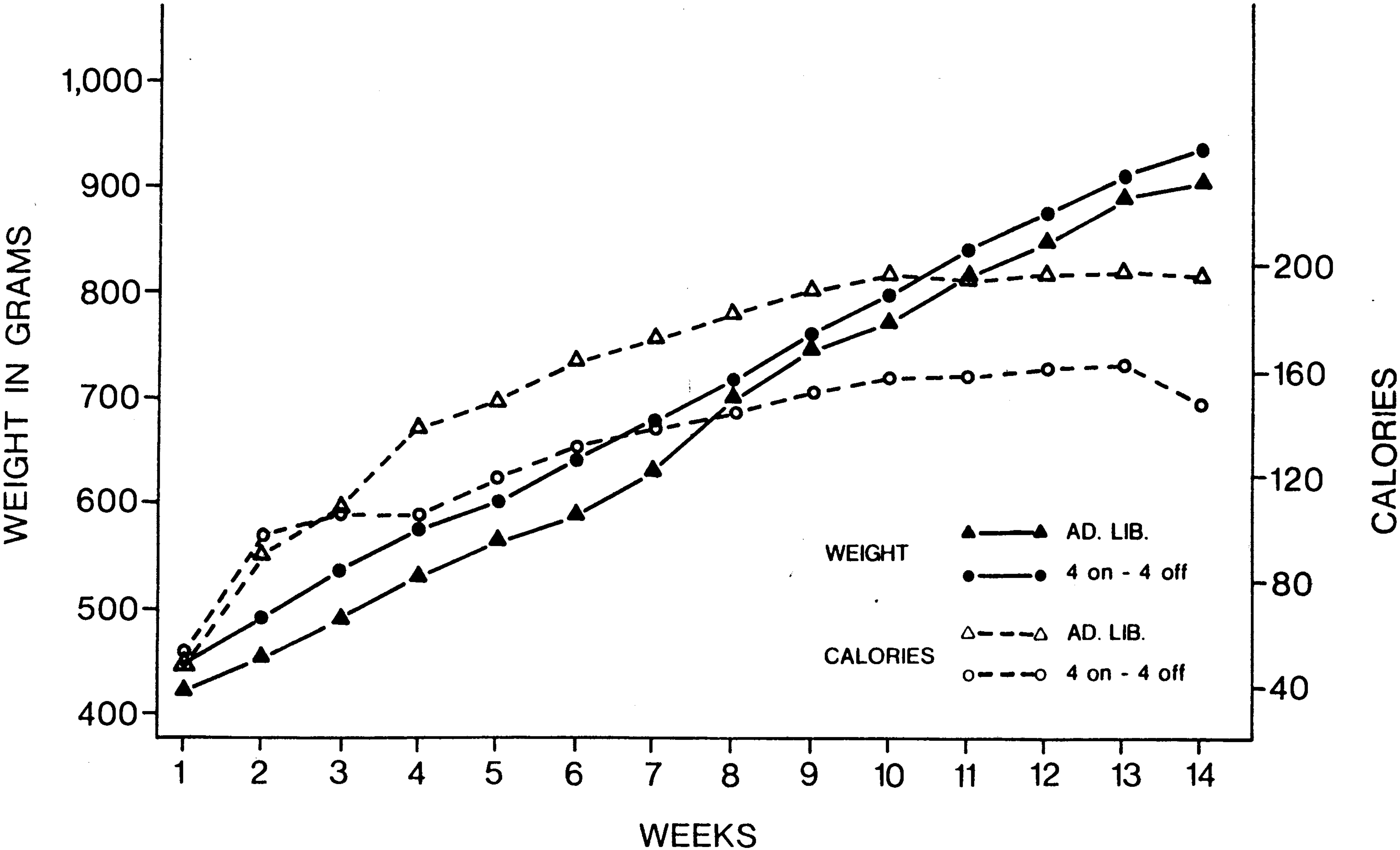


FIGURE 9

Female Caloric Intake and Weight Gain



<u>Hand Rearing Techniques for Neonatal Exotic Animals</u>

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<u>Monitoring Neonatal Exotic Animals</u>

Most neonatal exotic animals make the transition from intrauterine life to extrauterine life without help or interference. Species survival depends on this. Initially, most newborn animals do little more than eat, sleep, and grow. Hand feeding the neonate is important both nutritionally and psychologically. It involves more than providing the correct nutrients to sustain and support life. Many factors relating to the feeding process are important and can influence the success of the hand rearing attempt. Among these are formula composition; feeding frequency; amount fed; formula preparation; feeding technique; nipple/bottle type; stimulation before, during and after feeding; formation of social bonds and behavior learned in association with feeding; introduction of solid food; and transition to adult life.(12)

Accurate, complete record keeping is time consuming; however, it is absolutely essential if hand raising techniques are to become more than guesswork. Objective as well as subjective information should be recorded in an accurate, orderly fashion. With neonatal exotic animals, they may have to function as their own controls or normals which makes it even more important to keep accurate records. Illness may have to be evaluated by comparing the animal's own past and present clinical values. As more animals are hand raised, information can be gathered which will provide guidelines for future animals. Baseline information should be collected on all new animals including weight; body temperature, pulse, and respiration; mucous membrane color and capillary refill; vitality; chest and abnormal sounds; a review of organ systems with particular emphasis on congenital abnormalities; state of hydration; and an assessment of any injuries or illness.(12) Whenever possible a complete blood count and a chemistry panel should be submitted in addition to fecal cultures and a urinalysis. Urine may be squeezed directly from towels or diapers if catching a sample is difficult. After the animal has been stabilized, accurate record keeping is just as important. During the first few weeks of life, neonates should be weighed at least once or twice daily at the same time each day. Later this may be done weekly or even monthly. Vital signs should be monitored daily in addition to information about stool and urine frequency, quantity, and character. Formula type and instructions for preparation; feeding, frequency, bottle and nipple type, actual 24 hour formula intake, and amount of formula offered; addition of solid foods; behavior or housing information; and notations of any changes should also be noted.(12) Without keeping track of these items, neonatology in exotic animals will not progress, and many mistakes will be repeated.

Milk Composition and Feeding Techniques

The formula fed to the neonatal animal should provide a complete and balanced diet adequate for growth and development. Sometimes there is little or no information available to help determine what formula should be fed. It can be helpful to look at the basic lifestyle of the animal and the major milk types. The first category includes animals that raise their young in pouches (marsupials), dams that are continuously available for nursing during hibernation (ursidae), young that are continuously carried (most primates), and dams that are always available for nursing (equidae and some artiodactyls).(17) Milk is low in fat and relatively dilute. Opossum milk has 4.7% fat, 4.0% protein, 4.5% carbohydrate, and 0.77% ash.(2) Chimpanzee milk has 3.7% fat, 1.2% protein, 7.0% carbohydrate, and 0.21% ash.(2)

The second category includes animals that house their immature young in burrows (many carnivores and rodents), and dams that leave their young and return to them periodically to feed them (cervidae and some artiodactyls). (17) Milk is concentrated with a high fat content. Grant's gazelle milk has 19.5% fat, 10.4% protein, 2.8% carbohydrate, and 1.5% ash.(2) Puma milk contains 18.6% fat, 12% protein, 3.9% carbohydrate, and 1.0% ash.(2)

The third category includes those animals which live in a cold, wet environment (pinnipedia and cetacea).(17) This milk is very concentrated with an extremely high fat content. California sea lion milk contains 36.5% fat, 13% protein, 0%carbohydrate, and 0.64% ash.(2) Caution should be taken when basing formula compositions on milk analyses. Milk composition changes over the course of the lactation cycle. A sample taken at the beginning of lactation may be quite different than a sample taken in mid-lactation or at the end of lactation. Sampling number is also important. There is much more room for error with small sampling numbers or volumes. Using milk analyses and/or major lactation categories offer guidelines only. The animal itself will be the best indicator of the success of the formula. If the animal appears developmentally normal, then the formula is functioning as it should. Do not try to make the animal fit the formula. The formula should be adjusted until it fits the animal's needs.

Fortunately there are commercially available products which may be used to feed most exotic neonatal animals. Domestic cat, dog, pig, and horse milk replacers are available in addition to a large number of products made for human infants.(12) Often these products may be fed as is or they may provide the basic components for individually tailoring formulas for neonatal exotic animals. The great apes, old world monkeys, and new world monkeys can be fed products used for human neonates.(12) The carnivores may be offered domestic kitten, puppy or pig replacers. Puppy milk replacer appears to be adequate for most canids.(11) Bears have been successfully reared on kitten milk replacer or puppy milk replacer with or without supplementation (whipping cream, egg yolks, honey, karo syrup, high protein cereal, goats' milk).(11) The procyonids, mustelids, viverrids, and hyaenids have been raised on puppy milk replacer and on a few occasions evaporated milk or kitten milk replacer.(11) The small felids have few dietary problems with kitten milk replacer; however, there are differences of opinion about feeding the large felids. Variable results have been achieved with both kitten milk replacer and puppy milk replacer. Both formulas have been implicated in formula related diarrheas in large felids.(3,8,9) The addition of 10 ml corn oil, 1.5 Tbs milk protein supplement, and 70 ml water to each 100 ml kitten milk replacer have produced excellent results.(11) Other formula additions for carnivores may include high protein cereal, protein or fat sources, small amounts of meat or prepared carnivore diet, meat or chicken baby food, and additional calcium sources. Most marsupials survive on sweetened condensed milk diluted 2:1 with water.(12) Intolerance to galactose, lactose, and sucrose can cause cataract formation in herbivorous marsupials, although this has not been a common occurrence.(18,19) Similar problems have been reported in canids. Most hoofstock may be raised on foal milk replacer (equids), sweetened condensed milk diluted 1:1 with water, goats' milk, pig milk replacer, or a combination of these formulas.(12)

The feeding technique can be as important as the formula being fed. The feeding frequency should mimic the natural nursing frequency of the species whenever possible. Initially many animals do well if fed every two hours for at least nine feedings per day.(12) This is not always practical or possible, so feeding schedules can be adjusted as long as the neonate eats enough to gain weight and grow without gastric overload or upset. Some small, weak neonates must be fed every one to two hours around the clock to thrive, and they take much patience to feed. Often these animals will fall asleep while nursing and must be awakened to finish the feeding. Sometimes stimulation of the lips, face, and tongue with a finger, ice cube, or vibrator will encourage nursing. Most hoofstock should be fed 10-15% of their body weight each day.(12) Primates are generally fed 10-30% of their body weight daily although there are exceptions. Lemurs have been known to consume nearly 100% of their body weight/day in formula at peak growth periods.(14) Great apes and human infants generally take 10-15% of their body weight/day, and carnivores are usually offered 20-40% of their body weight daily.(1,11,12) The 24 hour intake is then divided by the number of feedings daily to determine what is offered at each feeding. The gastric capacity of most mammals is about 50ml/kg, but problems can occur if the stomach is filled to capacity. Vomiting may be seen with gastric overload and improper or inadequate burping. Vomiting caused by improper burping is usually seen just after feeding, while vomiting due to gastric overload usually occurs up to several hours after feeding.

Try to pick a nipple similar to the teat of the dam. Premature and standard human nipples, small doll or pet nipples, intravenous catheters, eyedroppers, goat nipples, and calf nipples may be used. Customized nipples may be made using latex in those cases where specialized nipples are necessary. Make sure the holes in the nipple suit the sucking reflex of the animal. Too much formula can cause an aspiration pneumonia, and animals with a weak sucking reflex will become discouraged if they have to work too hard to obtain formula. Neonates are obligate nose breathers.(1) They cannot breathe through their mouths and nurse at the same time. Respiratory infections cause a great deal of trouble because they not only interfere with breathing but they also make nursing difficult or impossible. Nasal suctioning and decongestants may help alleviate the problem. Gavage feeding may be necessary if the animal cannot breathe well enough to nurse.

Patience is vital when teaching a neonatal exotic animal to nurse. Most animals will nurse if placed in their normal nursing positions. Primates should be held like human infants, and carnivores should be in ventral recumbency with the head elevated. Often they prefer to push against something with their front feet. Hoofstock usually prefer to feed while standing with the head elevated although some will nurse while lying down.

Hoofstock are notoriously difficult to teach to bottle feed especially if the neonate has already nursed from the dam. It may be helpful to approach the neonate slowly and at their level; imitate the sounds made by the dam; allow the neonate to suckle on fingers, nose, or chin and then substitute the nipple; cover the animal's head, the bottle, and the handler with a towel; place the nipple in the animal's mouth and gently hold the mouth shut; squeeze out a small amount of milk into the animal's mouth and then gently move the nipple in and out; stimulate the neonate to move around or eliminate prior to offering food; and try different nipple types and sizes. It can take up to a week to teach some animals to nurse consistently. Occasionally they will nurse well one feeding and then appear to forget for several feedings.

Gastrointestinal Problems

When a young animal is sick, it may be difficult to differentiate between dietary problems and other causes of illness. The animal may be presented with some type of gastrointestinal disturbance and a failure to thrive. Because of this, it is very important to change only one thing at a time when making dietary adjustments. If several items are changed simultaneously, it is difficult to analyze any problems. The formula itself may not be creating the illness - formula concentration, feeding frequency, gastric overload, and rapid changes can also produce gastrointestinal signs. It is safest to make dietary changes slowly and conservatively. Over feeding and extremely rapid feedings should be avoided. Animals should not be forced to take more formula than they want. Young ruminants are functionally monogastric, and force feeding them tends to cause milk to accumulate in the rumen.(12) The esophageal grove which normally causes milk to bypass the rumen does not form when these animals are tube fed or force fed. When milk accumulated in the rumen, the animals are prone to rumen stasis and fungal or bacterial rumenitis which may be fatal. In addition, some neonates - large felids in particular - should not be fed ad lib since they have a tendency to overeat and bloat.

Normally, neonates will show signs of formula intolerance shortly after starting on the problem formulation. Nutritional inadequacies generally become apparent later, are associated with a failure to thrive or specific nutritional defects, and are often not accompanied by gastrointestinal upset. Acute difficulties generally become apparent within a few hours to a few days. Signs include: vomiting; diarrhea; bloating; refusal to nurse; irritability; bloody feces;

weight loss or failure to gain; and abnormal behavior.(12) This must be differentiated from things like gastrointestinal or generalized infection, gastrointestinal emergencies, parasitism, and failure of other organ systems. A thorough physical examination is vital. It is important to determine the cause of the illness rapidly so correct therapy may be begun since most neonates have limited reserves. Changes in the white cell numbers and types can indicate fungal or bacterial infections in combination with fecal, pharyngeal, and blood cultures. A direct examination of the feces for parasites, white cells, blood, and large numbers of specific bacteria or yeast can also be diagnostic. Auscultation and radiology of the abdomen with or without contrast media may be useful. If none of these items is diagnostic and there has been a recent formula change, then formula intolerance should be considered.(12)

Fortunately, much of the symptomatic treatment for gastrointestinal illness is similar regardless of the cause. The animal should be treated for diarrhea, vomiting, dehydration, and shock if they are present. Other signs should be treated as well. Sepsis should always be considered secondarily. Many neonates are prime candidates for infection because of the insult to their gastrointestinal tract and their potential immunodeficient status. Some neonates will be immunodeficient if they have not received maternal colostrum.(10) Mild diarrhea may not require cessation of oral fluids, although it may be helpful to switch to a balanced electrolyte solution for 12 to 24 hours. Several over the counter products are available for human consumption which will work for neonatal animals. When the animal has severe diarrhea or vomiting, it may be necessary to give nothing orally and support the animal with parenteral fluids. These may be given intravenously or if this is not feasible, fluids may be given subcutaneously. Administration of fluids by clysis is not adequate in severely dehydrated animals, however it works well in neonates requiring moderate short term fluid support. If the neonate is hypothermic, oral fluids should be withheld until body temperature approaches normal. Gastrointestinal function is altered in hypothermia, and gastroenteritis and bloat may result. When body temperatures are subnormal, peripheral circulation is also affected. Fluids given by clysis may not be readily absorbed. Intravenous fluid support is best in hypothermia or shock.(12)

FLUID, ELECTROLYTE, CALORIC, AND PROTEIN THERAPY

Water is the most plentiful compound in the body. It is the single most important nutrient necessary for proper functioning of living cells. In the absence of trauma, all fluid losses and gains from the body occur via the gastrointestinal tract, kidneys, lungs, and skin. Insensible fluid loss in the neonatal period is influenced by maturity, respiratory rate, body and environmental temperatures, relative humidity, and activity levels. (1,15) These must be considered when calculating fluid requirements. The renal function of the human neonatal kidney is immature (1), and there is a limited ability to concentrate urine - 600-700 mosm compared to 1200 mosm in the adult. The status of the neonatal kidney in exotic animals is not known, however, some species may have comparable renal immaturity.(20) Human neonates require 100-145 ml fluids/kg/day (1,20) excluding other losses i.e., vomiting or diarrhea. Estimates for fluid requirements for exotic neonatal animals are 10-15% body weight/day. This decreases as animals get larger and mature. Adult dogs and cats require about 60 ml water/kg/day for maintenance. Water requirements may also be estimated at 125 ml water/100 Kcal required.(4,17)

The concentration of the major electrolytes in the body are similar in many different species. Neonatal serum electrolytes are similar to those found in adults, although serum calcium tends to be lower in neonates, and the serum phosphorus and potassium tend to be higher.(5,7) Electrolyte imbalances are influenced by the type of disease process. Clinical signs are only helpful in severe alterations. Severe vomiting causes a decrease in sodium, chloride, and potassium.(4) Generally in diarrhea, fluids are lost that contain sodium, potassium, chloride, bicarbonate and to a lesser extent, calcium and magnesium.(4) Usually lactated ringers solution or solutions for fluid replacement can be used in neonates. Severe deficiencies should be treated individually as they would be with adult animals. Five percent glucose may also be used as a fluid and energy source. Both lactated ringers solution and 5% glucose are isotonic and may be used for subcutaneous fluid replacement. Hypertonic solutions should only be given intravenously in a large bore vein like the jugular vein or vena cava.(13)

The caloric requirements and normal growth curves have not been established for most zoological species-especially neonates. However, basal energy requirements can be estimated for mature homeotherms using the following formula: Kilocalories/day = 70 x body weight in kg raised to the 0.75 power.(17) The energy requirements for growth and development can be estimated as three to four times the adult basal rate.(16) Milk energy intake at peak lactation is similar for most species at 200-250 Kcal/kg body weight raised to the 0.83 power.(16) Human neonates require 115-135 Kcal/kg body weight/day.(1) A 500-1000 g neonate requires an average of 250 Kcal/kg body weight/day. A neonate weighing between 1-10 kg needs an average of 150 Kcal /kg body weight/day.(12) Many factors can influence energy requirements. For each degree Fahrenheit above the normal rectal temperature, add 8% of the maintenance energy requirements. Add up to 30% of the maintenance needs for increased activity levels. In man, multiple fractures use 110-130% of normal metabolic expenditures, peritonitis requires 125-145%, and burns/septicemia need 140-200+%.(5,13)

Protein requirements must be considered in tandem with energy needs. If adequate energy sources are not provided, the protein will be broken down to provide energy. Clinical studies in man have demonstrated that nitrogen balance is achieved when the calories to nitrogen ratio is between 175-200 Kcal to 1 g nitrogen.(6) Puppies and kittens require an estimated 50-100 Kcal to 1 g nitrogen.(4) Human neonates require higher levels than adults for both essential amino acids and total protein/kg body weight and a neonate requires 2.5-4.0 g protein/kg body weight each day.(6) Neonatal ruminants are functionally monogastric so their protein and caloric needs resemble other monogastric animals more closely than functioning herbivores.

Short term fluid therapy can be life saving in neonatal animals. Commercially available intravenous or oral fluids work well in neonates and should be used vigorously whenever fluid support is indicated. Often fluid therapy is only required for several days. Neonatal ruminants are especially prone to hypoglycemia particularly when they have not nursed, are not yet readily accepting bottle feeding, and may have suffered a hypothermic insult as well. These animals may require intravenous glucose support for up to a week. Laboratory reagent strips can provide immediate information about the glucose status of the neonate and use only a drop of blood. It is not unusual to have blood glucose readings as low as 0-25 mg/dl. Clinical signs include lethargy, inability to stand, incoordination, depression, and rarely, convulsions.(12) Animals may need slow intravenous infusions of up to 15-20% glucose to maintain adequate blood glucose levels. Hypertonic solutions should only be given through a large bore vein to avoid tissue damage to the vessel walls. Glucose therapy should be withdrawn slowly to prevent an insulin rebound and subsequent return of the hypoglycemia. As oral intake increases, parenteral therapy can be withdrawn. Often administration of glucose and normal support care

are the only treatment needed by hypothermic, hypoglycemic herbivores.

When neonatal animals need fluid support for more than a few days, total parenteral hyperalimentation (TPH) should be considered. Fluid therapy is used for animals that cannot maintain their own homeostasis due to illness or injury. The goal of fluid therapy is to restore fluid and electrolyte losses and maintain that balance during the period of illness. It does not provide total nutritional support. Total parenteral hyperalimentation takes the process one step further. It involves the infusion of highly concentrated solutions of carbohydrates, lipids, amino acids, electrolytes, and other necessary nutrients through an indwelling catheter in a large bore vein.(6,13) Not every neonate needing fluid support is a candidate for TPH. Those animals in good nutritional status needing only temporary therapy as a supplement to oral intake or until oral intake is established do not need TPH. The principal indications for TPH are found in seriously ill patients suffering from malnutrition, sepsis, or surgical or accidental trauma when nutritional requirements cannot be met through the use of the gastrointestinal tract.(6,13)

The principles used in fluid therapy are the same as those used for TPH except protein, caloric, and vitamin and mineral needs are also calculated. There are five basic steps for formulating TPH solutions. First, determine total fluid needs per day - deficits, maintenance, plus continuing abnormal losses.(13) Second, determine electrolyte requirements per day- maintenance, plus continuing abnormal losses. Subtract the fluid volume needed for electrolyte supplementation from total fluid volume. The remainder is the volume available for protein and calorie sources.(13) Third, determine the protein requirements per day. Take into consideration those things which increase the requirements. Subtract the fluid volume needed for protein supplementation from the fluid volume calculated in the second step. The remaining fluid volume is available for caloric sources.(13) The fourth step is to determine the caloric requirements per day, again taking into consideration those things which increase the needed levels. Lipids and dextrose would be used together in a proportion similar to the milk of the species if possible. The volume available for caloric supplementation is known so the concentration of dextrose and amount of lipids can be calculated to stay within the volume limitations.(13) The fifth step is to determine the daily vitamin requirements and add those to the TPH solutions. If necessary, sterile water is used to reach the final desired fluid volume.(13) TPH fluids must be prepared sterilely, and extreme care should be used when inserting or handling catheters, IV tubing, or the TPH solutions. Sepsis is the major complication of TPH.(6)

PSYCHOLOGICAL EFFECTS OF HAND REARING

Exotic animals appear to be more susceptible to stress-related problems than their domestic counterparts. Precocial neonates, especially hoofstock removed from their dams after the first 24 hours of life, are particularly vulnerable.(12) They are easily agitated and show fight or flight reactions. Dimming or darkening the environment and providing visual barriers may be helpful. Caretakers should speak to the animals and move slowly and quietly. A radio may help acclimate animals to noises it will have to face as it grows older. If the animal appears healthy, delaying examinations and routine therapy can speed the onset of nursing and prevent injury.

Delayed physical or mental development, failure to thrive, and over-reaction to a new environment are signs of maladjustment. Stereotypic behaviors include self mutilation, pacing, rocking, head pressing, hair plucking, and excessive sucking on themselves or others.(12) It is difficult to avoid these problems in exotic neonatal animals that must be hand-raised, especially if the animals are solitary and isolated. Sibling contact allows the neonate to interact with other animals. Contact with siblings of the same species is desirable but not always possible. Contact with a similar species or a domestic counterpart is helpful. Apes of similar size can be housed together. Young sheep, goats, cattle, dogs, cats, and in some cases tolerant adults can be used. Occasionally neonates can be raised by surrogate dams. With birds, puppets may be used to hand feed baby birds and can act as imprinting models. When no other animal contact is possible, it is important to provide human contact. Some of the more delicate langur species have a better survival rate if they are carried for most of the day rather than placing them in an isolette or crib.

Good housing and environmental enrichment can also reduce maladjustment problems. As soon as possible, animals should be housed in areas similar to the environment they will encounter as adults. There should be room for physical development and play. Ingenuity should be used to devise play structures and toys. Feeding opportunities and use of foods should not be overlooked as a means of psychological stimulation. In addition, artificial surrogate mothers are helpful for those neonates that are carried by their dams. Rolled up towels, paint rollers, pieces of carpet, fake fur, and stuffed toys allow the neonate to cling. A pouch made from a pillow case works well for marsupials. They can assume the natural in-pouch posture, which seems to be important for development.

Hand raising neonatal exotic animals is dependent on a number of different factors which combine to influence the outcome. Providing nutritionally adequate formula at reasonable intervals in appropriate volumes is vital. Accurate record keeping, an appropriate psychological and physical environment, and medical treatment for illness or injury are just as important. Caretakers must learn to recognize subtle changes since neonatal exotic animals may not give much indication of problems until they become life threatening. The best indicator for the success of the rearing attempt is the animal itself. If the neonate grows, thrives, appears developmentally normal, and makes the transition to adult life, then the rearing attempt has been successful.

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MAKING FORAGE ANALYSIS WORK FOR YOU IN BALANCING LIVESTOCK RATIONS AND MARKETING HAY

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Alfalfa and other legume forages cut early and without rain damage set the pace with top feed value

Forage and grain samples differ in their chemical composition and digestibility. These qualities -- along with the amount animals eat and the efficiency of their metabolism -- strongly influence meat, milk and wool production, as well as animal performance. Everyone involved with livestock needs a standard way to analyze forage and feed samples that is accurate, precise, fast, simple, reliable and low cost. The method must express feed value in terms that can be translated into livestock products produced. Near infrared reflectance spectroscopy (NIRs), properly calibrated, can predict the nutritional value of feeds and animal responses to their consumption. It is important to understand NIRs terminology so that analytical results benefit the forage producer and the livestock producer to their fullest potential.

How Forage and Feed Quality is Expressed

Since the mid-1800's, scientists have evaluated forage by using the proximate analysis system. But scientists have shown that the concepts in this method may be incorrect. They now have found that acid-detergent fiber (ADF) and neutral-detergent fiber (NDF) provide better routing estimates of invivo (inside animal) dry matter digestibility and dry matter intake in animals.

The NIRs system measures components that are basic parts of plant structure and that relate to animal digestion and production (Table 1). The digestible energy concept, which NIRs is based on, uses detergents to partition forage and feed dry matter into: (1) cell contents -- the highly digestible fraction unaffected by lignification and soluble in neutral detergent, (2) the partially digestible fraction, hemicellulose, soluble in acid detergent, and (3) the highly indigestible portion of the plant. The concentration of cell contents ranges from 90 percent in corn grain to 60 percent in immature to 30 percent in mature grass.

How Terms in the NIRs System are Defined

Crude Protein (CP) is a mixture of true protein and nonprotein nitrogen. CP indicates the capacity of the feed to meet an animal's protein needs, although it is of little value in predicting energy available to animals. Generally, high CP is desirable. Forage cut early or with a high proportion of legume has a high CP content. In legumes, protein availability usually increases as the amount of CP increases. CP has little value in predicting energy availability.

Dry Matter (DM) is the percentage of the feed that is not water. DM equals 100 percent on a DM basis. Therefore, a sample of haulage -- low moisture silage -- containing 55 percent DM is 45 percent water. If the same sample contains 20 percent CP on a 100 percent DM basis, the sample has 20 percent of 55 percent, or 11 percent CP on an "as is" basis.

Neutral detergent fiber (NDF) is the percentage of cell wall material or plant structure in a feed. This constituent is insoluble in neutral detergent and is only partially available to animals. The lower the NDF percentage, the more an animal will eat. NDF includes acid detergent fiber and is inversely related to intake. Thus, a low percentage of NDF is desirable.

Acid detergent fiber (ADF) is the percentage of highly indigestible plant material in a feed or forage (Table 1). This constituent is insoluble in acid detergent. ADF differs from crude fiber in that ADF contains silica. Silica and lignin in plants are associated with low in vivo digestibility. The lower the ADF, the more feed an animal can digest. Thus, a low ADF percentage is desirable.

Digestible dry matter (DDM) is an estimate of the percentage of the feed or forage that is digestible, based on feeding trials with animals and is determined from ADF concentration.

Dry matter intake (DMI) is an estimate of the relative amount of forage an animal will eat. It is based on the feeding trials with animals and is determined from ADF concentration. DMI is expressed as $gms/Wkg^{0.75}$.

Digestible dry matter intake (DDMI) is an estimate of how much DDM an animal will consume. DDMI also estimated digestible energy intake (DEI). DDMI is calculated by the equation DDM x DMI/100. This value is used to calculate relative feed value from an assumed base.

Relative feed value (RFV) compares one forage to another according to the relationship DDM x DMI divided by a constant.
We have used 65.2, based on alfalfa between three fourths and full bloom, as the constant in table 4. The difference between high quality and low quality as shown by RFV is used to evaluate a forage.

Calcium (Ca), phosphorous (P), and potassium (K) are expressed as a percentage of each nutrient in the feed. Ca concentration is higher in legumes than in grasses. K and P are usually higher under adequate and top fertility programs.

Insoluble crude protein (ICP) is really acid detergent insoluble nitrogen (ADIN). ICP measures the amount of nitrogen (N) compounds chemically linked to lignin compounds. ICP varies with the amount of heating that has occurred and the amount of plant N that is insoluble. Legumes and immature forages have less ICP than grasses and mature forages, respectively. ADIN also may be expressed as acid detergent fiber nitrogen (ADF - N). The CP available for animal use is called available crude protein (ACP).

If the ratio of ICP to CP (ICP/CP) is less than 10, harvest and storage practices were correct. If the ratio is near or above 15, the moisture content when stored, harvest and storage were correct. Insoluble nitrogen apparently increases with maturity and appears to be higher in grasses than legumes at like stages of maturity. This is why a high CP is sometimes misleading. When the ratio is near 15, use ACP to balance rations.

How to Use Forage Quality Measures

Forage production is big business in Wisconsin. About one-half of the alfalfa is harvested as hay, most of which is fed on the farm.

Market hay grades are based on maturity and specie composition (Table 2). Legumes are highest, followed by legume-grass mixtures, grasses, and heavily weathered forage. These same grade descriptions represent changes in haulage quality.

Estimated feed value of corn silage based on harvest maturity and management (Table 3) helps to show where corn silage RFV fits in with forage RFV. Corn silage DDM should probably not exceed 63 percent for high-producing dairy cows and 68 percent for sheep and beef. DMI is low compared to forage because of a high concentration of cell wall material as indicated by NDF. Hybrids with low ear contents have low feed value. Leaving 18 inch stalks in the field improves feed value.

Equations found in Table 4 determine digestibility, intake, energy and relative feed value. Most dairy and livestock producers are familiar with the concept of digestibility and express it as total digestible nutrients (TDN). DDM is an estimate of digestible energy (equation C, Table 4). Recent information shows that intake exerts a greater influence on animal performance than does digestibility (70 and 30 percent, respectively).

In practice, the difference in DMI estimates between a high and a low quality forage can be used to estimate the difference in intake potential for rations. For example: the value of prime alfalfa compared to full bloom alfalfa equals 30 grams for a 636 kg (1,400 lb) cow, an 8.4 lb per day increase in intake (equation E, Table 4) with prime alfalfa. Simply put, each 3.5 gms/$Wkg^{0.75}$ change represents one pound per day change in intake for cattle and horses. A different equation is use for sheep and goats (Table 4).

Ration balancing uses CP, ADF, NDF, Ca and P as direct inputs for cattle, sheep and horses. Farmers can use these values to estimate digestibility and intake for each forage lot tested. The concentrations of ADF and NDF in forage specify, respectively, the minimum and maximum forage proportion to use in total mixed rations (TMR) in table 5.

Hay dealers report that they purchase much of their hay one day and sell it the next. Time doesn't permit obtaining a laboratory analysis for forage quality. Therefore, hay that is sold isn't evaluated properly unless the producer does it. NIRs analyses provided information to give a rapid, precise evaluation of hay and haulage. The mobile NIRs van permits on-site testing at hay auctions where dairy and livestock producers can obtain a reasonable estimate of how their animals will perform on each hay lot.

Summary

Alfalfa and other forage legumes set the pace in forage quality. NIRs based on new forage analyses provides a precise, rapid, easy and inexpensive method for forage quality analyses. NIRs, properly used and understood, can help in market hay grades, equation development, ration balancing and hay marketing.

Table 1. DIVISION OF FORAGE ORGANIC MATTER BY THE SYSTEM OF ANALYSIS USING DETERGENTS[a]

Fraction	Components	Nutritional availability[b] Ruminant	Non-ruminant
A. Cell Contents (Soluble in neutral-detergent)	Lipids	V.C.	H.A.
	Sugars	"	"
	Organic Acids and water	"	"
	Soluble Matter	"	"
	Starch	"	"
	Non-Protein Nitrogen	"	"
	Soluble Protein	"	"
	Pectin	"	"
B. Cell Walls (NDF)[c]			
(1) Soluble in acid-detergent	Hemicellulose	Partial	Very Low
(2) Insoluble in acid-detergent (Acid-Detergent)	Cellulose	Partial	Very Low
	Lignin	Ind.	Ind.
	Lignified N Cmpds	"	"
	Heat damaged Protein	"	"
	Keratin	"	"
	Silica	"	"

[a]Jorgenson, 1971
[b]V.C.=Virtually Complete, H.A.=Highly available, Ind.=Indigestible
[c]NDF=Neutral Detergent Fiber Insoluble in Neutral Detergent Fiber - ADF)

Table 2. Market Hay Grades for legumes, legume-grass mixtures, and grasses - AFGC Hay Marketing Task force[a]
"A continuum from legume pre bloom to grass headed and/or heavily weathered forage"

Grade	Description[b]	CP %	ADF %	NDF %	DDM %	DMI[c] gm/Wkg$^{0.75}$	DDMI gm/Wkg$^{0.75}$	RFV %
Prime	Leg.-Pre.B1	>19	<30	<39	>65.5	>143	>93.5	>143
1	Leg.-EB1., 20% grass-V.	17-19	31-35	40-46	62-65	134-143	82-93	126-143
2	Leg.-MB1., 30% Grass-EH	14-16	36-40	47-53	58-61	128-133	74-81	113-126
3	Leg.-FB1 40% grass-head	11-13	40-42	53-60	56-57	113-127	64-73[d]	97-113[d]
4	Leg.FB1 50% grass-head	8-10	43-45	61-65	53-55	106-112	55-63	86-97
Fair 6	Grass-Head, and/or Rain Damaged Sample	<8	>46	>65	<53	<105	<55	<86

[a]Description and DDM adopted by Nat. Alfalfa Hay Quality Committee
[b]Pre bloom, EB1=Early bloom, MB1=Mid bloom, FB1=Mid to full bloom, V=Vegetative, EH=Early Head
[c]DMI for sheep and goats = >82,76-81, 72-75, 63-71, 52-62, and <56 for grades Prime through Fair, respectively.
[d]Reference hay mid to full bloom alfalfa (Lema and Kawas and Jorgenson) DDM-54.2, DMI=120.2 gms/wk$^{0.75}$

Table 3. Feed value of corn silage for cows as influenced by harvest maturity and harvest management[a]

Stage of Maturity	Chemical composition-% CP	ADF	NDF	DDM %	DMI gm/$Wkg^{0.75}$	DDMI gm/$Wkg^{0.75}$	RFV
75% Silk	11	31.5	53	61.6	59.6	36.7	56
Milk[b]	8.8	29.5	54.2	61.5	68.0	41.8	64
Phy.Mat (PM)[c]	7.9	23.9	45.5	67.5	96.7	65.3	100
Black Layer	7.8	22.0	39.6	69.9	97.6	68.1	104
PM less 18"[d]	7.8	22.0	42.0	69.7	98.2	68.5	105
Low ear Hyb[e]	7.7	31.4	52.7	61.8	81.2	50.2	77

[a]Average of Normal, waxy, low lignin, and opaques 2 hybrids- 10 yrs.
[b]24 days after 75% silk
[c]55 days after 75% silk
[d]Normal hybrids with 18 inches stalk left in field reduced by 220 lbs/A in 22 ton/A crop.
[e]Low eared hybrid at Phy. Mat. resembles high sugar corns.

Table 4. Equations used in determining digestibility, intake, energy, and Relative feed values.

Crop	Equation			
A. Legumes, Legume-grass mixtures and grass		R^2%	R	S^D
	DDM = 88.9 - 0.779 ADF%	77	.88	2.26
	DMI = 96.4-.0003 CP%-.0482 NDF%-.0085 NDF%	79	.89	6.22
B. Corn Silage				
	DDM = 429.6 + 12.087 ADF% - 133.4252 ADF%	83	.91	--
	DMI = -722.1 - 18.6 NDF% + 240.6383 NDF%	85	.92	--

C. DE Mcal/kg = 0.0027 + 0.0428 DDM%

D. RFV = (DDM x DMI)/65.2

E. Determine relative value

Cattle/Horses: Difference gm/Wkg$^{0.75}$ x kg animal wt
454 gm/lb = lbs/day difference intake[a]

Sheep/goats: Difference gm/Wkg$^{0.75}$ 1.75 x kg animal wt
454 gm/lb = lbs/day difference intake

[a]Each 3.5 gm/Wkg$^{0.75}$ = one pound per day change in intake.

Table 5. Influence of ADF and NDF on WISPLAN ration formula.

A. ADF Influence on minimum TMR proportion forage

Type Cow	Minimum Percent Forage in TMR with					
Forage ADF%	25	30	35	40	45	50
Milking	63	53	45	40	35	32
Dry	98	81	70	61	54	49

B. NDF influence on maximum proportion forage in TMR.

Lactation	Maximum percent forage in TMR with					
Forage NDF%	40	45	50	55	60	65
Early	65	58	52	47	43	40
Mid.	80	71	64	58	53	49
Late	95	84	76	69	63	58
Dry	100	100	100	91	83	77

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PROTEIN IN ZOO ANIMAL DIETS

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INTRODUCTION

Proteins are essential components of animal tissues and are found in high concentrations in muscle, bone, eggs, hooves, hair, antlers and horn. Proteins are synthesized by all animal cells and serve many different functions. Hormones, enzymes, antibodies and catalysts are proteins. Collagen in connective tissue, elastin in arteries, keratin in hair, hemoglobin in blood and myosin in muscle are all specific proteins vital to the structure and function of tissues. Proteins are also present bound to carbohydrates and fats, forming specific compounds that have essential functions.

Reference is often made to an animal's dietary protein requirement, but at the tissue level, specific amino acids, not specific proteins, are required. A protein consists of amino acids that are linked together in specific sequences to form a characteristic protein. All amino acids contain nitrogen, carbon, hydrogen and oxygen. Cystine, methionine and taurine also contain sulfur. When protein in food is ingested, the body uses these constituent parts of the protein, the amino acids, to manufacture the specific proteins essential to cell function. All of the protein we eat is first broken up in the gut by digestive enzymes so that individual amino acids, and paired amino acids (dipeptides) can be absorbed by the mucosal cells. The amino acids enter the circulation and travel to target tissues where they are used by cells to synthesize proteins. In adult mammals, proteins typically cannot be absorbed intact as entire molecules. In some suckling animals, immunoglobulins found in colostrum are absorbed through the intestinal wall during the first few hours of life. This phenomenon is short-lived however, but apparently serves an important function in conferring passive immunity to young whose immune systems are not fully functional.

There are approximately 22 amino acids present in proteins. Some of these are considered dietary essential amino acids, i.e. they cannot be synthesized by the animal and must be ingested. The exact number of amino acids that are essential varies somewhat with the species. For example, most mammals require 10 amino acids, but the domestic cat, and perhaps other felids, also require taurine (National Research Council, 1986). Taurine is unusual because it is a free amino acid not found as part of protein. During growth, the young of some species have requirements for amino acids that disappear when the animal reaches maturity or when growth slows. Birds also have somewhat different amino acid requirements.

Dietary protein is just one of the nutrients of concern when formulating zoo animal diets. In the absence of established requirements for exotics, we must estimate appropriate dietary concentrations of protein by comparison to data on domestic species. In this presentation, I will not directly address the ways in which we estimate requirements. Instead, I will focus on some commonly asked questions about protein, foods and zoo animals. Should we feed our wolves the same diets as we feed our tigers? Do ruminants really require less protein than non-ruminant herbivores? Should we feed vegetables to primates, rather than fruits? There are no definitive answers to these questions, but armed with an increased awareness of the composition of foods and animal physiology, more appropriate decisions about diets can be made.

<u>PROTEIN AND CARNIVORES</u>

There are idiosyncrasies about the nutrient requirements of the cat that set it apart from other animals that have been studied, including the domestic dog. The most obvious differences occur in nitrogen and amino acid metabolism. The kitten requires higher levels of most essential amino acids than puppies, even though they grow at about the same relative rate. The adult cat requires 3 times the level of dietary protein as compared to the adult rat, human and dog (Rogers and Morris, 1982). In the cat liver, some of the enzymes that prepare nitrogen for excretion cannot adjust to variations in dietary protein levels. When low-protein diets are consumed, the cat still excretes large amounts of nitrogen. In the dog, these enzymes can adjust to changes in protein levels, conserving nitrogen when it is limiting. Canids and more omnivorous carnivores seem to have more flexible biochemical responses which may relate to their need to subsist at various times on plant materials rather than animals.

The cat is especially sensitive to a deficiency of the amino acid, arginine. Arginine synthesis occurs in the cat, but at a much lower rate than in most other mammals. In the wild, felids obtain large amounts of protein and amino acids from vertebrate prey, so there is little disadvantage to higher requirements for such an obligate carnivore.

Cats are also unique in that they require relatively high levels of the sulfur-containing amino acids, cystine and methionine. This is apparently related to their need for taurine. Taurine is a non-essential amino acid for most other species that have been studied. It appears that cats cannot synthesize enough taurine from cystine and methionine to satisfy their requirements. Although a precise dietary requirement has not yet been established, it is recommended that taurine levels in the diet be 400 mg/kg of diet for the kitten and 500 mg/kg of diet to support reproduction. Taurine deficiency in the cat causes feline central retinal degeneration (FCRD) which is characterized by retinal lesions, reduced visual acuity and loss of vision (National Research Council, 1986). It has also been reported recently that taurine will prevent acute cardiomyopathy in the cat (Pion et al., 1987). In a group of leopard cats (Felis bengalensis), signs of taurine deficiency occurred even though the canned diet fed contained three times the recommended level (Howard, et al., 1987). Degenerative changes in the retina were noted and plasma taurine levels were extremely low. Cats were subsequently fed a commercial, frozen feline diet and plasma taurine levels increased significantly. The reasons for development of taurine deficiency signs, in spite of high dietary levels are unclear. It is suspected that there may be nutrient interactions peculiar to the canned diet that render taurine either poorly available or hasten its excretion.

The reasons that we feed cats high protein diets should be clear. Yet diets similar in protein content are often fed to zoo canids. Some commercially available dog foods contain 50% protein (dry matter basis) (M. Allen, unpublished data) which is far in excess of the established requirements of the growing puppy (National Research Council, 1985). If such diets are diluted with other foods, such as vegetables or low-protein dog kibble, the overall protein concentration could be reduced somewhat. There may be deleterious effects of chronic consumption of high-protein diets at least among old animals with compromised renal function (Lewis and Morris, 1984).

Excessive excretion of cystine by humans and dogs is due to an inherited defect. The cystinuria seen in maned wolves (Chrysocyon brachyurus) may also have a genetic component. In a study of captive and wild maned wolves in South America, 34 out of 42 animals had high urinary cystine levels (Bovee et al., 1981). Cystine stones were present in 4 wolves and three died due to urinary obstruction.

Animals that are herbivorous tend to produce alkaline urine. Urine pH tends to be acidic in animals that consume high-protein diets (National Research Council, 1986; Coles, 1986). Cystine stones are relatively insoluble in urine with an acid pH. In dogs with cystinuria, management usually includes maintaining a urine pH of 7.5 or higher. Sodium bicarbonate has been used to produce a more alkaline pH in cystinuric dogs (Lewis and Morris, 1984; Treacher, 1966).

Although there may be a genetic predisposition to cystinuria in maned wolves, there is some evidence that increasing dietary protein levels will increase the amount of cystine in the urine, at least in cystinuric dogs (Hess and Sullivan, 1942). Maned wolves are reported to be quite omnivorous in the wild (Dietz, 1984). It would seem reasonable to lower the dietary protein fed to captive maned wolves in an attempt to increase urine pH.

PROTEIN AND RUMINANTS

The ruminant animal is equipped with a foregut fermentation system which enables it to effectively utilize plant fiber. The presence of appropriate numbers and kinds of microbes (bacteria and protozoa) in the rumen supports the proper function of this digestive organ. These microbes, through the action of enzymes, can attack and degrade plant fiber.

Another important function that the rumen microbes perform is the synthesis of amino acids for the host animal. Enzymes produced by these bacteria degrade ingested proteins into their constituent amino acids. These amino acids can be used directly by bacteria or be broken down further, releasing ammonia. The ammonia can then be used by the bacteria for amino acid synthesis. The amino acids and protein synthesized by rumen microbes become available to the ruminant. When we feed a ruminant, we are really feeding the bacteria in the rumen, which in turn are food for the host animal. Microbial protein synthesis, and degradation of plant fiber, are also important to such ruminant-like species as leaf-eating primates, camels and macropod marsupials.

One of the reasons to recommend slow diet change in ruminant animals is that the rumen houses millions of microbes. The types and numbers of microbes that occur in the rumen differ with changes in types of feeds fed (VanSoest, 1982; Hungate, 1966). Sudden dietary change may cause the rumen environment to change rapidly (e.g. change in pH), resulting in the death of many bacteria and an overall disruption of this "ecosystem". When new feeds are introduced slowly, there is less chance of a digestive disturbance. Shifts in microbial populations will occur, although at a slower rate.

Non-protein nitrogen sources are typically added to the rations of many domestic ruminants, since microbes can use nitrogen for amino acid synthesis. This practice helps reduce feed costs since non-protein nitrogen is less expensive than intact protein. Ruminants have specific amino acid requirements but these can be met by the amino acids contained in, and produced by, the microbes. The use of urea and other sources of non-protein nitrogen is not recommended in diets for zoo ruminants. These compounds can be toxic if amounts fed are not carefully controlled. Animals must be gradually acclimated to the addition of urea.

In general, ruminants do not have lower protein requirements than do animals with hindgut fermentation systems, but they can effectively use non-protein nitrogen to help meet their needs for protein and amino acids (National Research Council, 1984; 1985; 1989). Amino acid production also occurs in the hindguts (ceca and large intestines) of herbivores such as the horse, rabbit and some rodents due to the action of microbes.

Because amino acids are absorbed in the small intestine, amino acids synthesized in the lower gut are of little benefit to the host animal. However, animals that reingest their feces (corprophagy) may benefit from ingestion of amino acids produced by microbes in the hindgut.

PROTEIN AND PRIMATES

Zoo primates are often fed "cafeteria-style" diets. Diets typically contain a commercially available primate biscuit or a canned primate diet with fruits and vegetables, insects, browse, seeds and sometimes nuts. The types of fruits and vegetables are often varied on a day to day basis to provide diversity and increase interest in food.

The protein requirements for primates are poorly defined. To satisfy protein needs for growth, New World primates are thought to require 25% crude protein on a dry matter basis (DMB) and Old World primates, 15% crude protein (DMB) (National Research Council, 1978). Although these estimates are based on limited data from a few species, they represent guidelines against which diets for zoo primates can be compared. Commercially available primate diets are usually formulated to contain between 15% and 25% crude protein (DMB). Most of these diets were designed to be used for laboratory primates that receive little supplemental produce, compared to zoo primates. If significant amounts of low-protein foods are fed to primates in zoos, it may result in a dilution of the protein, and other nutrients, in the final diet.

Foods selected by different species of wild primates include fruits, tubers, shoots, flowers and leaves as well as invertebrates and vertebrates, gums, eggs, seeds and nuts. In captivity the primate's natural diet cannot be duplicated, but we feed other items in addition to offering a commercial diet, in an attempt to mimic food choices in the wild. Insects and baby mice may be offered to tamarins and marmosets, and langurs and colobus usually receive some browse. However, it seems that fruits and vegetables are always included in zoo primate diets.

In a report of the composition of plants and plant parts consumed by wild western gorillas, Calvert (1985) observed that the wild fruits were very variable in protein content, with some fruits as high as 10 and 14% protein (DMB). Other plant parts consumed (shoots and leaves) were as high as 16 and 32% crude protein (DMB). In general, the preferred foods of the western gorillas had less lignin and more protein. In this light, it is interesting to examine the protein content of some of the produce items commonly offered to zoo primates (Table 1). Leafy vegetables contain two to six times the protein content of fruits. Root vegetables also contain more protein than fruits. These differences should be taken account when planning diets for zoo primates, especially animals that have increased dietary demands due to lactation and growth.

Table 1. Comparison of the crude protein (CP) content (DMB) of some fruits and vegetables fed to captive primates.

	% CP
I. Fruits	
Apple	2.1
Banana	3.8
Grape	2.9
Orange	5.8
Raisin	1.4
II. Root Vegetables	
Carrot	6.9
Onion	12.5
Potato	8.7
Sw. Potato	4.0
Turnip	11.9
III. Leafy Vegetables	
Cabbage	20
Celery	14
Kale	34
Lettuce	24
Spinach	34

Reference: Paul and Southgate, 1978.

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MARSUPIAL HERBIVORES AND FORAGE SUITABILITY

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INTRODUCTION

Like placental mammals, members of the order Marsupialia display a wide variety of feeding habits ranging from specialized carnivory to specialized herbivory. Although the processes of nutrient digestion, absorption and microbial fermentation are comparable between the two groups, unique behavioral, anatomical and physiological specializations of marsupials set them quite apart from placental mammals. These differences, as with all species, must be recognized in order to develop captive feeding regimes which satisfy known or estimated nutrient requirements.

This paper attempts to illustrate the diversity of digestive "strategies" among marsupial herbivores by citing specific examples including the koala, the wombat, and large and small macropod species. Additionally, physio-chemical characteristics of primary forages consumed by these species are discussed.

The ultimate goal of a captive feeding program is to meet known nutrient requirements through available feedstuffs at the lowest possible cost. Since natural feedstuffs are often not available, at least 3 factors must be integrated in order to estimate the most appropriate forage substitute:

1) nutrient requirements of the herbivore
2) nutrients supplied by the given forage, and
3) the processes utilized in assimilating those nutrients.

BASIC PHYSIOLOGY

A primary difference between marsupial and eutherian mammals is a lower basal metabolic rate (BMR) in marsupials (Nicol, 1978), with the marsupial mean approximately 70% that of eutherians of similar body mass. Complicating that generalized statement is the fact that preferred habit and/or diet appear closely correlated with BMR in both marsupials and placentals. The preponderance of desert-dwelling marsupial species among those most extensive studied may, in fact, influence this generalization because mammals inhabiting arid areas are known to display lower BMRs than more mesic-zone counterparts. The relationship between climate and BMR, however, remains to be firmly established.

Nonetheless, it appears that marsupials in general have lower BMRs, maintenance energy and nitrogen requirements, and lower rates of water turnover than placentals of similar body mass (Hume, 1982).

GUT ARCHITECTURE

The utilization of plant cell wall constituents as an energy source requires microbial fermentation, since mammalian enzymes cannot break the carbohydrate linkages of cellulose. Thus herbivores display a wide variety of gut modifications for harboring a microbial population. Van Soest (1982) discusses body mass and the site of fermentation in a number of placental herbivores. In general, very small (< 10 kg) and very large (> 1000 kg) mammals are hindgut fermenters, whereas foregut modification primarily occurs in mid-weight ranges.

Marsupial herbivores also display both hindgut and foregut modifications wherein microbial fermentation occurs, although to a more limited extent than placentals due to: 1) fewer species of marsupial herbivores and 2) the absence (extinction) of Australian megafauna.

HINDGUT FERMENTATION

Microbial fermentation occurs to some extent in the hindgut of all herbivores. Extreme development of the cecum, colon, or both is found in all members of the marsupial families Phalangeridae, Phascolarctidae, and Vombatidae.

KOALA

Clearly the most popular marsupial hindgut fermenter is the koala (*Phascolarctos cinereus*), which is remarkable for its strict diet consisting almost exclusively of Eucalyptus leaves --a fact well known to most zoos that don't have a ready source of these trees.

The digestive tract of the koala shows extensive development of both the cecum and the proximal colon (Figure 1 (a)). Digestible dry matter intake of the koala is low, approximately 25 g x kgBW $^{-.75}$ X DAY $^{-1}$ (Cork, 1981), suggesting a low energy requirement. Dietary nitrogen requirements are approximately 280 mg N x kg$^{-.75}$ x day^{-1}.

Passage of digesta through the koala gastrointestinal tract (GIT) is the slowest measured in any marsupial -- a further indication of low metabolic rate. Cork et al. (1977) measured a mean retention time (MRT) of 110 hours for particulate matter and 251 hours (extremes up to 739!) for fluid. Liquid and small particles were selectively retained in the cecum and proximal colon. In part, this action may function in water resorption, but it also significantly affects forage digestion.

In examining the chemical composition of Eucalyptus foliage (Figure 2), it is apparent that very few differences occur even with species, seasonal and maturity variation among trees sampled. Furthermore, no chemical parameters consistently distinguish rejected versus consumed forage in various studies.

Cell wall constituents comprise no more than 40% of total dry matter for Eucalyptus forage. Thus, by chemical analysis, Eucalyptus is not a particularly fibrous feed. However, 35 - 45% of the total cell wall fraction (NDF) analyzes as lignin -- an indigestible feed fraction (Van Soest, 1982). Thus, only 55-65% of the cell wall is potentially available to supply energy to the koala via microbial fermentation, or approximately 26% of the total dry matter of Eucalyptus forage.

Cell contents, on the other hand, comprise 50 - 80% of Eucalyptus foliage, with crude protein a minor proportion of total dry matter (< 10%). Thus the major component of Eucalyptus foliage is the soluble organic fraction including lipids, soluble sugars and phenolics.

Fermentable phenolics and essential oils require extended time for microflora adaptation and action (Van Soest, 1982) thus, the extended and selective retention of solutes in the koala cecum may be the mechanism by which this species utilizes its specialized diet. In support of this, Cork (1981) found that phenolics, lipids and soluble sugars contributed 10 - 20% of total digestible energy.

This understanding of digestive physiology and anatomy in the koala is valuable in developing a captive feeding regime. Perhaps more important, however, are behavioral considerations. Thus far, no suitable substitute for eucalyptus foliage has been identified, and likely will not be until we understand the basis for feed selection in this species.

In this regard, components of the cell contents should be more closely examined. The koala produces specialized cecatrophs (fecal pellets originating from cecal contents) which are consumed by the offspring only at weaning. Although it has been suggested that gut inoculation is the major function of such cecatrophy (McBee, 1971), another possibility is that behaviorally, the young are being imprinted with sensual (odor and/or taste) cues important for later diet selection.

<u>WOMBAT</u>

The wombat is an example of a colonic fermenter. There are two species of wombat in Australia -- the common wombat (<u>Vombatis ursinus</u>) and the hairy-nosed wombat (<u>Lasiorhinus latifrons</u>). Common wombats inhabit moist, forested regions of eastern Australia and Tasmania whereas the hairy-nosed wombat is found with limited distribution in arid and semi-arid zones. Wombats are the largest burrowing mammals -- up to 35 kg in weight. Very few are exhibited in zoos outside of Australia, with Brookfield and Toronto the only North American exhibitors.

Wombats have a dental structure that is unique among the marsupials, possessing a single pair of upper and lower incisors (similar to rodents). All teeth grow continuously throughout the lifetime.

The digestive tract of the wombat is shown in Figure 1 (b). The cecum is almost non-existent, whereas the proximal colon is extremely enlarged. Seventy-five percent of gut contents (on a wet weight basis) are contained in the colon-- a specialization likely developed for the resorption of water. Wombats do not normally consume free water, and fecal pellet moisture can be as low as 40%.

The metabolic rate of the hairy-nosed wombat is the lowest measured in any marsupial, as are rates of water turnover (Wells, 1973). Along with the low metabolic rate (and similar to the koala) is an extreme digesta MRT of 95-210 hours, depending on level of intake ranging from 5-32 $g \cdot kgBW^{-.75} \cdot day^{-1}$ (Wells, 1973). Liquid passage has not been examined in this species, but no mechanisms for differential retention of particulate and liquid fractions are currently being investigated in the common wombat (Hume, personal communication). Passage should be faster in this species than the hairy-nosed wombat based on earlier observations of 48-144 hours (Honigmann, 1936, from Hume, 1982).

Most field studies of wombats indicate that they are primarily grazers, and their digestive tract and physiology seem particularly well suited for the consumption of grasses. The chemical composition of various stages of growth of a major forage (Stipa nitida) of the hairy-nosed wombat near Blanchetown in South Australia is shown in Figure 3.

Total cell wall constituents (CWC) comprise 40-60% of dry matter. An average of less than 20% of CWC comprises the lignin fraction, regardless of stage of growth. Grasses, as a group, possess the most available (least lignified)CWC among forages. Thus extended retention of grass forages in the gut of the wombat would result in extended fermentation of CWC, as opposed to the example of Eucalyptus previously discussed, where 50% of the cell wall is unavailable regardless of length of exposure to fermentation. Grasses are suitable as a forage for the wombat for two major reasons: 1) the low nitrogen requirement of the wombat would be met, even with hayed off, dead grass and 2) the slow fermentation rate of grasses would supply a contiguous energy source as volatile fatty acids (VFA) even on limited intakes.

Observations from a field study of the hairy-nosed wombat under conditions of severe drought (Dierenfeld, 1984) indicate that the animals will browse extensively when grasses are not available. However, intakes are greater when consuming browses over grasses. Studies on rates of microbial fermentation of browse plants and concentrates such as fruits and vegetables or alfalfa suggest that these forages ferment more rapidly than grasses, and/or are more variable in extent of fermentation. The hairy-nosed wombat, with its low basal metabolic and digesta passage rates, does not require and cannot economically utilize these more rapidly fermenting substrates.

Fresh grasses are particularly relished. Free-ranging wombats graze closely in a circular pattern surrounding the warren system, consuming succulent daily growth from which they obtain water and other nutrients. Thus grass forages, although possessing the lowest nitrogen and highest cell wall contents of typical zoo feedstuffs, supply adequate nutrients to the wombat, an animal adapted to low quality and, more frequently, low quantity, feed supplies.

FOREGUT FERMENTATION

Aspects of the digestive physiology of marsupials with foregut specializations have been studied more extensively than hindgut fermenters (see Hume, 1982). The digestive process in these marsupials has often been compared to rumination; however, a number of significant differences are apparent.

First, marsupial herbivores don't ruminate, or chew cud. Regurgitation of food boluses and periodic jaw movements have been observed in macropod marsupials (both captive and wild feeding situations), but the irregular process has been termed merycism in these animals. Marsupials appear to initially masticate their feed to a finer particle size than ruminants of similar body mass. The function of merycism, then, may be increased saliva flow to aid in stomach buffering and/or microbial substrate delivery, but is presently not clear.

A second major difference between marsupial foregut fermenters and grazing ruminants of similar body mass is the retention of digesta in the stomach. Digesta remains in the stomach longer than any other gut part in both these groups of herbivores, but overall retention time is longer in ruminants. Thus the extent of digestion of the same feed by marsupials is generally slightly less than ruminants.

Finally, anatomically, the stomachs of macropod marsupials and ruminants are very different. Marsupials possess no omasal orifice through which ingesta of a maximal particle size may pass. This fact alone frees marsupials from feed quality intake restrictions common within ruminants. Interrelationships among these three factors are currently being assessed in a variety of both ruminant and marsupial studies.

The diversity of stomach anatomy within ruminants has been illustrated in an excellent monograph by Hofmann (1973), who classified numerous East African ruminants as concentrate selectors, intermediate feeders, or bulk and roughage eaters based upon rumen papillation and omasal structure factors. Sanson (1978) similarly separated marsupial foregut fermenters into grazing, browsing and intermediate grade feeders (Table 1); however, his classification system was based primarily upon tooth structure. Teeth of grazers have a cutting action on feed; those of browsers tend to crush. Stomach morphology also varies among these macropod marsupial herbivores, as will be illustrated.

GRAZERS

Large macropod marsupials are grazers, and most studies of diet selection and physiology compare them with sheep of similar size. The stomach of Macropus giganteus, the Eastern grey kangaroo, is illustrated in Figure 1 (c). Three segments of the stomach have been defined -- the saccular, tubular and glandular sections. Hydrochloric acid and pepsin secreting glands are only found in the glandular portion of the stomach, whereas microbial fermentation occurs in the two forestomach segments. The tubular section holds approximately 72% of total stomach capacity in this species (Langer et al., 1980).

Maintenance dietary nitrogen requirements for M. giganteus have been calculated at 350 $mg \cdot kgBW^{-.75} \cdot day^{-1}$ (Foley et al., 1980). Energy requirements have not been measured directly, but intake figures from several studies (i.e. Foot and Romberg, 1965; Hume, 1974; Dellow, 1979, from Hume, 1982) suggest maintenance requirements are approximately 80% of those of sheep of similar mass. These requirements can be fulfilled in captivity by feeding any good quality forage (either grass or legume) at a level of 50-55 $g \cdot kgBW^{-.75} \cdot day^{-1}$. Kangaroo pellets comprised primarily of alfalfa are popular in Australia for feeding pet kangaroos and laboratory animals.

Requirements for the Western grey kangaroo (M. fuliginosus) can only be inferred from limited laboratory and field studies (Dierenfield, 1984; Wells et al., 1984) and comparison with the most similar species, M. giganteus. Free-ranging Western grey kangaroos inhabit harsher habitats and browse poorer quality forages than has been reported for the Eastern grey kangaroo, particularly during drought. They may, in fact, have lower nitrogen and energy requirements than Eastern greys; however, laboratory studies are needed to confirm that hypothesis. Thus any diet suitable for M. giganteus would likely be adequate for M. fuliginosus.

Also primarily a grazer, the red kangaroo (M. rufus) differs significantly from the grey kangaroo(s) in nutrient requirements, feeding behavior and overall physiology. Free-ranging red kangaroos meet their relatively high dietary nitrogen requirement of approximately 800 $mg \cdot kgBW^{-.75} \cdot day^{-1}$ (calculated from the data of Foot and Romberg, 1965; Forbes and Tribe, 1970; and Hume, 1974) through selective feeding habits coupled with fairly stringent habitat requirements. Red kangaroos select fresh green grasses or chenopod shrub leaves only, even when quantities are quite limited.

In captivity, then, red kangaroos should be allowed to express their selective abilities by offering them high quality and morphologically differentiated forages. Green leafy forages and even hydroponics are highly preferred; pelleted feeds should contain high quality nitrogen sources of at least 12-15% crude protein. Large macropods, as a group, can be adequately maintained on high fiber diets, but at least the red kangaroo requires a higher nitrogen feed than ruminants. Non-ruminant herbivore pellets should supply these nutrients adequately.

The MRT of particulate matter is between 30-50 hours for both M. giganteus and M. rufus (Hume, 1982). Solutes appear to travel along the gastric sulcus on the inner curvature of the stomach, as determined by radiographic studies (Dellow, 1979, from Hume, 1982). This separation and differential retention of digesta occurs only in the stomach.

BROWSERS

Most wallabies and the tree kangaroos are categorized as browsers (see Table 1). Thylogale thetis, the red-necked pademelon, represents a browsing macropod species. Johnson (1977) found them to be highly selective feeders, consuming soft, low fiber herbs, grasses and succulent shrubs -- never dry feeds.

The stomach structure of T. thetis (Figure 1 (d)) indicates that the sacciform section is the largest subdivision of the stomach, containing >52% of ingesta (Langer, 1979, from Hume, 1982). This enlarged forestomach segment may provide a greater surface area for the absorption of VFA from rapidly fermenting substrates as those consumed by the pademelon. Passage is rapid, with the MRT of particulate ingesta 24 hours, and liquids, 11 hours (Hume and Dellow, 1978).

The nitrogen requirement of T. thetis is 600 mg$\cdot$kgBW$^{-.80}\cdot$day^{-1}, more than twice that of other macropod species except the red kangaroo. It appears that this species can't cope with seasonally limited feed quality or quantity. In captivity, T. thetis should be fed high quality legume hays, fresh forages including leafy vegetables, and/or other feeds high in nitrogen with rapid fermentation characteristics.

Little is known of the natural diets of other browsing species, with the exception of Wallabia cicolor and Setonix brachyurus (Hume, 1982). Studies of those species indicate that the animals consume small quantities of a variety of succulent forb and shrub species year-round. Stomach structure varies somewhat among these species, but the saccular forestomach is the largest single compartment.

VEGETATION CHARACTERISTICS

The animal is only one-half of herbivore nutrition. Understanding forage characteristics is also essential to successfully manipulate animal-plant interfaces. Knowledge of chemical composition is important, but can be incomplete by itself.

Cellular contents, including (but not limited to) nitrogen, soluble carbohydrates, fats and oils can be assumed to be almost completely (85-100%) available for digestion by any given herbivore (Van Soest, 1982). Thus, percentages in the diet multiplied by total dietary intake are good indicators of these nutrient supplies.

A major energy source for herbivores, however, comes from VFA produced through the fermentation of cell walls. At least three factors influence microbial fermentation of cell walls: microbial attachment, rate of fermentation, and extent of fermentation. Variation in any one of these factors (which are characteristics of the substrate or forage source) can substantially alter diet digestibility and, subsequently, nutrient supply to the herbivore (see Figure 4).

Microbial attachment and in vitro rates of fermentation of grasses are, in general, slower but less variable than those of browses, fruits and vegetables (Van Soest, 1982). However, the lignification of cell walls determines the potential extent of fermentation when passage factors allow. Although slower, the overall fermentation of grasses may provide more total VFA for energy per unit substrate, given no time constraint. It is in this manner that digestive anatomy, related passage of digesta, and forage consumed must be considered and examined in more depth.

SUMMARY

Diversity amongst marsupial herbivores has been examined with respect to both animal and plant characteristics. Balancing the physiological as well as psychological nutrient needs of the animal with available vegetation in a captive situation should be not only possible, but highly successful, provided the limitations of both systems are recognized.

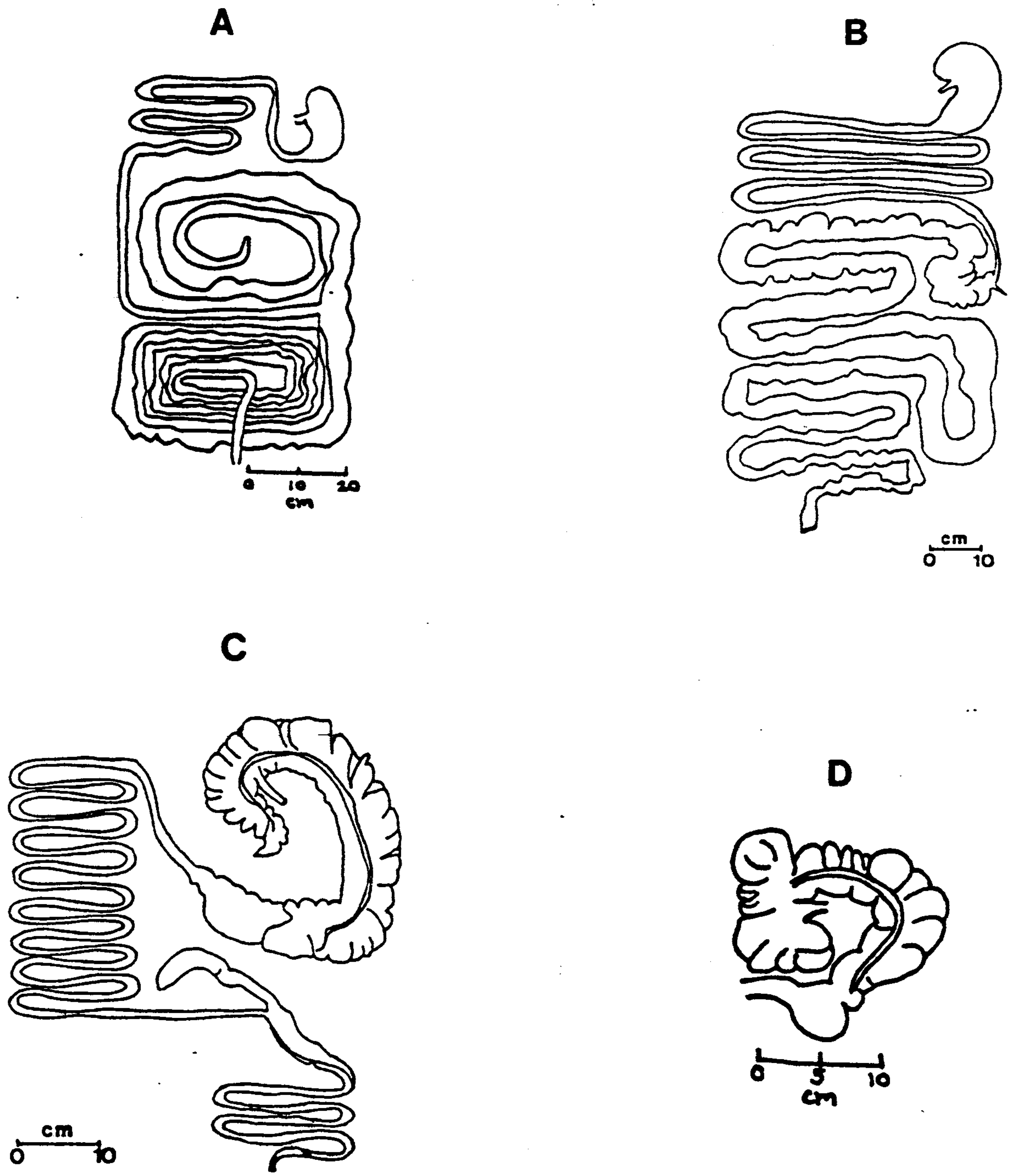

Figure 1. Digestive tracts of the koala (A), the hairy-nosed wombat (B), the eastern grey kangaroo (C), and stomach of the red-necked pademelon (D).

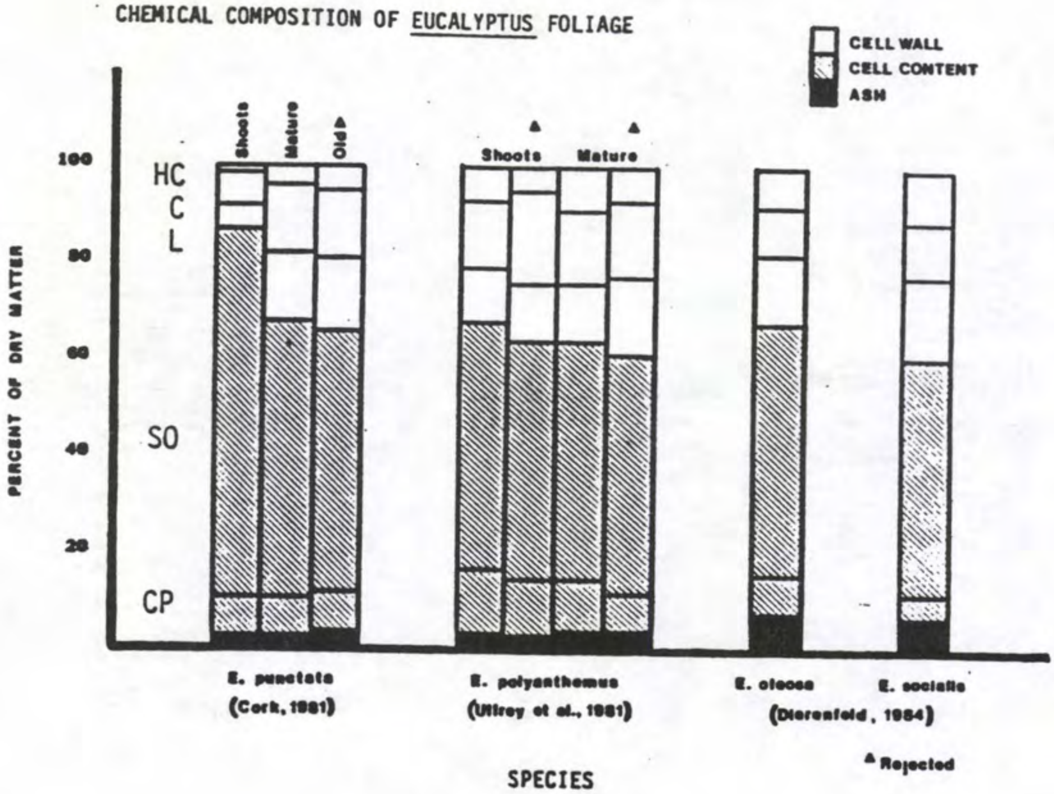

Figure 2. Cell wall constituents include hemicellulose (H), cellulose (C) and lignin (L). Cell contents include soluble organics (SO) and crude protein (CP) fractions.

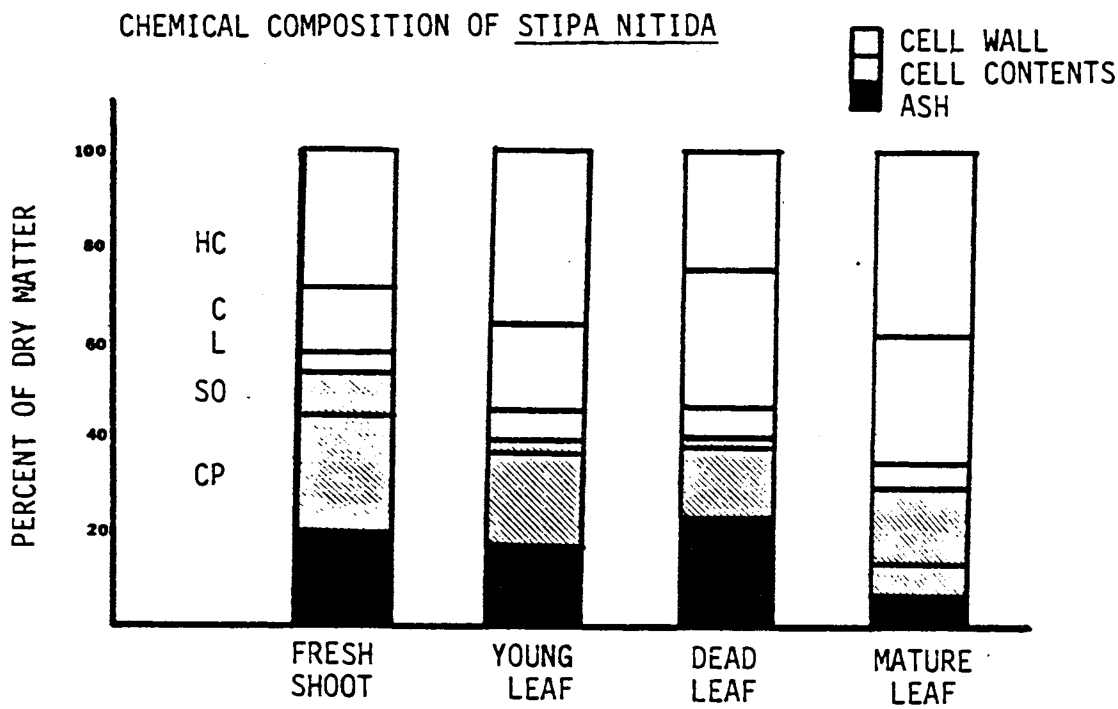

Figure 3. Chemical composition of speargrass. (Symbols as in Figure 2.)

Table 1. Feeding habit classification of macropod marsupials based on tooth structure.

Browsing Grade	Intermediate	Grazing Grade
Wallabia	Petrogale	Macropus
Dorcopsis		Peradorcus
Dorcopsulus		Onychogalea
Dendrolagus		Lagorchestes
Thylogale		
Setonix		
Lagostrophus		

After Sanson (1978).

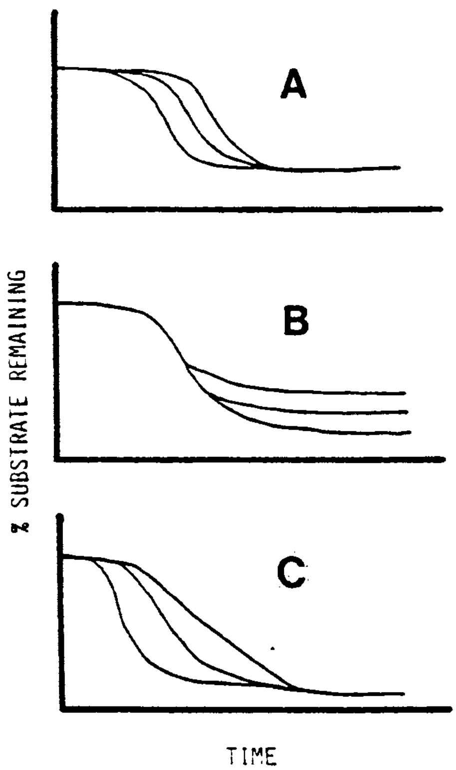

Figure 4. Theoretical forage fermentation curves altered by: A) microbial attachment; B) lignification; and C) rate factors.

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DO ZOO ANIMALS NEED TO SEE THE SUN?

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The conservation of endangered animal species is a primary raison d'etre for all major zoos. Thus, such zoos attempt to provide an environment that will maintain adults in good health and that will support reproduction and successful development of young. In cold seasons and climates, subtropical and tropical species must be protected from low temperatures and are usually housed indoors, often without sunlight exposure. Skylights or windows may be used, but they are commonly made of materials that don't transmit the typical solar spectrum. In particular, most glass excludes wavelengths below 330 nm. As noted below, light in the range of 285-315 nm is particularly important in the photobiogenesis of vitamin D. Thus, we suspect that many of the persistent problems with rickets in nursing new-world primates are due to a failure of photobiogenic conversion of provitamin D_3, 7-dehydrocholesterol, to previtamin D_3 and ultimately to vitamin D_3 itself. If solid foods containing vitamin D are not consumed or if mother's milk is low in this nutrient, then vitamin D deficiency might be expected.

A typical case of rickets was seen in a Bolivian red howler (Alouatta seniculus) infant born in an exhibit without sunlight exposure. The mother's ration included a commercial primate diet plus various fruits and vegetables. The primate diet was not relished and there was some question about the amount consumed. The infant nursed exclusively for five months, ate very little solid food subsequently, and did not choose vitamin D-containing dietary items.

The hypothesis developed from consideration of the above and similar cases, plus current knowledge of vitamin D metabolism, is that howler monkeys, like other new-world monkeys (Hunt et al. 1967), do not use vitamin D_2 effectively. Since they are strictly vegetarian (Braza et al. 1983), dietary intakes of vitamin D_3 sources in the wild are unlikely. Thus, they are dependent for their vitamin D supplies upon photobiogenetic conversion of vitamin D precursor in the skin. Howler milk, like cattle and human milk (Hollis et al. 1981, Reeve et al. 1982), is probably low in vitamin D-active compounds and does not respond efficiently to increased levels of vitamin D added to the diet of the lactating female. As a consequence, nursing howler infants must have exposure to sunlight or to artificial light with a radiant spectrum in the range of 285-315 nm.

Rickets was a major medical problem among human infants as the nineteenth century turned into the twentieth. Suggestions as diverse as heredity and syphilis were proposed as causes of this debilitating disease (Norman 1979). Ultimately, it was established that rickets could result from a lack of sunlight or a deficiency of a fat-soluble dietary factor. Early in this research it was noted that "a map of the incidence of rickets (was)...the practical equivalent of a map ...of deficiency of sunlight" (Hess 1929), and Huldschinsky (1919) demonstrated that rickets could be effectively treated by ultraviolet rays. At about the same time, Mellanby (1921) produced rickets in puppies when they were raised indoors on a high-cereal, low-fat diet. If cod liver oil or butterfat were added to the diet, rickets were prevented, Mellanby suggested that the effective factor was vitamin A. This proved not to be the case, and the distinction between vitamin A and the antirachitic factor came when McCollum (1922) showed that vitamin A was destroyed by aerating and heating cod-liver oil to 100°C for 14 hours, while the antirachitic factor survived. He named this factor vitamin D.

In succeeding years, the photobiogenesis of vitamin D_3, cholecalciferol, in cutaneous tissues was described. Figure 2 represents current understanding of this phenomenon. Provitamin D_3, 7-dehydrocholesterol, in the malpighigian layer of the epidermis, is converted to previtamin D_3 by UV irradiation in the range of 285-315 nm, with maximum conversion at 297 (Holick et al. 1982) to 303 nm (Takada et al. 1979). Previtamin D_3, in turn, undergoes thermal isomerization to vitamin D_3 at a skin temperature of 37°C. Vitamin D_3 attached to a binding protein is transported in the blood plasma to the liver where it is hydroxylated to 25-OH-D_3. Further hydroxylation to 1,25-$(OH)_2$-D_3 takes place in the kidney. It is this compound which appears most active in promoting intestinal calcium and phosphate absorption and osteoclastic-mediated bone resorption. Other vitamin D_3 metabolites, with differing biological activities and significance, have been described by DeLuca and Schnoes (1983).

In 1924, Steenbock and Black noted that UV irradiation of a diet fed to rachitic rats resulted in a cure of rickets, but the same diet without irradiation had no effect on the disease. Subsequently, it was discovered that the provitamin, ergosterol, present in plant tissues like those in the rat diet, could be converted to vitamin D_2, ergocalciferol, by UV exposure. Still later it was determined that vitamin D_2 undergoes hydroxylation in the liver and kidney of mammals as does vitamin D_3.

Thus it was established that certain vertebrates may have the option of deriving vitamin D need from exposure of the skin to the sun or by consuming vitamin D-active compounds from an irradiated vegetable diet. It should be noted that for this irradiation to be effective, the plant tissues should be dead. In the case of carnivores or omnivores, vitamin D supplies may also be derived from preformed vitamin D compounds in animal tissue, potentially both vitamin D_2 and D_3.

The evolutionary significance of the relative ability of 63 vertebrate species to bind vitamin D_2 or D_3 to plasma transport proteins has been investigated by Hay and Watson (1977). If vitamin D binding to plasma proteins correlates with the biological usefulness of the vitamin compounds, then their findings are relevant to the problem under consideration. All species of fish, reptiles and birds which they studied bound vitamin D_2 with considerably less efficiency than vitamin D_3. This was true also for a mammalian monotreme, the tasmanian echidna. Other mammals which bound vitamin D_2 with somewhat less efficiency (10-30%) than D_3 were Bennett's Wallaby, European hedgehog, large tree-shrew, agoutis, lion, tiger, bactrian camel and goat. Other mammals, such as rats, pigs and calves recently have also been found to metabolize oral vitamin D_2 and D_3 differently, with significant discrimination against vitamin D_2 (Horst et al. 1982, Sommerfeldt et al. 1983). In any case, Hay and Watson (1977) speculated that vitamin D_2 may have a very limited role in vertebrates other than mammals. If true, this poses a particularly difficult problem for non-mammalian vertebrates that are nocturnal or insectivorous. Ergosterol is an essential sterol for many invertebrates (Bills 1954, Gilmour 1961), and it appears that irradiation of some invertebrates produces an antirachitic effect in rats, similar to vitamin D_2 (Van der Vliet 1942, Rosenberg and Waddell 1951). However, it is not clear whether invertebrates provide vitamin D_3-like compounds. Considering the poor performance and high incidence of rickets in heliotrophic, insectivorous lizards such as the giant day gecko (Phelsuma madegascariensis), when solar radiation is not provided, it is likely that artificial lights including wavelengths of 285-315 nm are essential to meet vitamin D needs.

Some preliminary data on the spectral transmission characteristics of skylight materials have been obtained through the assistance of S.E. Kaupp, National Marine Fisheries Service, Southwest Fisheries Center, La Jolla, CA, M.A. Strzelewicz of Michigan State University and of R. Ruff, EG & G Gamma Scientific, Inc., San Diego, CA. Polyurethane-fiberglass, acrylic fiberglass, acrylic double skin and xcelite double skin do not transmit light effectively below 370 nm. Vinyl transmits little light below 305 nm. Cellulose triacetate, plexiglass G-UVT (Rohm and Haas) and teflon do have potential to permit entry of biologically-effective UV radiation into animal exhibits.

Preliminary tests on a variety of artificial light sources indicate that few provide effective energy levels within the desired 285-315 nm range. On the other hand, unless screened with cellulose triacetate, the Westinghouse sunlamp emits radiant energy of sufficient intensity at wavelengths below 285 to be potentially dangerous (Setlow 1974).

Further research is urgently needed to solve these important problems. Studies are currently underway at the San Diego Zoo, and it is hoped that sufficient data will soon be available to provide practical guidelines for exhibit design.

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GASTROINTESTINAL DISORDERS OF ADULT ZOO MAMMALS

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Introduction

Food, or nutrition, in the widest application of the term means everything ingested that goes either directly or indirectly to the growth of the animal, to the repair of body tissues, or to the production of energy. A proper diet, therefore, must be one on which the animal will attain maximum development, maintain normal weight, breed and rear healthy offspring, and live out the full term of life. It is important to remember that all of these phenomena must continue when food is withheld or supplied in insufficient quantities for whatever the reason. Under these latter conditions, the process goes on at the expense of body tissues, as these tissues are protected from degradation only when the diet is adequate in every respect (Corson-White, 1923). Likewise, under these latter conditions the animal becomes more susceptible to disease and disorder. Thus, food in its chemical content must supply the needs of the animal, and must act as a protectorate. The war on understanding the chemical nature of food is being won, even in the areas of the exotic animals for which we have a common interest. But lest we forget, it is not only the chemical nature of food which determines its quality. In its physical properties, food must conform to the prehensile mechanics of the animal and to the morphological demands of each type of gastrointestinal system.

To evaluate fully the influence of food upon the individual animal, whether that influence be of good or bad character, it is necessary to understand the relationship of food to (1) the type of digestive system, (2) the type of bacterial fauna within that system, (3) the chemical needs of the animal, (4) the metabolic changes associated with various food sources and (5) the exercise, or more correctly the lack of exercise which we seen in captive animals, keeping in mind the constant interdependence of all factors. Within this presentation major emphasis will be given to the type of digestive system, the bacterial fauna, and the metabolic changes associated with altered food resources.

Varied studies on nutrition have shown that the chemical requirements of a diet are basically similar for all forms of mammalian life. That is to say the requirements for protein, fats, carbohydrates, per kilogram of metabolic body weight, are approximately the same for all animals. Why then the varied diets: While the chemical constituents of food define the basic needs, it is the morphological design of the digestive system which determines the physical properties of the diet.

Gastrointestinal Structure and Function

Were we to review the gross anatomical features of the digestive tract, as presented by Stevens and by van Hoven in the 1982 Dr. Scholl Conference, we would recall the marked variation in anatomical features. You may recall the simplistic nature of the carnivore's tract (Figure 1). Food derived from animal flesh is high in protein, moisture and often fat. It is readily digested, but also highly susceptible to putrification.

Quite often the food is consumed in bulk quantities and within a rather short time span. In these animals acute gastritis or gastroenteritis are of major concern.

Omnivorous animals occupy a position somewhat between the strict carnivore and the herbivorous creatures. Omnivorous diets are of a mixed nature, and most often consumed in a less gluttonous fashion than that of the carnivore. Likewise the tract is well suited for the diet providing for the consumption of smaller, more frequent meals, and for the retention of the somewhat less digestible constituents (Figure 2), yet too small for the bulky vegetative diet of the true herbivore. Among these omnivorous animals colitis is common due principally to the sluggish movement of contents within the distal segments of the tract.

Herbivorous animals make up the largest proportion of our captive mammals. The physical properties of the vegetative diet (i.e. the bulk) must be accommodated for by a large, voluminous digestive system. For many of these animals the accommodation is provided for by a very large foregut (Figure 3). The slowly degraded diet is retained for an extended period of time to enhance the digestive process. Note also that this group of herbivores tends to consume their diet within two or three rapid bouts of feeding throughout the daily cycle. For these foregut fermenters, bloat and acidosis are the principle digestive disorders. For the other group of herbivorous mammals, the bulky vegetative diet is accommodated for by either a large, voluminous cecum, or a large, voluminous cecum and colon (Figure 4). The foregut is less adapted to volume consumption, thus these herbivores tend to feed in a less volatile manner, yet at more frequent intervals. While bloat or acidosis are not of concern, impaction, torsion and colic are more prevalent.

Gastrointestinal Disorders

There are but a limited number of studies on disorders of zoo mammals. Most of these reports deal with specific mammalian orders or mammalian families. The single comparative study, although dated, provides for some informative insight as to the origin of digestive disorders (Table 1). These data clearly indicate the expected frequency of disorders relative to diet selection and suggest the possible cause(s) of these disorders. From the table it is obvious that gastrointestinal disorders far outweigh the frequency of all other pathological findings. Furthermore, acute gastrointestinal disorders are some five to ten times more prevalent than chronic disorders. In addition, we can see that such acute intestinal disorders are most prevalent in carnivores and least prevalent in herbivores. Thus, the zookeeper, zoo nutritionist and zoo veterinarian should be attuned to acute digestive problems. The questions we should be asking ourselves are (1) why the major difference between groups of mammals, and (2) what can we do to minimize these disorders.

Table 1. Pathological Findings of 1,860 Necropsied Adult Zoo Mammals

Disordered State	**Carnivora**	**Omnivora**	**Herbivora**	
			Fruits& Grains	**Succulent Vegetation**
Gastro-intestinal				
Acute	**63.2%**	**42.5%**	**35.9%**	**32.2%**
Chronic	**13.2%**	**5.4%**	**5.6%**	**7.7%**
Liver & Pancreas	**11.5%**	**4.4%**	**10.5%**	**4.6%**
Respiratory	**3.5%**	**32.6%**	**9.6%**	**3.5%**
Cardiovascular	**4.1%**	**4.7%**	**4.8%**	**1.5%**
Renal	**23.8%**	**13.6%**	**20.2%**	**19.4%**

From E.P. Corson-White, The Relation of Diets to Disease (1923)

It is my analysis that the factors attributing to the varied frequency and to the cause of the disorders are the combined effects of three components. They are the result of the prehensile mechanics of the animal, the opportunity for diet alteration and the design of the digestive system. We have the ability to at least influence factors one and two and the knowledge to understand the third.

Prehension & Gastrointestinal Disorders

Prehension is a rather foreign concept to most of us.

We tend to pay considerable attention to what the animal eats, have little concern for how the animal acquires food. Yet it is the prehensile mechanics that define the rate of ingestion, the size of the food item consumed and the ability of that animal to select or disregard specific food items. The more versatile the prehensile tools, that is the teeth, lips, tongue, fingers, trunk, etc., the greater the selective capacity of that individual. It is this selective capacity, the prehensile mechanics, which initiates many digestive disorders.

Primates have been most generously supplied with prehensile tools. For these omnivorous creatures the enhanced ability to select food items sets the opportunity for digestive disorders of two magnitudes. The first is that of acute gastroenteritis via the rate of consumption and the second is malnutrition via restricted consumption. It is important to recognize that both disordered states are principally the results of competitive feeding.

Animals reared in colonies develop social structures. The social rank often defines the feeding position. Such feeding behavior is not restricted to primates, nor even to omnivores, but is carried through for most mammalian species. As a result of social rank, the subordinate individuals are left with two alternatives: the first is to rush in and compete for food, the other to hold back and wait their respective turn. Under the former conditions, the subordinate individual must consume the food item rapidly if he is to enhance his intake potential and minimize the direct encounter with the more dominant individuals. Such subordinate individuals are under obvious stress. Both events, the stress of competition and the rapid food intake, incite gastric disorders. As a result, the observed incidence of acute digestive disorders correlates well with the prehensile mechanics of the animal and the willingness of that animal to compete for food.

Carnivorous mammals are highly competitive. Furthermore, their prehensile mechanics, although less selective than that of primates, provides for rapid, bulk intake. The stress of competition and the abrupt digestive demands associated with rapid food intake precipitate the more frequent acute gastritis in the carnivorous species (Table 1). Most omnivorous mammals, though possessing greater prehensile advantage, are somewhat restricted in their rate of intake. They are also less competitive in feeding habits than carnivores, although some degree of competition is undoubtedly present. As a result, acute digestive disorders are less prevalent in omnivores than in carnivores (Table 1). Subordinate omnivores tend to hold back more often and delay feeding until the superior, more dominant individuals have completed their meal. This behavior provides for a higher incidence of malnutrition and is again the direct result of prehensile mechanics. Thus, the ability of the dominant individual to select the choice, nutritious food items enhances the opportunity for the subordinate individual to become undernourished in both quantity and quality of food. For this reason, the incidence of malnutrition among mammals with versatile prehensile tools is several fold greater than among those with limited prehensile mechanics (Table 2). Herbivorous mammals are generally less susceptible to acute digestive disorders and to malnutrition due principally to their limited selective prehension and to their aggressive feeding behavior.

Table 2. Frequency of Malnutrition in Adult Zoo Mammals

Mammalian Order	Percent Malnourished	Number Necropsied
Primates	18%	288
Rodentia	17%	28
Carnivora	1%	164
Perissodactyla	4%	79
Artiodactyla	2%	143

From L.A. Griner, Pathology of Zoo Animals (1983)

When speaking in general terms we should be aware that exceptions are not uncommon, and that variations occur within mammalian orders, mammalian families and even species. For example, among rhinoceros the prehensile lip of the black rhinoceros allows this subspecies to be a select feeder (browser), while the flat nosed white rhinoceros has little ability for diet selection. Similarly, the captive black rhinoceros is several times more susceptible to digestive disorders than is its white counterpart.

Prehensile mechanics provide for the increased incidence of digestive disorders of yet another magnitude. For the captive animal quite often the greater selective capacity may enhance the incidence of pica, that is, disordered feeding and the consumption of foreign material.

Diet Alteration & Gastrointestinal Disorders

The second factor contributing to the varied incidence of digestive disorders is the opportunity for diet alteration. It is important at this point to note that gross pathological lesions of gastro-entero-colonic origin are similar for most mammals and birds. And that the occurrence of salmonellosis, colibaccillosis, clostridia, campylobacterisis, are not restricted to a select group of animals but can be found in most species of mammals whether they be herbivorous, omnivorous, or carnivorous. The microflora and fauna harbored within the digestive tract are closely related to the type of food and to the character of the digestive system. There are two important criteria to consider when discussing the influence of diet on intestinal flora and their subsequent effects on digestive disorders. The first is the stability associated with the monotonous diet and the second is the changes in metabolism when existing bacteria are subject to diet alteration.

Reviewing the functional anatomy of the digestive system one would suspect that due to the comparative simplicity of the carnivorous gut, the ability of these animals to disgorge, and the apparent ease with which diarrhea could clean the short bowel (Figure 1), that such factors would warrant a low incidence of inflammation. Such is not the fact, for on the contrary the carnivorous mammals show the highest incidence of bacterial and parasitic infection (Table 3). This more prominent disease state in carnivores points once again to diet as the predisposing cause. Diets of animal flesh, you recall, are high in protein, and distinctly putrifiable. Thus they yield both chemical and bacterial components of potential toxins. Such toxins may be produced prior to the consumption of the food item, that is, in the potential freezing and thawing process at the time of animal slaughter, in transport of the product to the zoo environment, in storage of the meat product, and at the time of feeding. More importantly, the source of these animal products is highly variable being of fish, poultry or red meat origin. Variations in source also are evident within each of these groups (i.e. beef, pork, lamb, horse flesh, etc). For the carnivore then pathogens can be derived from toxins produced within the food item prior to feeding and again from the altered intestinal flora and fauna at the time of feeding.

TABLE 3. Frequency of Gastrointestinal Disorders in Adult Zoo Mammals

DISORDERED STATE	Carnivora	Omnivora		Herbivora
		Primate	Rodentia	
Bacterial Infection	7.2%	4.4%	2.0%	2.2%
Parasite Infection	5.8%	3.6%	2.0%	2.0%
Obstruction	0.2%	---	---	0.8%

From H. Fox, Disease in Captive Wild Mammals and Birds

Obviously the diet of the omnivore is much less susceptible to spoilage during processing, storage and feeding. And more than likely the source of grain, vegetables, fruit, etc., is much less variable than meat products. However, the tendency to provide a truly omnivorous diet, that is one comprised of many food items, places the intestinal flora of the omnivore in a constant state of flux. Facultative, opportunistic microorganisms of the intestine are subject to bouts of proliferation and suppression providing for the incidence of digestive disorders. However, note that the pathogens are derived principally from intestinal origin, and not from the diet prior to feeding.

Once again the herbivorous mammals are the least susceptible to bacterial inflammation (Table 3) and to digestive disorders (Table 1). The tons of dry forage stored and fed the captive herbivores provides for a most stable and monotonous diet. Toxins are rarely produced in the forage prior to feeding, intestinal flora are not subject to diet alteration and the limited prehensile mechanics of the herbivore reduces disorders due to selective feeding or rate of intake.

Gastrointestinal Design & Digestive Disorders

The third factor contributing to the varied frequency and to the cause of digestive disorders is the design of the digestive system. It is in this capacity, the physical design of the system contributing to digestive disorders, that the herbivorous mammals encounter the highest frequency. The voluminous, complex nature of the herbivore digestive tract permits retention of bulky, heavy, materials, whether it be in the foregut or the large bowel (Figures 3 & 4). The weight of the material, its retention and sluggish movements, the chance for entrapment of foreign bodies and the rough irritating fibrous nature of the diet all enhance the opportunity for obstruction, twisting, impaction or rupture. We should also note that among the herbivores, the ungulates have the highest tendency for consumption of their bedding, and that ingestion of this material can promote digestive disorders.

Clinical Signs & Gastrointestinal Disorders

Of final concern is the ability to detect digestive disorders, and to relate to their severity. Clinical signs, that is the outward expression of the disordered state, enable the animal caretaker, as well as the zoo veterinarian, to recognize the onset of digestive disorders and to assess some preliminary diagnosis. Foregut disorders are distinctly characteristic of the varied animals (Table 4). Carnivores and omnivores will attempt to dislodge dietary toxins by the vomiting reflex. Herbivorous mammals, you recall, rarely encounter dietary toxins and rarely vomit. In fact, should the herbivore vomit you undoubtedly have a digestive problem of major concern. It is interesting to note that carnivores will divert to herbivority to induce vomiting with dietary toxins, and quite often with physical obstructions. It is also interesting to note that we rarely provide the captive carnivore with a source of fresh vegetation to assist his needs.

Table 4. Clinical Signs of Stomach Disorders

Disordered State	Carnivora	Omnivora	Herbivora
Dietary Toxin	Vomiting	Vomiting	Rare
Metabolic Toxin	Rare	$\downarrow$ Activity	$\downarrow$ Activity
Physical Obstruction	Δ Posture Vomiting	Δ Posture Activity	Δ Posture Activity

Gastric metabolic disorders are rare in carnivores, while such disorders are expressed in omnivores and herbivores with inactivity and a truly lethargic state. Physical obstruction within the foregut of omnivores and herbivores are expressed by inactivity and abnormal body posture, such as the tucked under or crouched appearance. Carnivores will show posture changes and vomiting. Gastric dilation and rupture are not of dietary origin, but are the result of the emotional state of the animal and are expressed as physical obstruction, and accompanied by acute abdominal distention and/or hyperventilation.

The clinical signs of intestinal disorders are also obvious (Table 5). Because of the ease of vomiting, carnivorous mammals rarely encounter intestinal disorders derived from dietary toxins. Such toxins will, however, produce diarrhea in the omnivores and herbivores. Metabolic toxins, those derived from within the animal, excite diarrhea and increase body activities within the animal. Physical obstruction most often inhibits the passage of feces and induces pain expressed by the animal by increased activity and attention to abdominal areas (colic).

Table 5. Clinical Signs of Intestinal Disorders

Disordered State	Carnivora	Omnivora	Herbivora
Dietary Toxin	Rare	Diarrhea	Diarrhea
Metabolic Toxin	Diarrhea	Diarrhea, $\uparrow$ Activity	Diarrhea, $\uparrow$ Activity
Physical Obstruction	$\uparrow$ Activity, Colic	$\uparrow$ Activity, Colic	$\uparrow$ Activity, Colic

Diarrheas are of principal concern because of their life threatening potential. However, it is important to note that the small bowel diarrheas are of the most eminent concern. This is the result of their more prominent effects on fluid and body weight loss. Such small bowel disorders are easily distinguished from those of the large bowel via several clinical signs (Table 6). The animal with small bowel diarrhea will often show prominent signs of hunger and thirst, and the abdominal area may be bloated. Bouts of small bowel diarrhea are much less frequent than those of the large bowel, yet the stool quantity is large and absent of mucous material.

Table 6. Clinical Signs of Chronic Diarrhea

Clinical Sign	Small Intestine	Large Intestine
Weight Loss	Prominent	Minimal
Appetite	May be ravenous	Usually normal
Bloated abdomen	Common	Rare
Stool Quantity	Large	Small
Number of Stools per day	Near Normal	Many
Mucous in stools	Absent	Present

We should close by saying that a thorough knowledge of the animal's physiology, behavioral characteristics, as well as nutritional needs, are the key to reducing digestive disorders.

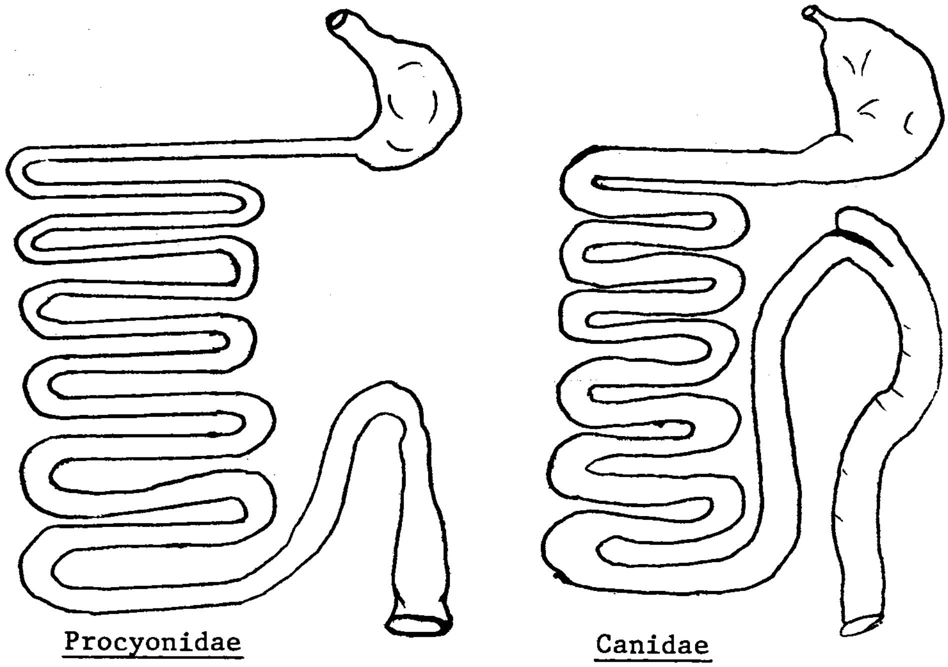


Figure 1. Scaled drawings of the Carnivora digestive tract, as represented by members of the family Procyonidae and Canidae. (From Stevens, 1977 and Clemens & Stevens, 1979).

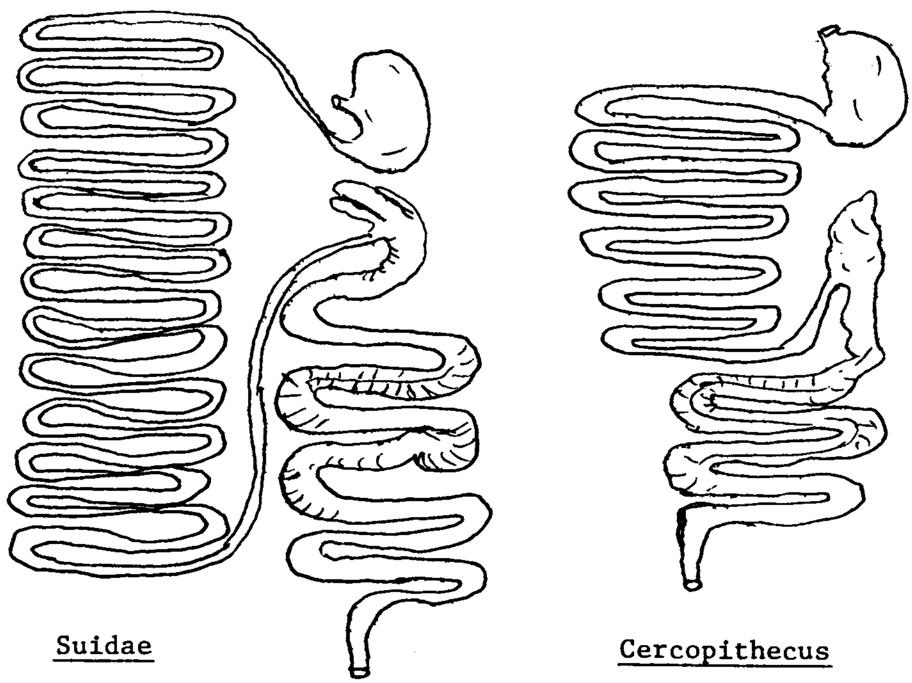
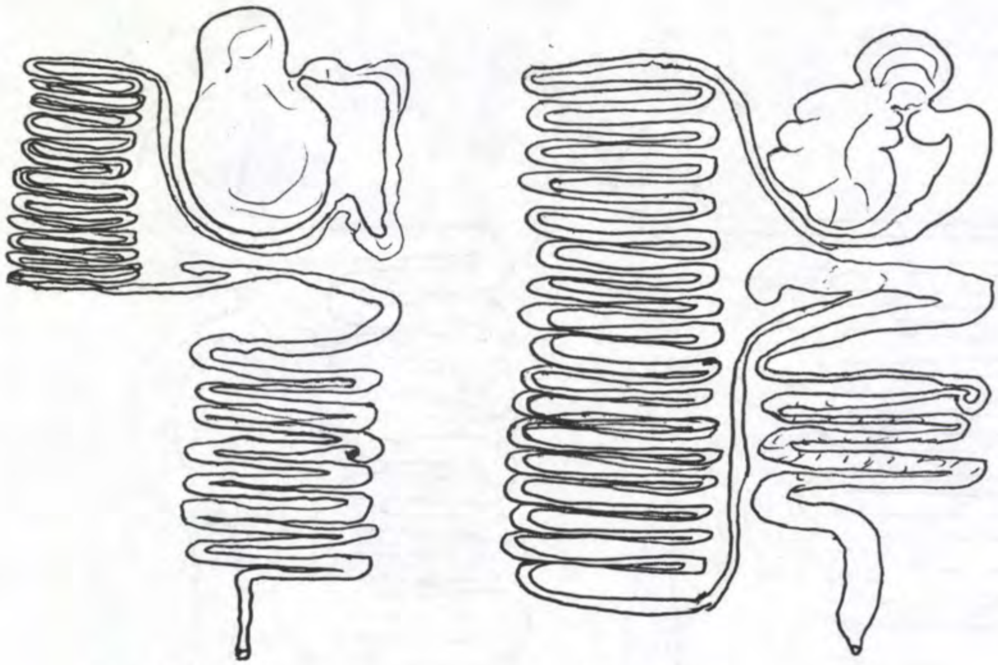
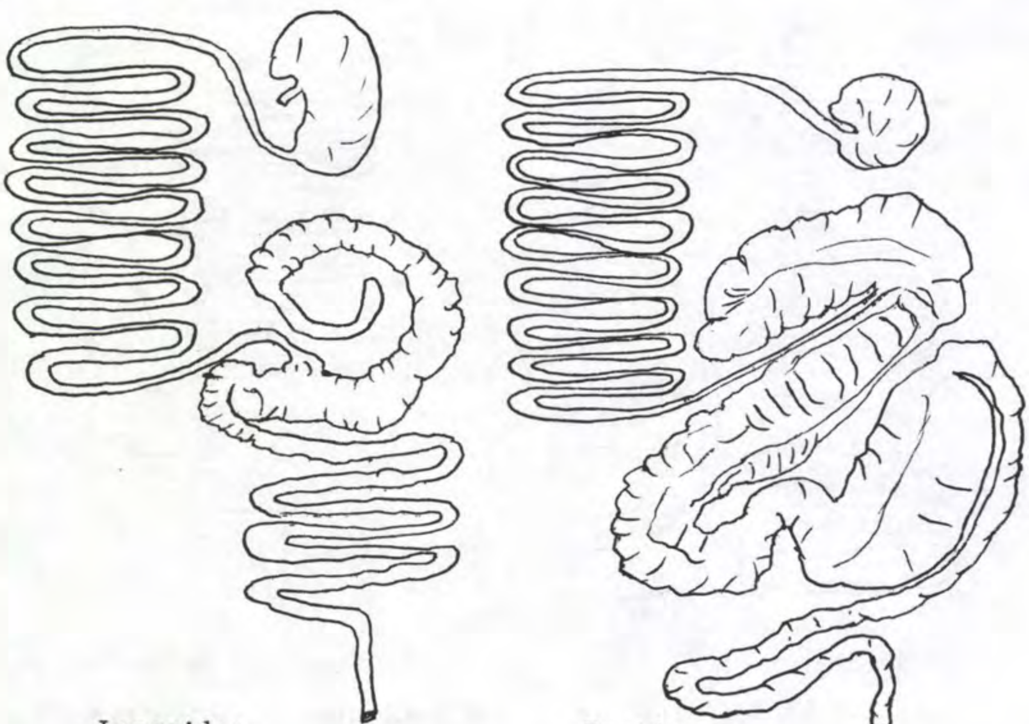


Figure 2. Scaled drawings of the Omnivora digestive tract, as represented by members of the family Suidae and Circopithecus (from Stevens, 1977 and Clemens, 1980).



Camelidae　　　　　　　　Cervidae

Figure 3. Scaled drawings of the Herbivora digestive tract, as represented by members of the family Camelidae and Cervidae (from Stevens, 1977).



Leporidae　　　　　　　　Equidae

Figure 4. Scaled drawings of the Herbivora digestive tract, as represented by members of the family Leporidae and Equidae (from Stevens, 1977).

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ECONOMIC CONSIDERATIONS IN FEEDING ZOO ANIMALS

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INTRODUCTION

Animal health and productivity are of primary importance when feeding zoo animals. Economics are, and certainly should be, a secondary consideration. Because many zoo animals are very valuable from genetic, public and economic standpoints and because zoos are judged foremost on the successful management of their collections, it is understandable that the best possible foods are desired for the animals. Maximizing diet quality is often easy to justify because animal food costs usually make up only a small percentage of overall operating costs (e.g., less than 5% at large zoos).

WHY BE CONCERNED WITH ECONOMICS?

Even though the cost of animal food might be small relative to a zoo's overall operating costs, it nevertheless can represent a large amount of money. Food budgets for medium to large zoos typically range between $100,000 and $400,000 per year. By changing the diets of a few large or small but numerous species, it is sometimes possible for a single institution to save thousands or even tens of thousands of dollars a year. Even though such costs might easily be absorbed by many zoos, this money could certainly be put to more productive uses (e.g., funding zoo animal nutrition research, improving animal and commissary facilities, etc.)

A diet made up of expensive ingredients is not necessarily more nutritious than a less expensive diet. Zoo diets often contain expensive ingredients that have little or no special nutritional justification other than their historical use in diets that have been considered satisfactory. There is often a great reluctance to change a "proven diet" no matter what the cost of its ingredients or the amount of labor required for its preparation. Exotic foods and ingredients are sometimes added to diets to provide an added "edge" that might improve animal health and increase productivity. Once again, there is often little nutritional basis for these special and often expensive foods.

It should be noted that purchasing poor quality food at any price is not only poor nutritional management but bad economics as well. Only good quality foods and feeds should be used. Purchasing and using foods and feeds that are moldy, old, contaminated, spoiled or substandard for any reason not only jeopardizes the health of the animals but will also ultimately have a negative economic impact due to increased mortality, morbidity and reduced productivity.

COST FACTORS

What is Fed

What is fed to the animals is the primary factor affecting the cost of feeding in zoos. Although diet preparation, purchasing strategy, and methods of food handling and feeding can significantly influence feeding costs, these factors are ancillary to what components comprise the diets. The cost of diet components can vary greatly depending on region, season and local sources. An item that is difficult to obtain and expensive for one zoo may be readily available and inexpensive for another. Significant savings can often result by taking full advantage of what a particular locality has to offer.

Donations...Zoos frequently receive offers for food donations. Unless the donated food (1) can be stored, (2) is similar to something already being used or (3) will be available on a regular basis, there is usually little economic advantage to using donated items. Making a short-term change in an animal's diet to include a new food that has been donated is generally not desirable because of possible digestive disturbances nor practical because many animals are reluctant to try new foods. Novelty food items are typically fed out in addition to rather than in place of regular foods.

Water...Water is cheap - at least it should be. However, zoos often buy large amounts of very expensive water in the form of high moisture foods. H_2O is H_2O whether is comes from produce, live prey or from a tap. If a zoo purchases 2,500 lbs of produce a week it is probably getting at least 2,000 lbs of water and less than 500 lbs of dry matter. There is no evidence that water naturally contained in foods has any nutritional advantage over plain water. Water quality depends on what the water contains - not on the water itself. Some species rely primarily on their food for moisture since they naturally drink little or no free-water. However, even with these species moisture can come from water naturally contained in the food or from water added as part of an artificial diet. Animal nutritionists working with domestic animals have long realized that economic comparisons of feeds and diets should always be made on a 100% dry matter basis. Comparisons of the dry matter content, typical cost/unit as fed and cost/kg dry matter reveal tremendous variability among different foods frequently used in zoos (Table 1). This variability is even more pronounced when foods are compared on the basis of cost/kg of crude protein. Crude protein is usually the most expensive component required in animal diets. Generally, an inverse relationship exists between dry matter content and cost per unit of dry matter for foods used in zoos.

Nutrients Versus Foods...A distinction is often made in zoos between artificial diets and so-called natural foods. Natural foods are items that maintain their individual integrity in the diet such as produce, meat, live prey, eggs and hay. Although considered "natural" these foods often bear little relationship to foods actually eaten by the animal in the wild. Artificial diets, on the other hand, are typically formulated to meet desired nutrient specifications by combining several inexpensive and readily available ingredients (e.g., grain and grain by-products, alfalfa meal, soybean meal, animal products and by-products) and fortifying the mixture with concentrated forms of those nutrients that might otherwise be deficient (e.g., minerals, vitamins, fatty acids, and amino acids). The final products may be pelleted, expanded, extruded, ground or homogenized in such a manner that the individual ingredients can no longer be readily distinguished. Artificial diets are commonly used for domestic animals and are now available commercially for many exotic species.

Diets composed of a high percentage of natural foods that must be purchased at non-discounted prices are usually considerably more expensive to feed than artificial diets (hay is usually an exception). Many natural foods used in zoos are also used by humans (e.g. milk products), are only seasonally available and have a short shelf life (e.g. produce) and/or are specialty items with a limited market (e.g. live prey) and therefore are relatively expensive. From a nutritional standpoint, the advantages of feeding natural foods versus artificial diets are usually not as clear-cut as the economic disadvantages. It is well established that animals require specific nutrients rather than specific foods. Many species grow, reproduce and live long healthy lives when fed properly formulated artificial diets. Artificial diets can (1) be formulated to exact nutrient specifications, thus avoiding deficiencies that occur in many natural foods, (2) obviate sorting by the animals and ensure consumption of the desired concentration of nutrients, and (3) can provide more information about a species' nutrient requirements because their nutrient contents can be more easily characterized on a quantitative basis. Potential disadvantages of artificial diets include the fact that nutrient requirements of most exotic species have not been well established. Since artificial diets are in large part formulated at the nutrient level there is concern that nutrient requirements established for domestic species may not be appropriate for some exotics. Natural foods are also often more palatable than artificial diets. Indeed, some species are so stenophagic that satisfactory artificial diets have yet to be developed (e.g., koala, many reptiles, cetaceans). Another possible advantage of natural foods is the way they affect the behavior of some animals. Watching a koala pull down a eucalyptus branch to eat the leaves or a giant panda eat bamboo is more natural and inherently more interesting than it would be to watch these species eat an artificial diet. Conversely, many "natural" foods consumed in captivity are vastly different in shape, texture and composition than native foods consumed in the wild (e.g., many cultivated fruits).

More money is often spent by zoos on produce (fruits and vegetables), particularly zoos with large primate collections, than any other food group. Possible advantages of produce are (1) its palatability, (2) it provides a source of moisture, (3) it may affect stool consistency and digesta passage, depending on other components in the diet and (4) it can be occupational for the animals because it provides nutrients in a more dilute form than most artificial diets and therefore more time is spent feeding. Other possible advantages of produce are it might provide unknown factors that can promote health that aren't currently recognized in the formulation of artificial diets (e.g., the protective effect cruciferous vegetables have been reported to have against some forms of colon cancer) or conversely, that it doesn't contain additives often added to maintain quality of artificial diets. With the possible exceptions of (1) and (4), above benefits of produce are either questionable or could be duplicated with properly formulated artificial diets. The disadvantages of produce are much more obvious than the possible advantages. It (1) is usually expensive on a dry matter basis, (2) has a high spoilage rate (e.g., > 10% loss in storage is common for items such as spinach and lettuce), (3) is labor intensive to handle because of its bulk and weight - much of which is water - and is often chopped by hand, (4) usually has poor quality control unlike most commercial artificial diets, (5) usually requires refrigeration, (6) can lead to an imbalanced diet if animals are given the opportunity to select a large proportion of preferred foods (particularly fruit) and (7) can contain residual pesticides.

As indicated by the example in Tables 2 and 3, primate diet costs are often directly related to the proportion of produce fed and inversely related to the proportion of commercial chows. Many primates quickly tire of a monotonous diet comprised primarily of a single commercial chow. Food intake can decline and animals may become listless. One way to improve intake of commercial products and thus include a higher proportion of chows in the diet is to offer more than one type. Several brands of monkey biscuits are currently marketed by reputable manufacturers in the United States. The differences in taste and consistency of the various brands are obvious from the pronounced preferences that individual animals will often display.

<u>Supplements</u>...Supplements in the form of tablets, capsules, powders and liquids are often added to diets of zoo animals to provide additional vitamins, minerals, fatty acids, amino acids/protein and/or energy. Supplements are also sometimes given to provide components not traditionally recognized as being required (e.g., enzymes and microbial

cultures). Often the need for supplements is not adequately evaluated and they are used as a matter of course. Supplements are given for 2 reasons: (1) to compensate for nutrients known or likely to be deficient in the regular diet and (2) to provide blind insurance that all nutrient needs are being met. The use of supplements for the first reason is entirely justifiable and is based on knowledge of diet nutrition composition and nutrient requirements. Use of supplements for the latter reason might be justifiable if there is large, uncontrollable variability in nutrient content of the diet or if there is insufficient knowledge of diet nutrient composition or nutrient requirements. If supplements are used for these reasons, the diet components should be reviewed or the efficacy of the supplementation should be evaluated, respectively. Supplements cannot be justified from the standpoint that if a little is good, more must be better. This not only results in a waste of money but may be harmful to the animals. Excessive amounts of vitamin A, vitamin D and most minerals, for example, can have untoward effects.

Once the need for a supplement has been established, a decision must be made which source of the required nutrient or nutrients should be used. Primary consideration should be given to differences among species in their ability to utilize different forms of nutrients and secondarily to economics. Many less expensive generic substitutes are available for brand-name supplements used by humans. An example of the relative cost of different sources of calcium is shown in Table 4.

Whole Animal Foods...Artificial diets such as commercial bird of prey diets often offer a satisfactory and less costly alternative, at least in part, to feeding mice, rats, chicks, etc. When whole vertebrate prey is considered necessary, considerable savings might result from purchasing frozen instead of live prey. Mice and rats can be purchased from some large suppliers for considerably less if frozen versus live because it gives producers a convenient outlet for overproduction animals. Care must be taken that the source of frozen prey is reputable, the animals are kept frozen until thawed for feeding and that storage does not exceed 6 months.

Food Sources and Purchasing

Food Production...Production of food by zoos offers another possible alternative for reducing costs. Labor is usually the most expensive aspect of in-house food production and as such is the foremost item to be cost justified.

Several zoos grow hydroponic grasses and sprouts. The economic advantage of using hydroponics is often dubious even though claims of cost savings are frequently made. Whether or not an economic advantage exists depends on (1) the need for hydroponics, (2) the cost of produce and the extent to which hydroponics supplant produce and (3) the cost of labor, facilities, seed and other expenses necessary to operate the hydroponics unit. The justification for feeding hydroponics is often based on nutritional reasons in addition to economics. However, because hydroponics contain approximately 90% water, the small amount of dry matter they contribute to the diets of most animals, particularly hoofstock, is often insignificant.

Savings can sometimes result from raising instead of purchasing live prey (ie., mice, rats, chicks, quail, crickets, mealworms). Labor, space requirements and cage facilities are the primary factors to be considered. Food and substrate costs are generally the least expensive aspects of live food production. At Brookfield Zoo, a colony of 375 breeder mice producing approximately 500 pups per week require about 8 hours per week to manage.

Production of hay by zoos that have available land can offer substantial economic advantages but requires acceptance of certain risks. Hay quality is determined by (1) the percentage of undesirable hay (e.g., weeds, grass, dirt), (2) the stage of maturity at cutting and (3) harvest, baling and storage conditions. Uncontrollable environmental variables can significantly affect the latter two factors and result in production of poor quality hay.

Use of surplus animals as food can be economically advantageous and convenient but depends on the policies and philosophy of the institution and the emotional climate of the area.

Raising trees and shrubs for browse might help defray produce and forage costs. However, year-round use of browse by most zoos requires freezer storage of clippings during winter.

Commercial Versus In-House Diets and Supplements...For most zoos, labor and equipment costs generally prohibit exclusive in-house production of diets for large carnivores, hoofstock, and primates. Depending on local sources of ingredients and quantities used, some zoos might be able to cost justify in-house preparations for these animals but only if they have the necessary expertise to formulate proper diets. Conversely, making up diets in-house that are not labor intensive and do not require expensive equipment (e.g., do not have to be pelleted, extruded, baked, ground, etc.) is often economically advantageous for many zoos. Insectile mixtures, nectars, gruels and various powdered mixtures can often be produced exclusively in-house at less than the cost of commercial products. Perhaps in-house production of supplements, if considered necessary, offers the greatest potential for savings in most zoos without requiring the purchasing of expensive equipment. The cost of commercial supplements is usually much higher than the summed cost of the individual ingredients they contain. In other words, there is often a big profit margin. The ingredients used in most commercial supplements are readily available from suppliers such as ICN Biochemicals, Teklad and Hoffman-Roche. In addition, many ingredients included in commercial supplements have little nutritional basis (e.g., vitamin C and potassium in hoofstock supplements) and omitting these ingredients further reduces costs. Computers greatly simplify calculations involved in formulating supplements. As examples of the potential savings, the following are in-house supplements prepared at Brookfield Zoo compared to the cost of commercial supplements previously used: protein supplement (3 times less), fatty acid supplement (4 times less), and horse and pachyderm vitamin supplement (26 times less).

Food Purchasing...All food purchasing for a zoo should be consolidated under one department to maximize labor efficiency and take advantage of volume price reductions.

Comparative pricing of foods and feeds can result in significant savings to zoos. On items such as produce and live prey, price markups can vary greatly among different wholesalers. Most zoos realize the importance of getting competitive bids for major food items. However, it is sometimes easy to opt for the convenience of consistently buying from the same sources without investigating alternatives. Negotiation of long-term price agreements is often desirable and allows for more accurate budget forecasting. Shipping costs should always be considered when comparing prices.

Buying foods and feeds in large quantities can often result in price reductions. However, caution must be exercised whenever large quantities of food are purchased because losses may occur in storage or the nutritional value may deteriorate significantly before the product can be used. Some items such as hay and some fish species are only harvested during certain seasons and must be stored for use during the remainder of the year. Substantial savings can often result by stockpiling hay and purchasing fish during harvest seasons. Low prices during harvest are generally followed by price increases during the rest of the year. Conversely, the quality of available products often declines because the best are the first to be sold. Depending on supply and demand, prices may decline just prior to the next harvest. However, only inferior products are often available and significant deterioration may have occurred in storage. The economic advantages of stockpiling must be weighed against the cost of storage and capital investment.

Buying feeds and grains bulk instead of bagged can also reduce costs. A savings of about $0.50 per 50 lbs is typical. Again, there are potential disadvantages of purchasing bulk feeds that should be considered (e.g., moisture and pest proof storage facilities must be available, bulk feeds often require more labor to distribute and handle, etc.).

Purchasing food based on nutrient specifications can offer economic advantages as well as safeguard animal health. Hay perhaps offers the greatest potential for pricing based on chemical analysis. Many commercial labs and some Universities and State Agriculture Departments provide forage analyses at modest cost. Laboratories using near infra-red spectroscopy can usually provide results within a few days. Crude protein, acid detergent fiber, neutral detergent fiber and acid insoluble protein are particularly useful for evaluating hay quality and can be used to set minimum specifications and establish a sliding price scale.

How Diets Are Prepared and Fed

Labor...Labor is often the single most expensive item in the operating budgets of zoos. Reducing labor costs should be a goal of any attempt to streamline feeding expenses. Labor can be reduced by minimizing the amount of food purchased, and the time required for food handling and processing. Purchasing dry complete feeds usually minimizes all labor aspects because bagged feeds can be handled, stored, distributed and fed more efficiently than natural foods. Food should be received and stored in areas that minimize distribution distance. Food preparation should not become habituated to labor intensive diets if possible (i.e., diets that require unnecessary chopping, cooking, mixing, etc.). Ideally, diets should result in well formed stools that facilitate easy cleanup.

Food Presentation...Food waste is a common problem in zoos. Waste can result from overfeeding, animal feeding habits and preferences, consumption by pests and spoilage. Overfeeding not only increases feeding costs but jeopardizes animal health. Not offering food free choice, keeping daily food consumption records and observing the condition of the animals can minimize waste from overfeeding. Sometimes it is desirable to separate animals when dominant individuals are consuming more than their share of food. Food wasted by the feeding habits of animals can sometimes be reduced by changing the method of food presentation. Offering food in larger pieces can sometimes reduce waste by large species and also reduce consumption by pests - particularly birds. Conversely, feeding smaller food pieces can reduce waste by some arboreal mammals such as small primates that often drop food after a few bites. Handfeeding species such as piscivorous birds minimizes waste and facilitates accurate individual food consumption records. Placing food in smaller containers,dividing feedings or placing hay in racks with less space between bars and with catchments can also reduce waste. Besides implementing pest control, food losses to rodents and birds can sometimes be reduced by making food less accessible (e.g., placing food pans on posts that can't be climbed by mice, feeding animals indoors to reduce losses to birds).

Table 1A. Comparison of Produce Costs

Item	Percent		$/KG*	
	Dry Matter	Crude Protein DMB	Dry Matter	Crude Protein
Banana	24.0	4.5	2.39	53.11
Apple	15.9	1.3	2.63	202.31
Carrots	11.9	9.3	4.45	47.85
Orange	13.7	7.1	4.83	68.03
Avocado**	26.0	8.1	5.43	66.99
TS Grapes	19.8	3.1	6.68	215.49
Kale	12.5	33.6	8.47	25.19
Celery	6.0	15.3	9.19	60.07
Lettuce	3.7	20.0	11.92	59.60
Spinach	8.9	34.4	13.13	38.17
Papaya	11.3	5.3	16.58	312.89

*Based on average 1984 prices, Brookfield, IL
**24% inedible
DMB = Dry Matter Basis

Table 1B. Comparison of Food and Feed Costs

	Percent		$/KG*	
	Dry Matter	Crude Protein DMB	Dry Matter	Crude Protein
HAY				
Timothy	89.2	11.0	0.14	1.24
Alfalfa	86.8	20.6	0.16	0.77
DRY COMMERCIAL DIETS				
Exotic Ruminant Pellet	90.0	17.8	0.37	2.08
Primate Biscuit Brand A	90.0	27.8	0.67	2.41
Primate Biscuit Brand B	92.0	22.8	1.37	5.99
Primate Biscuit Brand C	90.0	27.8	0.78	2.82
Omnivore Biscuit	92.0	23.3	0.96	4.12
Dry Dog Food Brand A	90.0	28.9	0.67	2.32
Dry Dog Food Brand B	88.0	23.9	0.73	2.78
Dry Cat Food	88.0	23.0	1.47	6.40
FROZEN COMMERCIAL DIETS				
Canine	38.0	38.2	2.09	5.48
Feline	38.0	50.0	2.15	4.30
Bird of Prey	38.0	50.0	2.38	4.76
CANNED COMMERCIAL PRODUCTS				
Primate Diet	40.3	21.9	2.67	12.19
Feline Diet	38.6	43.5	4.03	9.25
Dog Food	25.0	41.0	4.03	9.83
Cat Food	25.0	35.0	7.05	20.14
MEATS AND ORGANS				
Horse Liver	30.0	66.7	1.84	2.75
Horse Meat	31.0	63.0	4.20	6.67
Beef Heart, Lean	22.5	76.0	7.34	9.66
LIVE PREY				
Chick (1 day)	27.6	62.8	18.12	28.85
Mealworm Larvae	42.3	52.8	30.51	57.76
Adult Mouse	35.4	56.1	37.66	67.13
Crickets (Adult)	29.6	73.5	69.31	94.36
Mouse Pup (7 days)	29.3	44.0	255.71	580.90
Mouse Pup (1 day)	18.8	63.5	1,063.26	1.675.22
MISCELLANEOUS				
eggs	26.3	49.0	3.80	7.76
Nonfat Dried Milk	96.5	37.8	3.95	10.45
Casein	91.0	92.7	10.08	10.87
Plain Yogurt	15.0	35.2	11.46	32.57
Commercial Protein Supplement	91.0	60.0	26.45	44.09

*Based on average 1984 costs, Brookfield, IL.
DMB = Dry Matter Basis

Table 2. Example - Primate Salad

Item	% As Fed
Apple	15
Orange	10
Banana	15
Carrot	10
Boiled Sweet Potato	10
Iceberg Lettuce	10
Kale	10
Spinach	10
Celery	5
Hardboiled Egg	5
Total	100

Table 3. Example of Primate Feeding Costs

	Percent, Dry Matter Basis										
Primate Salad*	100	75	75	50	50	25	25	10	10	0	0
Canned Primate	0	10	0	25	0	25	0	15	0	25	0
HI-PRO Monkey Biscuit	0	15	25	25	50	50	75	75	90	75	100
Dry Matter	15.5	19.1	19.6	24.2	26.4	35.8	40.9	50.7	60.8	68.8	90
Crude Protein	13.1	16.2	16.8	19.0	20.4	22.6	24.1	25.0	26.3	26.3	27.8
Calcium	0.31	0.51	0.51	0.70	0.71	0.90	0.91	1.01	1.03	1.10	1.11
Phosphorus	0.25	0.38	0.36	0.52	0.46	0.62	0.56	0.66	0.63	0.72	0.67
ME (Kcal/kg)	3,783	3,845	3,810	3,927	3,839	3,956	3,859	3,946	3,888	3,987	3,900
$/KG, Dry Matter**	4.47	3.73	3.53	3.09	2.57	2.15	1.62	1.48	1.05	1.18	0.67
$/50 Primates /Yr***	16,316	13,615	12,885	11,279	9,381	7,848	5,913	5,403	3,833	4,307	2,446

*See Table 2
**Based on average 1984 costs, Brookfield, IL
***Assumes average body weight = 10 kg and dry matter intake = 2% of body weight.

Table 4. Comparison of Calcium Supplements.

Calcium Source	%Ca	$/kg	$/kg Ca
Powdered Limestone ($CaCO_3$)	38	0.12	0.30
Steamed Bone Meal	29.8	0.70	2.33
Calcium Lactate	18.4	16.89	91.94
Calcium Gluconate	8.9	13.16	148.70

*Based on 1984 cost, Brookfield, IL

Paper Received 1985

POISONING IN ZOO ANIMALS

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INTRODUCTION

The National Animal Poison Control Center at the University of Illinois College of Veterinary Medicine is a 24-hour telephone hotline available to veterinarians, owners, and anyone with an animal toxicosis question. The center was established in 1978 and has rapidly expanded from a few hundred calls per year to 10,000.

Because of the nature of your responsibility in the care of wild animals that have become totally dependent on human beings for their welfare, it is important for you to think critically about toxic as well as nontoxic causes of health problems. To aid you in this, I would like to make you aware of the National Animal Poison Control Center (NAPCC) and to alert you to some possible toxicity problems that may arise in zoo animals.

TABLE 1. Summary of cases involving zoo animals, 1 January 1982 through 31 July 1984.

Class	Number of cases	Percent
Plant	79	35
Heavy metals	13	6
Veterinary medications	22	9
Pesticides	60	26
Biotoxins	11	5
Construction & misc chemicals	42	19
TOTAL	227	100

Table I is a summary of calls concerning zoo animals that the NAPCC has received. Although zoo animals are in a protected environment they are not sheltered from exposure to toxic substances. The percentages of calls are in the same general proportion as the calls we receive involving all species of animals. That is, plants and pesticides comprise the bulk of our calls while construction materials and chemicals are also common but less frequent.

INDOOR PLANTS

Most of the calls we receive from zoos about plants concern indoor plants. We presume this reflects the increasing popularity of natural habitat exhibits. We are frequently questioned by zoo personnel about the choice of plants for exhibits. There are several that may result in poisoning.

The philodendron (Philodendron spp.) is a common indoor plant and is available in a variety of forms. Contact with the leaves can cause dermatitis and eating them can result in severe diarrhea and vomiting.

Devil's Ivy, which is also called Pothos (Scindapus aureus), may also cause dermatitis. If the leaves of this plant are simply mouthed by an animal, they may cause irritation of the mouth and tongue. If the leaves are swallowed, vomiting may result.

The ability of plants to irritate mucous membranes (mouth, tongue, stomach, etc.) is probably a protective mechanism for the plant. Another plant that produces burning and irritation if chewed is the Elephant Ear (Caladium sp.). The juice of the leaves contain calcium oxalate crystals that cause intense itching and burning.

As you may know, Dumbcane (Dieffenbachia sp.) is given that name because biting into, chewing, or tasting this plant can rapidly produce irritation of the mouth and swelling of the tongue which can impair swallowing, vocalization, and most importantly, breathing (Kingsbury, 1964).

There are several varieties of the rubber plant (Indian rubber tree, Ficus elastica; Fiddleleaf fig, F. lyata; Weeping fig, F. benjamina; as well as others). Exposure to the sap can cause irritation. Although not particularly harmful unless the leaves or stem are broken and the sap released, we do not recommend putting these plants in an enclosure.

OUTDOOR PLANTS

There are several outdoor plants that are poisonous. The oak tree (Quercus spp.) is common and there are approximately sixty species in the United States. The leaves, acorns, and buds contain a toxic substance that affects the kidneys and stomach. However, an animal must graze a lot of leaves to cause a problem. The sprouted acorns are especially toxic (Duncan, 1961; Osweiler, 1981).

The leaves of the Red Maple tree (Acer rubrum) contain an unknown toxin that affects the kidneys and blood cells, and it has been reported to cause blood clots in the lungs as well (Warner, 1984; Long and Payne, 1984).

The leaves and the fruit of the Chestnut tree are more toxic than those of the Buckeye (Aesculus spp.). It should be noted that this chestnut tree is not the same family as the chestnut from which edible chestnuts are obtained.

Eating the leaves or fruit of these trees may produce subtle nervous system signs (animals are described as "acting strange") or the signs may be limited to gastrointestinal disturbances. Abortion in livestock has been reported. The leaves of some species have been crushed and thrown into the water to stun fish (Kornheiser, 1983; Gadd, 1980; Williams and Olsen, 1984).

The Black Locust tree (Robina pseudoacacia) is also called Black Acacia, but it should not be confused with the acacia trees that are eaten by animals in Africa. These trees contain a toxin called toxalbumin. There is a lag period between the time of ingestion and the appearance of the signs of poisoning. I have been told about some zoo monkeys given a cut limb as a toy that demonstrated some toxic signs. Fatalities are rare (Kingsbury, 1964; Hulbert and Oehme, 1968).

The NAPCC has been asked about the signs that could occur after a giraffe was exposed to a Kentucky Coffee tree (Glymnocladus dioca). Gastrointestinal irritation and nervous signs may occur but none were reported in this giraffe (Kingsbury, 1964). Poisoning in other animals has occurred when this tree was being pruned or cut down and the cuttings were available to the animals.

Cyanide is the toxic component of peach and cherry tree leaves and twigs (Prunus sp.). Sudden death may occur if these are eaten. It has been suspected, although not proven, that ingestion of a small amount over a long period of time may affect the peripheral nerves (Hulbert and Oehme, 1968; Siegmund, 1979).

The privet (Ligustrum spp.) is a common shrub or small tree that is used as a hedge. If eaten, it will cause vomiting (or colic, in species that can't vomit) and diarrhea (Kingsbury, 1964).

Another common hedge that has characteristic red berries is the Japanese Yew (Taxus cuspidata). If a very small amount is eaten, irritation of the stomach and intestines resulting in diarrhea will occur, but it does not require much more to affect both the nervous system and heart, and cause sudden death (Fowler, 1981a; Fowler, 1981b).

Oleander (Nerium spp.) leaves, both fresh and dried, contain a glycoside which blocks the normal electric impulses that cause the heart to beat. This results in abnormal rhythms that can cause death (Mahin et al., 1984; Schwartz et al., 1974). Four ounces is enough to poison a horse (Bailey et al., 1979).

All members of the Heath family (Ericaceae) are poisonous. These include rhododendron (Rhododendron sp.), Japanese pieris (Pieris japonica), and mountain laurel (Kalmia sp.). Signs in animals are essentially identical for all these plants. There is a period of approximately 6 to 12 hours after eating when there are no signs, but this is followed by a loss of appetite, copious salivation, repeated swallowing or belching, depression, vomiting and abdominal pain (Kingsbury, 1964). Three to five ounces eaten by a 150-pound goat (0.25% of body weight) can produce signs (Smith, 1978).

There are several flowers that are poisonous. You might find some of these in your park. Lily of the Valley (Convallaris majalis) has a poison in the leaves, berry, and root that causes the action of the heart to become infrequent and irregular (Gadd, 1980).

Stomach and bowel irritation would result if an animal ate iris (Iris spp.), especially the root (Gadd, 1980).

If eaten in quantity, Foxglove (Digitalis purpura) affects the heart causing a weak and irregular pulse and possibly death (Fowler, 1981b).

Daffodils and jonquils (Narcissus sp.) are common spring flowers. The NAPCC has received several calls about animals that are vomiting and have diarrhea and a tender abdomen after eating the bulbs or drinking the water the bulbs were soaked in.

WEEDS

Weeds that occur along the fence rows or grow up in a temporarily unused enclosure could cause problems. As the exhibits are made more complex, more places for weeds to grow are created as well.

The Pigweed (Amarantus retroflexus) plant contains a substance that affects the kidneys and causes abnormal accumulation of fluid around the lungs, heart, and in the abdomen (Osweiler, 1981).

Devastating losses have occurred when livestock consumed milkweed (Asclepias sp.). The plant's toxin can affect either the gastrointestinal tract or the nervous system (Fowler, 1981a). It has been observed that wild birds eating butterflies that have fed on the sap of these plants vomit shortly afterward (Edwards, et.al., 1982).

The Blacknightshade (Solanum nigrum) has distinctive flowers. The plant may climb or have a bush form. Diarrhea may be the first sign seen. Muscular weakness may then occur and be followed by total paralysis of the hindlimbs (Levy and Primack, 1984).

Jimsonweed (Datura stramonium) grows well in trampled areas. When eaten by animals, the animals appear restless and have muscular twitching that leads to incoordination and paralysis (Hulbert and Oehme, 1968).

Poison hemlock (Conium maculatum) is a springtime weed and small quantities can cause loss of muscle strength and, possibly, coma (Bailey et.al., 1979; Hulbert and Oehme, 1968).

HAY

A lot of hay is purchased for consumption by zoo animals, and there are some poisons that may occur in hay. Blister beetles are 12-20 mm long and have longitudinal stripes. They produce a blistering compound that has been used medicinally by people as early as 1799. The dried, powdered adults are still used today in some parts of the world as the ingredients of Spanish Fly, an aphrodisiac. Cantharidin, the blistering compound in the beetle's body, is highly toxic and causes the signs listed in Table 2 (Beasley et. al., 1983).

TABLE 2. Cantharidin (blister beetle) toxicosis in horses, sheep and cattle.

Fever
Increased Heart Rate
Colic
Diarrhea
Frequent urination
Straining

Animals become exposed when they eat alfalfa hay in which the beetles have become trapped during baling. This only happens in a droughty summer when the beetles' normal forage is lost, they move into the alfalfa and a crimper is used to harvest the hay. The two species in the United States occur from the Plains States to the East Coast (Adams and Selander, 1979; Schoeb and Panciera, 1978). Examine hay carefully that comes from these areas in a dry summer.

"Bovine Bonkers" or the "Crazy Cow" syndrome can occur when cereal grain hay that has been treated with anhydrous ammonia is fed to livestock (Table 3).

TABLE 3. "Bovine Bonkers Syndrome"

Ingestion of cereal grain hay treated with anhydrous ammonia
Extreme excitability
Trembling
Twitching
Salivation
Chomping

Application of ammonia to hay is done to increase palatability, digestibility, and the protein content of the hay; however, ammoniation of hay that contains the grain portion of the plant allows formation of a toxic imidazole compound that results in this syndrome.

There has been an increased occurrence of this in the past two years and feeding a high quality forage that is ammonia treated is not recommended (Johns et al., 1984; Brown, 1984).

INSECTICIDES

Exposure to insecticides may cause poisoning of the nervous system. Table 4 lists the major categories and an example of each.

TABLE 4. Insecticides, categories.

Chlorinated hydrocarbons (e.g., Chlordane)
Organophosphates (e.g., Orthene)
Carbamates (e.g., Sevin)
Pyrethrins (e.g., Ambush)

When questioned by zoo personnel, we usually recommend the use of pyrethrins; however, toxic signs have also been reported in animals following exposure to pyrethrin insecticides (Table 5).

TABLE 5. Reported signs in animals following exposure to pyrethrin insecticides.

Salivation
Depression
Hyperactivity
Vomiting
Diarrhea
Incoordination
Seizure

The pyrethrin as well as the noninsecticide ingredients may cause these signs (NAPCC, 1984).

CLEANING AGENTS

Cleaning agents are a group of compounds that are quite common and can cause a variety of problems (Table 6).

TABLE 6. Cleaning compounds.

Irritants
non-ionic detergents (e.g., dish soap)
Corrosive
cationic detergents (e.g., Roccal)
disinfectants (e.g., low phosphate detergents and drain openers)
bleach
Liver and kidney damage
phenolic disinfectants in cats (e.g., Environ)
pine oil cleaners (e.g., Pinesol)

Nonionic detergents, such as dish soap, can irritate the gastrointestinal tract and cause vomiting and diarrhea when ingested. Of more serious consideration are the corrosive compounds such as cationic detergents, disinfectant and bleach. The mouth, esophagus, and stomach are primarily affected if such cleaners are consumed.

Kidney and liver damage can be caused by some agents, particularly those containing phenols and pine oils. Cats are especially sensitive to these compounds.

CONCLUSION

This has been a brief survey of the toxicity of some things that zoo animals may come in contact with. It is not possible, of course, to cover the variety of toxins to which these animals can be exposed. A major purpose of this review is to encourage you to think critically about the toxic as well as nontoxic cause of problems. Become familiar with what is in the exhibit as well as what is nearby and taken into the animals' enclosures. The veterinarians at the National Animal Poison Control Center are available to help with information and management recommendations: (217/333-3611).

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Fifth Annual Dr. Scholl Nutrition Conference
on the Nutrition of Captive Wild Animals

Rearing Orphaned Wild Mammals

*Richard H. Evans, D.V.M., M.S.**

Experienced, competent veterinary assistance has become a necessity in the field of wildlife rehabilitation. Although many colleges have developed programs in wildlife medicine, most stress the fundamentals of treating disease and repairing injuries. Little if any time is devoted to instruction in the care and management of orphaned neonates and their rehabilitation and reintroduction into the wild. The purpose of this article is to familiarize practicing veterinarians with techniques for rearing orphaned mammals.

In general, medical and surgical techniques and treatments used in domestic animals can be readily adapted for use in wild animals. Major physiologic idiosyncrasies and species-specific drug dosages are less frequent considerations, but the major problems encountered are inherent behavioral differences between wild and domestic species. Wild animals are much more difficult to restrain. Because of their well-developed defense mechanisms, they are more physiologically stressed by restraint than are domestic animals. For example, restraining a 10-lb juvenile raccoon can be very difficult for two or even three adult human beings. A 6-lb newborn white-tailed deer fawn can inflict serious injuries with its sharp swift hoofs and is susceptible to capture myopathy from prolonged restraint.

Restraint can only be successful when man is familiar with the animal's normal offensive and defensive behavior. A basic understanding of how wild animals respond to their environment as well as to each other is mandatory. The clinician is encouraged to gain experience in normal behavior patterns through the study of the biological literature and personal observations from hands-on practice in an area rehabilitation center. In particular, the clinician caring for wild animals should be thoroughly practiced in techniques of restraint and handling of wild species.[21]

TECHNIQUES IN REARING ORPHANED WILD MAMMALS

Medical Database and Physical Examination

The rearing of orphaned wild mammals requires that an initial database be established for the purpose of monitoring growth rate and physical and

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behavioral development. At the time the animal is admitted, a complete and expeditious physical examination should be conducted to establish this database. In some species, such as mustelids and rodents, a thorough physical examination is frequently not possible because of the animals' reluctance to tolerate manual restraint. However, with experience and knowledge of the normal behavior, morphology and physiology, of common wild species, the clinician can develop a comprehensive and rapid method of examination that covers important areas such as the respiratory, digestive, and integumentary systems. Physiologically and behaviorally, young wild animals do not begin to respond as adults until the time of weaning. These responses may be delayed if adequate conspecific socialization is not allowed to occur. Chemical restraint should not be routinely used as an alternative to manual restraint. The hazards far outweigh the benefits of this practice. If immobilization is necessary, it is recommended that one of the reversible narcotics such as oxymorphone be utilized as detailed in the following section.

The initial database should include a signalment as well as a report of physical examination (Fig. 1). The signalment should include (1) admission accession number; (2) date of admission; (3) name, address, and phone number of person presenting the animal; (4) species; (5) age; and (6) sex. The report of the physical examination should include (1) annotation of vital signs, such as heart rate, mucous membrane color and capillary refill time, body temperature, respiratory rate, and body condition, such as weight and hydration status; and (2) a systems-oriented report that details any problems or abnormalities encountered in each body system. In addition, an admission and disposition record can be prepared as a quick reference to a particular animal's medical history (Fig. 2).

Prior to examination, the animal is weighed on a triple-beam balance. Old coffee cans with plastic lids, pillow cases, zippered bags, or weighing cages for laboratory animals can be used to prevent the animal from moving or escaping while being weighed. When the animal is removed from the weighing device, it should be properly restrained and its temperature taken. Digital electronic thermometers with neonatal probes work well. When taking a temperature with a thermometer, it should be held firmly against the ventral portion of the tail to prevent any trauma to the colorectum if the animal moves unexpectedly. Plastic heat-sensitive tapes can also be used, but not without considerable error. If the temperature indicates hypothermia, the physical examination should be suspended and rewarming practices instituted immediately.

The procedure for examining neonatal wild animals is the same as for their corresponding domestic counterparts. For example, wild canids should be examined as dogs are examined; wild felids, procyons, and mustelids, as cats; wild cervids (deer), as cows; and wild rodents, as laboratory rodents. All body systems should be evaluated during this physical examination, but particular attention should be paid to the special senses and the integumentary, respiratory, nervous, and digestive systems. The degree and quality of pelage development should be assessed as an indication of nutritional status and physical development. A thorough search for wounds or lacerations should be made because the thick fur coat of many species may hide serious injuries.

TREEHOUSE
WILDLIFE CENTER INCORPORATED
[illegible] BRIGHTON, IL [illegible]
WILDLIFE REHABILITATION AND DISEASE STUDY CENTER

DATE	Accession Number
9/6/83	155M-83

Species: Raccoon
Age: 39 days Sex: Female
Weight: 356 gm
Body Condition: Fair
Hydration Status: 8-10 % deficit
Temp: 105.6° Pulse: Weak Resp: 60+labored

Integumentary System: Scaley dermatitis over crown, back, and chest. Vesicular eruptions on medial aspect of forepaw toes, lips, and external nares. Generalized bristling of guard hairs.

Special Senses: Dull, fixed, staring gaze.

Nervous System: Intermittent tonic/clonic convulsions, chorea, random-sided circling, excessive vocalization.

Cardiovascular System: Heart rate is irregular, correlated with labored breathing.

Digestive System: Mucous membranes are dry and pale; capillary refill time is 10-15 seconds; stool is loose and mucoid.

Endocrine System: ——

Respiratory System: Labored, open-mouth breathing; severe purulent rhinitis and conjunctivitis.

Urogenital System: Distended bladder.

Musculoskeletal System: NSL

Other:

Figure 1. Record of physical examination.

The eyes and ears should be examined for any disease, especially congenital defects (anophthalmia, cataracts), and stage of development. As is the case with dogs and cats, it appears that most wild canids do not open their eyes until the second week of life.[23,42] Pupillary reflexes and normal visual functions appear at 3 to 5 weeks. Full auditory capacity develops at about 5 weeks of age. Most wild rodents and mustelids take about twice as long for these events to occur.

The respiratory system is examined for evidence of rhinitis, conjunctivitis, or pneumonia. Auscultation is all but impossible in rodents, mustelids, and small felids because of their very active nature and tendency to hyperventilate during handling. Examining the quality and frequency of

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Admission accession Number: 155M-83
Admission Date: 9/6/83
Species: Raccoon
Age: 39 days Sex: Female
Animal Obtained From: Joan Martin, 1213 New Street, Alton, Illinois 376-8920

History Prior to Admission: Animal found in urban backyard, wandering in circles and crying, 6 hours prior to admission.

Cause of Admission (Specify Type):
[ ] Fracture:
[ ] Soft Tissue Wound:
[ ] Blunt Trauma:
[x] Infectious Disease: Generalized ataxia, lack of fear of humans, purulent rhinitis
[ ] Toxicosis:
[ ] Starvation:
[ ] Nuisance/Former Pet:
[ ] Legal Impoundment:
[x] Orphan:
[ ] Other:

Treatment
[ ] Surgery
[x] Medicine Supportive fluid therapy, CDV-FA on conjunctival and buffy coat smear---positive

Disposition: Date:
[ ] Released: Location (Include Lat/Long):
USFWS Band Number:
[ ] Permanent Resident: [ ] Educational, [ ] Foster Parent, USFWS Band:
[ ] Transfer: Location:
[x] Euthanized/ [ ] Died 9/7/83
[x] Gross Post Mortem Examination: Thymic atrophy, blanched lymph nodes, pneumonia
[x] Histological Examination: Generalized canine distemper, 2° cryptosporidiosis

Figure 2. Admission and disposition record.

ventilation before handling the animal is more appropriate for these species. The cardiovascular system is examined by auscultation, bearing in mind that restraint almost invariably precipitates "fear tachycardia," except in the opossum and armadillo in which "fear bradycardia" commonly occurs.

When examining the digestive system, observe the mucous membranes to determine whether they are the appropriate color and hydrated. One should obtain capillary refill time if the animal will allow such manipulation. It is most important that the eruption pattern of the upper and lower dental arcades be noted, as this pattern is one of the most reliable methods of determining the age of neonatal mammals. Mouth gags, large forceps, or a tongue depressor padded with tape can be used to open the mouth sufficiently for examination of the teeth.

It is often difficult to fully evaluate the nervous system in domestic and wild neonates.[6] The author has found that previously published protocols on the examination of the nervous system in neonatal domestic dogs lend themselves readily to wild canines.[43]

General body condition is most readily assessed by comparing the degree of pelage and musculoskeletal development with body weight and patterns of dental eruption. Hydration status can be assessed with the method used for domestic animals. However, it should be noted that in most canids, felids, procyons, and some rodents, extensive elasticity of the cervical integument (used as a handle by which the mother can carry her young) precludes its use as an evaluation of hydration status. Once the physical examination is completed, appropriate restorative treatments, such as rehydration and the maintenance of body temperature, can be performed.

RESTORATIVE TREATMENTS

The maintenance of normothermia is one of the most important procedures in rearing wild neonatal mammals. Because small, unfurred neonatal animals have a tremendous surface area for heat loss and cannot thermoregulate until about 3 to 4 weeks of age, they readily become hypothermic after as little as 45 to 60 minutes of exposure to ambient temperatures. Hypothermia may result in an impaired suckling reflex, gastrointestinal hypomotility, and impaired digestion just as in domestic species.[34] Devices available for rewarming include heating pads, hot water bottles, and heat lamps. In the author's experience, none of these methods are as effective in raising the body core temperature as a warm water bath (105 to 100°F) with cutaneous massage, followed by immediate and complete drying under a heat lamp or hair dryer. This method has been reported to raise body temperature by 5 to 6°F within 5 minutes.[22] The use of heating pads is discouraged because they merely warm the animal superficially one side at a time.

Rehydration is undertaken by the usual methods established for small domestic animals. A balanced electrolyte solution, such as Normosol-R in 5 per cent dextrose, should be given orally. Dextrose (2.5 per cent) in half strength lactated Ringer's solution may be given subcutaneously. If dehydration is severe (10 to 12 per cent), replacement fluids must be given intravenously using a jugular catheter.

In assessing fluid needs for neonates, the clinician should note that neonatal requirements may be two to three times those of adults because total body water in neonates is about 70 to 80 per cent of body weight, compared with 60 per cent in adults. Daily maintenance fluid requirements (35 to 40 ml per kg) also must be met until the animal is on a diet of milk replacer. A highly successful regimen is to give 40 to 50 ml per kg of body weight of replacement fluids orally by gavage in divided doses every 12 hours until rehydration is complete. From this stage until release, a medical record treatment and progress sheet should be kept (Fig. 3).

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Accession Number: 155M-83
Species: Raccoon

DATE	TREATMENT & PROGRESS	WEIGHT
9/6/83	Tentative diagnosis: Canine distemper	356 gm
	Normosol-R in D5W orally every 4 hours --18cc	
	x 8am x 12am x 6pm x 8pm x 12 pm	
	Isolation	
	CDV-FA on conjunctival and nasal smear	
9/7/83	Positive CDV-FA; euthanized at 9am; burned carcass;	310 gm
	Gross postmortem examination: Canine distemper	
9/21/83	Histological examination and PAP: Canine distemper	

Figure 3. Treatment and progress record.

SUCKLING FORMULAS AND FEEDING METHODS

Once the patient is normothermic, it should be placed in a nursing unit and feeding with milk replacer should be initiated. Ideally, the nursing unit should consist of a climate-controlled incubator in which the relative humidity is maintained at 50 to 60 per cent and the temperature between 80 and 85°F for the 1st week of life, 80°F during the 2nd week, and 70 to 75°F until thermoregulation is achieved at about 3 to 4 weeks of age.

In lieu of an incubator, a 1 foot by 2 foot glass aquarium with a ventilated top can be used to house up to three neonates the size of 3-week-old raccoons.

A heating pad is placed on the floor at one end and set on low. A blanket or towel that does not unravel or shred is placed over the heating pad to form a bottom sheet. The neonate is placed in the aquarium, and a top sheet is loosely draped over it. This allows the neonate the feeling of being brooded as well as an opportunity to crawl between warm and cool areas.[15] For neonatal cervids (deer), outdoor housing consisting of a 10 foot by 20 foot by 8 foot run, having one end enclosed with fiberglass panels and provided with a straw floor, prevents the fawn from being exposed to dramatic changes in temperature or humidity or inclement weather. When thermoregulation is achieved, larger caging with appropriate-sized nest boxes, such as the bottom half of a plastic dog-carrying crate, is needed.

Milk Replacer Formulation

It should be noted that an artificial milk replacer cannot be expected to perform as well as mother's milk. Rather, the goal is to produce a positive growth rate to enable the neonate to wean itself to a solid diet.

In order to provide a neonate with proper nutrition and, hence, facilitate its growth while it is being fed an artificial milk replacer, one should remember the following concepts: (1) Protein, fat, carbohydrates, energy, vitamins, and minerals must be supplied in amounts and proportions that support a positive growth rate. (2) The amount fed at each feeding should not exceed the maximum comfortable stomach capacity. (3) The number of feedings per day should be adequate to supply daily energy requirements considering the finite amount that can be delivered at each feeding. (4) Every effort should be made to promote weaning to a complete and balanced solid diet when physiologically possible.

Table 1 lists the constituents of mother's milk for a variety of small wild mammals. Species are subgrouped to demonstrate trends among taxonomic groups. Comparison of these analyses to available commercial milk replacers such as Esbilac,*KMR,* and Multi-Milk* will allow for an appropriate choice of a milk replacer (Table 2). Table 1 also reflects the paucity of data available on the composition of milk of some wild species. In addition, these data were obtained by a variety of techniques, some of which have high inherent margins of error. In some cases, samples were taken at unreported stages of lactation and were few in number. As a result, a degree of skepticism over their validity is in order.[37] Despite the sources of error, practical experience has shown that these data generally are adequate for formulation of artificial milk replacers.

Until recently, it was necessary to utilize commercial fat and protein supplements, whipping cream, eggs, or dilution procedures to alter the fat, protein, and energy content of commercial milk replacers.[22] For example, milk replacers for dogs and cats contain moderate levels of carbohydrates.[5] Such formulas are contraindicated in rodents and lagomorphs, whose milk is normally low in carbohydrates.

Because these supplements usually contain a proponderance of one macronutrient, addition of these supplements to a milk replacer can result in an imbalanced diet. For example, the current use of whipping cream to

*Borden, Inc., Elgin, Illinois.

Table 1. *Composition of Mammalian Milks (as Per Cent of Diet)*[5,28,35,37]

SPECIES	SOLIDS	FAT	PROTEIN	CARBOHYDRATES	ASH	ENERGY (KCAL/ML)*
Marsupials						
Opossum	24.00	7.00	4.80	4.10	—	1.08
Rodents						
Nutria	41.50	27.90	13.60	0.60	1.30	3.34
Beaver	33.00	19.80	9.00	2.20	2.00	2.42
Woodchuck	—	10.60	8.00	—	—	1.44†
Muskrat	—	—	—	—	—	—
Chipmunk	—	—	—	—	—	—
Gray squirrel	39.60	24.70	7.40	3.70	1.00	2.83
Fox squirrel	—	—	—	—	—	—
Flying squirrel	—	—	—	—	—	—
Lagomorphs						
Cottontail rabbit	35.20	14.40	15.80	2.70	2.10	2.33
Black-Tail jackrabbit	—	—	—	—	—	—
White-Tail jackrabbit	40.80	13.90	23.70	1.70	1.50	2.73
Mustelids						
Weasel	—	—	—	—	—	—
Badger	26.80	6.30	7.20	3.50	1.60	1.13
River otter	38.00	23.90	11.00	0.10	0.75	2.83
Striped skunk	30.60	13.80	9.90	3.00	1.50	1.97
Mink	21.70	7.30	5.60	4.50	1.00	1.18
Ursids						
Black bear	44.50	24.50	14.50	0.40	1.80	1.95
Brown bear	33.60	18.50	8.50	2.30	1.50	2.28
Procyonids						
Raccoon	14.10	5.01	4.05	4.75	0.93	0.88
Felids						
Bobcat	18.50	6.20	10.20	4.50	0.80	1.34‡
Mountain lion	35.00	18.60	12.00	3.90	1.00	2.55
Canids						
Wolf	23.10	9.60	9.20	3.40	1.20	1.55
Coyote	22.10	10.70	9.90	3.00	0.90	1.67
Red fox	18.10	5.80	6.70	4.60	0.90	1.09
Gray fox	—	—	—	—	—	—
Cervids						
White-tail deer	22.50	7.70	8.20	4.60	1.50	1.35
Black-tail deer	25.50	12.60	7.20	4.60	1.40	1.76
Mule deer	25.30	10.90	7.59	5.39	1.40	1.65
Suids						
Collared peccary	17.00	3.97	5.60	6.10	0.64	0.93

*Calculations based on Perrin.[40]

†Energy values at least this figure.

‡Data actually from closely related species (lynx).

Table 2. *Analysis of Commercial Animal Milk Replacers*

PRODUCT	SOLIDS	FAT	PROTEIN	CARBOHYDRATES	ASH	ENERGY (KCAL/ML)
Esbilac						
Undiluted powder	95.00	40.00	33.00	15.80	6.00	6.20
Diluted 1:3*	15.00	6.00	4.95	2.38	0.90	0.93
Diluted 1:1.5*	30.00	12.00	9.90	4.76	1.80	1.86
Liquid product	15.00	6.00	4.95	2.38	0.90	0.93
KMR						
Undiluted powder	95.00	25.00	42.00	26.00	7.00	5.77
Diluted 1:3*	18.00	4.50	7.56	4.68	1.26	1.04
Diluted 1:1.5*	36.00	9.00	15.12	9.36	2.52	2.07
Liquid product	18.00	4.50	7.56	4.68	1.26	1.04
Multi-Milk						
Undiluted powder	97.50	53.00	34.50	0	6.63	6.85
Diluted 1:1*	22.70	12.00	7.83	0	1.51	1.55
Diluted 1.5:1*	36.00	19.59	12.75	0	2.54	2.47
Doe milk replacer						
Undiluted powder	98.00	30.00	30.00	31.80	7.00	5.86
Diluted as per instructions	22.00	6.70	6.80	7.00	1.50	1.29
Evaporated milk						
Undiluted product	22.00	7.00	7.90	9.70	0.70	1.49
Lamb milk replacer	19.00	7.50	5.50	4.80	0.80	0.70
Goat milk replacer	13.20	3.80	2.90	4.70	0.70	0.70
SPF-LAC	15.20	5.56	5.02	3.27	0.70	0.90
Multi-Milk:KMR†						
1:1*	22.81	8.93	8.71	3.20	1.55	1.45
3:1	22.90	10.97	8.63	1.54	1.59	1.57
4:1	22.90	10.90	8.27	1.17	1.50	1.52
1:3	22.70	7.28	9.10	4.39	2.30	1.37
1:4	22.60	6.95	9.16	4.68	1.57	1.36
Multi-Milk:KMR‡						
1:1	34.22	13.40	13.07	4.80	2.33	2.18
3:1	34.55	16.46	13.03	2.31	2.39	2.36
4:1	34.55	16.35	12.41	1.76	2.25	2.28
1:3	34.05	10.92	13.65	6.59	3.45	2.06
1:4	33.90	10.43	13.74	7.02	2.36	2.04
Multi-Milk:Esbilac†						
1:1	22.81	10.63	7.70	1.78	1.44	1.49
3:1	22.93	11.63	8.00	0.89	1.52	1.56
4:1	22.90	11.60	7.86	0.71	1.49	1.55
1:3	22.70	9.81	8.75	2.67	2.13	1.51
1:4	22.60	9.65	7.54	2.84	1.39	1.43
Multi-Milk:Esbilac‡						
1:1	34.22	15.95	11.55	2.67	2.16	2.24
3:1	34.40	17.45	12.00	1.34	2.28	2.33
4:1	34.35	17.40	11.79	1.07	2.24	2.33
1:3	34.05	14.72	13.13	4.01	3.20	2.28
1:4	33.90	14.48	11.31	4.26	2.09	2.15

*Ratio of powder to water.
†Ratio of powder to powder, diluted 1 part powder to 1 part water.
‡Ratio of powder to powder, diluted 1.5 part powder to 1 part water.

elevate the fat content of Esbilac for rodents and lagomorphs has also resulted in substantially lowered protein levels. The advent of Multi-Milk, a multipurpose milk replacer high in fat and protein and free of carbohydrates, has enabled fat, protein, and energy levels of other milk replacers to be altered without creating an unbalanced diet. Prior to its introduction, Multi-Milk was tested at our center on several species of wild rodents and carnivores that have high levels of fat, protein, and energy in their milk. Excellent palatability and very good rates of growth and physical development were observed. Combinations of Multi-Milk with Esbilac or KMR powder are listed in Table 2. A 1:1 dilution of these combinations with water results in a formula with 22 to 23 per cent solids, whereas a 1.5:1 dilution (powder combination:water) produces a 30 to 35 per cent solids formula. To approximate the milk solids of opossums, rodents, lagomorphs, and mustelids, we have utilized the 30 to 35 per cent solids dilution. However, in limited trials, such formulas appear not to be sufficiently liquid for easy acceptance by the intended species. Further research is needed in this area.

The amount fed at each feeding should probably not exceed the maximum comfortable stomach capacity. Neonates should not be allowed to bottle-nurse at will. Milk replacers are usually highly palatable and will promote overeating and subsequent diarrhea when fed ad libitum. Excessive feeding can also lead to vomiting, gastric distension, atony, and/or torsion. The maximum comfortable stomach capacity in neonatal rodents, carnivores, and marsupials appears to be 50 to 66 ml per kg of body weight, or about 5 to 7 per cent of their body weight. Exceptions to this are the muskrat, whose stomach capacity is about 15 to 25 ml per kg, or 1.5 to 2 per cent of its body weight, and lagomorphs, whose stomach capacities are 100 to 125 ml per kg of body weight, or 10 to 25 per cent of their body weight.

Of all dietary constituents, energy is perhaps the most important regulator of neonatal growth. Energy is derived from the major macronutrients—fat, protein, and carbohydrates. Energy is the fuel that runs metabolic pathways responsible for growth, thermoregulation, and many other functions. In addition to having a sufficient daily energy intake, the sources of this energy must be balanced (that is, a certain percentage of the energy intake must derive from each of the above macronutrients). This concept is now being used practically to formulate domestic animal diets, but it has as yet to be applied to feeding wild suckling mammals in captivity. In a 1984 review of milk compositions at peak lactation, Oftedal tabulated energy balances for selected species.[37] These data showed that rodents, lagomorphs, and canids derive almost all of their energy from fat and protein, whereas hoofed species also utilize substantial dietary carbohydrate for energy. In general, it has been found that the basal daily metabolic rate (BMR) of adult mammals can be estimated by the formula $70 \times \text{body weight (kg)}^{.75}$ (in kilocalories). For young growing animals, the energy requirements appear to be two to four times the BMR of the adult.

Using the previous discussions on nutrient and energy requirements and feeding amounts and intervals, a practical daily feeding schedule is demonstrated in Table 3. Such a table may be constructed by listing the following columns from left to right: (1) the animal's weight in kilograms, ounces, and pounds; (2) daily caloric requirements in kilocalories per day

Table 3. *Daily Feeding Chart for Suckling Raccoons*[15]

BODY WEIGHT				DAILY ENERGY	RECOMMENDED AMOUNT PER	AMOUNT FED AT VARIOUS INTERVALS‡			
OZ	LB	G	KG	REQUIREMENT*	FEEDING†	3×	4×	5×	6×
2.82	0.17	75	0.08	21 (22)	4.00			4.4	3.7
3.53	0.22	100	0.10	25 (26)	5.00			5.2	4.3
4.59	0.28	125	0.13	30 (32)	6.50			6.4	5.3
5.29	0.33	150	0.15	34 (36)	7.50			7.2	6.0
6.35	0.39	175	0.18	39 (41)	9.00		10.25	8.2	6.8
7.05	0.44	200	0.20	42 (44)	10.00		11.00	8.8	7.3
7.41	0.46	210	0.21	43 (46)	10.50		11.50	9.2	7.7
7.76	0.49	220	0.22	45 (47)	11.00		11.75	9.4	
8.11	0.51	230	0.23	47 (49)	11.50		12.25	9.8	
8.46	0.53	240	0.24	48 (51)	12.00		12.75	10.2	
8.82	0.55	250	0.25	50 (52)	12.50		13.00	10.4	
9.88	0.61	275	0.28	54 (57)	14.00		14.25	11.4	
10.58	0.66	300	0.30	57 (60)	15.00	20.0	15.0	12.0	
11.64	0.72	325	0.33	61 (64)	16.50	21.3	16.0	12.8	
13.40	0.83	375	0.38	68 (71)	19.00	23.6	17.75	14.2	
14.11	0.88	400	0.40	70 (74)	20.00	24.6	18.5	14.8	
17.64	1.10	500	0.50	83 (88)	25.00	29.3	22.0	17.6	
21.16	1.32	600	0.60	96 (101)	30.00	33.6	25.3	20.2	
				Beginning Weaning Process					
24.69	1.54	700	0.70	107 (113)	35.00	37.6	28.3	22.6	
28.22	1.76	800	0.80	118 (125)	40.00	41.7	31.3	25.0	
31.74	1.98	900	0.90	129 (136)	45.00	45.3	34.0		
35.27	2.20	1000	1.00	140 (147)	50.00	49.0	36.75		
38.80	2.43	1100	1.10	150 (158)	55.00	52.7	39.5		
42.32	2.65	1200	1.20	161 (170)	60.00	56.7	42.5		
45.85	2.87	1300	1.30	171 (180)	65.00	60.0	45.0		
49.38	3.12	1400	1.40	181 (190)	70.00	63.0	47.50		

*Daily energy requirement in kilocalories derived from 2 to 2.5 [70 × body weight (kg)$^{.75}$]. Figure in parentheses is the daily formula requirement derived by the formula:

$$\frac{\text{Daily energy requirement (kcal/day)}}{\text{Energy content of formula (kcal/ml)}}$$

†Recommended feeding amount is derived by the formula:

Maximum comfortable stomach capacity (ml/kg) × body weight (kg).

‡These values are derived by dividing various intervals (3×, 4×, 5×, 6×, etc.) into the daily formula requirement.

derived by the formula 2 to 2.5 [70 × body weight (kg)$^{.75}$] (the volume of milk replacer needed to supply this requirement is calculated by dividing the caloric density [kilocalories per milliter] of the formula into the daily caloric requirement [in kilocalories]; this value is added in parentheses beside the daily caloric requirement); (3) recommended amount of formula per feeding, which is derived by multiplying the maximum comfortable stomach capacity (milliliter per kilogram) by the animal's body weight; and (4) amount to be fed at various intervals, which is calculated by dividing various intervals into the amounts of formula calculated to supply daily caloric requirements. Only those values that do not exceed the recommended feeding amount should be utilized. Table 3 was formulated for raccoons utilizing KMR, a kitten milk replacer, because it closely approximates available data on raccoon milk. For example, to feed a 500-gm raccoon, 83 kcal of energy are needed daily. This can be supplied by 88 ml of KMR given daily. As shown in the last column, 22 ml of KMR fed four times a day will supply daily energy needs without exceeding the maximum comfortable capacity of 25 ml. This system eliminates problems due to overfeeding and produces a growth rate that equals or exceeds that expected from mother's milk.[14] Such tables, however, are only to be used as a guideline for feeding neonates. Some individuals may require 20 to 50 per cent more or less milk than shown in the table.[14]

Species Recommendations

Esbilac has been used successfully to rear the Virginia opossum; however, there was a demonstrable depression and elongation of the growth curve in these opossum as compared with that of young reared by their dam. The addition of whipping cream to Esbilac increases its energy content and produces a better growth curve. The use of Multi-Milk and Esbilac or KMR in a 1:1 combination diluted 1:1 with water further improves the growth rate because this combination more closely approximates opossum milk. Nonetheless, it is still not unusual to observe depressed growth rates in neonatal opossums, which improve when they are weaned onto solid food. Such problems are inherent to this species and are possibly genetically based, as the opossum "exhibits a frustrating degree of variability in almost every phase of growth and development."[24]

Rodents have been raised on Esbilac or, more recently, Esbilac with whipping cream to approximate the high-fat calorie-dense milk of this species. Growth rates and physical development are good, but seldom equivalent to wild counterparts. A 3:1 mixture of Multi-Milk and Esbilac powder diluted 1:1 with water results in much improved growth rates and physical development in fox squirrels, gray and flying squirrels, and chipmunks. As discussed previously, attempts to produce more concentrated (1.5 part powder mixture to 1 part water) formulas that more closely approximate the milk of these species have not met with success. Furthermore, combinations of Multi-Milk and KMR at dilutions more concentrated than 1:1 should be avoided owing to excessive levels of carbohydrate.

The lagomorphs (rabbits and hares) have always presented special problems in rearing because of their unusual milk constituents, delicate large bowel bacterial flora, and inability to acclimate to captivity. In addition to a simple stomach digestive system, the lagomorphs possess ceca. Volatile fatty acids, which are the product of microbial cellulose (plant cell wall) fermentation in the ceca, are absorbed through the cecal wall into the blood stream, serving as a major energy source. Large numbers of anaerobic bacteria populate the ceca to facilitate fermentation. The milk of wild and domestic rabbits and hares differs from that of other species.[1a,20,27,31] It has been shown that these differences produce an essentially sterile stomach and small intestine owing to the bactericidal effect of the fatty acids. Cow's milk and commercial milk replacer-based formulas do not support these bacterial floral patterns.[20] Instead, they commonly result in floral imbalances with subsequent bacterial enterotoxemia and diarrhea. Furthermore, antibiotics such as penicillin, ampicillin, amoxicillin, clindamycin, lincomycin, and, to a lesser extent, the cephalosporins and aminoglycosides may also cause bacterial floral imbalances and enterotoxemia.[10,25] For this reason, the rabbit is one of the animal models for antibiotic-induced pseudomembranous colitis in man.[10] In addition, almost any physiologically stressful occurrence (handling, excessive light or noise, and fluctuations in temperature or humidity) can produce floral imbalances in the large bowel and subsequent enterotoxemia in rabbits, both wild and domestic.[10,25] The rabbit's natural environment is a forum, or shallow depression in the ground, covered by a layer of vegetation that helps maintain relatively constant temperature and humidity, and a dark quiet environment.

Rabbits reared in captivity may suffer mortality rates of up to 100 per cent from *Clostridium spiriforme* enterotoxemia,[25] colibacillosis, and other enteropathies due to cecal floral imbalances.

Despite these problems, Cottontails and Jackrabbits have sometimes been successfully raised solely on cow's milk[7] or solely on Esbilac with supplemental fat (coffee cream, whipping cream, and so on). Present recommendations for these species would be 1:1 dilutions of a 3:1 or 4:1 combination of Multi-Milk and either KMR or Esbilac. Multi-Milk diluted 1:1 with water is also adequate. As with rodents, a more concentrated dilution of 1.5:1 (1.5 part powder combinations to 1 part water) rather than 1:1 is not readily accepted. As occurs in nature, rabbits should be fed a volume approximating 10 to 25 per cent of their body weight (100 to 250 ml per kg) one to three times daily.[12] This reduces the amount of stress from handling. They should be isolated and housed in artificial forums that are kept at a constant summertime ambient temperature and humidity. Formula-feeding devices and housing materials should be kept clean to prevent excessive bacterial contamination. Most importantly, young Cottontails and Jackrabbits should be weaned and released as early as physiologically possible (10 to 14 days and 21 to 27 days, respectively).[45] Rabbits develop an increasing inability to accept the stress of captivity as they approach weaning age. Captivity beyond age 21 to 27 days is likely to result in high mortality from clostridial enterotoxemia.[10] Young can be weaned successfully by placing a large pile of vegetation (see Table 5) within 1 foot of their forum at 7 days of age.

The milk of mustelids and ursids, like rodents and lagomorphs, is high in solids, fat, and protein. KMR is usually used to raise these species. However, a 3:1 or 4:1 mixture of Multi-Milk and either Esbilac or KMR or

Multi-Milk alone diluted 1:1 with water appears to be a better choice because of the much lower levels of carbohydrates. Again, more concentrated dilutions (1.5 part powder combinations to 1 part water) appear to be more appropriate, but confirmation of acceptance is needed. The 3:1 combination of Multi-Milk and Esbilac has been used to raise long-tailed weasels, striped skunks, and mink, realizing a natural-length growth curve without the diarrhea that commonly results from excessive feeding of carbohydrates. KMR supports natural growth rates and excellent physical development in raccoons.[16] Recent reports from several zoos have indicated that Multi-Milk given alone at a 1:1 dilution with water has been used to raise several species of ursids, achieving better results than either KMR or Esbilac.

Felids, such as bobcats and mountain lions, should be reared on KMR.[36] The mountain lion and bear present special problems because of their large size and aggressive behavior. Their rehabilitation is best left to experts. Recent work suggests that orphaned black bear cubs are successfully fostered to wild mothers in lieu of rearing in captivity.[1]

With the exception of the wolf and coyote, canids are as successfully reared on Esbilac as are domestic dogs. Because of their high fat and protein requirements (Table 1),[4] the wolf and coyote are best raised on a 3:1 or 4:1 combination of Multi-Milk and KMR or Esbilac, or Multi-Milk alone diluted 1:1 with water.

The cervids are relatively easy to raise because they readily take to a bottle with a minimum of coaxing. Their milk constituents approximate that of 50 per cent concentrated cow's milk (for example, evaporated milk). Cow's milk has been used to raise deer, but diarrhea is very common. Goat's milk and lamb milk replacers have also been used successfully in rearing black-tailed and white-tailed deer. However, evaporated milk has been the most widely used and successful artificial formula.[44] Doe milk replacer* gives results equal to those from evaporated milk, and both result in growth rates equaling those of wild deer. Commercial cattle milk replacers such as Nurse-Gro† should not be used to rear cervids because they are not meant to be fed as the sole source of nutrition, but rather must be used with a creep feeding program. Wild cervids do not have well-developed rumen physiology until about 5 weeks of age and, thus, cannot utilize the creep feed program used with cattle. Several schemes for feeding have been developed for deer.[8,39,46] The most effective scheme is a composite of these, carried out between the hours of 8:00 AM and 8:00 PM (Table 4).

The peccary is raised as if it were a domestic piglet. Although Esbilac and whipping cream have been used to raise collared peccaries, SPF-LAC,‡ a commercial piglet milk replacer, is more suited to this species' needs (see Table 2).

Feeding Methods

After restorative treatments, feeding should be initiated with a dilute formula that has been warmed to the animal's body temperature. For the first two to four feedings, the formula should be diluted to one third of

*Formost-McKesson, Downey, California.
†Ralston Purina Company, St. Louis, Missouri.
‡Borden, Inc., Elgin, Illinois.

Table 4.

AGE (DAYS)	FEED	AMOUNT FED (ML)	FEEDING INTERVALS
1–4	Bovine colostrum, evaporated milk, doe milk replacer	50–60	7 × (q2–3 hours)
4–14	Evaporated milk, doe milk replacer	80–120	5 × (q3 hours)
15–28	Evaporated milk, doe milk replacer	150–200	4 × (q4 hours)
29–49	Evaporated milk, doe milk replacer	200–250	4 × (q4 hours)
50–56	Evaporated milk, doe milk replacer	250–300	3 × (q6 hours)
57–63	Evaporated milk, doe milk replacer	350–400	2 × (q12 hours)
64–84 (weaning)	Evaporated milk, doe milk replacer	400	1 ×

normal concentration, followed by one half of normal concentration for the next two to four feedings. Feeding of the full concentration should not commence earlier than 24 hours after the first feeding. This will enable the animal's physiology and bacterial flora to acclimate to the new formula.

Usually within 24 hours of feeding the full concentration of milk replacer, a normal stool, golden brown in color and the consistency of peanut butter, is voided. It is not uncommon, however, to see mild or moderately loose stools or even no stool for up to 96 hours following feeding of the full concentration. The latter case is common in neonates that have received no food for 24 hours or more. At least four to five feedings are necessary to facilitate stool formation because of the high digestibility of milk replacer constituents.

Opossums, rodents, lagomorphs, and the smaller mustelids are best fed with a 1- to 5-ml regular tip syringe. This is placed in the dental diastema, and a small amount of milk is injected to start the animal suckling. In contrast to small animal nursing bottles, syringes offer much more controlled delivery of milk, lessening the risk of aspiration. Raccoons, canids, felids, and the larger mustelids are best fed with a 4-ounce bottle used for human babies and a nipple used for premature human infants. During the later suckling period, a regular-sized baby nipple can be substituted as the animal becomes more proficient at suckling. Ursids, suids, and cervids are fed using a 4- to 8-ounce baby bottle or a soda bottle with a regular-sized nipple used for human babies, sheep, or lambs.

The neonate should be suckled from a natural position and should have to perform some degree of work to obtain its milk. Milk should not flow freely from the bottle. Cervids and suids are suckled in the standing position or in sternal recumbency. Carnivores and rodents are suckled in a sitting position, with the forelegs elevated to the level of the stomach. This position facilitates gravity flow of milk to the stomach, which is necessary because the swallowing reflex is not fully developed until at least 3 to 4 weeks of age in infant carnivores and rodents, as is the case in dogs and cats.[42] Very young lagomorphs and opossums often must be fed by gavage. Lagomorphs resist even the most determined attempts to get them suckling. As a result, they may be stressed to the point of death if repeated attempts are made to feed them against their will. Compared with eutherian mammals, young opossums weighing less than 50 gm, because of their semipermanent mouth-to-nipple attachment in the pouch, do not require a good suckling reflex.

Getting the neonate to accept the nipple may be a frustrating experience. As discussed, lagomorphs are the most problematic. Rodents usually will accept the nipple or syringe readily. Cervids object to manipulation of the head during feeding. Placing a hand behind the head and on the back and covering the eyes usually helps carnivores accept the bottle. With carnivores and deer, it may be necessary to use one hand to hold the lips closed around the nipple to facilitate proper suction. Great care should be exercised in this manipulation to avoid obstructing the trachea and nose or touching the eyes.

In nature, small animals do not defecate or urinate without maternal stimulation until mid- to late lactation. Thus, it is necessary to stimulate the animal after every meal gently patting (not rubbing) the rectogenital area with a cottonball or gauze pad soaked in warm water.

Weaning

Table 5 lists the weaning completion dates of common mammals, as well as preferred weaning diets. It should be noted that weaning actually begins at midlactation, when milk output peaks and eruption of cheek teeth (and incisors in rodents) begins in preparation for eating solid food. For example, tree squirrels are able to begin eating solid food when their incisors erupt at about 5 weeks of age. Raccoons lose dependence on mother's milk and begin weaning at 7 weeks of age.[14,16] Lagomorphs will begin eating grass, clover, alfalfa, and so on as early as 10 days of age.

Weaning is a maternal-dependent, forced process in that mothers decrease their milk output slowly as a neonate approaches an age when it can eat solid food. This necessitates that the youngster wean itself to receive its nutritional needs. In the wild, species such as deer can sometimes be found suckling well past weaning age. This should not be taken as extended weaning, but rather as the actions of an overindulgent mother. The youngster has long since lost its nutritional dependence on mother's milk. Attempts should not be made to mimic these practices. Neonates allowed to full suckle significantly beyond the weaning period will resist weaning. Their growth rates will slow because their nutritional needs have exceeded that which can be provided by milk. Metabolic diseases such as milk sugar and lactose-induced cataracts may develop. The youngster is also robbed of precious time needed to develop the skills to effectively feed itself in the wild.

To mimic the natural weaning process, milk consumption should be slowly reduced while the weaning diet and fresh, clean water are offered ad libitum. Monitoring body weight and stool quality will allow a good assessment of the degree to which the animal is accepting the weaning diet. At first, the rate of weight gain will plateau, rising again when the animal begins to properly assimilate the weaning diet, thus producing the biphasic growth curve common to most mammals. The stool color and consistency will change to that characteristic of the adult. In carnivores, for example, the stools become medium-brown in color and more voluminous and have a fine to medium granular consistency. After weaning, especially in northern states, weaning diets should be fed ad libitum to facilitate the fat deposition that is necessary for overwintering.

Readers should note the recommendations given for mink and ferret food as weaning diets for opossums, mustelids, ursids, and some canids. Reports indicate growth and survivability are much better on these diets than the commonly recommended commercial dog and cat foods.[4] The author's preference, based on palatability and ingredient quality, is Ralston Purina Ferret Chow (No. 5280).* One should also note that recommended weaning diets are not conglomerations of "natural foods." Natural diets are almost impossible to balance nutritionally due to ignorance of the exact nutrient requirements and the inability to procure the variety of natural feedstuffs eaten by most species. Such ingredients are expensive, usually perishable, and time-consuming to prepare. They can also promote palatability-based selective eating habits. As a result, these diets frequently lead to nutritional deficiencies such as rickets.[41]

Contrary to popular belief, it is not necessary to wean wild species to natural foodstuffs in order for them to recognize food when they see it in the wild. Anyone who has put a live mouse in a cage with a suckling carnivore, or a fresh branch of sassafras in with a white-tailed deer fawn can readily appreciate the animal's almost immediate acceptance of it as food. What is more important for these species is a time during which they can learn the most effective means of procuring food in the wild by trial and error. In the wild, this is accomplished with varying degrees of maternal guidance or instruction, ranging from almost none in rodents to up to a year or more in felids. This guidance or instruction can be mimicked by the slow-release methods of reintroduction described previously.[6]

Felids and cervids should not be fed nonnatural diets. Felids require long periods of time to develop hunting skills and should be weaned on a combination of dead and live prey. A variety of broad-leafed herbs and a good-quality hay should constitute the weaning diet of cervids to promote development of proper rumen function prior to release. Grain-based commercial bovine starter diets necessitate a dramatic shift in rumen microbiology, frequently leading to enteropathies if the animal is released after being weaned on such a diet.

It is recommended that natural foods be supplemented between weaning and reintroduction, as detailed in the footnotes to Table 5, to serve as an initiator of normal feeding behavior prior to the reintroduction.

RECORD-KEEPING AND PATIENT MONITORING

During the rearing of wild animals, it is good practice to monitor the animal by periodic weighing, physical weighing, physical examination, and written notes on behavioral and physical development. The correlation of these data (see Fig. 3) will enable growth problems or diseases to be diagnosed early, allowing treatment measures to be instituted before problems

*Purina Mills, Inc., St. Louis, Missouri.

Table 5. *Physiologic Norms of Selected Wild Animals*

SPECIES	BODY TEMPERATURE (°F)	EYES OPEN (DAYS)	WEANING AGE (WK)	WEANING DIET
Opossum	90–99	58–72	13–15	Mink/ferret food,* dog/cat food
Nutria	97–100	Birth	6–8	Rodent food
Beaver	98–101	Birth	6–9	Rodent food
Woodchuck	99–100	28	6–8	Rabbit food
Muskrat	98–101	14–16	4–5	Rodent food
Chipmunks	99–101	30–33	5–6	Rodent food†
Gray squirrel	98–102	28–35	6–8	Rodent food
Fox squirrel	98–102	28–35	6–8	Rodent food
Flying squirrel	98–102	29–40	6–8	Rodent food
Cottontail rabbit	100–103	6–8	2–3	Rabbit pellets‡
Jackrabbit				
Black tail	101–103	Birth	3–4	Rabbit pellets
White tail	101–103	Birth	3–4	Rabbit pellets
Weasel, long tail	100–103	30–35	3–5	Mink/ferret food§
Badger	99–101	30–35	8–10	Puppy/kitten food
Otter, river	99–102	30–35	12–13	Puppy/kitten food
Skunk, striped	101–102	28–30	7–8	Puppy/kitten food
Mink	99–102	30–35	4–6	Puppy/kitten food
Raccoon	100–103	21–24	13–16	Puppy food
Brown bear	100–102	35–40	24–32	Mink/ferret/puppy food‖
Black bear	100–102	35–42	Up to 88	Mink/ferret/puppy food‖
Bobcat	99–102	9–11	7–12	Live prey
Mountain lion	99–102	9–12	10–12	Live prey
Wolf	100–102	11–15	6–9	Mink/ferret food
Coyote	100–103	10–14	5–7	Mink/ferret food
Red fox	100–103	8–9	7–8	Puppy food
Gray fox	100–103	9–12	7–8	Puppy food
White-tail deer	100–101	Birth	12–20	Broad leaf forbs, hay
Black-tail deer	100–101	Birth	12–20	Calf starters
Mule deer	99–101	Birth	12–20	Calf starters
Peccary	99–101	Birth	10–12	Pig starter/grower, puppy food

*Supplement with dead rodents, etc.

†Supplement after weaning with hard-shell nuts, acorns, walnuts, etc.

‡Supplement with grass clippings, dandelion leaves, alfalfa, clover, plantains, lambsquarter, poison ivy.

§Supplement with live prey.

‖These species are best not raised in captivity, but fostered to wild mothers.

become life-threatening. Animals should be weighed every 48 to 72 hours during the first 3 weeks of life, preferably in the morning when the digestive tract is empty. From mid- to late lactation, weights can be taken once weekly. Weights should be plotted on a graph of age versus weight to show the growth rate. Regular inspections of the color, consistency, and patterns of defecation and urination should be made. Aspects of physical and behavioral development such as eye opening, tooth eruption, pelage development, vocalization, locomotion, and sibling interactions should be described. These data can also be very useful for monitoring the progress of others or of species for which growth and development data are scarce or unavailable. Physical examinations should be conducted weekly, with particular attention paid to the respiratory and digestive systems. In tree squirrels, it is necessary to inspect the genitals frequently to ensure that they have not been mutilated. Occasionally, siblings will suckle on any handy appendage between feedings, producing severe trauma to the genitals.

COMPLICATIONS OF HAND-REARING WILD ANIMALS

Runting

Usually the diagnosis of runting is quite easy to make when it involves one or more animals in an otherwise normal litter. However, when siblings are not available for comparison, diagnosis may be difficult, if not impossible, as physical development may be retarded to the point that a determination of true chronologic age for comparative purposes may not be possible.

Studies over the past 6 to 7 years have enabled us to describe two types of runting syndromes.[15] Features common to both syndromes include retarded behavioral and physical development and depressed growth rates, resulting in body weights lower than expected for the true chronologic age. In type 1 cases, the growth curve is of the characteristic configuration, but shifted in time to the right. Growth is, therefore, retarded until late in the suckling period or just after weaning. Type 1 animals show a progression in behavioral and physical development that parallels the growth rate of their apparent, rather than true, age. The key to resolving type 1 cases is to limit the daily intake of calories and nutrients to the apparent, rather than the real, age-dependent requirements, raising the caloric intake slowly as development is noted. Opossums, especially those weighing less than 50 gm, are prone to this type of runting.

Type 2 cases also show a shift in the growth curve. Unlike type 1 cases, however, there is a marked depression or flattening of the curve. Affected animals are sickly and inactive compared with normal littermates. Clinical findings include pallor, hypoproteinemia, leukopenia, cardiac arrhythmias, chronic hydrothorax and/or ascites, chronic diarrhea, intestinal gas, and a variety of other gastrointestinal disorders.

With time and treatment, type 1 cases usually become robust, healthy juveniles. Type 2 cases seldom recover and usually die of a malnutrition/starvation syndrome regardless of treatment.

Metabolic Bone Disease

Dietary osteopenia, or rickets, often occurs in juvenile wild mammals fed homemade imbalanced natural foods as weaning diets and is usually the result of calcium or phosphorus imbalances and/or deficiencies.[22] The formulation of a balanced diet of natural ingredients requires a thorough knowledge of foodstuffs and their compositions, as well as experience in mathematically formulating diets. Even if a balanced homemade diet is correctly formulated, selective eating habits based on palatability can easily predispose to metabolic bone disease.

Treatment of metabolic bone disease is accomplished by feeding a complete and balanced diet, such as commercial cat, dog, mink, or ferret foods. This also prevents selective eating habits. Natural foods are then supplemented at a rate not to exceed 10 per cent by weight of the daily food intake. Altering the vitamin and/or mineral levels of the homemade diets to resolve deficiencies is difficult, if not impossible, without thoroughly analyzing the diet to determine its shortcomings. Indiscriminate supplementation may cause further imbalances. For example, excessive calcium supplementation may lead to induced zinc deficiency.[30]

Enteropathies

Diet-induced diarrheas are without a doubt the most common problems encountered in rearing orphaned wild mammals. The vast majority are the result of too rapid a change from dam's milk to artificial milk replacers and/or overfeeding, both of which cause imbalances in intestinal flora. Young suckling carnivores have immature digestive enzyme systems. Excessive caloric intakes of even 25 to 30 per cent may overload digestive capabilities. Undigested and unabsorbed protein, fat, and carbohydrates remain in the lumen of the bowel, acting as an osmotic sponge and promoting bacterial overgrowth and toxin release, which ultimately results in diarrhea. At the outset of caloric overload, the feces are a pale green owing to excessive bile secretion and lack of bile reabsorption in the large bowel. As the digestive enzymes become depleted, the stool color becomes grayish-green to gray. Complete depletion of enzymes is marked by yellow to white stools.[34] In addition, if there are large amounts of lactose in the diet, the stomach secretes excessive hydrochloric acid. This alters the pH in the small bowel, further decreasing the effectiveness of its digestive enzyme systems.

Treatment of diarrhea includes resting the bowels (by reducing feed intake) and rehydration. Oral rehydration by gavage with a replacement electrolyte solution containing 2½ to 5 per cent glucose is most effective. For severe cases, intravenous procedures should be used. Standard clinical pathologic measurements, such as hemograms, plasma chemistries, and urograms, should be used to assess the efficacy of rehydration regimens. At the same time as rehydration is being accomplished, milk feedings should be restricted or suspended. Feeding may be reinstituted 48 to 96 hours later in the manner described previously for initiating feeding of milk replacer. During these treatments, every effort should be made to maintain a normal body temperature. Antibiotics should not be used routinely in dietary enteropathies because antibiotic therapy may further disrupt bowel flora and worsen the diarrhea. However, the clinician should not assume that all enteropathies in neonates are diet-induced. A diagnostic work-up should be performed to attempt to determine if the condition is solely dietary or is, in fact, a primary viral bacterial or parasitic bowel disease requiring specific antimicrobial or anthelmintic therapy.

Hypothermia

Almost all neonatal orphaned wild mammals are presented with some degree of hypothermia. There are species-related differences in susceptibility to hypothermia, which appear to be related to the stage of development at birth and the rapidity with which thermoregulatory abilities are developed. In order of increasing susceptibility to hypothermia are the cervids, lagomorphs, canids, felids, ursids, mustelids, rodents, and the opossum.

Woodchuck pups younger than 4 weeks of age are extremely susceptible to hypothermia, even at ambient spring temperatures.

Because digestive and metabolic activities are temperature-dependent, hypothermia can impair these processes, resulting in enteropathies. Young mammals are unable to nurse, and organ function is greatly compromised. Metabolic acidosis and tissue hypoxia become profound when body temperatures fall below 94°F. Feeding a neonate in this condition only serves to distend the bowel with undigested food, promoting bacterial overgrowth and diarrhea. When the body temperature falls to about 80°F, the neonate becomes torpid and cold to the touch and begins to vocalize, probably from the combined effects of hunger, cold, pain, and lack of maternal contact. At body temperatures of 70°F or below, the neonate is comatose. Respirations are very slow and shallow, with occasional agonal air hunger breaths. Death rapidly ensues.

Methods of rewarming have been described previously (restorative treatments). When the body temperature is below 90°F, rewarming should be performed slowly. Studies in human beings and dogs have shown that a rapid shift to normothermia in severely hypothermic patients can cause acute necrosis of the brain and heart, resulting from the rapid shift in metabolic activity from a state of almost torpor to one of normality. Fluid therapy (warmed, balanced electrolyte solution) must also be instituted with slow warming to maintain renal function and hydration.

Congenital Defects

During the physical examination upon the animal's admission, a thorough search should be made for congenital defects that may prevent the animal's successful reintroduction into the wild. We have found juvenile cataracts and central nervous system vascular problems in cervids. With the exception of anophthalmia, optic nerve agenesis, and abnormal cranial morphology in raccoon kits, congenital defects appear to be uncommon in wild carnivores. A variety of visceral organ anomalies, as well as cataracts and deformities of the dental arcade, have been seen in rodents and lagomorphs. The opossum is rather susceptible to congenital problems, probably because of its unusual reproductive physiology and embryologic growth and development.

Injuries

The most common injuries found in orphaned wild mammals result from automobile accidents, domestic animal attacks (especially dog and cat bites), and falls. Broken bones (usually of the limbs and cranium), skin lacerations, and deep puncture wounds are common. Deep puncture wounds usually can be found on either side of the thorax, frequently hidden from view by the thick pelage. Penetration of the lungs and heart or a rapidly fatal massive thoracic bacterial infection are common complications.

Proper treatments for such injuries are those routinely used for small domestic animals. However, sutures and external coaptation devices are seldom tolerated and frequently lead to excessive self-trauma during the patient's attempts to remove them. Third-intention healing has been used rather successfully in wild animals, even those with large and gaping wounds.

Aspiration Pneumonia

Aspiration of food or stomach contents into the lungs can result in foreign body and/or bacterial pneumonia. Milk aspiration usually results from the too rapid delivery of milk, excessively vigorous suckling, overfeeding by gavage, and improper suckling position. Unfortunately, the relative inactivity of most suckling mammals usually prevents obvious development of dyspnea until the condition is well advanced. or even terminal. In all but mild cases, treatment is frequently unrewarding. Pathologic studies have revealed that recovery invariably is accomplished by loss of lung tissue from reparative fibrosis. Therefore, prevention is obviously the best treatment. Force-feeding by gavage should be reserved for patients that cannot or will not feed normally. When gavage is used, the intubator should make all efforts to ensure proper placement of the tube, and volumes fed should be restricted to the maximum stomach capacity. Too vigorous suckling, leading to aspiration (milk bubbling from the nose) and dyspnea, is a common problem with raccoons, lagomorphs, and tree squirrels. In such instances, the bottle should be removed immediately and the nostrils cleared by burping or nasal suction. Feeding may be resumed when the nostrils are cleared and normal breathing is resumed. If the problem persists, a nipple with a smaller orifice or a 1- to 5-ml regular tip syringe should be substituted. A discussion of appropriate positions for suckling is described in the section on feeding methods.

Infectious Diseases

Wild orphaned mammals suffer from the same variety of bacterial, fungal, viral, and parasitic diseases as do their domestic counterparts.[13] The differences in behavioral characteristics of wild species seldom allow the clinician to render a diagnosis early unless he or she is familiar with such characteristics. Continuous monitoring of the neonate during suckling and a good background knowledge of normal behavior will frequently overcome this problem and allow the clinician to diagnose the illness early. It should be stressed that it is not recommended that these diseases be treated as they are in domestic animals. The essence of wildlife rehabilitation is the reintroduction of a healthy, reproductively capable animal to the wild. The reintroduction of disease carriers is of no benefit and can result in devastating problems for wild populations. For this reason, the author does not recommend the treatment of viral diseases in carnivores or of congenital defects, type 2 runting and secondary accompanying diseases, or injuries such as fractured limbs in cervids.

Bacterial Diseases

Localized Infections. Small orphaned mammals are commonly admitted with lacerations and puncture wounds that are infected by a variety of bacteria common to the attackers' oral flora (most commonly, *Pasteurella multocida, Staphylococcus aureus, Streptococcus* spp., and several coliforms). Standard treatments include debridement and cleaning with primary closure. Drain installation may be used. However, the clinician should remember that wild animals frequently do not tolerate sutures, bandages, and drains. Keeping the wound clean and moist and allowing healing by second or third intention is probably the easiest and most efficacious way to manage such wounds. It is not always necessary or desirable to employ antimicrobial therapy for any wound—antibiotics should be used judiciously on the basis of aerobic and anaerobic bacterial culture and sensitivity patterns.

Bacterial Enteritis. Primary bacterial enteritis is not a common occurrence in neonatal wild species. Enteritis secondary to nutritional problems such as overfeeding is common (see Enteropathies). However, primary *Campylobacter* (muskrats, woodchucks, and mustelids), and *Salmonella* (rodents and raccoons) infections do occur. Their treatment is controversial, because at present, there is no evidence indicating that antibiotics will clear an affected animal of the carrier state. Caution again is given in the routine use of antibiotics, especially in rodents and lagomorphs, which are extremely susceptible to antibiotic-induced colitis.

Viral Diseases

Canine Distemper. The most common viral disease of carnivores is canine distemper. The clinical syndrome, pathobiology, and epidemiology of canine distemper in wild carnivores and especially raccoons has been described.[18] Canine distemper is a highly contagious viral disease of carnivores that results in very high morbidity and mortality in mustelids, procyons, and canids. Aerosolization of nasal discharges is the chief avenue of contagion. Infection usually results in generalized disease that affects the hematopoietic, immune, nervous, integumentary, respiratory, and, to a lesser extent, digestive systems. Table 6 lists the most common signs observed by the author following a study of over 500 raccoons.[18] Although clinical signs related to most of the above body systems can be noted, bizarre neurologic signs frequently overshadow other signs. The neurologic signs are frequently indistinguishable from those of rabies. The typical early picture in 8- to 10-week-old raccoons is a hunched stance, shrunken jowls, glaring, almost fixed eyes, a lack of fear of human beings, diarrhea, and anorexia. Morbidity and mortality may approach 70 to 100 per cent in mustelids and procyons and 50 to 70 percent in canids. The incubation period averages 7 to 14 days but may extend to as long as 30 days. Virus shedding is a common finding in raccoons during the recovery stage. Animals suspected of having canine distemper should be isolated from other susceptible species.

Because of the highly contagious nature of canine distemper in wild carnivores, as well as the high mortality, it is not recommended that animals with canine distemper be treated. Rather, animals with canine distemper should be euthanatized. The vaccination of wild carnivores is, to say the least, a controversial issue. It is illegal by most state laws and is not recommended by the American Veterinary Medical Association Committee on Rabies Vaccination. However, whenever large numbers of susceptible carnivores are kept in captivity, vaccination is necessary to prevent devastating losses from canine distemper. The author and others[18,26,33] have studied several commercial canine distemper vaccines in wild carnivores and have found that modified live vaccines raised in other than avian cell cultures frequently are pathogenic to wild carnivores. However, even some avianized varieties

Table 6. *Type and Frequency of Clinical Signs Observed*[18]

CLINICAL SIGNS	NO. ANIMALS EXHIBITING SIGN	PER CENT
Neurologic		
Depression/malaise	530	98
Ataxia, incoordination	514	95
Paroxysmal tonic/clonic convulsions, eleptiform seizures	384	71
Lack of fear of humans/tameness	395	73
Aimless wandering/disorientation	357	66
Myoclonic flexor spasms, spasmodic muscular twitching (chorea)	346	64
Self-mutilation (sensory neuropathy or paresthesia)	298	55
Rear leg paralysis/paresis (ascending)	233	43
Head tilt, circling (vestibular signs)	227	42
Aggressive behavior	162	30
Excessive salivation (frothy)	152	28
Facial paralysis/paresis (progressive)	86	16
Excessive vocalization (barking or crying)	76	14
Blindness (fixed pupils and conjunctivitis)	43	6
Comatose	22	4
Respiratory		
Mucoid or mucopurulent rhinorrhea	541	98
Mucopurulent ocular discharge and conjunctivitis	525	97
Coughing, dyspnea, orthopnea, moist to coarse rales	49	9
Gastrointestinal		
Diarrhea	390	72
Fetid, mucoid	152	28
Watery (projectile/incontinent)	238	44
Severe, yellowish-green	54	10
Mild to moderate, greenish-tinged	184	34
"Cowpie" stools	76	14
Miscellaneous		
Anorexia	444	82
Dehydration	433	80
Erythematous, papular, vesicular, and/or ulcerative pododermatitis or dermatitis	103	19
Pale mucous membranes	92	17
Icteric mucous membranes	22	4
Emaciation, inanition	65	12
Depraved appetite	16	3

can be pathogenic for some species, especially mustelids and ailurapodids (pandas).[9,11] Studies with avianized commercial dog vaccine[47] in healthy raccoons, skunks, red foxes, and gray foxes have shown good antibody production without viral shedding following two doses given 2 weeks apart, between 8 and 12 weeks of age.[18] Raccoons vaccinated with this product have shown excellent protection against experimental infection.[18] In addition to describing the safety and efficacy of this vaccine in gray foxes, recent studies have described vaccine-induced disease in vaccinates with subnormal immunoglobulin levels.[26] Thus, runts or unhealthy animals should never be vaccinated with a modified live vaccine. Furthermore, it is not advisable to vaccinate neonates younger than 3 weeks of age because of their immunologic immaturity.

Parvoviral Enteropathy. For 40 to 50 years, it has been known that procyons and many mustelids are highly susceptible to a disease almost identical to feline panleukopenia. Recent studies have shown that this disease is caused by a genetic variant of feline panleukopenia (FPV).[38] Feline panleukopenia has been experimentally inoculated into raccoons, red foxes, mink, and striped skunks. The resulting disease was extremely contagious and caused devastating mortality in mink and raccoons. Red foxes and striped skunks remained asymptomatic.[3] Clinical signs develop rapidly (within 6 to 12 days) and include depression, anorexia, dehydration, varying degrees of leukopenia, and watery, mucus-laden, bile-stained, and/or hemorrhagic diarrhea.

Canine parvovirus (CPV-2) has been reported in coyotes.[2] Experimental studies have shown that raccoons, striped skunks, and red foxes are not susceptible.[3] Outbreaks of parvoviral disease in raccoons have been studied in rehabilitation centers, in zoos, and in the wild.

Attempts at treatment of parvoviral disease in wild carnivores are usually futile, and there is good circumstantial evidence that, in many cases, sufficient amounts of infectious virus may be shed during and after recovery to produce a point source of infection. For these reasons, it is recommended that such cases be euthanatized rather than treated. Vaccine trials with several modified live and killed commercial dog and cat vaccines have failed to produce demonstrable immunity or protection from the development of clinical signs in wild carnivores. A recent report indicated that passive immunization of dogs with hyperimmune canine serum before and up to 24 hours after oral challenge with CPV-2 protected against infection.[32] Such therapy may be of benefit in wild carnivores.

Rotaviral Enteropathy. Rotavirus-associated diarrhea has been reported in raccoons, skunks, and foxes.[17] This virus is one of the most common causes of neonatal diarrhea in human beings and many species of animals, especially hoofed mammals. Clinical signs of diarrhea, anorexia, and dehydration are usually self-limiting and resolve in 2 to 3 weeks with supportive care. In untreated neonates, however, especially those with bacterial or parasitic infections, the outcome is frequently fatal.

Parasites. A wide variety of nematodes, trematodes, cestodes, and protozoan parasites infect small wild mammals. Infections usually do not result in clinical disease. Exceptions occur in the very old and young or those with predisposing immunosuppression. The situation is very different in captivity, where housing restrictions usually put animals in constant contact with large numbers of infective parasite eggs. Furthermore, the stresses of captivity have long been known to precipitate clinical infections by many parasites, most notably *Coccidia* in carnivores. Fecal examination should be performed at admission and at least every 3 to 4 weeks thereafter until reintroduction into the wild. When parasites are present, the animals can be treated with the appropriate antiparasitic drugs listed in Table 7.

Some veterinarians advocate that treatment not be undertaken unless there is evidence of severe infection. They propose that wild mammals are all parasitized in the wild state and must be able immunologically to cope with such infections. Parasite-free reintroductions are, thus, deficient in this respect. Although this theory may have some basis in fact, the clinician must

Table 7. *Antiparasitic Drugs for Wild Mammals*

DRUG	TRADE NAME AND MANUFACTURER	DOSAGE*
Pyrantel pamoate	Nemex, Strongid-T Pfizer Inc., New York, NY	10–20 mg/kg PO
Fenbendazole	Panacur American Hoechst Corp., Somerville, NJ	50 mg/kg PO for 3 days
Mebendazole	Telmin Pitman-Moore, Inc., Washington Crossing, NJ	25–40 mg/kg PO for 3–5 days
Levamisole	Levasole Pitman-Moore, Inc., Washington Crossing, NJ	4–10 mg/kg PO, SC
Dichlorvos	Task E. R. Squibb and Sons, Inc., Princeton, NJ	30 mg/kg PO
Praziquantel	Droncit Haver-Lockhart Labs, Shawnee, KS	5–10 mg/kg PO 10–15 mg/kg SC
Amprolium	Corid Merck and Co., Inc., Rahway, NJ	100–200 mg/kg PO for 7 days
Ivermectin	Ivomec Merck and Co., Inc., Rahway, NJ	200 μg/kg PO, SC, Cut
Sulfadimethoxine	Albon Roche Chemical Division, Nutley, NJ	25 mg/kg PO
Metronidazole	Flagyl Searle Pharmaceuticals, Chicago, IL	60 mg/kg PO for 3–5 days

*Fecal examinations should be used to assess efficacy of treatment. It may be necessary to repeat treatments 2 to 3 weeks later.

weigh the effects of parasitism on young stressed animals in captivity, as well as the high zoonotic potential of many of the common parasites. As an example, it is highly recommended that all raccoons be treated for *Baylisascaris proyconis*, the common roundworm. This nematode has a rather remarkable potential to cause cerebrospinal nematodiasis in a variety of mammals, including man.[19,29] Patent infections do not occur until raccoon kits are at least 60 days old. Thus, eggs are not evident in the feces of raccoon kits younger than 8 weeks of age; however, kits can succumb to intestinal pathology and blockage from immature worms during this period. Each bowel movement can result in the shedding of up to 20,000,000 eggs having an incubation period of 30 days. Eggs are impervious to nature, remaining viable in the ground for periods of up to 8 years. With the exception of formalin and burning with a 50:50 mixture of xylene and alcohol, most disinfectants have no affect on eggs of ***Baylisascaris*** spp. Nemex* and Panacur† are highly effective against intestinal nematodes of wild animals. These are recommended because of their very wide margin of safety. Nemex is highly palatable for carnivores; therefore, caution should be exercised in administering it to raccoons because they often become highly aggressive in their attempts to consume it. Many of the trematodes, such as *Heterobilharzia, Alaria, Eurytrema, Paragonimus,* and *Schistosomes,* can be effectively treated with Droncit.‡ This drug is also highly effective against cestodes. Protozoan species such as *Eimeria* or *Isospora* have been effectively treated with amprolium or sulfadimethoxine. No antiparasitic drug has yet been found for the treatment of *Cryptosporidia. Giardia* can be effectively treated with Flagyl.§

Immobilization and Anesthesia. The use of immobilizing agents or anesthetics in suckling mammals presents special problems. An excellent review of anesthesia in pediatric patients has recently been published.[42] Readers are encouraged to consult this review prior to anesthetizing young wild animals. Local anesthesia can be accomplished with infiltration of 1 per cent Xylocaine.|| Atropine (0.04 ml per kg intramuscularly) can be used to prevent bradycardia during general anesthesia. For sedation, immobilization, or minor surgical procedures, Acepropmazine maleate¶ at 0.1 mg per kg intramuscularly, oxymorphone hydrochloride** at 0.1 mg per kg intramuscularly, or ketamine hydrochloride†† at 4 to 10 mg per kg intramuscularly can be used. Oxymorphone can be reversed with naloxone‡‡ at 0.01 mg per kg intravenously, intramuscularly, or subcutaneously. Large doses of ketamine should not be used because of respiratory depression. Xylazine should not be used to control muscle rigidity and convulsions caused by ketamine because of its depressive effects on the cardiovascular system. Most anesthesiologists agree that gaseous anesthesia is preferred for general anesthesia of healthy and unhealthy young animals. Halothane,§§ methoxyflurane,|||| and isoflurane¶¶ can all be used safely. Gaseous anesthetics are delivered by the Ayre's T-piece system or one of its modifications, such as a Norman's masked elbow or the Bain coxial circuit. Alternately, pediatric human circle systems can be used. Gaseous anesthetic delivery devices should always have an appropriate system to remove waste gases from the operating room.

*Pyrantel pamoate. Pfizer Laboratories, New York, New York.
†Fenbendazole. American Hoechst, Somerville, New Jersey.
‡Praziquantel. Haver-Lockhart Laboratories, Shawnee, Kansas.
§Metronidazole. Searle Pharmaceuticals, Chicago, Illinois.
||Lidocaine. Astra Pharmaceutical Products, Worcester, Massachusetts.
¶Fort Dodge Laboratories, Fort Dodge, Iowa.
**Numorphan. Endo Labs, Garden City, New York.
††Ketaset. Bristol Laboratories, Syracuse, New York.
‡‡Narcan. Endo Labs, Garden City, New York.
§§Fluothane. Ayerst Labs, New York, New York.
||||Metofane. Pitman-Moore, Washington Crossing, New Jersey.
¶¶Forane. Ohio Medical

CONCLUSION

The information contained in this article and a good background knowledge of the behavior, physiology, and anatomy of wild animals will enable the practicing veterinarian to aid wildlife rehabilitators. Although rehabilitation is far from a glamorous, routinely successful endeavor, competent medical assistance can and does greatly increase the chance of reintroduction.

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SOME CONSIDERATIONS IN THE FEEDING OF CAPTIVE REPTILES

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INTRODUCTION

Nutrition is the sum of the processes involved with intake, assimilation and utilization of nutrients to produce optimal growth, condition and reproduction. Reptiles present great variation in feeding habits and preferences but show little divergence from the nutritional requirements of endothermic species. All chordates, regardless of class, require water, protein (amino acids), fatty acids, vitamins and minerals. How reptiles obtain these nutrients depends on the conditions of their environment.

A successful nutritional program must provide a balanced diet; one that contains nutrients similar in proportion to those found in the species' natural diet. This is not to imply that every natural diet is complete and balanced, but only that the continued success of a species in the wild is proof that a nutritionally adequate diet is being obtained. Once the choice of foodstuffs is restricted or reduced by captive conditions, the chance for nutritional imbalance increases.

Nutrition and feeding are quite different. Feeding is the act of taking in food; nutrition refers to the quality and adequacy of food. The feeding response cannot be used as an indicator of the nutritional adequacy of a food item; acceptability and adequacy are in no way related.

Reptiles, more so than endotherms, depend on an acceptable environment for the maintenance of optimal nutritional status. This is because the digestive physiology of reptiles is regulated by environmental conditions, and the limits of these conditions are determined by the natural environment of each particular specimen. An acceptable environment and an adequate diet are essential for longevity, health and reproduction in captive reptiles.

METABOLIC RATE

Nutrition is directly related to metabolic rate, and several factors influence the metabolic rate of rep tiles. Metabolic rate is temperature dependent, and for most specimens maximal efficiency occurs between 30 and 40 degrees C (Cloudsley-Thompson, 1971). Most reptiles adapt very poorly to cool environments. Many species are found in temperate areas and are able to survive because of their low metabolic rate and their ability to exist on large, infrequent meals (Benedict, 1932). Winter dormancy occurs in temperate species and is accompanied by a fasting period with a concurrent reduction in metabolic rate.

In captivity, the term, "preferred temperature optimum", is used to describe that temperature within a thermal gradient at which an ectotherm chooses to spend the majority of its time (Cloudsley-Thompson, 1971). Fossorial species are able to choose the preferred temperature in their natural environment and to a lesser extent in captivity. However, aquatic forms are dependent upon water temperature for determining their body temperature. Consequently these aquatic species are more restricted to the temperature range of the environment with respect to maintenance of normal body functions.

Muscular activity in animals results in the production of heat. In reptiles, thermogenesis is generally poor, but in some species an elevation of body temperature above ambient has been noted (Asplund, 1970). Endothermy is more efficient in larger reptiles, and core body temperature can remain elevated 4-6 degrees C above the ambient for long periods of time (Cloudsley-Thompson, 1971).

Temperature and the Regulation of Functions

Physiological functions are regulated by enzyme systems. These biochemical systems in reptiles are temperature dependent to varying degrees. The enzyme ATPase, which is essential in energy-producing reactions, is temperature dependent and activity is reduced as temperature declines. Alkaline phosphatase, on the other hand, does not show this temperature specificity, and functions over a wider temperature range (Licht, 1967). Trypsins, in those reptiles studied, appear to be isoenzymes. A seasonal fluctuation in trypsin isoenzyme activities has been noted. One isoenzyme (substrate affinity increases as temperature increases) is more prevalent in the spring. Another isoenzyme (substrate affinity decreases as temperature increases) shows greater activity in the fall (Hofer, et al., 1975a; Hofer, et al., 1975b). Due to such differences in enzyme temperature optima in reptiles, there may not be a single preferred temperature, but rather several preferred temperatures may exist.

Long term exposure to preferred temperature optima without fluctuations in temperature can be fatal to certain reptiles (Wilhoft, 1958). Weight loss and sterility due to testicular degeneration occurred in several species of lizards when kept constantly at preferred temperature optima (Licht, 1965). This does not occur in every species subjected to these conditions (Wilhoft, 1958).

In ectotherms, as well as endotherms, the digestive process is temperature dependent, starting with feeding and ending with elimination (Regal, 1966). However, in reptiles, the processes of food acquisition, gastric secretion, gut motility and nutrient absorption depend on appropriate ambient temperatures to assure appropriate core temperatures (Bustard, 1968; Regal, 1966; MacK ay, 1968). There is no constructive purpose to feed an animal if body temperature is so low that digestion cannot occur. Active feeding, followed by lowering of body temperature has resulted in toxemia and subsequent death, due to autolysis of food in the gut.

Temperature fluctuations in the environment are normal and may be necessary to assure optimal physiological function in reptiles. Every attempt should be made to provide captive reptiles with environmental conditions appropriate for the species.

CARNIVORY AND HERBIVORY IN REPTILES

Reptiles may be classified as carnivorous, herbivorous or omnivorous. One might actually consider carnivores as secondary omnivores since many prey species consumed by reptiles are herbivorous, and the gut contents of the prey include large quantities of partially digested plant material.

In lizards herbivory appears to be weight dependent, and most specimens under 300 grams are frequently carnivorous (insectivorous). Their small size and higher activity levels allow for quickness in seizing prey without an undue expenditure of energy. Many lizards weighing more than 500 grams are herbivorous. This strategy allows them to take food leisurely and to obtain desired quantities of the foodstuff without an undue energy expenditure. Exceptions exist in those lizard species with specialized adaptations for food acquisition; regardless of weight these remain carnivorous. Both the varanids and chameleonids show specialized adaptations for prey acquisition. The varanids seize prey with a short, quick sudden burst of movement with a presumed low energy output. The chameleonids seize prey through the rapid movement of an elongate tongue; the net result is the use of minor portions of the body muscle mass, again resulting in a presumed low net energy expenditure. Species that are carnivorous are able to maintain this status only because the net energy intake of a prey item is greater than the net energy expenditure associated with the capture (Pough, 1971).

The young of some species of lizards tend to be carnivorous, at least during the first few months of life, later shifting to more herbivorous diets. However, Iverson (1982) states that in lizards that are true herbivores as adults this ontogenetic shift from carnivory to omnivory does not occur. In those lizards which start out with carnivorous habits, they apparently are taking advantage of high calorie, low fiber content of whole prey items. In general, herbivores have a readily available food supply and expend little energy during food acquisition. However, it has been noted that seasonal differences in food availability or suitability, and food quality or quantity, can slow growth and inhibit reproductive success in herbivorous lizards (Iverson, 1982).

Considerations in Feeding Prey

Vertebrate prey, as a food source, may generally be considered nutritionally adequate. However, there can be problems associated with the feeding of whole animals, since a prey item that is fasted or starved may not be nutritionally adequate. In such instances, protein catabolism occurs and muscle protein is utilized by the animal for maintenance. There is no synthesis of protein, fat is rapidly depleted and stores of vitamins and minerals also diminish (Maynard, et al., 1979). Juvenile and adult vertebrate prey (mouse, rat, chick, fish) should be maintained on nutritionally complete, balanced diets formulated specifically for the particular species. Suckling young (mouse, rat) should be kept with lactating females up until their use as food. Fresh, clean water should be available to all prey species.

Invertebrate prey, such as crickets and mealworm larvae also need to be adequately fed. The use of nutritionally complete foods, rather than rolled oats or bran, are preferred. Extruded dog or primate food can be ground and provided in shallow pans. Ground poultry and rodent diets have also been used successfully as food for insect colonies. When such dry feeds are used, fresh water must always be available. Since crickets and mealworm larvae are very poor sources of calcium (Allen and Oftedal, 1982; Jones, et al., 1972) a supplemental source of this mineral must be provided. This can be done by either dusting the insects with a calcium source (ground calcium carbonate) or feeding a high-calcium diet (Allen and Oftedal, 1982; 1989).

Dormancy Fasts

Fasting is physiologically normal for many reptiles at certain periods during the year (Bellairs, 1967). During a prolonged fast, morphological changes are seen in the cells of the hypothalamus. The relationship of these changes to metabolic and physiological alterations have not been determined (Banerjee and Pahari, 1970). Each species responds differently to a fast. During fasting, metabolic pathways are altered and physiological and behavioral changes may occur.

In certain fasting lizards, calories for maintenance are derived from protein via gluconeogenesis, rather than from the catabolism of visceral fat bodies. In these species, no alteration in the weight of the fat bodies was observed, but an overall decrease in body protein was observed (Momin, 1975). In other lizard species under near identical conditions, the visceral fat bodies are metabolized first, as the primary energy source. In this case, liver glycogen and blood glucose decrease rapidly and early in the fast (Gist, 1972).

However, in certain chelonian species, kidney, liver, muscle and heart glycogen remained constant throughout an eighteen-week fast. There was no change in physical activity level (Morlock, et al., 1972), nor was there any alteration in enzyme activities following a fast in semi-aquatic turtles (Penney and Papademas, 1975). In snakes, an eighteen-week fast had no significant effect on blood chemistry values except for a slight decrease in serum cholesterol and serum sodium (Martin and Bagby, 1973).

Fasting appears to be a major biological adaptation to temperate climates (and tropical) and/or seasonal fluctuations in food availability. A variety of environmental regulators and adaptive features are important in determining the periodicity and duration of fasting. During periods of environmental harshness, the available biomass becomes reduced and a period of fasting may result. The dormancy fast of reptiles in temperate climates corresponds to periods of low environmental temperature or drought. Fasting under these conditions is accompanied by a concurrent reduction in activity levels and metabolic rate.

Under captive conditions, fasting is seen with great regularity and can be predictably controlled. Many crocodilians will undergo a fast if the environmental temperature drops below 28 degrees C. Lizards, snakes and turtles also fast at reduced temperatures; the conditions under which fasting occurs is probably species dependent. A captive fasting animal is not necessarily experiencing a disease process. If the failure to eat is due to poor captive conditions, it may reverse once the environmental conditions are improved (Bellairs, 1967). First year temperate species will frequently fast regardless of environmental conditions, and this should not be considered indicative of a disease condition. However, there may be deleterious effects after prolonged fasts in captive reptiles that attempt to hibernate under less than ideal conditions (R. Pawley, pers. comm.).

CONCLUSION

The role of nutrition in reproduction is linked to the metabolic requirements and natural food preferences of each reptilian species. Environmental factors play an important role in determining the onset of reproductive behavior (Laszlo, 1975), but nutrition appears to regulate overall reproductive performance. The future of reptiles in captivity may ultimately be determined by our ability to determine nutritional, environmental, ethological and physiological requirements of each species. No longer can chance feeding practices be used when dealing with endangered and threatened species if we are to succeed in fulfilling our roles as the managers of collections of captive reptiles.

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IDENTIFYING ZOO MAMMALS WITH SPECIAL NUTRITIONAL NEEDS

Antinomy:

In the 19th century, British jurists sought to modify the laws permitting a husband to "chastise his wife with any reasonable instrument," by dictating that the instrument be a "rod no thicker than his thumb." Hence, the rule of thumb. (Psychology Today, 1983).

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Introduction

It is convenient and often necessary to group animals together when identifying their nutritional requirements. There are, however, individuals within each group with special nutritional needs. It is important to identify these individuals, recognize their needs, and adjust the nutritional program appropriately. In the zoo environment the difficulties of identifying and problem solving are much greater than in the agricultural and domestic communities. There are an estimated 4,201 known species of mammals (Nowak and Paradiso, 1983), more than half of which are available for zoological display. Furthermore, there is an obvious lack of information on the nutritional needs of zoo mammals (Ullrey & Allen, 1986). Thus, we are left to discuss nutritional principles, understanding generalities, and to follow the so-called "rules of thumb."

The law, or rule of thumb, as the British jurists intended, implies a measure of "reasonable" uniformity to meet the needs of the existing crisis by allowing "a rod no larger than the thumb." Yet also a degree of flexibility providing the administrator some latitude for a dose-response application. The law states not how long the chastisement shall last, and the husband is provided the option of selecting a rod smaller than his thumb if he so desires. We need to bear in mind then that there are options available when considering the value of any "rule of thumb." We need also to remember that the original British decree was in fact an "antinomy." That is, "a contradiction between principles that seem equally necessary and reasonable." As with the Giraffe, the tallest of land mammals; it is endowed with a coat of camouflage and has been graced with horns coated with a fine felt covering. By today's standards, the literal interpretation of this 19th century practice is against all moral principles, yet may have, at one time, appeared reasonable to some. Keep in mind then, that the rules of thumb being presented here, although appearing contradictory, are in fact reasonable and perhaps necessary.

<u>Assessing a Nutritional Problem:</u>

The difficulties associated with detecting the nature of a nutritional problem and directing its outcome can be immense. Decisions must be made as to the origin of the disorder, if the disorder is of a primary or secondary nutritional involvement, if it is a single or complex multi-nutrient disorder, and what therapeutic steps should be taken. Admittedly, the likeliness of making a correct and precise diagnosis of a complex nutritional problem is remote. And since, in many cases, time is also a limiting factor in the decision-making process, the professional ultimately proceeds with the "best estimate" of the disorder. Based on available information, he or she must incorporate prior knowledge and technique to attack the problem, relying on the animal's response to therapy as support for the accuracy of their decision. A logical and methodical approach to problem solving enhances the success in any profession. Sound judgment decrees that nutritional disorders be approached from those of the greatest frequency to those of a lesser frequency and from the general disorder to the more specific.

Based on frequency of occurrence, nutritional disorders of many domestic animals occur in the order of: (i) water being the most frequently abused nutrient, with (ii) energy malnutrition being the second most prevalent disorder, and this may be an oversupply of dietary energy more often than a lack of sufficient energy. Energy malnutrition is followed closely by (iii) protein malnutrition in occurrence. The least frequent of all nutritional disorders relates to (iv) vitamin and mineral malnutrition. The "rule of thumb" associated with assessing a nutritional problem simply states that "when considering a nutritional problem, place your concerns with water being the most important nutrient, followed by energy, then protein, and least of concern minerals and vitamins.

Realizing that water is the most important and most frequently abused nutrient, the "rule of thumb" applying to the animal's fluid needs, whether it be for preventative or for therapeutic purposes, is to "always provide a clean, abundant, and accessible water supply."

NON-DISEASE STRESS EVENTS

There are four major non-disease stress events in the life of the adult mammal. These are periods of change in the ambient temperature (i.e. environmental stress), the aging process (i.e. the stress of the elderly animal), and for the female, periods of pregnancy and lactation (Perry, 1984). For each stress period there are special nutritional needs. We will consider each stress individually.

Environmental Stress

Extremes in environmental temperatures often place considerable stress on the animal. Such stress is often reflected in their nutritional needs. Both extremes in ambient temperature, that is heat and cold stress, cause an increase in the maintenance requirements of the animal (Collier, 1985; Figure 1). For the cold stressed animal, behavioural aspects often coincide with the increased nutritional needs. That is to say, food intake will generally increase with a decrease in ambient temperature, although fluid intake may fall below the desired level. We should remember, however, that most animals' "appetite" will not respond immediately to cold stress. Often a short period of weight loss will occur. Then they will eat more as the cold period proceeds until a plateau is reached between intake and weight maintenance. When the animal's winter coat has developed appropriately, appetite may drop slightly to compensate for the added insulation. Most temperate animals will adapt well to prolonged periods of cold stress. It is those periods of rapid flux in the environmental temperatures that have the detrimental effects on the animal's ability to establish proper food intake.

The "rule of thumb" applying to cold stress is to "feed a one-percent increase in energy intake with each degree F below the thermocomfort zone" (Ward, 1984). For most mammals, this would be in the 35 to 40 degree F range. Those of us accustomed to feeding the cold stressed animal realize that forages are a good source of body heat (i.e. the specific dynamic action of fiber digestion), although not a high energy density feed. Thus, both components, fiber and grain, should be considered when feeding the cold stressed animal. An added note is that water consumption can be enhanced by simply providing a warmed water source.

Heat stress, contrary to popular belief, also causes an increase in the maintenance requirements of the animal. Unfortunately with heat stress the animal tends to reduce feed intake and increase fluid consumption (Figure 1).

The knowledgeable nutritionist will increase the energy density of the feed (i.e. less fiber and more grain) so as to aid the animal in meeting its energy needs. Another valuable tool is to grind the feed and moisten it before feeding, thus encouraging the animal to eat more, meeting both their energy needs and providing some additional fluids. Note that for the environmentally stressed animal, the nutrients of concern are water and energy.

Gestation

Gestation is a time of obvious increased nutritional demands, for the expectant mother must provide for her own requirements as well as those of her forthcoming offspring. Unlike the environmentally stressed animal, principal concerns are for an increase in the energy and protein needs of the pregnant female. The NRC recommendations for various mammals suggest that the increase in energy needs are less than 50% above maintenance for most mammals, with the larger species having an increased requirement of as little as 20 to 25% (Table I). We may conclude that gestation is far less costly and stressful to the larger mammals, perhaps because of their relatively smaller fetus per unit size of the parent. The larger animals may also have the ability to reduce the maternal demands by distributing total energy costs over a longer gestation period. The rabbit must produce its offspring within the 30 to 32 day gestation period, while the antelope may take several months. Also note that the smaller species tend to have multiple births while the larger species generally produce a single offspring. And for these smaller species the greater surface area to body mass creates an additional energy demand via the increased heat loss. As much as 60% of the gestation energy requirements of the rodent may be lost as body heat (Battaglia & Meschia, 1981).

Dietary protein is of greater significance for the pregnant animal than is energy. Whereas energy requirements were noted to increase by less than 50% above maintenance, protein requirements generally exceed the 50% increase and in some cases are upwards of several hundred percent (Table I). Like the energy demands, however, protein requirements of the larger species are less. This may again be due to the longer gestation period and fewer number of offspring per birth.

Remembering that protein is the nutrient of principal concern, the "rule of thumb" associated with feeding the pregnant female is to "feed for the condition of the dam, but only during the first two trimesters of pregnancy." Note that during the first 2/3 of pregnancy, fetal growth is less than 40% of its final size and more often only 1/4 to 1/3 its weight at birth (Robbins & Robbins, 1979). It is the time during pregnancy when the female can look well, can maintain her body proportions, and her condition can be judged visually. It is important to maintain a female in good condition during the early periods of pregnancy so as to assist her in meeting the increased demands of late gestation. <u>Ad libitum</u> feeding is recommended during early gestation if the animal had been accustomed to such a feeding program prior to becoming pregnant. Early pregnancy is also a good time to increase the vitamin and mineral stores of the animal for later gestation and lactation demands.

The second half of this "rule of thumb" and probably the most important half, is "not to feed for the condition of the dam during the last 1/3 of gestation"; for in late pregnancy the female seldom looks fit in relation to her non-pregnant counterparts, is often out of proportion, and her condition is not easily assessed visually. More importantly, fetal growth is 60% or more during this period (Robbins & Robbins, 1979). Little, if any dietary nutrients consumed by the female goes to meeting her needs, and certainly all excess nutrients greatly increase the size of the fetus, enhancing the chance for dystocia. It is also significant to note that the increased fetal size infringes upon the stomach of the female, reducing her intake capacity. Late gestation thus becomes the critical time for increasing the dietary protein and minerals for fetal development.

Lactation

Lactation is much more energy expensive than is pregnancy. At parturition the transfer of nutrients from the maternal unit to her offspring shifts from the uterus to the mammary gland. The rapidly increasing body mass and growth rate of the neonate is reflected in the increased nutrient drain from the mother. Unlike gestation, however, where protein was the principle nutrient, in lactation, energy becomes a nutrient of equal concern (Table II). Associated with the increase in neonatal growth is the fact that the offspring now becomes more mobile, has an increased metabolic rate over that of its parent, and must provide for its own thermogenesis. All these energy demands of the offspring must be supplied by the maternal milk. Whereas the increased energy demands of the lactating female are increased by 100, 200 or almost 300% above maintenance (Table II). As much as 80% of the dietary energy consumed by the lactating female may be devoted to producing milk (Collier, 1985).

The protein requirements of the lactating female tend to parallel those of her energy requirements in that values of 100, 200 and 300% above maintenance are observed. As it was with gestation, the protein requirements of the smaller lactating species and those females which have multiple offspring increased to a greater extent than those of the larger species. And as it was with the gestating animal, the lactation period of the larder mammals is extended over a longer time span than it is for their smaller counterparts, reducing the daily demands for energy and protein of the maternal unit of larger species.

The "rule of thumb" relating to the feeding of a lactating female is to "feed her in accordance with the weight of the offspring." Roughly speaking, this can be calculated as approximately 220 Kcal per kg of infant weight, or 100 Kcal per pound of offspring, in addition to the maintenance requirements of a non-pregnant female of similar size (Anonymous, 1977). This is a rather handy tool to use since it is comparatively easier to measure the weight of the offspring and feed in accordance with their increasing size than it is to estimate the weight and needs of the lactating female.

Realizing again the highly elevated energy demands of lactation and that, more often than not, the fetus is born in the spring and suckled during the heat of summer, the "rule of thumb" suggested for feeding the heat stressed animal applies to feeding the lactating female. That is, fine ground, high energy density feeds which have been moistened to enhance intake, thus replenishing the energy and fluid demands of lactation.

We should remember that various species suckle their offspring at different intervals. For those species providing continual contact with their offspring, energy demands are less than for those species who permit their offspring to suckle at infrequent intervals such as the lagomorphs and pinnipeds (Table III. For these latter species to concentrate their milk requires a greater increment of energy needs.

Aging

Aging is a slowly progressing process in which there is a reduction in the amount and size of many anatomical components of the body. These changes may be evident both grossly in the outward appearance of the animal and microscopically. For example, as the animal becomes older, there is a reduction in muscle mass and bone density. Specific cellular enzyme activity is also reduced (Perry, 1984). These anatomical, biochemical, and physiological changes result in a reduction in the caloric demands of the dietary animal. Thus, dietary energy requirements of the aging animal are of minimal concern. Of principal concern are the specific minerals and vitamins, and to a lesser extent dietary protein. The dietary calcium requirements generally increase as do the phosphorus requirements to maintain the appropriate Calcium : Phosphorus ratio. The vitamin requirements of the aging animal also increase, especially the water soluble B complex vitamins, which should be supplied in abundance. The "rule of thumb" for the nutritional needs of the aging animal then, with the exception of fluid requirements, are reversed from that of the younger stressed individual. The nutrients of principal concern for the aged animal are water, followed by vitamins and minerals, with adequate protein and dietary energy needs of least significance.

Table I. Gestation Energy and Protein Requirements for Various Mammals

	Energy Requirements			Protein Requirements		
	MNTN*	GSTN**	Increase	MNTN*	GSTN**	Increase
Cricetidae (0.3kg)	173	253	46%	1.91	8.42	341%
Cebidae (2.4kg)	100	125	25%	2.85	5.17	81%
Leporidae (4.5kg)	63	105	67%	4.26	7.33	72%
Felidae (32 kg)	70	100	43%	3.12	4.46	43%
Canidae (32 kg)	54	79	46%	3.75	5.48	46%
Bovidae (70 kg)	34	63	85	1.52	3.00	97%
Suidae (110 kg)	49	58	19%	2.29	2.54	11%
Bovidae (500 kg)	27	33	22%	1.23	1.87	26%
Equidae (500 kg)	26	32	23%	1.28	1.55	46%

Data derived from the National Research Council (NRC bulletins on the Nutrient Requirements of Domestic Animals) and from Gaines Professional Service Bulletin on the Basic Guide to Canine Nutrition. Data on Felidae protein requirements not available, values calculated to equal energy increase.

*MNTN = Maintenance in kcal/kgBW.
**GSTN = Gestation in kcal/kgBW.

Table II. Lactation Energy and Protein Requirements for Various Mammals

	Energy Requirements			Protein Requirements		
	MNTN*	LCTN**	Increase	MNTN*	LCTN**	Increase
Cricetidae (0.3kg)	173	573	231%	1.91	14.6	665%
Cebidae (2.4kg)	100	270	170%	2.85	7.30	156%
Leporidae (4.5kg)	63	232	268%	4.26	20.8	366%
Felidae (32 kg)	70	250	257%	3.12	11.2	257%
Canidae (32 kg)	54	198	266%	3.75	13.7	266%
Bovidae (70 kg)	34	86	153%	1.52	4.11	170%
Suidae (110 kg)	49	115	135%	2.29	5.45	138%
Bovidae (500 kg)	27	48	77%	1.23	2.74	114%
Equidae (500 kg)	26	42	62%	1.28	2.36	92%

Data derived from the National Research Council (NRC bulletins on the Nutrient Requirements of Domestic Animals) and from Gaines Professional Service Bulletin on the Basic Guide to Canine Nutrition. Data on Felidae protein requirements not available, values calculated to equal energy increase.

*MNTN = Maintenance in kcal/kgBW.
**LCTN = Lactation in kcal/kgBW.

Table III. Mid-Lactation Milk Consumption and Energy Content for Various Mammals.

	Water (%)	Protein (%)	Energy (kcal/g)
Marsupials	76.4	7.9	1.06
Primates	86.8	1.8	0.68
Lagomorphs	66.8	12.7	2.19
Rodents	73.0	8.5	1.58
Carnivores (fissipeds)	75.7	8.7	1.68
Carnivores (pinnipeds)	43.3	10.3	4.49
Probiscids	82.5	4.3	1.00
Perissodactyls	90.6	6.4	0.42
Artiodactyls	80.9	5.5	1.20

Adapted from Robbins, C.T. (1983)

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VITAMIN E DEFICIENCY IN ZOO ANIMALS

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Introduction

Vitamin E deficiency syndromes in laboratory and domestic animals have been recognized since the 1920's. Deficiency of vitamin E can be manifested in many different ways, including reproductive failure (e.g., fetal resorption or testicular atrophy in rate), skeletal muscle necrosis (e.g., white muscle disease in lambs and calves), cardiomyopathy (e.g., "mulberry heart" in swine), vascular disorders (e.g., exudative diatheses in chicks), and central nervous system disorders (e.g., encephalomalacia in chicks and a spinocerebellar syndrome in humans). (1,2) "Capture myopathy", a form of muscular dystrophy often precipitated by exertion, is also thought to be related to insufficiency of vitamin E. Capture myopathy has been reported in many wild ruminants (3,5), in zebras (3), rhinoceros (3), elephants (3), baboons (6), and flamingos (7). Muscular dystrophy responsive to vitamin E has been reported in captive tree kangaroos (8) and the quokka (9).

In several species of animals kept at the New York Zoological Park (NYZP), pathological conditions consistent with vitamin E deficiency have been observed during the past several years. These have included cardiomyopathy in gelada baboons (10) and several ruminants (11,12), skeletal muscle necrosis in the Nyala (12), and myelopathy in the Mongolian wild horse (13). Analysis of plasma and tissues of many of these animals revealed low levels of vitamin E. Subsequent supplementation of diets of different mammals and birds with vitamin E has resulted in increased plasma and tissue levels of the vitamin. Concurrently, the occurrence of certain of the previously observed pathological conditions has declined. Following are several examples of observed low vitamin E status in animals at NYZP and the effects of dietary supplementation on vitamin E status and particular pathologies. All vitamin E analyses prior to 1985 were done at outside laboratories and those in 1985 at our own. Because of the nutritional interaction of vitamin E and selenium and because selenium deficiency can sometimes resemble vitamin E deficiency, plasma selenium concentrations were also investigated in some cases.

1. NYALA ANTELOPE (Tragelaphus angasi)

A significant mortality rate was noted in the Nyala herd (composed of 15 to 20 animals at any one time), with 32 animals being necropsied and 21 reported as having myopathy during the period 1972 to 1981. Of nine animals sampled from the herd in 1981, five had no detectable vitamin E in their plasma. Plasma selenium concentrations measured in three normal animals were 0.30 to 0.33 ug/ml. The feed offered to those animals during that period was estimated from feed composition tables and hay analysis to provide 50-100 International Units (IU of vitamin E per animal per day, or 0.52 IU per kg body weight per day. In addition, some animals had access to some green pasture for 5 months of the year. Beginning in 1981, additional vitamin E was provided as 1) a top dressing of powdered alpha-tocopheryl acetate added to the feed of the females, which fed as a group, 2) alpha-tocopheryl acetate mixed with drinking water of the males, which were housed together in groups of two or three, and 3) a single intramuscular injection of alpha-tocopherol for newborn animals. The supplementation program was calculated to provide approximately 5 IU vitamin E per kg body weight per day. Subsequent plasma vitamin E values rose to 3.1 +/- 2.1, n=10 (range 1.0 to 7.7 ug/ml) in 1982, holding at that level in 1984 (3.2 +/- 2.0, n=11, range 0.5 to 7 ug/ml). During that time, the death rate in the herd declined, with no cases of myopathy being recognized after 1982.

2. MONGOLIAN WILD HORSE (Equus przewalskii)

During the period of 1977 to 1983, three Mongolian wild horses displayed ataxia, dating from 2 or 3 months of age. The severity of gait disturbance eventually necessitated their being euthanized. Three other horses that died or were euthanized for other causes had shown mild ataxia. Necropsies revealed neuronal degeneration in all six horses, suggesting vitamin E deficiency. The plasma tocopherol levels of five of the affected horses ranged from undetectable (<0.3 ug/ml) to 0.8 ug/ml (mean 0.4 +/- 0.1 ug/ml). Seven clinically normal horses had levels ranging from undetectable to 3.0 ug/ml (mean 1.1 +/- 0.2 ug/ml). Plasma selenium levels (n=4) ranged from 0.04 to 0.14 ug/ml.

Calculated from feed composition tables and hay analysis, the vitamin E provided to the horses by the commercial horse pellets and timothy hay was 220 IU per animal per day. Early in 1983, the diet was supplemented with an additional 250 IU per animal per day by top-dressing of grain with alpha-tocopheryl acetate, and later in 1983 supplementation was increased to 1300 IU per animal per animal per day, making the estimated daily intake about 1500 IU per animal per day, or about 4 IU per kg body weight per day. In 1984 plasma vitamin E concentrations averaged near 5 ug/ml.

Since supplementation was begun in 1983, no new cases of ataxia or neuropathy have been observed in the herd of 16 to 22 animals, including among the ten foals born during that period.

3. ELEPHANT (Elaphus maximus indicus)

In 1981, a 17-month-old Asian elephant born at the zoo died with "Mulberry heart" disease. Plasma tocopherol was not detectable in this animal or others of the herd. Plasma selenium concentration ranged from 0.08 to 0.14 ug/ml. Daily vitamin E intake for these 5,000 to 8,000 pound animals was estimated to be about 2,000 IU, or about 0.6 to 0.8 IU per kg body weight. In 1982, the feed was supplemented by top-dressing of grain with alpha-tocopheryl acetate to provide 3,700 IU vitamin E per animal per day, or 1.0 to 1.6 IU per kg body weight per day. In 1985, plasma vitamin E in the four elephants sampled ranged from 0.2 to 0.6 ug/ml (mean 0.50 +/- .16).

4. GORILLA (Gorilla g. gorilla)

In 1980 measurement of plasma alpha-tocopherol levels in gorillas at NYZP revealed low levels (normal 5-15 ug/ml) (14). Dietary vitamin E intake was estimated from feed composition tables to be about 140 IU per animal per day. In late 1981, this level was increased by top-dressing of vegetables with alpha-tocopheryl acetate to 400 IU/day for females and 640 IU/day for males, amounting to approximately 1.4 IU per kg body weight per day. The plasma levels of alpha-tocopherol increased slightly by 1982 (3.0, 3.3, and 6.0 in the three animals tested) but were significantly higher by 1984 at 10 to 25 ug/ml. However, in 1984 1 13-year-old male gorilla died suddenly with cardiomyopathy. Vitamin E was undetectable in both plasma and liver samples taken at necropsy, although the gorilla had been eating the same supplemented foods as the other gorillas.

DISCUSSION

The majority of studies of vitamin E deficiency concern quantifying the amount of dietary vitamin E necessary to prevent vitamin E deficiency signs under defined conditions and have not reported plasma vitamin E levels. While the actual plasma vitamin E concentration of captive animals very likely differ from those of their wild counterparts due to differences in diet and other factors, we do not know what "normal" or optimal levels for most animals are under either condition. Our few measurements show wide variation among species at the NYZP. For example, the plasma vitamin E concentrations of two Siberian tigers (Panthera tigris altaica), fed less than one IU per kg body weight per day, were near 30 ug/ml, whereas a sample of 25 mouflon (Ovis musimon), fed more than 3 IU per kg body weight per day, have remained at 1.4 +/- 0.6 ug/ml.

The pre-supplementation feed for the NYZP Nyala herd contained an estimated 95 IU vitamin E/kg dry diet. The estimated requirement of vitamin E for young beef cattle is 15 to 60 IU per kg of dry diet (15). Vitamin E can deteriorate during storage and the level in the Nyala diet may have been lower than estimated. It is also possible that the requirement of captive Nyala for vitamin E does not closely resemble that of dairy or beef cattle. The supplemented level of vitamin E for the Nyala herd greatly exceeded the estimated required levels for cattle. Yet, the plasma vitamin E concentrations of about 3 ug/ml are below those reported as normal (4 ug/ml and above) (16) for cattle. Cows with plasma levels of 2.4 ug alpha-tocopherol/ml have borne dystrophic calves (17).

The plasma selenium concentrations of the three normal Nyala were above the range considered adequate (0.1 - 0.2 ug/ml) in domestic livestock. Therefore, it is unlikely that the dystrophy problems in the herd were due to selenium insufficiency.

Plasma vitamin E concentrations in healthy domestic horses on New York breeding farms have been reported to range between 1.7 and 9.5 ug/ml (18). Horses receiving 200 IU vitamin E/day maintained plasma concentrations of 4.4 to 4.8 ug/ml (18). Although the presupplementation diet of the Mongolian wild horses at NYZP was estimated to provide 220 IU vitamin E per day, their plasma vitamin E concentrations were below any reported "normal" value for domestic horses. It is possible that the diet actually provided much less. Estimates based on feed composition tables can be greatly in error. After supplementation, the plasma vitamin E concentrations of the Mongolian wild horses were within the range of normal domestic horses. It is not known whether these concentrations could have been achieved with a lower level of supplementation.

Whole blood selenium of horses raised on local New York feeds has been reported by Maylin 1980 (16) to be 0.077 ug/ml +/- 0.005. Horses raised on commercial feeds were 0.156 +/- 0.007. Plasma selenium concentrations of three of the four NYZP wild horses tested were within this range. (Plasma selenium and whole blood selenium are nearly equivalent.)

In spite of supplementation of their ordinary diet with vitamin E, the elephants in the NYZP herd maintain very low concentrations of plasma vitamin E. The reason for this is not understood. Neither is it known whether these low concentrations are adequate. The quality of the diet of an elephant does not differ significantly from that of a horse. The supplemented level of vitamin E intake for the Mongolian wild horses was greater than that for the elephants by a factor of about 3 when considered per kg body weight. Yet, the plasma concentrations of the horses exceeded that of the elephants nearly 10 to 20 fold. It is known that raising plasma lipid levels results in the elevation of plasma tocopherol, even when dietary intake alpha-tocopherol is unchanged (19). Plasma cholesterol measurements in the elephants were, on the average, about half of those in the Mongolian wild horses (52 mg/dl compared to 99 mg/dl).

Perhaps low plasma lipid levels in the elephant account for the low vitamin E concentration.

The low vitamin E concentrations of the NYZP gorillas before supplementation were not associated with any particular pathology. The reproduction rate among captive gorillas, including those at the NYZP prior to 1984, has been notably low. The improvement in vitamin E status may have been a contributing factor to the increased birth rate experienced in the NYZP gorilla colony since 1984, but low reproduction rates can be due to many other causes and, in this situation, may have had nothing at all to do with vitamin E.

Cardiomyopathies may be related to vitamin E-deficiency in certain animals. It is not known whether cardiomyopathy in gorillas is related to vitamin E deficiency. The absence of vitamin E in the plasma and liver of the gorilla which died of cardiomyopathy is a curious finding, since the gorilla was consuming vitamin E and had no known lipid malabsorption. It is possible that the vitamin E assay was erroneous or that this particular gorilla had a specific defect in vitamin E absorption, as has been reported in one human case (20).

The above cases suggest that vitamin E deficiency is not uncommon among zoo animals. Furthermore, they show that supplementation of the diet with alpha-tocopheryl acetate can raise plasma vitamin E concentrations and can overcome conditions related to vitamin E deficiency. Optimal plasma vitamin E concentrations for each species and the degree of supplementation to achieve those have yet to be established.

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Improving the Feeding of Captive Felines Through Application of Field Data

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The tactics employed by large felines in food-getting in the wild are contrasted with the conditions which prevail in captivity. While zoos cannot recreate a completely natural existence, there are points at which nature's ways can guide management in improving the quality of life for zoo animals. Equating an adequate diet with good nutrition leads to dietary substitutions which ignore non-nutritive requirements. Among the issues discussed are substitute activities, oral health in relation to food texture, and the psychological aspects of feeding.

Key words: felines, oral health, diet, husbandry, psychological well-being

INTRODUCTION

In 1966 the *International Zoo Yearbook* published a special section on the nutrition of zoo animals. A frequently referenced paper in that section, by Richard Fiennes, pathologist at the Zoological Society of London, concluded with this statement: "Without adequate feeding there can be little breeding." The breeding of exotics is clearly a major concern of zoological institutions today, and leads us to a careful consideration of the diverse factors which impinge on fecundity, including its relationship to feeding behavior and diet composition. While Fiennes spoke of several aspects of captive feeding, it is clear when discussing "adequate" diets, his concern was primarily with nutrition.

Zoo personnel universally share in this concern. The nutritional aspects of food dominate our thinking at virtually all levels of management, from the keeper who feeds, to the accountant who keeps a wary eye on costs. The extreme view is that which Hediger, in the symposium referred to above, called the "retort" theory of feeding. This theory holds that if nutritionally adequate food is provided, then good health, increased longevity, and improved breeding will ensue. Hediger himself stands at the other end of the continuum in arguing for a more naturalistic approach. Even he recognized, however, that there is need for substitution and modification of natural diet regimes, given the constraints of a captive existence. Yet a current reading of the

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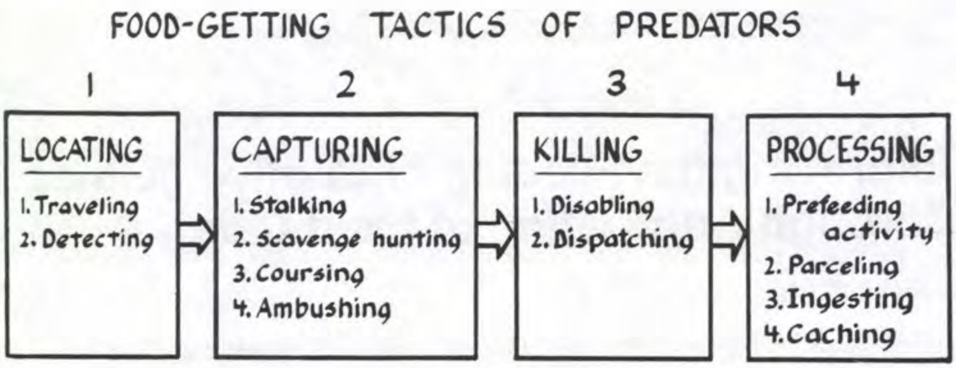

Fig. 1. The food quest for felines in the wild state entails a series of energy-demanding activities. The captive animal is deprived of all but the act of consumption.

zoo literature leads inexorably to the conclusion that, in our practice of animal management, non-nutritional aspects remain poorly understood, are infrequently studied, and stand as a footnote to concerns with the captive feeding of exotic species. Wackernagel's [1968] statement of nearly 20 years ago remains as the prevailing view: "We want to make it clear that, in planning diets, the physiological considerations should have priority."

An example from the captive breeding of cheetahs at the San Diego Wild Animal Park highlights the contention that there is more to food consumption than mere assimilation of balanced quantities of protein, fat, carbohydrates, minerals, and vitamins. A first indication of a broader problem was that individuals being carefully groomed for breeding would often have to be detoured to the hospital for treatment of infections of the mouth and nasal passages. A second indication arose from a study of activity budgets which revealed that cheetahs were virtually inactive day and night, despite having a 4-acre area at their disposal, and that activity consisted primarily of trips between food bowl and resting sites. A third observation was of markedly different reactions to minced, frozen meat as compared to occasional feeding of rabbit, chicken, or ungulate carcasses. In the latter case one sees improved appetites, a greater tenacity about possession of food, and sometimes even bouts of play centered around the carcass.

These observations point to the importance of nonphysiological variables inherent in styles of provisioning and in the palatability of food to improved husbandry and breeding. A review of the activities involved in capturing and ingesting food in the wild state provides a starting point for examining the many ramifications of captive provisioning. Field data for this report are drawn from observations on the tiger, lion, leopard, and cheetah, since these are among the better studied in the wild, though the findings for large felines probably apply in a general way to other cats as well.

THE PREDATORY SEQUENCE

The feeding activity of large felines can be divided into four components: location of prey, capture tactics, the killing act, and behavior at the kill (Fig. 1). Each component entails a considerable expenditure of effort, and brings into use the appropriate foraging and feeding equipment, i.e., the sensory modalities, the limbs, claws, teeth, and jaws. The total complex of activities involved in food-getting are discussed in light of potential importance to physical and psychological health of felines maintained in captivity.

Searching for Prey

Schaller [1967] states that much of the Bengal tiger's daily activity revolves around its food supply, whether hunting, feeding, or resting satiated beside the remains of its kill. Its usual method of hunting is to walk through its range in search of prey. Hunting primarily at night, the tiger will cover an average distance of 10 to 20 miles during an unsuccessful night of searching. Total energy expended in the location of prey will depend on availability, luck, success rate in capturing, and frequency with which the species must feed. Success rates for tigers at Kanha Park in India were estimated by Schaller to be one kill in every 20 attempts. Once a kill is made, a tiger may feed for 3 to 4 nights, the duration depending on size of prey and number of feeding individuals.

Cheetahs in Nairobi Park, Kenya, averaged 8 km of travel per day according to Eaton [1974], most of this in search of food. Success rates for cheetahs are much higher than for tigers, estimated at from 50–70%. Cheetahs habitually stay with the carcass for a single feeding, if in fact it is not appropriated by other carnivores, as is frequently the case. Solitary cheetahs were estimated by McLaughlin [1970] to make 150 kills per year, on the average.

Being primarily a nocturnal hunter, and the most catholic in diet of the four species here considered, it is less clear how much leopards must work at locating prey. Kill rates for an 8-month period at Seronera were determined by Schaller [1972] to be about one gazelle per week, representing about two-thirds of the total diet.

Lions may key on vultures [Bartlett and Bartlett, 1982] or hyena behavior at a kill [Schaller, 1972] to locate food, thereby reducing search time. Schaller's detailed descriptions indicate that lions also are notable in the extent to which they wait for quarry to wander within stalking range, as opposed to searching over long distances. However, in areas such as the Kalahari, where prey may be seasonally scarce, searching for food is a major and sometimes fruitless activity [Owens and Owens, 1984]. At his Serengeti study site, Schaller [1972] observed that most kills were made by females, and nearly half of all hunts involved two or more lions. Between 17% and 30% of stalks were successful, the higher rates pertaining when two or more lions hunted together.

According to Caro [cited in Lewin, 1987], a female cheetah with an average litter of three cubs spends 40% of her time searching for prey. Though comparable figures have not been published for the other species under review here, it is clear that the food quest requires a substantial expenditure of energy in all.

Methods of Capture

Once prey are located, several tactics may be used in the capture attempt. Those shown in Figure 1 are adapted from Hamilton [1973], and are intended to be all inclusive for predators. Stalking, as the term implies, entails the use of stealth to approach the target to within striking distance. The ambush tactic (Hamilton's "sentinel") is one in which the predator takes up a position and waits for prey to approach.

Stealth and camouflage are important to the success of this tactic. While scavenge predation commonly refers to feeding on carrion, Hamilton has in mind active predation, which does not rely on concealment and which is directed at prey which are small and often incapable of rapid flight. Prey in this instance are pursued upon being flushed from cover as the predator openly travels over its range. Coursing (Hamilton's "group hunting") is a pack activity such as that used by wild dogs, and depends on long-distance pursuit during which the prey is driven to exhaustion.

The first three tactics are used in varying degrees by large cats, though stalking is more common. Cautious stalks of up to a half-hour or more have been described, followed by a rapid sprint to close the distance on the surprised target. A major difference exists between the cheetah and other large cats in that it depends more on speed than on stealth. Cheetahs have in fact been observed to ignore prey which failed to show flight [Ammann and Ammann, 1985]. Varaday [1964] clocked by auto a group of five cheetahs running along a dirt road in Bechuanaland at 60 mph, and cites other tests indicating even greater speed. Because of its reliance on speed, the cheetah can begin its capture sprint from distances as great as 300 yards. Field observers consistently report that the cheetah, at the end of its sprint, must rest for about one-half hour before it can begin feeding. While other cats depend less on pure speed, capture by stalking usually entails a series of momentarily exhausting chases before success is obtained, and represents an expenditure of energy which must be added to that spent in locating food.

Killing Tactics

The killing bout also differs between cheetahs and other large cats [Kruuk and Turner, 1967]. Using either the dewclaw for tripping or a glancing blow with its forepaw, the cheetah relies on the rapidly fleeing prey's loss of balance in closing in for the death-bite. Because its jaws are less powerful than those of larger cats [Ewer, 1973], its preferred mode of killing is the throat bite, which induces strangulation. This may require holding down a struggling animal for periods of 5 minutes or more in the case of larger prey. The larger cats use their weight to advantage in dragging down prey and may either suffocate by a throat hold or bite into the nape of the neck, thereby damaging the spinal cord.

All of the cats under consideration commonly drag or carry the carcass some distance before feeding. Suggested reasons are to seek shade or cover, to protect the kill from other predators, or to be near water or a litter of cubs. For the cheetah this is a relatively easy matter, since its preference is for the smaller gazelles or other relatively lightweight prey. The other cats in our sample, on the other hand, may expend substantial effort in relocating before feeding. A tiger estimated to weigh 250 kg has been recorded as dragging a 320-kg sambar a distance of 150 yards [Breeden, 1984]. Schaller [1972] reports adult lions dragging 275-kg zebras, and leopards routinely maneuver kills of up to 70 kg into the safety of trees. Again, it should be noted that the procurement of food is hard work.

The Consumptive Phase

Several descriptions of consumption are reported in the literature. As a rule, all the large cats begin at the rear or underbelly, and work forward to the rib cage and forequarters, neck, and head. According to Schaller [1972], lions and leopards will sometimes eat the viscera first, perhaps to satisfy their fat and vitamin requirements.

After opening the skin, the scissorlike action of the carnassial dentition is used to slice through muscle. In addition, the jaws and teeth are used in ripping, pulling, and tearing actions as chunks of flesh are extracted and swallowed with minimum mastication. Estimates of consumption for large cats range as high as 25 kg of meat at one feeding, but a quantity of 10–20 kg is more common. Processing a carcass into ingestible portions places a substantial workload on the jaws and teeth, as does the gnawing on and crushing of manageable morsels of bone and cartilage.

Caching is most common in leopards, the kill being maneuvered into trees even before beginning to feed, or hidden in thickets in treeless areas. Tigers will on occasion cover remaining portions of a carcass with brush and leaves, but reports of caching by lions are doubted by Schaller [1972]. All observers agree that cheetahs make no attempt to retain unconsumed portions of a kill. Whether cached or simply guarded from other predators, vigilance from first to last meal constitutes an additional investment in food procurement.

EUROPHAGY

A final point of relevance to this topic is the diversity of prey consumed in the wild. Preferring prey of not more than 20 kg in body weight, the cheetah specializes in one or two regionally abundant species. Thompson's gazelles accounted for about 90% of the diet on the Serengeti [Schaller, 1972], while at Kruger National Park 68% of kills were impala [Pienaar, 1969]. Even so, at the latter site, 24 different kinds of prey in a sample of 2,527 kills were recorded.

At Kanha Park the chital deer made up about 50% of the diet of tigers, but Schaller [1967] mentions also birds, langurs, porcupines, even occasional reptiles, amphibians, and fish. In his words, a tiger will eat whatever it can catch.

The Serengeti lions prey mostly on wildebeest, zebra, buffalo, and topi, but in 3 years of study Schaller [1972] observed feeding on 18 different mammals, four birds, and an occasional crocodile. He cites other reports of opportunistic feeding on pythons, catfish, and locusts. Pienaar's [1969] list for Kruger National Park mentions 40 different prey species.

The leopard is said by both Schaller [1972] and Myers [1976] to be more catholic in diet than any other large cat, and Schaller notes that the food list in the Serengeti included hare, hyrax, various small and medium-sized antelopes, python, several kinds of birds, and several carnivores.

Diversity in prey consumed is probably dictated by regional availability and by opportunity. Whether large felids seek certain kinds of prey out of preference or need is unknown, but all evidence is consistent with the notion that choice is based solely on the possibility of capture.

To summarize, large cats in the wild feed primarily on one or a few species but opportunistically include up to 20–30 different kinds of prey for a given region, indicating that they are anything but monophagous. They often travel many miles in search of food, make numerous unsuccessful attempts at capture, drag carcasses to feeding sites when successful, and with the jaws and teeth parcel up prodigious amounts of flesh at any one feeding.

ISSUES IN CAPTIVE FEEDING

The application of knowledge derived from nature has great potential for improving the quality of life for captive exotics [Markowitz et al., 1978; Hancocks, 1980; Hutchins et al., 1983]. While nature cannot be entirely simulated in zoos, if management regimes meet the objectively measurable criteria of good health, display of ecologically valid behavior, and successful reproduction [Quick, 1984], they will have used field data to good cause. As regards the feeding of felines, nature informs us on several issues for which the substitutions constrained by captivity can be modified to meet these criteria, viz., activity levels, food packaging, and pleasure in food consumption.

Activity

The first three components in the acquisition of food (locating, capturing, and killing) have to do with considerable activity, hence energy expenditure and body conditioning. These are the most radically altered aspects of a captive existence, and zoos have few choices in the matter. But one should recognize that a tremendous void results from their removal, leading to boredom, the appearance of stereotyped behaviors, and generally poor condition. Substitute activities are a partial solution, and notable strides in this direction have been developed by Markowitz [1982]. Though cost is often perceived as a deterrent to "engineered" approaches, in the long run they may be good investments in improved health and vitality.

Food Packaging

The last component of the predatory sequence, behavior at the kill, provides information which is more readily applicable to the captive situation. Field reports of the last two decades contain information on what animals eat, and how they go about it. From nature's packaging of food items one can extract information about such attributes as texture, taste, temperature, smell, color, and shape. The most convincing evidence of the importance of the non-nutritive properties of carnivore food is in findings on oral health. In response to recurring nasal and mouth infections of cheetahs at the San Diego Wild Animal Park, Fitch and Fagan [1982] conducted a survey which revealed that of 20 cheetahs in U.S. collections which were fed formulated diets, 15 (75%) had focal palatine erosion, i.e., perforation of the palate by the penetrating action of the lower molars. By contrast, 39 individuals fed animal carcasses lacked the condition. Of 22 museum skulls, none of 14 wild-caught had focal palatine erosion, whereas 4 of 8 zoo-raised did (diet unknown). The authors proposed that dental malocclusion as a result of feeding a soft texture diet led to a self-inflicted wounding of the palatine mucosa and bone.

Two additional studies address this issue. The first, by Vosburgh et al. [1982], entailed experimental feeding of soft and hard diets to timber wolves and found that texture of food was a significant factor in the development of dental plaque, i.e., 50% less in those fed a hard diet. A second study, by Haberstroh et al. [1984], measured effects of providing beef femurs to Amur tigers which, when offered twice weekly, clearly improved gingival health and reduced plaque formation. Though still in its early stages, the testing of non-nutritive variables in the matter of carnivore diets favors hard-texture diets as a way of improving oral health, and thus reproductive success and longevity.

Pleasure in Feeding

The contrasting reactions of cheetahs to naturalistic (carcass) and to commercially prepared foods, as noted in the Introduction, suggest issues in palatability and thus in the psychological aspects of feeding which have rarely been objectively examined. Lacking hard data, we address the issue here by analogy. There are several parallels between the ways in which humans and zoo animals forage. Procurement and preparation is in neither case an individual activity, but the task of specialists. For humans, an entire industry exists to take care of nutritional balance, packaging, sterilizing, precooking, preserving, flavoring, etc., all of which greatly reduces forage time at the supermarket, as well as time spent in preparation of food for consumption. In a similar vein, grass for herbivores is pelleted; fruits and leaves for monkeys are chowed; and meat for carnivores is minced, packaged, and frozen, all for similar reasons of nutritional value, cost, and convenience. Like the human, the zoo animal invests little effort in foraging or in the processing of food items for ingestion.

The attention humans give to taste, texture, smell, color, and temperature of food, as well as to the time and place of ingesting, is a measure of the enjoyment derived from feeding. Food that is nutritionally balanced but lacking in those attributes which please the palate is disdained. Caution must be exercised in inferring the gustatory proclivities of animals, but field data do strongly suggest that they find "pleasure" in feeding. While psychological well-being remains an elusive concept, the difficulties encountered in its measurement do not render it unimportant. Until more refined techniques for assessing the mental state of animals in feeding are developed, we may be guided by the fact that the behaviors commonly associated with feeding in nature lead to the conclusion that much of their pleasure centers around food.

It would be impractical to advocate the abandonment of formulated foods. One may question, however, if it is wise to regard them as a complete and adequate solution to captive feeding. Testing with regard to oral health, though just beginning, points to the need for suitable supplementation, and there is reason to believe that as we examine the psychology of feeding with proper experimentation, we will find here as well significant relationships to health and to breeding.

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PRIMATE FEEDING ECOLOGY: THE INTERFACE BETWEEN WILD AND CAPTIVE FEEDING PATTERNS

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INTRODUCTION

Those of us who are deeply committed to wildlife conservation must consider the relative priority of studying natural populations and propagating wild animals in captivity. Most of us would agree, however, that both field research and studies of confined animals are essential and complementary. Here I emphasize work with wild and captive primates, and draw on my experiences in breeding colonies, health sciences laboratories, and zoological parks, as well as on some of my observations from travel in Africa and more extensive field work in Sulawesi (Celebes), Indonesia.

Others have dealt in depth with the topics addressed here, but this is not the appropriate place to attempt an exhaustive review. This point is made not so much to excuse myself from the obligations of scholarly rigor as to acknowledge that many scientists whose work is not cited here have made extensive contributions in these areas.

The basic questions I examine here are the following: 1) What food items are eaten? 2) How much is eaten? 3) When is the food eaten? 4) How much effort is expended acquiring food? 5) How do social or economic considerations apply? 6) How natural is the habitat of wild primates? and 7) What are the implications of feeding ecology for confined primates?

BACKGROUND

These comments are based on my experience with nonhuman primates in the following settings: 1) the National Center for Primate Biology/California Primate Research Center; 2) the breeding colony of the Regional Primate Research Center at University of Washington at Medical Lake, Washington; 3) the Comparative Development Laboratory at Peabody College; 4) Humboldt State University and the Sequoia Park Zoo; 5) the Brookfield Zoo of the Chicago Zoological Society; 6) in Kenya and Rwanda; and 7) in Indonesia, primarily in South Sulawesi and North Sulawesi. I have had the pleasure of working directly with more than 35 primate species, including the following: chimpanzees, gorillas, orangutans, gibbons (siamangs, white-handed), baboons (olive, Guinea, mandrills), sooty mangabeys, macaques (rhesus, pigtailed, longtailed, Japanese, tonkean, moor, booted, crested black, Gorontalo, Heck's, and Muna-Buton), langurs (Hanuman, spectacled, silvered leaf monkey), black-and-white colobus, guenons (Kolb's, Schmidt's redtailed, vervets, talapoins), patas, callimicos, tamarins (cottontop, golden lion), owl monkeys, spider monkeys, squirrel monkeys, titi monkeys, and black-capped capuchins. My training is in comparative psychology, not nutrition, so my emphasis here is on behavior.

WHAT IS EATEN?

Long lists of foods eaten by primates in the wild are compiled in feeding ecology studies (cf. Chivers, 1984, p. 279; Terborgh, 1983, pp. 63-73). Such studies usually note which plant parts are eaten (leaves, fruits, nuts/seeds, flowers). While most primates are primarily herbivorous, most eat some nonvegetable material, and some [e.g. tarsiers] are almost entirely carnivorous.

Precise knowledge of natural primate diets is extremely valuable in assessing carrying capacities of reserves, understanding energy resources and uses, quantifying ecological analyses, and determining the bases of social organization and habitat choice, not to mention, provision of appropriate diets in captivity. Complete information on food availability is very important because animals must choose among available foods. Some foods that are virtually always available may be taken only when more favored foods are unavailable.

Samples of foods eaten must be collected, analyzed, and identified. This task is especially difficult in areas such as Sulawesi, where many fruiting tree species have not yet been named or classified. Obtaining samples usually requires a system of tree-fall sampling baskets suspended appropriately throughout a study area. Some studies employ fecal analyses exclusively or in addition to direct observation and sampling of foods. In remote areas preservation of specimens in ways that allow nutritional analysis is especially problematic.

For the most part, foods eaten by primates in natural settings are completely unavailable in the areas where they are confined, but patterns of food choice in natural settings can provide clues regarding appropriate artificial diets. In captivity, most primates receive a canned or pelleted diet supplemented with some fresh fruits and vegetables. While the formulated diets are carefully standardized and balanced, they are designed for the limited number of species most commonly kept.

In some settings, additional feeding is allowed, either by the public or staff. Any additional feeding should be carefully planned and monitored. The variety of available foods is an important consideration in captivity; however, the frequently asserted importance of variety in psychosensory stimulation (e.g., variation in texture, taste, smell, color, etc.,) relative to nutritive value and temporal variation has not been fully established.

HOW MUCH IS EATEN?

The quantity of food consumed in the wild is very difficult to measure, especially in forest species such as the Sulawesi macaques. Techniques include actual counting of food items eaten followed by weighing and nutritional analysis of sample food items (cf. Iwamoto, 1974). Exhaustive counts can be impossible under some conditions, but good data on feeding rates for specific items under specific conditions can provide a basis for reliable estimation of intake based on amount of feeding time. Obviously, generalizability is limited by the extent to which the conditions during the estimate sample reflect the conditions during determination of the actual feeding rate.

Despite the common misperception that wild primates live in paradise, few wild primates obtain what we would consider optimal nutrition in the natural setting. They are free--free to starve. Nutrition is limited by the quality and the quantity of available resources, as well as by the intensity of competition from conspecifics and contraspecifics.

When the quality of the resource is poor, nutritional adequacy can be limited by the time available for foraging and feeding. When the density of a resource is reduced, range and energy expenditure must increase to obtain an equal quantity of the resource. Competition over a resource is likely to increase as quality increases and availability decreases.

Many wild primates survive at sub-optimal nutritional status. When available resources increase, food intake increases and eventually levels off. When available resources decline below carrying capacity, of course, reproductive problems and starvation can result in population crashes. We are afraid that severe droughts caused such a crash in the population of the crested black macaque of Sulawesi (Macaca nigra) between 1979 and 1985, although the extremely high density of this species in Tangkoko-Batuangus-Dua Saudara Nature Reserve in 1979 suggests that the population had exceeded the long-term carrying capacity of the area.

WHEN IS FOOD EATEN?

Feeding and foraging time in diurnal primates often occupies much of the day. In the various Sulawesi macaques that our team has studied, activity usually begins about 05:30, with animals moving away from the sleeping tree(s) by sunrise (which occurs year round at about 06:00, as in other equatorial locations). By 11:00 or so, the macaques have usually settled into some location where they may sleep off and on for two or three hours prior to the beginning of slow-paced afternoon foraging. After 16:00 movement usually begins toward the sleeping tree(s), where they typically are located no later than 18:00 (sundown).

As indicated above, the amount of foraging time required to obtain adequate nutrition depends on the quality and quantity of the resources. Interestingly, wild baboons that obtain supplementary nutrition from gardens or garbage areas substantially reduce foraging time (Forthman Quick, 1986). In captivity, some nonhuman primates are fed only once each day--usually a highly concentrated, nutritionally complete, formulated diet. If foraging time is reduced below the levels typical for a species, a sort of behavioral vacuum occurs--other activities (or inactivity) must fill the time that foraging would have ordinarily occupied. Spatially and/or temporally distributed feeding, especially of items that require some time to obtain or process can reduce the rates of excessive fighting or may otherwise redistribute behavioral patterns.

HOW MUCH EFFORT IS EXPENDED?

Low quality nutritional resources require more foraging time to acquire adequate nutrition than do high quality resources. Even if a low quality resource is easy to obtain, the amount of effort expended is positively related to the amount of time spent obtaining the resource. Processing of a food resource also requires varying degrees of effort and energy expenditure. Hard-to-crack nuts, other foods covered with hulls, and roots that require digging, all offer challenges to wild primates and require significant effort. Yet, exactly how much effort is required by these activities is difficult to measure, although techniques exist for determining how much energy is required to crack nuts of varying degrees of hardness.

A more common measure of energy expended is daily travel distance. The travel distance is often, but not exclusively, related to the distribution and quality of food resources--especially fruiting trees, in the case of the various Sulawesi macaques we have studied. It is actually possible to get some idea of relative preference for fruits by measuring the relative distance that is travelled to reach trees of various species.

In confined primates, activity levels can be measured directly or can be estimated from samples. In addition, apparatus can be used that requires solution of a variety of problems or varies the physical energy that is expended. Contingencies can be set up that require primates to be active in order to receive rewards (Markowitz, 1979).

<u>HOW DO SOCIAL AND ECONOMIC FACTORS INFLUENCE FORAGING?</u>

Ecological studies--especially those in behavioral ecology and physiological ecology--often employ economic theory. Economic theory applies to ecology in the sense that behavioral and physiological processes are enabled by energy and consume energy. The energy must come from somewhere and typically comes from food. Energy is obtained and expended within the context of time. Time and energy are finite and expendable commodities that lend themselves very well to economic analysis--that is, to the determination of cost-benefit relationships.

A balanced ecological system might be thought of as one in which the animal earns a fair wage (adequate nutrition and safety) for a fair day's work (foraging and vigilance activities). In the wild we can assess the adequacy of environmental resources and the efficiency of animal adaptations in terms of survivorship patterns (life tables) in response to perturbations in environmental variables (e.g., climatic factors). The fact that foraging time and daily travel distances vary as a function of the quality, density, and patchiness of food resources implicates foraging behavior as a major factor in the adaptation of animals to their environments.

It can be convincingly argued that the social structure of primates and other animals is a consequence of economic (cost-benefit) factors (Wrangham, 1987). In fact, economic models and ecological analyses are essential to the understanding of the evolution of primate social systems.

Economic models can also be applied to the evaluation of the adequacy of environments for confined primates and of the procedures employed in their care. Are we, for example, requiring too little of captive primates in the way of behavioral activity in exchange for meeting their nutritional needs? Do we "pay" the primates too readily without challenging them intellectually? Of course, the answer to these questions is usually "Yes." Systematic analyses of primate environments and feeding regimens using economic and ecological models can provide us with a basis for rational and effective changes that promote natural feeding systems and behavioral patterns.

HOW NATURAL IS THE HABITAT OF WILD PRIMATES?

We sometimes feel that data on behavior or nutrition are more valid from wild primates than from confined primates. While it may be true that the conditions of captivity can distort the behavior and physiology of primates somewhat, it is equally obvious when one sets about to study wild primates that the "natural" environment is seldom, if ever, pristine.

Data from relatively undisturbed settings are certainly important. In any case, regardless of the quality of the environment in which wild primates live, careful and detailed studies of feeding and foraging patterns are essential to an understanding of the quality of life in that setting. The information provided by such studies can provide some insight into the ultimate causes of behavior when the environment is relatively undisturbed. In more disturbed settings, feeding and foraging patterns can provide valuable insights relevant to the threats to survival of the populations.

In many areas, monkeys are notorious crop raiders. Given a free choice between the foods available to them throughout much of their natural history, some wild primates choose to raid corn or fruit trees from peoples' gardens. Others choose to live commensally with humans, obtaining food from markets, temple offerings, garbage dumps, or by stealing peoples' knapsacks.

I have seen corn gardens in North Sulawesi that had been devastated by crested black macaques (*Macaca nigra*). Papaya trees had been stripped of their unripe fruit--each fruit had a small bite taken from it before it was discarded. In North Sulawesi many people who are Christian like to eat monkey meat (unlike most other parts of Sulawesi where Muslim dietary habits prevail). The appetite for monkeys, coupled with the status of monkeys as crop raiders, places the monkeys of North Sulawesi in serious jeopardy.

IMPLICATIONS FOR CONFINED PRIMATES

Studies of the feeding ecology of primates under relatively natural conditions reveal that for many primates a remarkable variety of foods is eaten. We must remember that the specific food items available in the wild are seldom available in confinement, and we must weigh the merits of providing variety for its own sake against the prospects of meeting the real nutritional requirements of the animals.

Spaced feeding schedules in captivity may help to simulate the feeding and foraging patterns observed under natural conditions. This may be especially important for the leaf-eating monkeys. I am pleased to hear of progress in formulating diets that include the high-fiber content that is typical of the natural diets of primates.

As a comparative psychologist, I must emphasize the potential impact of feeding schedules, food quality, and spatial distribution of food on behavioral patterns relevant to captive management. Distribution of food across time or space can reduce the potential for competition. Spatial distribution can be especially effective in reducing the likelihood that dominant animals will get all the food. Temporal distribution of food provides opportunities for foraging as an ecologically valid alternative to agonistic behavior that can lead to injuries.

The point I especially want to make here is that careful research in zoological parks, in laboratories, and in the field is essential. Each setting provides evidence relevant to the others and contributes uniquely to a more complete understanding of the needs of the precious animals we work with. The problems we face as we attempt to conserve primates and preserve biological diversity are too important and the need for reliable information too great for any of us to decline to work cooperatively.

I must emphasize that the Sulawesi Primate Project has been greatly aided by funding from the National Institutes of Health as well as the National Geographic Society. Funding from the Chicago Zoological Society and the World Wildlife Fund - U.S., has also been very helpful, but population surveys and detailed studies of feeding ecology and behavior would hardly have been

possible without the support NIH provided for virology studies. Remarkable opportunities are developing for cooperation between conservation biologists and health scientists. Ignorance is the enemy of this relationship and communication is the key to a great storehouse of information that is critical to our conservation efforts.

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SOME BASIC CONCEPTS ABOUT ENERGY

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INTRODUCTION

Life as a process entails energy expenditure. Life also implies growth and reproduction, which in turn require the investment of energy-containing constituents (eg. protein, lipid, structural carbohydrate) in tissue formation. Unlike plants, which can capture solar energy, animals must obtain energy from ingested food. If the energy obtained from food exceeds energy expenditure (including energy output in reproductive products), animals achieve 'positive energy balance' (i.e. energy is stored via growth or fattening). By contrast, a shortfall in energy from food leads to 'negative energy balance', or mobilization of body energy stores. Large swings in energy balance (from positive to negative and the reverse) are very characteristic of animals in seasonal environments. The timing and pattern of reproduction are often geared to these swings.

Animals in zoos are largely isolated from seasonality in food supply, although other physiological phenomena may trigger changes in food intake and energy balance. Photoperiod effects depress appetite during winter in temperate cervids, leading to negative energy balance despite ad libitum feeding. This may not be bad if energy stores are sufficient to cover the shortfall. In zoos excessive energy accumulation ('obesity') is the greater problem.

The decision about how much food to provide a zoo animal should be based on energy balance goals. Do we want the animal to accumulate energy, to maintain zero energy balance, or to mobilize energy (i.e.. lose weight)? In this brief paper I will discuss some of the basic concepts of animal energetics, and try to relate them to practical concerns.

THE FACTORIAL APPROACH TO ENERGY REQUIREMENTS

Estimation of the energy requirements of animals is complicated by the fact that animals expend energy in many ways and for many purposes. Biochemists and biophysicists are concerned with the energetics of specific chemical reactions within cells, while physiologists may examine energy consumption by individual tissues and organ systems. Even at the organismic level, energy may be expended for a wide range of activities, for maintenance of body temperature, or for the production of tissues, eggs or milk.

It is obviously impossible to measure individually each and every metabolic process in estimating energy requirements of animals. A simplified approach involves measurement of energy utilization of the entire animal while it is maintained under standard conditions. Then a set of energetic factors may be developed to account for deviations from the standard conditions. Thus the 'factorial' method involves resolution of energy requirements into a series of components or factors that can be estimated separately, and then added together to produce an estimate of total energy needs. This method is widely used in estimating the energy requirements of domestic animals (eg. Agricultural Research Council, 1980; National Research Council, 1985, 1989a, 1989b) and may be applied to wild animals as well (eg. Oftedal 1985).

METABOLIC RATE VS. MAINTENANCE ENERGY REQUIREMENTS

The need for a standard measurement of energy expenditure led to the definition of 'basal metabolic rate' (Brody, 1945). Basal metabolism can only be measured when an animal is at rest (i.e. inactive and calm), in a thermoneutral environment (i.e. one in which the animal does not need to expend extra energy to maintain normal body temperature), and in a 'postabsorptive' state (i.e. the animal is not in the process of digesting or absorbing food nutrients). Unfortunately it is sometimes difficult to assure that a wild animal in a metabolism chamber is truly at rest (it may be inactive due to fear), and it is now clear that many animals exhibit diurnal and seasonal variation in their resting metabolic rates. Other problems arise if animals go into torpor (a state of reduced body temperature and metabolism) during measurements, or if digestive products are retained in the gut so long that only prolonged starvation can remove them.

Despite these methodological problems, it has become clear that there are big differences among animals in basal metabolic rate. Although the absolute rate (kcal/d) increases with an increase in animal size (kg), the relative rate (kcal/kg) decreases. There have been many discussions and arguments as to why this occurs, and how best to express the trend mathematically (Brody, 1945; Kleiber, 1961; Heusner, 1985). Nutritionists commonly use weight (kg) raised to the power 0.75 as an estimate of 'metabolic body size', and accept Kleiber's formula:

$$\text{Basal metabolic rate (kcal/d)} = 70 \times \text{weight}^{0.75}$$

where weight is measured in kg. Physiological zoologists have gone a step further, and often express measured metabolic rates of non-domestic animals as a percentage of the predicted 'Kleiber value'. By this criterion, some animals, such as insectivores, frugivores and arboreal folivores, appear to have very low basal metabolic rates (McNab, 1978, 1980, 1984, 1986).

Basal metabolic rate has virtue as a standardized measurement, but it need not be closely tied to actual daily energy expenditure, which includes such energetic components as the costs of digestion, activity and thermoregulation. The daily energy expenditure of a zoo animal may vary according to factors which influence activity, ambient temperature, or patterns of rest, such as cage design, social interactions, keeper or veterinary schedules, feeding practices, infectious disease and visitor disturbance.

Nutritionists are therefore more concerned with determination of daily energy requirements under a given set of conditions than with estimation of basal metabolism. A distinction is made between animals at a 'maintenance' plane of nutrition, and those that are being fed to produce additional results such as growth, fattening, work, gestation and lactation.

Maintenance is defined as the state in which animals 1. neither gain nor lose weight (zero energy balance), 2. are not producing reproductive products (fetal growth, milk production), and 3. are not performing additional work over and above that needed for survival. Maintenance energy requirements represent the energy that must be extracted from food in order to sustain zero energy balance. Maintenance requirements do vary with housing, however. For example, grazing animals are known to have greater maintenance requirements than animals confined in pens. The maintenance energy requirement for sheep at pasture is 60 to 70% greater than that for sheep housed indoors (Church and Pond, 1988).

Maintenance energy levels are usually determined by feeding trials in which the amount of energy extracted from the diet (i.e. ingested minus excreted) is measured during a period when no weight gain occurs (Hudson and Christopherson, 1985). Maintenance is a useful concept to understand, because once an animal's maintenance energy requirement is known, the energy required above maintenance for "productive" functions can be determined.

In domestic animals, maintenance energy needs are often about twice as high as basal metabolic expenditures. Of course the multiple may vary according to species and exhibit characteristics, and may be a lot higher for wild animals that must search out and capture (ingest) food items. In this case the wild animal may not be the best model for maintenance requirements of captive animals, and vice versa. In fact the maintenance requirements of penned domestic animals are more apt to resemble those of zoo animals.

ENERGY REQUIREMENTS FOR GROWTH AND FATTENING

Additional energy is required above maintenance for growth and for fattening. The distinction between growth and fattening is somewhat arbitrary, since even young, growing animals may be depositing fat during growth. For example, fat comprises 59% and 82% of body weight gain in suckling harp seals and hooded seals, respectively (Worthy and Lavigne, 1983; Oftedal, Bowen and Boness, 1989). Among terrestrial animals the fat content of body weight gain is typically 0 - 20% during early postnatal growth (Oftedal, 1986). The energy cost of growth is partly a function of the composition of the gain, and partly a function of the efficiency of energy use for growth. Species that deposit fat during growth require much more dietary energy because the energy content of fat is about 9 kcal/g as compared to about

1.1 kcal/g for lean mass gain. The efficiency of energy use depends on a number of factors, including the relative rate of growth, the composition of gain, and proportion of energy intake above maintenance that is devoted to locomotion, thermoregulation and other energy-demanding activities.

The extreme case of high energy requirements for growth occurs among some seals. For example, hooded seal pups double their birth weights (from about 50 lbs at birth to about 100 lbs at weaning) during a lactation period of just 4 days (Bowen, Oftedal and Boness, 1984). Because of the high proportion of fat in the gain, the total energy content of the pups quadruples in this short period. This is achieved by ingesting about 50,000 kcal per day (Oftedal, Bowen and Boness, 1989). This amount of energy would cover the daily requirements of about 20-25 adult humans, according to recommended intakes (National Research Council, 1980).

ENERGY REQUIREMENTS FOR PREGNANCY

The energy requirements for pregnancy (above maintenance) are related to the energy content of the fetus(es) at birth, the amounts of energy contained in associated tissues (uterus, placenta, mammary glands), any energy reserves deposited by the mother during pregnancy and the efficiency of energy use for these processes (Agricultural Research Council 1980). Although very little direct data are available for zoo animals, it is possible to estimate the energy requirement for pregnancy from data on birth weights and body composition at birth. It appears that newborn ungulates contain about 1.2 kcal/g while carnivores, which are more altricial, contain about 1.0 kcal/g (Oftedal, 1985; Oftedal and Gittleman, 1989). In ungulates the total energy requirement for pregnancy (above maintenance) is roughly equivalent to maintenance needs for 20-38 days (Oftedal, 1985). Since this energy cost is spread out over many months, the incremental requirement per day is not very large.

ENERGY REQUIREMENTS FOR LACTATION

The energy requirements for lactation (above maintenance) are related to the energy content of the milk, the amount of milk produced, and the efficiency of energy use for milk production (Agricultural Research

Council, 1980). Among mammals, milks are highly variable in composition and energy content. The range in energy content is more than 10-fold, from about 0.4 kcal/g in rhinos to 5-6 kcal/g in some seals (Oftedal, 1984; Oftedal, Boness and Tedman, 1987). Peak energy output in milk is related to such factors as maternal weight, litter size and mass, and phylogeny. In carnivores and other mammals, the daily energy output in milk may equal or exceed the total energy content of the litter at birth (Oftedal and Gittleman, 1989). Thus lactation is energetically extremely expensive. In ungulates, the total energy requirements for lactation (above maintenance) account for about 75-80% of the energy requirements for reproduction, and are equivalent to maintenance needs for about 90 to 125 days (Oftedal, 1985).

ENERGY DIGESTIBILITY AND METABOLIZABILITY

The elevated energy requirements of animals for increased activity, thermoregulation, growth and reproduction must be met by an increase in energy intake and digestion. For example, domestic cats rearing litters of 4-5 kittens increase energy intakes by 50-70% during pregnancy, and by 150-200% during lactation, as compared to maintenance (Loveridge, 1986). Clearly feeding programs at zoos must take into account increased energetic requirements associated with reproduction, growth and other conditions.

The actual usable energy in food will depend not only on food composition, but also on the digestibility of food and the amount of ingested energy that is lost in urine. Energy digestibility is determined as the difference between the energy in ingested food and the energy produced in feces (eg. Maynard et al., 1979; Church and Pond, 1988). If energy lost in urine (and, in herbivores with fermentation systems, energy lost as methane) is also subtracted, the resultant value is termed 'metabolisable energy' (ME). Estimation of amounts of food to feed on a metabolisable energy basis is more accurate than use of digestible energy values, but ME data are not easily obtained for zoo animals. Given the differences in digestive and metabolic processes among diverse zoo animals, extrapolation from one species to another may result in considerable error and should be done only among similar species.

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PROTEIN AND AMINO ACID REQUIREMENTS OF ANIMALS

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FUNCTIONS OF PROTEINS IN ANIMALS

The animal body is approximately 80% protein on a fat-free, dry matter basis. The functions of proteins include: 1) structural integrity (e.g., collagen, the most abundant protein in mammals, found in connective tissue; elastin found in tendons and arteries; keratins found in hair, horns, nails, and feathers; cell wall proteins); 2) contractile tissues (e.g., actin, myosin, and tropomyosin found in muscles); 3) hormones; 4) all enzymes and antibodies; 5) transport compounds (e.g., hemoglobin, myoglobin, cytochrome c); 6) osmoregulation (e.g., albumin); and 7) nucleoproteins.

PROTEIN COMPOSITION

Proteins are chains of amino acids joined by peptide bonds. Approximately 22 different alpha amino acids are found in animal proteins. The characteristics of a protein are determined by its composition and sequence of amino acids. Some amino acids are found in animals that are not incorporated into proteins (e.g., taurine, felinine - beta amino acids that cannot form peptide bonds).

PROTEIN DIGESTION AND ABSORPTION

Proteins are hydrolyzed into small peptides and amino acids by the action of pepsin and HCl in the stomach and, more importantly, by the action of enzymes secreted by the pancreas (e.g., trypsinogen, chymotrypsinogen, carboxypeptidases) and the brush border of the small intestine (e.g., oligopeptidases, dipeptidases).

Absorption of peptides and amino acids takes place almost exclusively in the small intestine. Generally, nothing larger than tripeptides can be absorbed by the epithelium of the small intestine. A notable exception is the absorption of immunoglobulins by endocytosis for a short period after birth in many species. Dipeptides and tripeptides are usually hydrolyzed to free amino acids in the mucosal cells of the small intestine before entering the portal circulation. Because proteins are broken down to their constituent amino acids before absorption, the requirement for protein is actually a requirement for amino acids. Indeed, animals will grow and reproduce on diets containing only free amino acids.

Most amino acids and small peptides are absorbed by active transport systems requiring ATP. Competition exists within certain amino acid groups for specific transport systems (e.g., basic amino acids: lysine vs arginine; neutral amino acids: leucine vs isoleucine). Transport systems show a specificity for L-amino acids.

In animals with pregastric fermentation such as ruminants, macropods, and colobids, bacteria play an important role in protein digestion. Proteolytic enzymes produced by bacteria in the foregut break proteins down into amino acids. These amino acids may be used directly by the bacteria or, more commonly, they are deaminated to produce ammonia, which in turn can be used by bacteria for amino acid or nucleic acid synthesis. Because bacteria can synthesize amino acids from ammonia, animals with foregut fermentation are able to utilize nonprotein nitrogen sources (i.e., urea, ammoniated feeds) to some degree as protein sources. Some protein escapes bacterial hydrolysis in the foregut (i.e., bypass or nondegradable protein). The % of total diet protein that will escape degradation in the rumen depends on the animal, microflora, passage rate, and protein characteristics. In domestic cattle, 40-60% of the protein in dehydrated alfalfa meal and corn grain will typically bypass the rumen (NRC, 1984a). Less than 40% of the protein in soybean meal will escape. Microbes passing from the foregut to the acid stomach and small intestine are digested by the animal. In domestic ruminants, roughly 50% of their protein requirement is provided by microbial protein.

Bacterial proteins produced in the cecum and large bowel are not available to the host animal unless the animal is coprophagous (e.g., lagomorphs and many rodents).

<u>ESSENTIAL/INDISPENSABLE AMINO ACIDS</u>

Of the 22 amino acids commonly found in animal tissues, approximately one-half cannot be synthesized by animals or cannot be synthesized rapidly enough to support optimum growth and reproduction. The amino acids that cannot be synthesized must be included in the diet or synthesized by pregastric bacteria (bacteria can synthesize all the required amino acids). These amino acids are termed essential or indispensable amino acids (IDAAs). Ten IDAAs are required by all vertebrates: methionine, arginine, threonine, tryptophan, histidine, isoleucine, leucine, lysine, valine, and proline (the acronym MATT HILL VP refers to these amino acids). In addition to the MATT HILL VP IDAAs, some birds (e.g., domestic poultry) require serine or glycine, used in the synthesis of uric acid, for optimum growth. Glycine or serine may not be required by some bird species, particularly slower growing species (Nitsan et al., 1983). Felines, and possibly some other obligate carnivores, require taurine in the diet. Most species can synthesize adequate taurine from methionine and cysteine. Rats require proline, asparagine, and glutamic acid for optimal growth (NRC, 1978). Alpha-keto acids (carbon skeletons of the amino acids) can substitute for all alpha IDAAs except lysine and threonine. Generally, IDAAs account for 25-50% of the total protein requirement.

Animals with well developed pregastric fermentation do not have a IDAA requirement per se because the amino acids are synthesized by bacteria and become available when the bacteria are digested.

Amino acids that can be adequately synthesized in vivo by the animal are called dispensable amino acids (DAAs). Although they are essential metabolically, DAAs are not required in the diet except as nonspecific sources of amino nitrogen. Even though considered dispensable, DAAs must be present in adequate quantities to spare IDAAs. There are limitations on the DAA profiles that are acceptable for different species. For example, the chick will do well if glutamic acid is the only DAA in the diet. However, cats will refuse to eat a diet when glutamic acid is the only DDA (MacDonald et al., 1984).

AMINO ACID METABOLISM

Once the absorbed amino acids enter the portal circulation, they are transported to the liver. In the liver the amino acids can enter many different metabolic pathways. Amino acids can serve as precursors for a variety of compounds including vitamins, hormones, nucleic acids, and other amino acids. Some DAAs, if present in the diet, can have a sparing effect on the requirements for IDAAs that serve specifically as their precursors. For example, in most species studied approximately 50% of the phenylalanine requirement can be met by tyrosine, approximately 50% of the methionine requirement can be met by cystine, and, in the rat, approximately 50% of the arginine requirement can be met by proline. In birds, glycine and serine can be used interchangeably. DAAs can be synthesized from other amino acids by transamination and other processes. Many amino acids are used for protein synthesis in the liver and other tissues. DNA serves as a template for RNA synthesis (transcription). The amino acid sequence of the protein to be synthesized is then translated from the mRNA base sequence. This is a very specific process. If an amino acid coded for by the mRNA base sequence is not available, the protein cannot be synthesized even though all other amino acids may be plentiful. The amino acid that has the greatest limiting effect on the rate protein synthesis is the "limiting amino acid". For an animal to meet its requirement for protein, it must satisfy its requirement for the most limiting amino acid.

Amino acids can also be deaminated and their carbon skeletons can be oxidized for energy or used for glucose, ketone, or lipid synthesis. In mammals, excess amino groups resulting from deamination are excreted primarily in the form of urea. In birds and reptiles, these excess amino groups are excreted primarily as uric acid.

Only the L stereoisomers of amino acids are found in animal tissues. D isomers of several amino acids can be used by animals, but these isomers require deamination and reamination to the L form. This transformation process combined with poorer absorption of D forms results in much less efficient use of D-amino acids compared to L forms.

PROTEIN DETERMINATION

The most common method for determining protein, the Kjeldahl procedure, is actually a measure of nitrogen (N). Protein is estimated by multiplying N by 6.25. The value obtained is termed "crude protein" and is based on an average of 16% N in most proteins (100%/16% = 6.25). The percentage of N in different proteins can vary considerably (e.g., 18-19% in seeds and nuts, 15.7% in milk) depending on their amino acid composition (e.g., tyrosine contains 8.5% N, arginine contains 32% N). Not all N is associated with protein. For example, approximately 20% of the nitrogen in bacteria is in nucleic acids. When applied to nonprotein nitrogen sources (NPN) such as urea, crude protein calculations can yield very spurious results. To determine total true protein, it is necessary to analyze for each amino acid and sum the results. This approach is usually too time consuming and expensive to be practical. For all its potential shortcomings, N x 6.25 gives a reasonable estimate of protein in most cases. However, it tells nothing about the availability or quality of protein in the diet.

DETERMINING NET PROTEIN REQUIREMENTS FOR MAINTENANCE

For comparative purposes, protein requirements can be best expressed on a net basis. Net protein is dietary protein that is actually utilized by the animal (i.e., digested, absorbed, and retained by the animal or its microflora). The net protein requirement for maintenance is equal to the sum of endogenous urinary nitrogen (EUN) plus metabolic fecal nitrogen (MFN) multiplied by 6.25.

EUN is N excreted in the urine that is of body origin. It can be defined as the amount of N excreted in the urine of an animal that is on a N-free diet that provides adequate energy to prevent the catabolism of protein for energy. Because animals often refuse to adequately consume protein-free diets, EUN is usually estimated by extrapolating to zero protein intake using diets with varying protein concentrations. Just as basal metabolic rate (BMR) represents the minimum, normal idling rate of energy metabolism, EUN represents the minimum idling rate of N metabolism. Indeed, EUN is often expressed in relation to BMR. In most mammals studied, EUN is about 1-2 mg N per basal kcal (Robbins, 1983). This is equivalent to 70-140 mg N/body weight kg^.75/day in adult eutherians. Similar to BMR, EUN, expressed per unit of body weight, is generally higher in young animals than in adults.

The two primary sources of EUN are body protein turnover and creatinine excretion. Body protein is in a dynamic state. For example, a 70 kg man breaks down and synthesizes approximately 1 lb of protein per day. Utilization of amino acids resulting from protein degradation is not 100% efficient. Excess N resulting from amino acid turnover is excreted in the form of urea in mammals and uric acid in birds and reptiles. Creatinine results from phosphocreatine in muscle. Creatinine excretion is related to lean body mass (i.e., muscle) and, typically, a fairly constant amount is excreted in the urine each day regardless of the amount of muscle activity.

A notable exception to the general rule of 1-2 mg N/basal kcal in animals occurs during hibernation. For example, bears are able to essentially cease EUN excretion during torpor (Nelson et al., 1983).

The second component of the net protein requirement for maintenance is MFN. MFN is the N in feces that is not of immediate food origin. Major sources of MFN include undigested microbes and microbial debris, digestive enzymes and urea not reabsorbed, sloughed off mucosal cells, and mucus.

MFN is related to fecal mass which in turn is related to dry matter intake and digestibility. The more eaten and the less digested, the more enzymes secreted, the more wear on the GI tract lining, and the more microbes carried out with the greater fecal mass. MFN is often expressed relative to dry matter intake because it is easier to apply than when expressed relative to fecal dry matter.

MFN is usually determined by plotting apparent protein digestibility relative to dry matter intake against different intakes of protein and extrapolating to zero protein intake (i.e., the Lucas Test). MFN can also be determined directly as the difference between total fecal N and neutral detergent fiber fecal N.

MFN usually ranges between 2 and 9 g N/kg of dry matter intake (Table 1). It is higher in pregastric and well developed hindgut fermenters because of the greater contribution of bacterial N. In domestic ruminants, bacterial N accounts for approximately 85-90% of MFN. MFN is also higher on high roughage, low digestibility diets and tends to constitute a greater percentage of the fecal dry matter in smaller species.

Because MFN increases as food intake increases, there is a minimum amount of digestible protein in the diet dry matter that must be present just to compensate for the protein-cost of eating. Because it will exacerbate a protein deficiency, it is not advantages for an animal to consume a diet that does not provide at least enough protein to offset the protein cost of eating. Animals do, in fact, typically decrease dry matter intake on low protein diets.

Because birds have a cloaca, it is not practical to differentiate between EUN and MFN. It is possible to get an estimate of the combined N losses by extrapolating to zero N intake. EUN and MFN losses in birds are approximately 0.1 g N/body weight kg^.75 or 1 mg N/basal kcal (Robbins, 1983).

DETERMINING NET PROTEIN REQUIREMENTS FOR GROWTH AND PRODUCTION

Net protein requirements for growth, reproduction and lactation can be determined by adding the amount of protein accreted in tissues or secreted in milk to the net protein requirement for maintenance (this approach is called the factorial method).

Net N (g/day)= MFN + EUN + Growth N + Conceptus N + Milk N + Miscellaneous N losses

Miscellaneous N losses include hair, feathers, saliva, skin, and blood loss.

In most growing animals, approximately 15-25% of their weight gain is protein. The theoretical maximum is approximately 30% due to the water-protein ratio. Exceptions to this rule are highly keratinized external structures such as hair, feathers, and horns. Hair contains approximately 90% protein. Feathers contain 82-98% protein. The IDAA composition of body proteins of different animals in fairly consistent (Table 2). Thus, net IDAA requirements for growth expressed as a percentage of net protein are probably similar

Table 1. Metabolic fecal nitrogen (MFN) excretion in mammals.

	MFN (grams) / Dry Matter Intake (kg)
Pregastric Fermenters	
Domestic Cattle	4.8
Cervids	4.97
Colobus Monkey	4.45
Macropod Marsupials	3.88
Postgastric Fermenters	
Domestic Horse	4.8
Capybara	4
Rhesus Monkey	1.04
Brushtail Possum	1.79-3.36
Rabbits & Hares	4.61-9
Small rodents	2.5

References: Robbins, 1983; Watkins et al., 1985.

for most animals.

The protein requirement for gestation in most mammals does not increase significantly until the last trimester of pregnancy. Fetuses and eggs generally contain 10-15% protein. Protein content (as is basis) of milk varies from as low as 1% in some primates and perissodactyls, to as high as 16% in lagomorphs and some pinnipeds (Oftedal, 1984). The protein requirement for miscellaneous N losses in cattle in approximately 2% of the maintenance requirement (NRC, 1984a).

Obviously, a great amount of effort would be necessary to quantify each of the factors that determine protein requirements. In domestic animals, allometric relationships and predictive equations have been determined for most species to estimate each of these factors from variables that can easily be measured (e.g., body weight, mature weight, rate of gain, dry matter intake, age, etc.). This would be virtually impossible to do on a species by species basis with wild and exotic animals because of the great number of species. However, because of the similarities among animals, particularly within taxa, interspecies equations offer potential for estimating net N requirements for a great variety of species.

Note that there is nothing in the factorial equation that relates to activity. Protein requirements do not appear to be markedly affected by activity per se (i.e., increased muscular activity does not usually have a major influence on the rate of protein turnover). Protein requirements appear to be affected by activity primarily in relation to the effect on energy requirements.

DETERMINING DIETARY PROTEIN REQUIREMENTS

Net protein requirements equal dietary protein requirements only when true protein digestibility is 100% and the amino acid composition of the diet perfectly matches the IDAA requirement (i.e., protein in the diet is perfect in quality).

True Protein Digest (%) = [Diet N - (Fecal N - MFN)]100 / Diet N

(True protein digestibility can also be calculated from the slope of the Lucas Test for protein.)

In practice, the actual amount of protein required in the diet is invariably something greater than the net protein requirement because dietary protein is seldom, if ever, perfect in quality.

In animals with well developed pregastric fermentation, protein digestibility is generally considered the most important aspect of dietary protein quality. Due to microbial modification, amino acid composition is generally of lesser importance.

Factors Influencing Protein Digestibility

Protein type...Different proteins have different solubilities and are susceptible to varying degrees to enzymatic breakdown (e.g., keratin proteins are poorly digested whereas albumin proteins are highly digestible). Once a protein is hydrolyzed, the absorption of the free amino acids can be affected by competitive interactions for specific active transport systems.

Proteolytic enzymes inhibitors...Some foods contain compounds that interfere with the action of proteolytic enzymes (e.g., anti-trypsin compounds in raw soybeans, kidney beans, barley, colostrum). Most of these compounds can be inactivated by heating or by microbial action.

Protein binding and heat damage...Certain secondary plant compounds such as phenolics can bind with dietary proteins making them indigestible. Phenolics can also bind digestive enzymes and other metabolic proteins. Heat damage can denature proteins and result in enzyme resistant cross-linkages. Heat can also cause the formation of indigestible Maillard products (a browning reaction that results when reducing sugars bind with certain amino acids).

Physical characteristics of food...Structural carbohydrates and lignin in foods of plant origin can protect cell wall proteins from digestion.

Microbial action...Pregastric bacteria can increase or decrease the digestibility of protein. By converting high quality protein to medium quality microbial protein, digestibility can be reduced. Conversely, by converting low quality proteins to medium quality microbial protein, digestibility can be increased.

Retention time...Generally, the faster the passage rate, the lower the digestibility of poor quality proteins such as keratins.

True protein digestibility probably ranges between 80-100% for most foods and feeds used in zoos.

Evaluating Amino Acid Composition

Amino acid composition of feeds can be determined directly by analysis. Although amino acid composition can provide useful information, the availability of the amino acids remains unknown. Amino acid composition and availability can be evaluated indirectly by calculating Biological Value (BV):

True BV = Protein Retained / Protein Absorbed
=[NI - (FN -MFN) - (UN - EUN)]100 / [NI - (FN - MFN)]

where, NI = nitrogen intake, FN = total fecal nitrogen, and UN = total urinary nitrogen.

True BV cannot be calculated if protein catabolism for energy is occurring. BV is usually calculated in growing animals. The biological values of some common foods as determined in growing rats are as follows (limiting amino acids are shown in parentheses): egg 100%, milk 92%, liver 79%, casein 78% (methionine), soybean meal 67% (methionine), whole wheat 48% (lysine), whole corn 45% (lysine), and gelatin 0% (tryptophan). Addition of the limiting amino acid can substantially increase BV of most proteins. The BV of rumen microbes is about 66-80%, owing, at least in part, to the high nucleic acid content of bacteria.

Calculating Protein Requirements

If the net N requirement, true N digestibility and true biological value are known, dietary N requirements can be calculated:

Diet N (g/day) = Net N (g/day) / (True N Digestibility x True BV)

This method is useful for comparisons among species, but it suffers from some disadvantages: (1) the actual amount of protein required is often underestimated because animals on higher protein diets tend to "waste" protein that could have been used more efficiently had protein intake been low (i.e., BV declines with increased protein intake); (2) the biological value of a protein used for production can differ from its biological value when used for maintenance; and (3) it is difficult to calculate the factors of the equation unless allometric and predictive equations can be used.

Another method for determining the dietary protein requirement of an animal on a particular type of diet at a given level of dry matter intake is the Nitrogen Balance Method.

N balance = N intake - N excretion.

When N balance equals zero, the maintenance N requirement is achieved. When N balance reaches its greatest positive value, the maximum growth requirement is achieved. The diets used in N balance trials must always provide adequate energy to give valid results.

Because protein is used more efficiently when protein intake is low, animals will often show zero N balance over a range of low protein intakes.

Dietary protein requirements can also be estimated by feeding diets with different protein concentrations and monitoring changes in body weight or growth and productive performance. Although this approach is not very rigorous, it does have obvious practical value.

DETERMINING DIETARY AMINO ACID REQUIREMENTS

Amino acid requirements can be determined by the minimum addition of a limiting amino acid necessary to achieve zero N balance (maintenance), maximum positive N balance (growth), prevent weight loss, or support normal growth or production. Amino acid composition of the body and turnover of isotopically labeled amino acids can also be used to establish amino acid requirements.

PROTEIN AND AMINO ACID REQUIREMENTS

As discussed, an animal's total dietary protein requirement can vary considerably depending on digestibility and amino acid composition of the dietary protein. For comparative purposes, protein requirements are best expressed on a net protein basis. Unfortunately, no system has been widely accepted and applied to accurately predict the net protein content of feeds and diets. The use of net protein is also complicated by the fact that net protein content of a particular food can change depending on other foods in the diet and the net protein content of a diet can vary depending on species. Therefore, tabular net protein values for feeds have limited application. From a practical standpoint, requirement data is of little value if counterpart food data is not available.

For monogastrics, it is possible to express the protein requirement in terms of each IDAA and the total quantity of DAAs. Requirements expressed in this manner are very useful but relating the amino acid composition of feeds to animal requirements is complicated by protein digestibility and amino acid availability.

Most commonly, protein requirements are simply expressed on the basis of total crude protein or N and reflect the average digestibility and utilization of protein in ingredients typically used to feed a species. Digestible protein values are also commonly used. In many cases, digestible protein values are simply predicted from crude protein values by multiplying by a general protein digestibility coefficient and therefore are little more accurate than crude protein values.

Table 2. Indispensable amino acid composition of body protein (cat, chicken, duck, mink, mouse, pig, rabbit, rat) expressed as a percentage of total protein.

IDAA	Mean %	Standard Error	N	Range
Arginine	6.2	0.15	8	5.8-7.1
Histidine	1.9	0.11	8	1.6-2.6
Isoleucine	3.7	0.19	8	3.0-4.7
Leucine	6.9	0.17	8	6.1-7.5
Lysine	6.8	0.39	8	5.6-8.5
Methionine	1.8	0.05	8	1.6-2.0
Cystine	1.6	0.21	4	1.0-2.0
Phenylalanine	3.7	0.11	8	3.2-4.2
Tyrosine	2.7	0.10	4	2.5-2.9
Threonine	3.9	0.08	8	3.7-4.3
Valine	5.1	0.23	8	4.4-6.0

Reference: Robbins, 1983.

Protein and amino acid requirements can be expressed in terms of % in the diet dry matter, amount/day, amount/metabolic body size, or amount/ME or DE kcal. The most common method of expressing protein and amino acid requirements of animals is in terms of % in the diet dry matter (Tables 3 and 4). This has practical value because body weight and food intake do not have to be known. This is often the case in zoos where animals are fed as groups. Diet evaluation is simplified because protein concentration in the diet can be compared directly to animal requirements. Expressing requirements in terms of % in the diet dry matter is not very applicable to free-ranging animals because requirements expressed as a % of DDM generally assume ad libitum intake.

It is difficult to make detailed comparisons among species based on reported protein and amino acid requirements expressed as a % of DDM. Different species are fed different kinds of proteins, energy density of diets varies, methods and criteria used to establish protein requirements varies and the amount of data available to determine requirements varies among species. However, it is possible to make some general observations concerning comparative protein requirements.

Cats and other obligate carnivores such as mink, have substantially higher protein requirements than omnivores and herbivores. At least in the case of the cat, this greater need is due primarily to the cat's inability to conserve nitrogen by regulating the activity of hepatic enzymes involved with the amino acid catabolism (MacDonald et al., 1984). Their higher protein requirement, therefore, primarily reflects the maintenance component of their overall requirement for protein.

IDAA requirements of different species expressed in terms of % diet dry matter are fairly similar (Table 4). Arginine shows the greatest variability between different species. Birds probably have a high dietary arginine requirement because they don't possess a urea cycle. The high arginine requirement of the cat may result from a slow rate of ornithine synthesis.

Protein and amino acid requirements can be expressed more accurately in terms of amount relative to energy content of the diet because food intake is related to ME content of the diet.

SIGNS OF PROTEIN AND AMINO ACID DEFICIENCY

Protein deficiency signs in animals are generally nonspecific. Many nutrition and non-nutrition related problems result in similar clinical and subclinical manifestations. Signs of a general protein deficiency include: reduced food intake, reduced growth or weight

Table 3. Crude protein requirements of animals (% of diet on a dry matter basis).

Species or Group	Milk	Growth			Maintenance	Gestation	Lactation
		Early	Average	Late			
Beef Cattle	26	24-12		15-7	7-8	8-10	9-11
Dairy Cattle	26	22-16		12	10	12	12-19
Sheep	25	17-15		15-9	9	11	13-15
Goat	22				8-11	10	
White-tailed Deer	35	25-18		18-14	10-12		
Horse	18	15		13-10	8	10-11	11-13
Rabbit	32		16		12	15	17
Pig	12	27-20		17-14	13	13	14
Dog	33		12				
Fox	38	30-28		25	20	30	35
Mink	26	38		32-38	22-26	38	45.7
Cat			24				
Rat	37		13		5	13	13
Mouse	31		14			20	
Gerbil			16				
Guinea Pig	36		20				
Golden Hamster	42		17				
Vole			14				
New World Primate			28				
Old World Primate	9-15		17				
Leghorn Chicken	-	20-17		13		15	
Turkey	-	31-21		18-16	13	16	
Goose	-	24		17		17	
Duck	-	24		18		17	
Pheasant	-	33		18		20	
Bobwhite Quail	-	31		22		27	
Japanese Quail	-		27			22	

Adapted primarily from NRC. Milk values represent milk protein concentrations (dry matter basis) usually at mid-lactation. Requirement values for the dog, cat, and rat represent minimum requirements when fed purified diets. Values for other species represent requirements for diets with typical ingredients and energy concentration.

Table 4. Amino acid requirements for growth (% of diet on a dry matter basis).

	Cat 5 ME	Dog 3.67 ME	Rat 4.2 DE	Pig 3.61 ME	Chick 3.22 ME
Arginine	1	0.5	0.67	0.44	0.92
Histidine	0.3	0.18	0.33	0.28	0.24
Isoleucine	0.5	0.36	0.56	0.59	0.55
Leucine	1.2	0.58	0.75	0.77	0.92
Lysine	0.8	0.51	0.78	1.05	0.66
Methionine + Cystine	0.75	0.39	0.67	0.53	0.55
Phe + Tyrosine	0.85	0.72	0.89	0.86	0.92
Threonine	0.7	0.47	0.56	0.62	0.63
Tryptophan	0.15	0.15	0.17	0.16	0.12
Valine	0.6	0.39	0.67	0.62	0.57
Serine + Glycine	0	0	0	0	0.64
Taurine	0.12	0	0	0	0

Adapted from NRC. Requirements based on the indicated metabolizable (ME) or digestible (DE) energy concentration of the diet (dry matter basis). Requirements for cat, dog, and rat based on the use of purified diets. Requirements for pig and chick based on the use of typical corn-soy diet. 10-20 kg pig; 6-14 wk leghorn chick.

loss, emaciation and muscle wasting, reduced feed efficiency, impaired reproduction, ova and fetal resorption, reduced milk production, rough and dull haircoat, poor feathering, reduced resistance to bacterial infection, hypoproteinemia, edema, reduced antibody formation, increased liver lipid concentration, and anemia.

Deficiencies of individual amino acids usually result in the same nonspecific signs as general protein deficiency. However, some amino acids do result in more specific deficiency signs.

Arginine deficiency...Omitting arginine from a single meal can cause ammonia toxicity in juvenile dogs, juvenile ferrets, and cats of all ages (Morris and Rogers, 1978; Thomas et al., 1986). It is likely that most primarily carnivorous members of the Carnivora, at least while young, are susceptible to an acute deficiency of arginine. Signs of ammonia toxicity include vomiting, salivation, ataxia, spasms, labored breathing, and death. Because arginine is widely found in foods, particularly animal products, it is unlikely that ammonia toxicity resulting from arginine deficiency would occur in carnivores fed practical diets. An acute deficiency of arginine does not result in ammonia toxicity in non-carnivorous mammals. In birds, an acute deficiency can cause weight loss and eventual death. Chronic deficiency results in abnormal, frizzled feathers in chicks (NRC, 1984b). Cataracts have been reported in young gray wolves fed a commercial milk replacer low in arginine (Vainisi et al., 1981).

Histidine deficiency...Reduced hemoglobin and hematocrit (dog, cat, rat); cataracts (cat, rat).

Isoleucine deficiency...Tongue deformity (chicken); crusty exudate around eyes, incoordination (cat).

Leucine deficiency...Tongue deformity (chicken).

Lysine deficiency...Lack of melanin in dark feathers (Gallinaceous birds); dental caries, blackened teeth, hunched stance, ataxia (rat).

Methionine/Cystine deficiency...fatty liver (most species - other amino acids also), cataracts (rat).

Threonine deficiency...Neurological dysfunction, lameness (cat).

Tryptophan deficiency...Cataracts, corneal vascularization, alopecia (rat, pig, guinea pig).

Taurine deficiency...Central retinal degeneration, congestive cardiomyopathy, reproductive failure, neurological abnormalities of offspring (cat).

EFFECTS OF EXCESS DIETARY PROTEIN

Unlike some nutrients that can cause obvious toxic effects if consumed in excess amounts (e.g., minerals and fat soluble vitamins), detrimental effects caused by excess dietary protein are generally not readily apparent. Excess protein can be deaminated and the nitrogen readily excreted as urea or uric acid. The carbon skeletons from the excess amino acids can be metabolized for energy or used in synthetic pathways. In domestic animal production, excess protein intake seldom occurs because protein is typically the most expensive component in animal diets. However, there are problems that might occur due to an excess of dietary protein or that have been frequently speculated to involve an excess of protein.

Excessive Growth

High protein levels in bird diets have been implicated in leg and wing problems in growing birds. Studies with domestic poultry have shown a higher than normal incidence of perosis, leg weakness, and curled toes in young chickens and turkeys fed high protein diets (Sauveur, 1984). High protein levels in diets for growing ratites, cranes, waterfowl and other birds may also be predisposing to leg and wing problems (e.g., slipped or angel wing) by supporting abnormally rapid growth.

Excess protein in the diet has often been suggested as a possible cause of hoof overgrowth in exotic ungulates. Studies with domestic ungulates have given little support to this theory, however (Butler and Hintz, 1977). Maintaining captive animals on a high plane of nutrition with little opportunity to exercise and wear hooves is probably more etiological than protein content of the diet.

Renal Damage

Kidney failure is often attributed to chronic high protein intakes, especially in dogs. It is well established that increased dietary protein can increase renal blood flow and pressure. Although a relationship between protein intake and the onset of chronic kidney failure has not been conclusively established, it seems prudent not to feed unnecessarily high levels of protein. Once kidney damage occurs, it is widely accepted that a low protein diet with high biological value can help slow the progression of renal failure and reduce uremia. Protein requirements generally increase as a result of kidney failure because proteinuria may occur. Although the turnover of IDAAs may increase over normal maintenance, the total amount of protein in the diet can often be reduced by omitting amino acids that would go unused by the animal and produce urea. Diets for kidney failure must contain adequate metabolizable energy in the form of carbohydrate and fat to prevent body protein catabolism.

Avian Gout

Excess protein intake has been suggested to predispose non-passerine birds to arthritic and visceral gout. This effect has not been clearly established although it is known that increased protein can result in increased uric acid levels in the blood. When abnormal uric acid deposition does occur, for example due to kidney damage or a genetic defect in metabolism, reducing protein level and feeding proteins with high BV can help slow progression of the disease.

Ammonia Toxicity

Ammonia toxicity as a result of excess crude protein intake is primarily a concern in ruminants receiving urea as a source of NPN. Ammonia toxicity is generally not a major concern with wild and exotic animals because NPN sources are seldom used. Because feeds for domestic cattle often contain urea and because diets for zoo hoofstock are often made by mills that also produce cattle feeds, there is always a possibility that urea could unintentionally get into the diets of exotics. To avoid ammonia toxicity in domestic ruminants, urea levels in the diet should usually not exceed 1% of the diet dry matter or one-third of the total crude protein in the diet (NRC, 1984a). High energy, low protein diets can be effectively supplemented with more NPN than low energy diets with a high degradable protein content. Postgastric fermenters such as the horse can tolerate higher levels of urea than ruminants.

Heat Stress and Water Deficiency

Heat produced by the deamination of amino acids is a major component of the heat increment. Feeding high protein diets to animals in hot weather can exacerbate heat stress.

High protein diets increase water requirements in mammals because water is necessary to dilute urea for excretion.

Miscellaneous Effects

Feeding high protein diets to chickens can reduce growth, reduce body fat deposition, and increase the size of the adrenal glands. High protein diets increase the loss of calcium in rats and humans.

Excesses of Specific Amino Acids and Amino Acid Imbalances

Amino acid excesses usually occur only as a result of supplementing diets with purified amino acids. A large excess of an amino acid can depress food intake and potentially induce a general protein deficiency if the amino acid in excess competes with a limiting amino acid for a specific transport system. Large excesses of specific amino acids can have pharmacological effects. Excess methionine fed to kittens reduced food intake and growth rate (Buffington et al., 1987; Fau et al., 1987). Cats fed excessive amounts of cystine developed debilitating neurological symptoms (Laidlaw et al., 1987).

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OVERVIEW OF ZOO ANIMAL NUTRITION-VITAMINS AND MINERALS

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VITAMINS

Vitamins are commonly divided into fat-soluble and water-soluble categories. The fat-soluble vitamins are vitamin A and carotenes, vitamin D, vitamin E, and vitamin K. The water-soluble vitamins are thiamin, riboflavin, niacin, pantothenic acid, vitamin B_6, biotin, folacin, myo-inositol, vitamin B_{12}, choline, and vitamin C. The vitamins in natural feedstuffs may be supplemented by microbial synthesis of vitamin K and the B-vitamins (all water-soluble vitamins except choline and vitamin C) in the ruminoreticulum, cecum or colon of herbivores. Commercially-produced vitamin supplements also may be used when necessary. While nearly any vitamin might be deficient in a particular diet, those vitamins of greatest practical significance in zoos are vitamin A, vitamin D, vitamin E, thiamin, riboflavin, niacin, pantothenic acid, vitamin B_{12}, and choline. Vitamin C is of practical significance in the diets of animals that are unable to synthesize this vitamin in their tissues. Such animals would include many primates, cavies, fruit bats, and the red-vented bulbul.

Vitamin A and carotenes. Vitamin A is found in animal tissues but not in plants. Carotenes in plants may be converted to vitamin A when these plants are consumed by animals. Green, leafy plants and yellow corn are among the best natural sources of carotenes. Animal liver or fish liver oils are among the best natural sources of vitamin A. A commercial vitamin A supplement, such as vitamin A palmitate, is commonly used in formulated diets because it is significantly more stable than natural vitamin A forms.

Vitamin A deficiency results in impaired vision, a failure in the remodeling of growing bone, and metaplasia of epithelial cells, resulting in increased susceptibility to infection. Vitamin A excess results in skin exfoliation, hemorrhage and exaggerated bone remodeling.

Dietary vitamin A requirements range from 2,000 to 10,000 IU/kg. Maximum tolerable dietary levels are 15,000 to 100,000 IU/kg.

Vitamin D. The two primary vitamin D forms found in nature are vitamin D_2 (ergocalciferol) and vitamin D_3 (cholecalciferol). Ultraviolet exposure of dead plant tissue and of the skin of animals results in the conversion of precursors to vitamins D_2 and D_3, respectively.

Vitamin D deficiency results in rickets in the young and in osteomalacia in the adult. Excesses may result in mineralization of soft tissue.

In the absence of sunlight, dietary vitamin D requirements range from 200 to 2,000 IU/kg. Maximum tolerable dietary levels are 3,000 to 20,000 IU/kg.

Vitamin E. There are eight natural vitamin E compounds found in lipid fractions of green leaves and in seed oils. Alpha-tocopherol is the most biologically active, functioning to protect unsaturated fatty acids in cell membranes against oxidation.

Signs of vitamin E deficiency are similar to those seen in selenium deficiency. These include skeletal and cardiac myopathies, exudative diathesis, hemolysis of red cells and anemia. Encephalomalacia is also seen. Excesses of vitamin E interfere with blood clotting, depress iodine uptake by the thyroid and depress growth rate.

Dietary vitamin E requirements range from 20 to 100 IU/kg. Maximum tolerable dietary levels are 1,000 to 2,000 IU/kg.

Thiamin. Thiamin is found in leafy forages and whole grains. Simple deficiencies are uncommon. However, thiaminases in improperly stored, frozen fish and antithiamins in plants, such as bracken fern, destroy thiamin or interfere with its functions.

Deficiency signs include loss of appetite, decreased erythrocyte transketolase activity, cardiac ventricular hypertrophy, sudden cardiac failure and death. Large excesses block nerve transmission and produce curare-like signs.

Dietary thiamin requirements are 0.5 to 3.0 mg/kg diet. Maximum tolerable dietary levels may be as much as 1000 times the requirement.

Riboflavin. Leafy forages are good sources of riboflavin. Seeds are generally poor.

Deficiency signs include poor growth, skin hyperkeratosis, anemia, corneal vascularization, and curled-toe paralysis in birds. Excess riboflavin may impair reproduction (at 100 mg/kg diet).

Dietary riboflavin requirements are 2 to 4 mg/kg. Maximum tolerable dietary levels have not been adequately established.

Niacin. Both nicotinic acid and nicotinamide have niacin activity. These compounds are found in leafy forages and seeds, but much of the niacin in seeds is bound and biologically unavailable to nonruminants.

Deficiency signs include inflammation and necrosis of oral tissues, anorexia, bloody diarrhea, dermatitis, central nervous system disturbances, and death. Excesses produce transient vasodilation of cutaneous blood vessels.

Niacin requirements are about 10 to 30 mg/kg diet. Maximum tolerable dietary levels are 350 mg/kg for nicotinamide and perhaps up to 4 times this level for nicotinic acid.

Pantothenic acid. Leafy forages, liver and kidney are good sources of pantothenic acid. Corn and rice are poor sources.

Deficiency signs include neuromotor disorders, bloody diarrhea, decreased steroid synthesis and loss of hair color. Effects of excesses have not been described.

Dietary requirements are 10 to 20 mg/kg. Maximum tolerable dietary levels probably exceed 20 g/kg.

Vitamin B_{12}. This vitamin contains cobalt and is synthesized by bacteria but not by higher plants. It is found in animal tissue as a consequence of ingestion or from microbial synthesis in the digestive tract.

Deficiency signs include impaired reproduction, neurological damage and fatty degeneration of the liver. Signs of excess have not been described.

Dietary requirements are 5 to 25 ug/kg. Maximum tolerable dietary levels probably are several hundred times the requirement.

Choline. Choline is widely distributed in animal tissues, is high in leafy forages, moderate in oil-seed meals and low in cereal grains. It serves, along with methionine, as a methyl donor.

Deficiency signs include fatty liver and hemorrhagic kidneys. Excesses may depress growth and erythropoeisis.

Dietary requirements depend on supplies of methionine, but nonruminant diets are commonly supplemented with 200 to 1,000 mg/kg. Maximum tolerable dietary levels have not been adequately established.

Vitamin C. Vitamin C is found in high concentrations in citrus fruits such as oranges, and generally in lower concentrations in other plant tissues. Many animals synthesize vitamin C in their tissues, but most primates, guinea pigs, red-vented bulbuls, fruit bats, trout and salmon lack an enzyme essential for this synthesis. Thus, these species require vitamin C in their diet.

Deficiency signs include pain in joints and muscles, gingivitis, and petechial and ecchymotic hemorrhages.

Excesses may result in oxaluria, uricosuria, hypoglycemia, excessive absorption of iron, diarrhea and increased activity of degradative enzymes of vitamin C.

Requirements are in the range of 50 to 100 mg/kg diet, but vitamin C is very unstable and larger levels may be necessary. Maximum tolerable dietary levels may exceed 1,000 mg/kg.

MINERALS

There are at least 23 mineral elements that have been proposed as dietary essentials. The essential macroelements include calcium, phosphorus, magnesium, sodium, chlorine, potassium and sulfur, and their concentrations are commonly expressed as a percentage of the diet. The essential microelements include iron, copper, iodine, manganese, zinc, cobalt, selenium, molybdenum, chromium, silicon, nickel, vanadium, tin, arsenic and lead. Their dietary concentrations are commonly expressed in parts per million (ppm). At present, deficiencies of molybdenum, silicon, nickel, vanadium, tin, arsenic and lead are considered only laboratory curiosities. Elements of practical importance in zoo diets are calcium, phosphorus, sodium, iron, copper, iodine, manganese, zinc, cobalt and selenium.

Calcium. Calcium serves a structural function as a part of bone mineral but also has an important neuromuscular role and participates in blood clotting.

Feed sources include legumes, limestone, dicalcium phosphate, bone meal and dried skimmilk.

Deficiency signs include rickets in the young and osteomalacia in adults. Excess calcium may decrease absorption of phosphorus, magnesium and zinc.

Calcium requirements range from 0.2 to 2.75% of the diet. Maximum tolerable dietary levels are 1 to 4%.

Phosphorus. Phosphorus is associated with calcium in the skeleton and teeth. Phosphorus in soft tissue functions in energy transformations, cell division and reproduction.

Feed sources include dicalcium phosphate, steamed bone meal, and meat and bone meal.

Deficiency signs include rickets in the young and osteomalacia in the adult. Anorexia and pica are also seen. Excessive intake may induce nutritional secondary hyperparathyroidism and interfere with absorption of calcium, manganese and iron.

Phosphorus requirements generally are 0.2 to 0.8% of the diet. Maximum tolerable dietary levels are 0.6 to 1.5%.

Sodium. Sodium is a major extracellular cation. Deficiency signs include pica for salt, anorexia and very low levels of urinary sodium. In the absence of fresh water, excesses result in neurological lesions and ataxia.

Sodium requirements are 0.08 to 0.30% of the diet. Maximum tolerable dietary levels are 2 to 9% if fresh water is available.

Iron. Iron functions in hemoglobin, myoglobin and heme enzymes. A deficiency results in microcytic, hypochromic anemia. Excesses may result in hemosiderosis, liver damage and neurological lesions.

Iron requirements are 40 to 100 ppm in the diet. Maximum tolerable levels are 500 to 1,000 ppm.

Copper. Copper is involved in the synthesis of connective tissue and melanin, mobilization of iron stores, formation of myelin, and stabilization of tertiary protein structure in wool and hair. Deficiency signs include anemia, impaired bone formation, neonatal ataxia, loss of hair color and cardiovascular rupture. Excess copper is particularly dangerous to sheep and results in hemolytic anemia and icterus.

Copper requirements are 5 to 10 ppm in the diet. Dietary copper-molybdenum ratios should not be less than 4:1. Maximum tolerable dietary levels are 25 to 800 ppm.

Iodine. Iodine functions as a part of thyroid hormones. Certain geographical regions are low in iodine, and a deficiency results in goiter, decreased metabolic rate, and birth of weak, dead or hairless young. Excess iodine also induces goiter, and increased susceptibility to infections.

Iodine requirements are 0.05 to 1.0 ppm in the diet. Maximum tolerable dietary levels are 5 to 400 ppm.

Manganese. Manganese is a cofactor for enzymes involved in gluconeogenesis, fat mobilization, and amino acid metabolism. A deficiency results in chondrodystrophy, and perosis. Excesses may depress growth and hemoglobin concentration.

Dietary requirements for birds are about 30 to 50 ppm, and for mammals are probably less than 10 ppm. Maximum tolerable dietary levels are 400 to 1,000 ppm.

Zinc. Zinc is involved in the synthesis of DNA and protein. Deficiency signs include anorexia, impaired growth, parakeratosis, poor wound healing and reproductive failure, particularly in males. Excesses may induce copper deficiency.

Dietary requirements are 40 to 80 ppm. Maximum tolerable dietary levels are 300 to 1,000 ppm.

Cobalt. Cobalt is part of vitamin B_{12}, which is involved in propionate metabolism. Vitamin B_{12} can be synthesized by digestive tract bacteria if adequate cobalt is present. Excess cobalt may induce cardiomyopathy and pancreatic degeneration.

Dietary requirements for ruminants are 0.1 ppm. Maximum tolerable dietary levels are 10 ppm.

Selenium. Selenium is a component of glutathione peroxidase, an enzyme that detoxifies organic peroxides and hydrogen peroxide. Deficiency signs include exudative diathesis, pancreatic fibrosis, and bilaterally symmetrical myopathies. Excesses result in hair loss, sloughing of hooves, joint erosion, anemia, and liver cirrhosis.

Dietary requirements are 0.1 to 0.3 ppm. Maximum tolerable dietary levels are 2 ppm.

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ASSESSING THE NEED FOR AN IN DEPTH STUDY OF A ZOO FEEDING PROGRAM

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In zoos, historically, diets have been formulated by curators, veterinarians, keepers, nutritionists, or any combination of these. The basis for diets have included factors such as, what free ranging wildlife eat, with attempts to mimic natural foods (feeding locally grown bamboo to red pandas); anecdotal information on what has worked in the past or for others; anthropomorphism (which is particularly notable when one looks at many primate diets); behavioral factors; individual animal food preferences; and ease of obtaining certain food items. Ideally, diets should be tailored to specific animals by employing measurable data generated by scientific methodology. The data should include background information such as: gut morphology, digestibility studies, metabolic requirements, proximate analysis of food items consumed, behavioral studies and analysis of growth rates, reproductive rates and maintenance on various planes of nutrition for both captive and free ranging animals. In addition to the background information, practical considerations such as local availability of foodstuffs, storage and handling capabilities, and manpower must be factored in.

One needs only to look at the majority of information produced on captive maintenance of wildlife to recognize that often hard data regarding nutrition is lacking. There is a paucity of baseline data about what is working, nutrition-wise in zoos. Meetings such as the one we are involved in are beginning to address the need to determine and disseminate high quality information on the science of feeding zoo animals.

In July 1985, the Dallas Zoo and the comparative nutrition group from Michigan State University, consisting of Dr. Ullrey, Mary Allen, David Baer and Cindy Brockway, performed a unique study designed to analyze the overall feeding program at the Dallas Zoo. I am going to discuss how it was determined that such a study was needed and how it was implemented from the zoo's end. Mary Allen will tell the story from the nutritionist's point of view and David Baer will discuss how the data that was obtained was handled in a meaningful way.

In the past, diets at the Dallas Zoo have been the responsibility of individual animal departments. Commissary operation was a step-child that was passed around to whichever department seemed to have enough supervisory personnel to manage it - until last year when it was placed in the veterinary department. Upon the arrival of a full time staff veterinarian 4+ years ago, the mammal curator began seeking cursory input from the vet before implementing diet changes. The procedure went something like this: keepers reported certain food preferences -- the supervisor recommended altering the diet -- the curator discussed it with the veterinarian and -- the diet was changed. Theoretically, all changes were reflected by production of a new diet card which was given to all affected personnel. If there was a specific medical problem associated with a diet, the curator and veterinarian would devise a new diet with input from the keepers as to what food items might be accepted by the animals. This procedure worked fairly well for mammals. However, for the bird department there really was no centralized system of keeping track of diets, although there were some diet cards maintained in various areas of the zoo. In the reptile department there were no written records of diets.

Initially, the veterinary department was only minimally involved in the feeding program. However, factors that indicated there was a need for evaluation of the feeding program became evident subsequently. The first hint of a problem was when it was discovered that monogastric herbivores were being fed a pelleted concentrate containing urea. Then, as data was accumulated on medical problems, causes of death and incidental findings at necropsy it became much clearer that not enough attention was being given to assessing the nutritional status of our animals.

Specific medical problems that were seen whose etiologies were determined to be due primarily to improper nutrition were:

1) White muscle disease in white-handed piping guan and a neonate giraffe.

2) Iron storage disease in Bali mynas, birds of paradise and catbirds.

3) Obesity in great apes, reptiles and birds.

4) Starvation in ducklings due to inappropriate food items being offered.

Problems that were multifactoral with improper nutrition planing a major role were:

1) An unusual number of fractures in small antelope. This occurred during a period of time when the animals had to be confined totally indoors for a prolonged time during inclement weather.

2) Splayed legs in a neonate small antelope. Due to slippery barn floors it was difficult to judge whether the splaying was a result of musculoskeletal weakness at birth or improper substrate for footing.

3) Degenerative hock disease in okapi. The two affected okapi were also inbred.

4) Low reproductive rates in birds.

If diets, as prescribed, appeared to be adequate, it was found that there was little quality control within the zoo. There was a semi-decentralized approach to feed preparation and storage. The primate section has two kitchens with as many as seven different people preparing food. The bird house has its own kitchen. And each hoofed stock area stored most of their own food. Often times, the diet cards present in the kitchen didn't match the ones in the curator's offices. Often, the diet cards were not being followed scrupulously. There were virtually no uniform methods of measurement. And there didn't seem to be any centralized responsibility.

If one looked at the labor involved, one could find duplication of efforts and an inordinate amount of keeper time being spent chopping vegetables. Labor costs aside, it appeared that there were inflated food costs due to very expensive food items being used per benefit derived. There was also greater than necessary food wastage due to multiple storage areas.

Lest I give you the impression that the Dallas Zoo was a morass of dietary mismanagement and nutritional ignorance with scores of animals wasting away year after year, I would like to point out that overall the zoo has been very successful at maintaining and reproducing an outstanding collection of animals over the years. Among the notable accomplishments of the animal management staff are long-term programs involving small antelope, snow leopards, spectacled langurs, proboscis monkeys, gorillas, flamingos, bongo, okapi, speke's and slender-horn gazelle, and many others. It should be noted, however, that prior to our study we would not have been able to tell you what plane of nutrition any of these animals were on. The situation at Dallas was really not much different than at most zoos.

When one is forced with trying to correct dietary deficiencies or excesses by modifying an existing diet, the first step is to determine what is being fed. If no baseline information regarding quantities of nutrient components exist, then any modification of the diet is potentially based on false premises. Ergo, the subsequent diet is only as valid as the preceding one. In other words, without baseline data, one is taking "shots in the dark" by modifying an existing diet. There are over 170 different diets being fed at the Dallas Zoo. It was and is beyond the capability of any one person with other job duties (such as curators or the veterinarian) to analyze all those diets as fed at a certain time. Thus, with the realization that baseline data was needed and that it couldn't be obtained in a timely manner in-house, outside assistance was sought.

There are three critical steps that must be taken prior to implementation of a nutrition study. They are: 1) The need for such a study must be recognized by appropriate personnel (curators, veterinary staff, director). This recognition usually doesn't happen all at once. It grows slowly as individual problems are discovered and discussed. 2) Expertise must be sought. In our case, although it was felt that the Michigan State group was the most knowledgeable in terms of overall captive wild animal nutrition, a concerted effort was made to tap into local resources. Calls were made to animal nutritionists within the state in an attempt to generate interest in a cooperative venture. Without exception none of our inquiries were successful. Thus, Dr. Ullrey was contacted and the process begun. 3) The third critical step is to find appropriate funding. In city-operated zoos it is nearly impossible to get money budgeted for a study like ours. Grant money is available through various agencies such as Institute of Museum Services and Nixon Griffis Foundation but often such sources are unreliable or untimely. In our case our zoological society was asked to fund the study. It is significant that up to that point, the Dallas Zoological Society (in its 30 years of existence), had only provided money for the purchase of animals and some equipment items.

Once the need was recognized, the nutritionists had been contacted and the zoological society targeted as the funding agency, the process of writing a proposal, modifying it, presenting it to zoo staff, modifying it and presenting it to the zoological society began. It took approximately 1 1/2 years from the first contact with Dr. Ullrey until his group was actually on site at the zoo to implement the study.

In conclusion: determining the need to analyze the zoo feeding program was based on the combination of identifying;

1) medical problems associated with improper nutrition;
2) quality control problems;
3) labor intensive practices; and
4) inflated costs.

Once the need was recognized, expertise was sought and funding obtained.

The entire process depends on maintaining open lines of communication among departments within a zoo. Sometimes one has to tread lightly when crossing lines between animal management areas and medical areas so that one department does not perceive an infringement on its area of expertise by another department. If all personnel involved keep in mind that the ultimate objectives are to provide high quality care for the animals in our collections and to advance the level of knowledge regarding how that is achieved studies such as ours will be successful.

Baseline data has now been obtained. This data is being analyzed and deficiencies or excesses are being noted and acted upon. The data will be correlated with information regarding the relative success of maintaining and reproducing certain species at the zoo. Hopefully, next year at this time I will be able to report on minimum dietary requirements of some zoo species.

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THE COMPREHENSIVE EVALUATION OF A ZOO FEEDING PROGRAM

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INTRODUCTION

Knowledge of the nutritional composition of zoo animal diets is obviously important to assure that appropriate amounts and ratios of nutrients are provided. Sound feeding practices can and should form the foundation of a preventative medicine program. Yet, attempts are rarely made to systematically evaluate all diets or the entire zoo feeding program, largely because such evaluations are time-consuming and complex.

When a specific diet is evaluated it is usually because of an obvious health problem. In the absence of a staff nutritionist, diet evaluation is usually the responsibility of veterinarians or curators who have little time for thorough dietary review or for food intake measurements. In such cases there may be little attention given to methods of food preparation or to the selection of alternate foods.

As stated in Dr. Raphael's report (Assessing the Need for an In Depth Study of a Zoo Feeding Program, these proceedings), the need for such a review was perceived by the staff at the Dallas Zoo. She has described the initial steps taken to plan and budget for this undertaking. I will discuss the evaluation process from the nutritionist's perspective.

The main objectives of a review of a zoo feeding program are: the documentation of nutrient concentrations in animal diets, evaluation of diet adequacy, formulation of revised diets, recommendation of alternate foods, evaluation of food handling, processing and distribution methods, and evaluation of cost-effectiveness of diets.

THE REQUIREMENTS FOR AN EVALUATION OF A FEEDING PROGRAM

The systematic review of a zoo feeding program, whether it is conducted by consulting nutritionists or by a staff nutritionist, has at least six essential components. These will be discussed in the context of the evaluation of animal diets at the Dallas Zoo, conducted in July of 1985.

1. Institutional Commitment

This is one of the most important factors that determines the success or failure of a project of this magnitude. The commitment of all zoo personnel, including the director, senior staff and keepers is essential. If the staff is not convinced that the documentation and evaluation of animal diets is important, the effectiveness of the review process will be undermined.

2.Nutritional and Zoological Expertise

It is important that the person or persons conducting the evaluation have a thorough understanding of the science of nutrition as well as an appreciation of the various aspects of zoo animal management. Knowledge of zoo animal husbandry methods, distribution of staff duties, food purchasing policy and breeding and animal health programs is essential.

3. Clear Communication

Dr. Raphael acted as our liaison to help coordinate the review before our arrival and once we were on site. This was important for the coordination of schedules and to facilitate discussion and communication among staff. Successful diet evaluation relies heavily on keeper expertise since they are the members of the staff most familiar with the daily care of animals. Good lines of communication between the nutritionists and the keepers assured that the information collected was accurate and useful. We presented brief seminars on such topics as, live prey, browse, primate nutrition and herbivore nutrition, to keeper and curatorial staff, during the two-week site visit. These group discussions helped to promote good communication and permitted staff to voice concerns and offer suggestions.

4. Background Information

Before we arrived at the Dallas Zoo, we needed some background information on the annual food budget, feed tags and labels, a list of all foods used and current diets fed, and a list of "problem" species whose diets were considered high-priority. It was also helpful to know something about exhibit characteristics and animal distribution within the zoo so that the time needed in each area could be anticipated.

5. Computer Capability

The timely evaluation of almost all of the diets in a major zoo can only be accomplished with the use of a computer program. The Zoo Diet Analysis Program (copyright 1984, David J. Baer) was used to calculate nutrient concentrations, and to formulate proposed revised diets. We also used this program to evaluate and compare diet costs. Other programs which can be used for zoo animal diet evaluation are now commercially available (e.g. Animal Nutritionist, N-Squared Computing, Silverton, Oregon).

6. Laboratory Support

The nutrient composition of many foods and animal feeds used in zoo animal diets is unknown. Part of the time spent at the Dallas Zoo included the collection of feed samples for laboratory analysis. Over 40 samples of commercial feeds, vertebrate and invertebrate prey and supplements were analyzed for dry matter, energy, protein, fat, ash, fiber fractions, calcium, phosphorus, magnesium, sodium, potassium, iron, manganese, copper, zinc and selenium by the Comparative Animal Nutrition Laboratory at the Department of Animal Science, Michigan State University. This information was subsequently entered into the data base of the computer program and used in diet calculations.

Compositional information on foods commonly used in some animal and human diets is readily available. In addition to data generated from our own laboratory analyses, we also used information of food composition from the following sources:

1. B.K. Watt and A.L. Merrill, 1975, Composition of Foods, Agriculture Handbook No.8, U.S. Department of Agriculture, Washington, D.C.

2. J.A.T. Pennington and H.N. Church (eds.), 1980, Bowes and Church's Food Values of Portions Commonly Used, J.B. Lippincott Co., Philadelphia.

3. A.A. Paul and D.A.T. Southgate, 1978, McCance and Widdowson's The Composition of Foods, fourth edition, Elsevier/North Holland Biomedical Press.

4. National Research Council, series on the Nutrient Requirements of Domestic Animals, National Academy Press, Washington, D.C.

CONDUCTING THE EVALUATION

Food Intake

The majority of the work during the two-week site visit involved working directly with keepers. Amounts of individual foods (apples, carrots, sunflower seeds, pellets, hay, etc.) offered were weighed as food pans were prepared. We used electronic balances for small items and hanging scales for bulky feeds, such as hay and pellets for large ungulates. Keepers also provided information on numbers of animals fed, dominance hierarchies, food preferences, feeding frequency, methods of food presentation, "treat" items, stool condition, reproductive histories and any problems with the exhibits, such as visitor feeding, rodent or insect pests or availability of native plants. Animal health records were also obtained from the animal hospital. All of this information was considered when we evaluated diets and formulated proposed diet revisions.

All of our diet calculations rely on weights of foods consumed. Since many zoo diets are prepared using estimates or volume measurements (cups, teaspoons, hands) we obtained unit weights for various items such as, teaspoons of vitamin supplements, cups of oystershell, flakes and bales of hay, and handfuls of seeds and nuts. We also obtained average weights on fruits and vegetables, mice, rats, chicks, fish and insects.

In most instances we returned to the animal areas later in the day or the following day to weigh uneaten food. In many cases, animals did not consume all that was offered. It was therefore important to determine the composition of the ingested diet. Adjustments were made to weights of uneaten food, based on estimates of losses due to desiccation or vermin. Some day-to day variation in food pan preparation is expected when duties are shared by many keepers. When possible, we returned to areas to attempt to document and account for any observed differences in amounts of offered food.

Food Preparation and Handling

The commissary prepared some food in bulk, including meat mixes and "salads". Diets for primates birds and most reptiles were prepared in individual kitchens located in animal areas. The methods of food preparation and equipment used throughout the park were evaluated for efficiency, sanitation and accuracy. We also evaluated food storage conditions in the commissary and in separate dry feed storage areas.

Calculation and Interpretation of Nutrient Concentrations

Once we returned to Michigan State University, we entered the collected data on offered or consumed diets into the computer program. When the laboratory analyses were completed, those data were also entered into the computer data base. The computer program calculated the composition of the entire diet and generated an output which provided the concentrations of up to 46 different nutrients. We then used a number of different sources of information to make judgments about diet adequacy. We compared these nutrient concentrations to standards derived from estimates of nutrient requirements of domestic animals. The adequacy of the diet for a given species was also based on information of feeding habits in the wild, the composition of diets used successfully at other zoos, gastrointestinal tract morphology, data on requirements, when known, of related or similar exotic species and suspected or observed health problems.

The assessment and interpretation of diet adequacy can be affected by a number of factors. The interpretation of evaluated diets must include such considerations as seasonal effects on intake. Diet intakes of animals in Dallas in July may not be representative of intakes of those same animals in December. Animal enclosure densities change throughout the year as animals are born, die or are moved. Stocking rate is known to affect food consumption in domestic species. The physiological state of an animal will also affect intake. The demands of growth and lactation will usually cause voluntary intake to increase dramatically. It is impossible to document all of the various factors that influence animal feeding and the interpretation of food consumption. However, recognizing these factors and carefully assessing their impact on diet adequacy is an essential part of the evaluation of a zoo feeding program.

Generation of Reports

The findings of our evaluation of the feeding program at the Dallas Zoo were prepared and submitted to the zoo administration for review and comment. The report consisted of a series of notebooks that contained a ten-page computer output for each diet evaluated. Over 150 diets were evaluated and approximately 80 revised diets were prepared. Summary reports of specific findings in individual areas were included. Where appropriate, recommendations for the use of alternate foods were made, based on suitability, availability, animal preferences or cost. We made a final zoo visit, after the reports were submitted, to present our findings to the staff.

CONCLUSIONS

To our knowledge, this was the first time a complete review of the entire feeding program at a major U.S. zoo was attempted. It is hoped that the information gained, by both the Dallas Zoo and by us, as nutritionists, will have a positive and long-term impact on animal husbandry methods and animal health.

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