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Comparison of the Cariogenicity of Cola, Honey, Cow Milk, Human Milk, and Sucrose

William H. Bowen, BDS, PhD*, and Ruth A. Lawrence, MD‡

ABSTRACT. *Objective.* **The purpose of this study was to determine and compare the cariogenicity of various fluids that are frequently fed to infants and toddlers. We chose to examine sucrose, cola drink, honey, human milk, cow milk, and water because some of these have been associated with development of early childhood caries, although direct experimental evidence is lacking.**

Methods. **We used our desalivated rat model because the approach mimics the situation found in infants, whereby the flow of saliva is interrupted through mechanical effects of a nipple. The animals received basic nutrition by gavage, and the fluids being tested were available ad libitum. Thus, the only substances that came in contact with teeth were the test fluids. The investigation continued for 14 days.**

Results. **Cola, sucrose, and honey were by far the most cariogenic. In addition, cola and honey induced considerable erosion. Human milk was significantly more cariogenic than cow milk probably because of its lower mineral content and higher level of lactose.**

Conclusions. **Our data show that the use of honey, cola, and sucrose water in nursing bottles should be discouraged. Although human milk is more cariogenic than cow milk, it is no more cariogenic than are common infant formulas. Protracted exposure to human milk or formula through allowing an infant to sleep on the nipple should be discouraged, and the need for oral hygiene after tooth eruption should be emphasized.** ***Pediatrics*** **2005;116:921–926;** ***dental caries, infants, toddlers, drinking fluids.***

ABBREVIATION. ECC, early childhood caries.

Despite enhanced awareness among professionals and the public, early childhood caries (ECC) continues to plague a significant proportion of the population. In ECC, cavities and overt demineralization occur extensively on free smooth surfaces of the primary teeth. The condition is frequently first observed by a pediatrician. This disease is costly to treat and may be a harbinger of caries in permanent dentitions. Those mostly affected are usually economically and socially deprived and carry additional burdens of ill health.[1–4] Children who display ECC frequently have a heavy infection of *Streptococcus mutans*[5] and in addition have been subjected to inappropriate feeding practices.[6,7] These may include placing sugared water, cola-type beverages, or honey in a nursing bottle that is left undisturbed in the infant's mouth for hours.[8] The adverse effect of these fluids is enhanced by the mechanical effects of the nipple or teat, which effectively restricts access by saliva to many tooth surfaces.[9,10]

Cow milk in a nursing bottle is often assumed incorrectly to be a primary causative agent in the induction of ECC.[11,12] Available experimental evidence in vivo and in vitro shows very clearly that cow milk has negligible cariogenicity.[9,13–15]

The cariogenicity of human milk is also the subject of some controversy. Several case reports seem to suggest that protracted breastfeeding, eg, allowing an infant to sleep for many hours while feeding, leads to enhanced levels of caries in some infants. Unfortunately, as with the studies on cow milk, information on the remainder of the child's diet is lacking.[16,17] Furthermore, the cariogenic potential of human milk seems not to have been explored experimentally[13] extensively in vivo.

Honey is occasionally recommended as an alternative sweetener for sucrose in the belief that it is either noncariogenic or less cariogenic than is sucrose.[18] Direct studies to explore the cariogenic potential of honey are also sparse.

On the basis of consumption data and anecdotally, cola-type beverages are being consumed in increasing quantities and are not infrequently placed in nursing bottles to "pacify" infants.[19] The composition of these beverages (high sugar and low pH) suggest that they are probably highly cariogenic, although direct experimental evidence is also lacking.

The purpose of the present study was to explore and compare the cariogenicity of various fluids that are frequently fed to infants in nursing bottles using our well-defined rodent model. Such information could aid in formulating clinical advice on the basis of experimental data and possibly help to reduce the scourge of ECC.

METHODS

Animals

Eight litters of 10 pups each, with their dams, were purchased from Harlan (Indianapolis, IN). The dams were screened for sialodacryoadenitis virus and mutans streptococci using our previously described methods[14]; neither agent was detected. The dams and pups were infected with *S mutans UA 159* and together with

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the litter fed laboratory chow (Purina, Gray Summit, MO) and 10% sucrose water to enhance establishment of infection.

The pups were weaned when aged 21 days and were infected by mouth on 2 successive days with an actively growing culture of *S mutans UA159*, which is resistant to streptomycin. This isolate had been passaged through rats and found to be virulent in animals that were fed diet 2000. In an attempt to mimic the situation in infants who suck on breast or the nipple of the bottle, which physically obstructs salivary flow around the mouth, we desalivated the pups at age 23 days surgically using our previously described methods.[20] After surgery, the animals were divided into 6 groups of 12 and paired in suspended screen-bottomed cages.

The animals received their essential nutrition by gavage. Each animal received 2 to 3 mL of liquid diet NCP #2 once daily.[21] In addition, each group received 1 of the following fluids by mouth ad libitum (each pair of animals ingested ~50 mL daily): (1) human milk (pH 6.7), (2) cow milk (2% fat; pH 6.8), (3) cola drink that contained sucrose (~10%; pH ~4.0), (4) honey (10% wt/vol solution; 7%–8% sugars; pH 4.1), (5) 10% (wt/vol) sucrose, and (6) sterile distilled water. Thus, the drinking fluids were the only substances that came in contact with the teeth, and lesions that developed could be ascribed to exposure to the test fluids; cariogenicity of the fluids therefore could be compared.

The human milk was primarily from a single normal healthy donor with a small amount from an additional donor. The milk was collected over several months, frozen, and stored until just before use, at which point the various collections were pooled. Thus, the effects of any daily variations in composition were obviated. It was gently sonicated to disperse fat globules.

Cow milk (2% fat), cola drink, and honey all were purchased from a local supermarket. A solution of honey 10% (wt/vol) was prepared using sterile distilled water; this resulted in a solution that contained 7% to 8% sugars.

Plating of oral swabs revealed that all animals were infected successfully by the labeled strain of *S mutans*. The study continued for 14 days, at which time the animals were killed by CO_2 asphyxiation followed by decapitation. Heads were defleshed, and caries was scored by using Larsen's modification of Keys[22] method.

Statistical Analysis

The total number of smooth surface and sulcal surface lesions and their severity were assessed separately. The data were transformed to stabilize variances; the smooth-surface and the sulcal-surface scores were expressed as proportions of the maximum possible values of 125 and 56, respectively. All of the data were subjected to analysis of variance and the Tukey-Kramer Honestly Significant Difference Test for Pairs using software for statistical visualization (JMP Version 2; SAS Institute Inc, Cary, NC).

RESULTS

All of the animals were infected successfully by *S mutans*. The experiment continued for 14 days, and all animals survived the duration of the investigation. As we have reported previously, there were significant differences in the weight gains among the groups, which is hardly surprising given the nutritional disparity among the fluids offered.[9] Most weight was gained by the group that was fed cow milk and least in the control group that was offered sterile distilled water.

The test fluids were the only substances that came in contact with the animals; hence, any carious lesions that developed may be ascribed to the substances the animals consumed.[21] There are large differences in the caries scores among the groups (Table 1). The highest smooth-surface caries scores were observed in the animals that were given the cola beverage, 10% sucrose, or 10% honey (Figs 1–3). These were significantly different from each other and from all other groups. In addition to extensive carious lesions on the smooth surface, considerable erosion was observed in the animals that were fed cola beverage and honey solution. Animals that were fed human milk developed significantly more smooth-surface lesions (Fig 4) than did those that were given cow milk (Fig 5).

Most sulcal surface caries was also observed in the cola, sucrose, and honey groups. The extent of the lesions was also particularly severe in the groups. A small number of sulcal-surface lesions were observed in the human milk group, and these were of negligible severity and did not differ statistically from the negative control sterile distilled water (Fig 6). It may be surprising to note any lesions recorded in the sterile distilled water group as all nutrition was fed by gavage. Rats' teeth erupt hypomineralized and usually become mineralized in a few days in the presence of saliva.[22,23] In the course of evaluation, all teeth are sectioned and stained to reveal hypomineralized and demineralized areas. As the evaluation is carried by an examiner who is unaware of groups, all stained areas are included as carious lesions.

DISCUSSION

The model used in this study offers 1 of the most intense carious challenges available while at the same time mimicking the situation that prevails in infants and toddlers who are allowed to indulge in protracted feeding. The devastation of the dentition in the cola-fed animals is hardly surprising in light of the widely held view that persistent use of cola-type drinks has adverse effects on dental health.[19] Clearly, the combination of sucrose and low pH exerts a heavy toll on enamel in terms of both erosion and carious lesions. The erosive action of these drinks when consumed directly from the bottle, however, seems not to have received the attention that it deserves.

TABLE 1. Caries Scores in Rats That Were Offered Various Beverages

	Cola	Sucrose (10%)	Honey (10%)	Human Milk	Cow's Milk	Sterile Distilled Water
Smooth surface caries (SD)	88.7 (3.7)	77.0 (7.3)	68.4 (9.8)	25.9 (16.7)	4.0 (3.7)	4.8 (3.8)
DS	63.7 (11.9)	62.1 (10.1)	41.5 (12.6)	1.1 (1.6)	0.7 (1.4)	0.2 (0.6)
DM	35.6 (15.6)	13.2 (9.9)	4.0 (4.0)	0.1 (0.3)	0.0	0.0
Sulcal surface caries (SD)	45.0 (3.2)	35.8 (2.7)	39.2 (4.7)	30.0 (6.7)	22.9 (3.6)	24.0 (5.2)
DS	17.6 (4.3)	13.3 (3.3)	15.3 (2.1)	7.0 (4.2)	3.6 (2.8)	1.0 (1.5)
DM	8.8 (5.5)	3.8 (2.4)	5.1 (2.2)	1.8 (1.8)	0.8 (1.0)	0.1 (0.3)

$N = 12$ per group. DS indicates lesion has extended slightly into dentine; DM, dentine is exposed. Values joined by underlining are not significantly different from each other. $P < .01$–$.05$.

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Fig 1. Teeth from a rat that was fed cola drink.

Fig 2. Carious teeth from a rat that was fed honey.

Fig 3. Teeth from a rat that was fed sucrose water.

Honey has been promoted as being good for dental health, although the evidence to support it is sparse indeed.[18] Our data are not consistent with that view and are certainly consistent with epidemiologic and in vitro data that support the concept that honey is indeed highly cariogenic.[24] Our results are hardly surprising because the major ingredients of honey are glucose 30% and fructose 38% and a small amount of sucrose. It was surprising to observe extensive erosion in addition to extensive cavitation in the animals that were fed honey; however, the average pH value of honey is 3.9 (range: 3.4–6.1). Gluconic is the major acid found in honey; acetic, lactic, butyric, and formic are also present, all of which could contribute to the erosive properties of honey.[25] Clearly, on the basis of the data presented

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Fig 4. Teeth from a rat that was fed human milk.

Fig 5. Teeth from a rat that was fed cow milk.

Fig 6. Teeth from a control rat that was given distilled water.

here, honey can be highly cariogenic and certainly cannot be recommended for use in infant feeding.

Our observations confirm and extend our previous results that showed very clearly that cow milk is essentially noncariogenic.[14,15] Milk has in the past been termed erroneously cariogenic,[11,12] in the ab-

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sence of direct evidence, because a distinction has not been drawn between use of a bottle or nipple per se and the content of the feeding bottle. The protracted presence of a teat or nipple in the mouth will obstruct the flow of saliva and result in promoting the cariogenic potential of the nonfluid part of the infant's diet. If the bottle contains a caries-promoting substrate, then clearly the potential for damage is greatly enhanced.

A systematic review of epidemiologic evidence suggests that breastfeeding for longer than 1 year and at night may be associated with increased prevalence of dental decay.[17] Results from other investigations show that there is no relationship between prevalence of caries and breastfeeding.[26] Our data reveal that human milk promotes development of smooth-surface caries and is significantly more cariogenic than is cow milk. The severity of lesions was significantly less than that observed in the honey, sucrose, or cola group. Significant differences in the caries scores of sulcal surfaces of the cow milk group and human milk were not detected.

There are several possibilities that may explain why human milk might be more cariogenic than cow milk. Human milk contains ~7% lactose compared with 5% in cow milk. In previous studies, we showed that aqueous solutions of lactose are modestly cariogenic in our model; clearly when present in cow milk, the additional constituents overcome the harmful effects of lactose.[14] Human milk differs in composition from cow milk in several important ways; for example, cow milk contains significantly more calcium (114 vs 22.0 mg) and phosphorus (96 vs 9.8 mg/100 g).[27,28] Our data are consistent with published observations of Thomson et al[13] and Rugg-Gunn et al,[29] who noted that incubation of saliva with human milk resulted in a greater decline in pH value than when cow milk was used as substrate. Furthermore, exposure of enamel covered by dental plaque to human milk led to enhanced demineralization compared with that observed with cow milk. Addition of Ca^2 and PO_4 to human milk prevented the demineralization to some degree. Raising the lactose concentration in cow milk to 7% did not enhance its ability to demineralize plaque-covered enamel. It seems, therefore, that the difference in the cariogenicity of the milk resides for the most part in the mineral content. Clearly, other factors such as casein content cannot be discounted.

By including a sucrose control in our study and giving the smooth-surface caries score in the sucrose group an arbitrary value of 1, we can compare the relative cariogenicity of the various fluids using this approach. The relative cariogenicity is as follows: sucrose, 1; cola, 1.16; honey, 0.88, human milk, 0.29; and cow milk, 0.01). Our data confirm our previously published data showing the relative low cariogenicity of cow milk. Furthermore, they show that human milk is no more cariogenic than many commonly used commercial infant formulas.[9]

There are many health benefits for promoting breastfeeding in infants; nevertheless, nursing mothers should be alerted to the need of oral hygiene in the infant after feeding. Switching from breastfeeding to cow milk is not being advocated here.

CONCLUSIONS

Our data show that cola and honey are highly caries promoting and erosive, and their use in nursing bottles should be actively discouraged. Human milk clearly has some potential to promote caries development, and the need to implement oral hygiene after tooth eruption at least should be emphasized. Prevention of early childhood caries is essential to help to ensure a healthy permanent dentition.

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