USE OF A HUMAN BEHAVIORAL CHANGE MODEL TO MODIFY ANIMAL DIET: MODIFICATION OF PRIMATE DIETS AND FEEDING REGIMES AT THE PHILADELPHIA ZOO

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Abstract
For over a century, the Philadelphia Zoo has evolved the feeding and nutrition of non-human primates in its care. Beginning with the work of Dr. Corson-White in the 1920s, and progressing with Drs. Ratcliff, Snyder, and colleagues through the twentieth century, the Zoo has long made primate nutrition an institutional priority. Despite this, as the Philadelphia Zoo moved through the 21st century, common issues were observed in captive primates at both our institution and within the larger zoological community: dental, skin, and pelage condition; weight control challenges, and behavioral concerns were present in the collections. In 2012, the Zoo participated in an intestinal microbiome study, the results of which indicated that gut microbial diversity in zoo-housed primates was reduced as compared with that in their wild counterparts. These results, along with emerging evidence for negative behavioral and health impacts associated with high sugar diets and dysbiosis in humans, prompted the Philadelphia Zoo to revamp primate diets. The goals of these diet modifications were to reduce total sugar, increase fiber content, and offer foods more consistent nutritionally to those consumed by the species in the wild. – a goal that would also require an extensive revamping of keepers' understanding of primate nutrition. To ensure the success of this major transition, the Transtheoretical Model (TTM) for change was used to guide the progression of the Zoo's dietary modifications, resulting in their successful implementation. This transition to a low sugar high fiber diet in our collection has resulted in documented improvements in weight management, skin and coat condition, fecal quality scores, and animal cooperation with behavioral husbandry.

Introduction
In 2012, the Zoo participated in a gut microflora project led by Jonathan Clayton that compared microbial diversity in individuals in zoos, sanctuaries in range countries, and in the wild. This study documented that the shift of gut bacteria in wild to zoo-housed primates mirrored differences in gut bacteria described for "non-Westernized" versus "Westernized" humans (Clayton *et al.*, 2016; Clayton, 2015). The Western diet has been implicated in the depletion of gut microbiome diversity (Prados, 2016), as well as in increased incidence of obesity, inflammatory autoimmune diseases (Carrera-Bastos *et al*., 2011; Manzel *et al*., 2014), and chronic kidney disease (Hariharan *et al*., 2015). Concurrent with the Zoo's participation in Clayton's work, behavior studies reported by the Whitley Wildlife Conservation Trust indicated that reduction in fruit, and consequently total sugar, in the diets of lemurs was followed by a decrease in interspecies animal aggression (Britt *et al*., 2015). Recent studies have reported that gut dysbiosis - an imbalance of intestinal microflora - is associated with certain neurological diseases (Daulatzai, 2013), mental illness (Rogers *et al*.,

2016) and aggression (Martínez-González & Andreo-Martínez, 2019) in humans, and with aggression in dogs (Mondo *et al.*, 2020).

Although animal nutritionists and researchers have reported for years on both the importance of fiber in animal diets (Crissey & Pribyl, 1997; Edwards & Ullrey, 1999; Ullrey *et al.,* 1991) and the nutrient differences between commercially propagated fruit and forest fruit (Schwitzer *et al*., 2009), primate diets have prominently featured commercial fruit. Appropriately feeding captive primates while actively managing them may appear counterintuitive, primarily due to the instinctually high value of "sweet" foods. All primates studied to date have the same five taste sensations; for all, "sweet" indicates a source of carbohydrates and ready energy (Bachmanov & Beauchamp, 2007). For this reason, primates are hyper-stimulated by "sweet" tastes; it is not surprising that animal managers have utilized this proclivity to their advantage to promote everything from food intake to the forging of human-animal bonds. The majority of primates are characterized as frugivores, though this includes some important distinctions, which have historically been under-appreciated. All primates, including frugivores, eat a variety of foods (Schwitzer *et al*., 2009); further, fruit consumption is seasonal and subject to competition (Conklin-Brittain *et al.,* 1998; Worman & Chapman, 2005), limiting natural intake. Additionally, forest fruits are generally low in sugar and high in fiber (O'Brien *et al*., 1998), as compared with commercial cultivated fruit.

While these concepts appear logical when presented as above, modifying animal diets by reducing commercial fruit is challenging. Keeper staff have been taught throughout their careers that (high sugar) commercially propagated fruit is a "healthy" food option. To achieve success in reducing the sugar content of our primate diets it was essential to educate our staff and change the human behaviors associated with feeding animals. Although it is the animals that are experiencing this dietary change, the implementation is a product of altering keeper behavior, and it is the caretakers who need support and guidance throughout the process.

The Transtheoretical Model (TTM) for change was used to guide the progression of the Zoo's dietary modifications. The TTM has been used successfully for years to modify human health behaviors (Prochaska & Velicer, 1997; Woods *et al*., 2002; Prochaska *et al.*, 2008; Prochaska *et al.,* 2013; Koo *et al.,* 2017)**.** TTM was used to help nutrition staff provide context for keeper experiences and to provide a five-stage path using tools and a proven methodology for making this transition.

Materials & Methods

To set targets for the revised diets, the natural feeding history and digestive morphology of each species were considered and a dietary goal established. In general, for species known to include more forest fruit in their diets, moderate-sugar produce items were included (less than 8.5% total sugar), with a dietary ratio of 3:1 sugar-to- fiber. For species known to depend more on leaves and other herbaceous plant parts, only low-sugar produce items were allowed (less than 5% total sugar), with a dietary sugar-to-fiber ratio of 1:2. For animals known to rely primarily on insects and gums (pygmy loris and pygmy marmoset), produce was removed from the daily diet entirely and used for managerial purposes (e.g., training) only. All diets meet 2003 NRC Nonhuman Primate recommendations for protein and micronutrients (NRC, 2003).

Stage 1: Precontemplation
In this stage, the animal caretaker is not aware of the issue. They may see aggression within animal groups or know that the animal has a medical condition such as diabetes or cardiovascular disease, but they have not yet connected those issues to diet. This was the starting point.

Stage 2: Contemplation -- Initiated February 2015
In this stage, the idea of diet playing a role in animal group dynamics or animal health has been introduced and the caretaker is beginning to appreciate these relationships. It is at this stage that education is critical. To help keepers understand the connections, in-person training sessions, discussing primate digestive morphology, the role of glucose in cellular energy production, composition of forest fruits, feeding-related natural history, and captive management issues were held. Clear messaging was used to ensure keepers understood the reasons for the modifications and the end goals.

Stage 3: Preparation -- Initiated March 2015
In this stage, the nutritionist met with each group of primate keepers (two groups responsible for primates housed in four buildings), answered questions and talked through concerns and strategies to handle those concerns. The reasons for the dietary modifications were reiterated and fluid plans for working through issues that might arise were discussed. Self-efficacy (the belief an individual can make a change) is critical to the success of any human behavioral change. Listening to keepers and providing stepping stones were key to the success of this diet modification. Additionally, keeper tools were developed to aid in the transition. A portion of one of these tools, the sugar-to-fiber ratio chart, is included as Figure 1. This chart allows food exchange options for keepers and provides additional information and guidance to assist with food selection to address individual animal palatability issues.

Stage 4: Action-- Initiated April 2015
In this stage, the actual diet modifications were introduced. To promote success, the transition from high-sugar fruit to moderate and low sugar produce was implemented gradually. The nutritionist worked first with the team most ready to make the dietary modifications to help promote success and navigate managerial issues. The transition was planned to extend over a six-month period; in reality, the initial transition took less than six weeks, and the keepers were amazed at the ease with which the animals adapted to their new diets. An allotment of management food (high-sugar fruit greater than 9% total sugar) was allocated in each animal diet. Management foods were included to assist keepers with the transition and allow normal animal management, allaying keeper concerns. The inclusion of the management food allotment provided the keeper self-efficacy needed. Once the first team was successful, the second primate team engaged.

Stage 5: Maintenance -- Ongoing
The fifth stage of the model is *maintenance*; at this point, the changes have been implemented and the human behavior and animal feeding practices are sustained. This stage is ongoing; as we learn more and advance in our animal care, our concept of "maintenance" may need to be modified.

Progress in diet transition and maintenance was tracked through the nutrition office. Diet modifications were issued when keepers believed individual animals had adapted to interim diet changes; as previously noted, this took less time than had been expected. Individual areas were (initially) allowed to progress at a rate and to the extent the keeper was comfortable with. As the

confidence of the keeper improved, further modifications towards the end goal were made. Ongoing information sharing with keepers was critical in the transition: journal articles, videos depicting natural feeding behaviors, and food were provided, and impromptu discussions continued.

Issues and resolution

Keeper concerns were the most important hurdles to overcome; specifically, welfare concerns regarding animals no longer receiving prized foods and the anticipated negative impact on behavioral animal management. Progressing at a keeper-driven pace, and allowing different groups of animals managed by different keepers to progress independently of each other was an extremely effective strategy. Issues were resolved at the individual keeper level, with modifications focused to address specific animals and needs.

Progress Documentation

To document the effects of the described diet modifications on individual animals, several evidence-based projects were initiated. Although many of these are ongoing, a brief overview follows:

- *2018 Gorilla Microbiome Study*: This was a 10-month longitudinal study tracking the impact of browse intake on gut bacterial communities. This project was initiated nearly 3 years after the initial diet modifications were instituted, with the objective to ascertain the influence of browse on the gut microbiome. Results of this study will be published.

- *Beginning in 2017: Dental Documentation*: A log was started in 2017 to document dental health in primates at the Philadelphia Zoo. Animal teeth are photographed as opportunities present themselves (e.g., during physicals or other veterinary procedures), entered into a log with veterinary characterization of the teeth and oral health. This is an ongoing project. Bioinformatic tools will be used to evaluate data at 5-year intervals.

- *Beginning in 2020: Primate Quarantine Study*: All primates entering the collection are quarantined according to Philadelphia Zoo Preventative Medicine: *Primates*. During quarantine, animals are transitioned from their arriving diet to the Philadelphia Zoo (PZ) diet, typically over a 14- day period. Improvement in skin/coat and fecal scores have been noted for some individuals in our records, but a more systematic approach for documenting any changes was deemed necessary. In 2020, a study was initiated between the Zoo's Veterinary & Nutrition Departments in collaboration with Dr. Clayton at the University of Nebraska, to track primate gut flora through quarantine and extending through the first six months of the animal's residence at PZ. This study will contribute to the growing body of data on gut bacteria in zoo primates and may eventually provide a meaningful method to evaluate animal diets.

Outcomes to Date

Weight Management

The most significant outcome of diet modification to date is weight management. The boxplot provided through Species360's Zoological Information Management Software (ZIMS) is used to assess animal weight over time, and condition scores are generated at animal physicals. The Director of Nutrition and the attending veterinarian score animals independently of each other and

then compare. A consensus score is recorded in ZIMS. Although some outlier over-conditioned animals remain, a significant improvement in weight management of individual animals within groups is apparent.

Fecal Score

Fecal score improvements are noted across the collection but are most noteworthy in callitrichids. In 2020, three animals arriving with loose/watery feces (score 1-2 out of 5, with 5 indicating "normal" or desired form and consistency) all achieved normal scores (consistently scored 4 or 5/5) by the conclusion of quarantine and most achieved normal stool scores by the completion of the diet transition period (typically 14-days). Fecal scores are recorded in ZIMS to aid in longitudinal tracking.

Skin and Coat Condition

Improvement in skin and coat condition has been anecdotally noted across the collection with documented improvement to the point of resolution in a callitrichid which arrived into quarantine with a prominent bald tail patch. Dysbiosis has been associated with skin disease in humans, including inflammatory diseases such as atopic dermatitis, psoriasis, and rosacea (Mann *et al*., 2020). The previously described quarantine microbiome study may help identify gut bacteria associated with skin and coat issues in some primate species.

Training Compliance

The removal of high-sugar produce from the daily diets has allowed these items to be used to establish desired behaviors. This aspect of the diet modification was anticipated, but has only recently been fully realized. The use of high value foods for training is not unusual; however, the removal of fruit over 9% total sugar from daily diets has allowed these items to rise to the level of high value and eliminating other more inappropriate "training" foods.

Next Steps

The described diet modifications have resulted in improvement in animal condition and welfare. Planned next steps include implementation of seasonally shifting diets that reflect the feeding cycles of each species. The PZ browse program, which gears up in May and phases out in October, provides a natural cycle that works for a northern zoo.

As an early example for our gorillas over the past two winters (Nov – March 2019-2020 & 2020-2021) an enrichment forage mix consisting of seeds, Goji berries, coconut chips, dried red peppers, and figs has been phased in. The mix is blended with alfalfa hay and bedding starting at the end of the browse season and phased out at the beginning of the next browse season. During this time the forage mix is gradually increased to a plateau held for 3 - 4 weeks and then quickly phased out, the plateau intended to mimic a forest mast. The described mix has a 1.5:1 sugar-to-fiber ratio.

This program was implemented as a trial. Keepers reported an increase in foraging time overall and longer foraging bouts. We had concerns that animal weights would spike upward during the forage food plateau, but this was not the case. The current sugar-to-fiber ratio in our gorilla winter diets is ~1:4 (alfalfa hay contributes ~ 60% of calculated kcal in the diet). The high fiber intake may offset the seasonal increase in dietary sugar provided by the enrichment forage. This simple trial proved very effective and well worth the time and expense of implementation. Based on the

success of this trial species appropriate seasonal plans will be developed and implemented throughout the PZ primate collection.

Discussion

Although formal use of the TTM for diet modification is novel in the zoological community, this model is well-established in the human medical community and used as a guide to modify human health behavior to achieve improved health outcomes. Using an established model for change created a framework around this change, provided guidance for progression, and resulted in positive interpersonal outcomes that made the keepers and nutrition department allies, rather than adversaries. Hurdles and concerns were identified and resolved cooperatively. Information was shared freely and the concerns of the keepers were respected and addressed throughout the process which has resulted in a general increase in cooperative engagement of keepers with nutrition staff.

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Figure 1. Excerpt from sugar to fiber ratio chart.

As Fed Sample	Source	Kcal/g	T. Sugar	T. Dietary Fiber	Sugar:Fiber
High Sugar Produce> 9%			%	%	Ratio
Grapes (red or green)	NDB #09132	1	15.5%	0.9%	15:1
Mango	NDB#09176	0.5	13.7%	1.6%	8.5:1
Bananas	NDB #09040	1	12.2%	2.6%	4.7:1
Blackberries	FDC ID# 872104	0.64	10.7%	5.0%	2.14:1
Apples	NDB #09003	0.5	10.4%	2.4%	4.3:1
Pears	NDB #09252	0.5	9.8%	3.1%	3.2:1
Starch Estimate > 3% *Dietary items may be exchanged outside this category; however, outside items cannot be exchanged for items within the SE category.*					
Leeks (8.4%)	NDB #11246	0.61	3.9%	1.8%	2.2:1
Potatoes, white (12.16%)	NDB #11354	1	1.2%	2.4%	0.48:1
Sweet Corn (bagged) (13.1%)	NDB #11900	1	3.2%	2.7%	1.2:1
Yam (23.28%)	NDB #11601	1	0.5%	4.1%	0.12:1
Canned Pumpkin	NBD#11424	0.34	3.3%	2.9%	1.1:1
Canned Butternut Squash	Label FM	0.39	2.0%	3.0%	0.5:1
Moderate Sugar Produce 6 - 8.5%					
Blueberries	NDB #09054	0.3	8.5%	2.7%	3.1:1
Yellow Peaches	NDB#09236	0.5	8.4%	1.5%	5.6:1
Feijoa	NDB#09334	1	8.2%	6.4%	1.2:1
Mulberries	NDB#09190	0.5	8.1%	1.7%	5:1
Honeydew Melon	NBD#09184	0.5	8.1%	0.8%	10.2:1
Papaya	NBD #09226	0.5	7.8%	1.7%	4.6:1
Grapefruit	NDB #09116	0.5	7.3%	1.1%	6.7:1
Blueberry Juice	Manf.	0.37	7.1%	0.0%	7.1:1
Beets	NDB #11080	0.5	6.8%	2.8%	2.4:1
Water Melon	NBD #09326	0.25	6.2%	0.4%	15.5:1
As Fed Sample	**Source**	**Kcal/g**	**T. Sugar**	**T. Dietary Fiber**	**Sugar:Fiber**
Low Sugar Produce <5% sugar	FOODS BELOW THIS LEVEL ARE FREE AND CAN BE OFFERED IN ADDTION TO THE DIET AT A RATE OF 2 GRAMS/KG BODY WEIGHT				
Carrots	NDB #11124	0.5	4.7%	2.8%	1.7:1
Rutabaga	NDB#11435	0.3	4.5%	3.2%	1.4:1
Raspberries	NDB#09302	0.5	4.4%	6.5%	0.67:1
Strawberries	NDB #11123	0.36	4.3%	2.1%	2:1
Red Peppers	NBD#11821	0.3	4.2%	2.1%	2:1
Carambola (Starfruit)	NBD#09060	0.5	4.0%	2.8%	1.4:1
Summer Squash Scallop	NDB# 11475	0.2	2.4%	1.2%	2:1
Brussels Sprouts	NDB #11098	0.5	2.2%	3.8%	0.58:1
As Fed Sample	**Source**	**Kcal/g**	**T. Sugar**	**T. Dietary Fiber**	**Sugar:Fiber**
Greens					
Kale	NDB #11233	0.5	2.3%	3.6%	0.63:1
Lettuce (iceberg)	NDB #11252	0.15	2.0%	1.2%	1.6:1
Mustard Greens	NDB11270	0.25	1.3%	3.2%	0.41:1
Lettuce (cos or romaine)	NDB #11251	0.15	1.2%	2.1%	0.57:1
Swiss Chard	NDB#11147	0.2	1.1%	1.6%	0.68:1

Items can be used for managerial purposes only.

Items may not be exchanged into the diet. Exchanges

Items with a S:F ratio above 5:1 cannot be used in the daily diet but can be exchanged in 1 X/week or used for managerial purposes.

https://ndb.nal.usda.gov/ndb/foods