Effect of Caffeinated Soft Drinks on Salivary Flow

Gary H. Hildebrandt,¹ Daranee Tantbirojn,^{2,*} David G. Augustson,³ and Hongfei Guo⁴

Background: Soft drinks containing caffeine have been associated with more aggressive forms of dental decay. Cariogenicity of caffeinated soft drinks may be attributed to the effect of caffeine on salivary flow. This study assessed whether caffeinated soft drinks produced short-term oral dryness in healthy adults.

Methods: The authors collected saliva on two separate days from 35 participants before and one hour after drinking a soft drink. On one of the days the soft drink was caffeinated and on the other day it was not. Saliva collection involved 15 minutes unstimulated whole saliva, 5 minutes paraffin-stimulated whole saliva, and 10 seconds labial minor salivary gland output.

Results: Unstimulated and stimulated flow rates slightly increased and minor gland output slightly decreased one hour after the soft drink consumption regardless of caffeine content. These changes were not statistically significant (two-period two-treatment crossover trial using two-stage Grizzle model, $p > 0.05$). A linear mixed model statistic did not show the caffeine effect on salivary flow rate.

Conclusions: Caffeinated soft drink consumption had no significant effect on salivary flow rate after one hour by any of the three measures employed in this study. Caffeine's contribution to the cariogenicity of soft drinks is likely by centrally-mediated effects on consumption patterns.

Introduction

FREQUENT EXPOSURE to fermentable carbohydrates has been recognized as the hallmark of a cariogenic diet.¹ In particular, regular consumption of sweetened soft drinks has been associated with an increase rate of dental caries.² Less described in the literature has been the association between the more aggressive forms of dental caries and regular consumption of caffeinated soft drinks. Caffeine-free soft drinks appear to be less frequently associated with aggressive forms of decay.³ One possible explanation for this association might be that the caffeine tends to promote patterns of consumption that are deleterious to dental health—more frequent, more prolonged, and perpetual. One mechanism by which caffeine could support these changes in diet is through its effect on salivary flow.

Sufficient salivary flow is necessary to maintain oral health and integrity of the dentition. Saliva acts as a lubricant, washes away residue, contains various host defense systems, and helps maintains dental mineral integrity. Hyposalivation is therefore associated with an increased risk of oral diseases, including dental caries.⁴ Additionally, a diminished salivary flow is associated with the adoption of deleterious dietary habits, such as sucking on hard can-

dies or using sweetened beverages to combat the sensation of oral dryness.⁵

Caffeine is a central nervous system stimulant with diuretic properties. Caffeine may reduce salivary flow by direct effects upon the salivary glands, through effects on the autonomic nervous system, or through diuresis and dehydration.⁶ Studies reported an increase in urine production after ingestion of caffeine equivalent to 3–6 cups of coffee.^{7,8} However, others found no effect of caffeine in standard serving sizes on hydration status.^{9,10}

The primary constituent of saliva is water. Degree of hydration is potentially the most important factor influencing salivary flow.¹¹ Dehydration or even hypohydration can cause decreased salivary flow.¹² Although negative fluid balance has not been evident when caffeinated beverages are consumed in moderation,¹³ whether or not oral dryness is a consequence of caffeine consumption has not yet been reported.

Children and adolescents who consume large amounts of carbonated soft drinks have high caries experience.^{2,14,15} The presence of fermentable carbohydrates in the beverage no doubt plays a major role in early initiation and rapid progression of dental caries. What is often overlooked is that over 60% of soft drinks sold in the United States contain caffeine as

¹Division of Operative Dentistry, Department of Restorative Sciences, School of Dentistry, University of Minnesota, Minneapolis, Minnesota.

²Department of Restorative Sciences, School of Dentistry, University of Minnesota, Minneapolis, Minnesota.

³School of Dentistry, University of Minnesota, Minneapolis, Minnesota.

⁴Division of Biostatistics and Clinical and Translational Science Institute, University of Minnesota, Minneapolis, Minnesota.

*Current affiliation: Department of Restorative Dentistry, College of Dentistry, University of Tennessee Health Science Center, Memphis, Tennessee.

a flavor additive.¹⁶ The combination of sugar and caffeine may encourage frequent and perpetual patterns of consumption, leading to early initiation and rapid progression of dental caries.¹⁵ Patients with rampant caries are frequently seen at the University of Minnesota School of Dentistry dental clinics (See Fig. 1). A common finding with these patients is the regular consumption of soda pop containing fermentable carbohydrates and caffeine.

The aim of the study was to examine the effect of caffeinated soft drinks on oral dryness. The hypothesis is that caffeinated soft drinks will lead to oral dryness by decreasing salivary flow, as compared to soft drinks without caffeine.

Materials and Methods

The University of Minnesota Institutional Review Board approved the conduct of this clinical study (IRB# 1005M81575).

Subject recruitment

Sample size was determined using the following mean and standard deviation flow rates: 0.3 ± 0.2 mL/min for unstimulated whole saliva, 3.0 ± 1.4 μ L/cm²·min for labial minor salivary gland secretion, and 2.2 ± 1.1 mL/min for stimulated whole saliva.¹⁷ Using $\alpha=0.05$, 34 participants per group would give 80% power to detect a 25% difference between baseline and post-caffeine stimulated and labial minor salivary gland flow rates and a 33% difference between baseline and post-caffeine unstimulated salivary flow rates.

We recruited 38 healthy adults of both genders, ages 19–63. The participants did not take stimulant-containing medications and did not have oral removable appliances. We asked the participants to abstain from caffeinated food or drink starting the night before and the morning of their appointment. Written informed consent was secured from, and demographic data recorded on, each participant.

Study protocol

The saliva collection took place at the same time for each participant on two separate mornings. After baseline saliva

collection, subjects consumed 355 mL (12 oz) of either caffeinated drink (Mountain Dew; PepsiCo) or caffeine-free drink (Caffeine-Free Mountain Dew; PepsiCo) on the first day of the study, followed by the alternate version on the second day. The order was randomly determined by a coin flip during the first appointment. The soft drinks were poured into unmarked plastic cups so that the subjects were blinded to the caffeine content. Subjects consumed the soft drinks within a 30-minute period, and were asked to refrain from eating, drinking, brushing, or chewing gum until after the second saliva collection was performed one hour later.

Saliva collection

Salivary flow rates were measured in this sequence: unstimulated whole saliva, minor salivary gland secretion, and stimulated whole saliva.

Unstimulated whole saliva. After swallowing to clear the mouth, participants sat quietly and expectorated any saliva that collected in the mouth into a preweighed paper cup for 15 minutes. To ensure natural salivary flow, participants were instructed not to think of food, talk, or chew. The weight (g) of the collected saliva was measured and the volume (mL) inferred, assuming salivary density of 1 g/mL.

Minor labial salivary secretion. Secretion from labial minor salivary glands was estimated using a Periotron (Model 8000; Oraflow, Inc.).¹⁸ The participant's lower lip was gently extended and dried with a gauze square, then a SialoPaper strip (Oraflow, Inc.) was placed on the midline of the labial mucosa for 10 seconds and moisture content estimated with the Periotron. Three consecutive measurements were recorded and averaged. The Periotron output was calibrated with known volumes of deionized water using a linear regression technique.

Stimulated whole saliva. After swallowing to clear the mouth, subjects chewed a 5-cm square of Parafilm (American National Can) and expectorated any saliva that developed into a preweighed paper cup for 5 minutes. The weight (g) of the collected saliva was measured and the volume (mL) inferred.

Statistical analysis

The effect of caffeinated soft drink on unstimulated, stimulated, and minor gland saliva production was analyzed using the two-stage Grizzle model for the two-period two-treatment crossover trial.^{19,20} First, the data were tested for the presence of a carry-over effect according to the sequence of consumption, that is, caffeine or caffeine-free on the first day. Then the caffeine effect was estimated using a linear mixed model. Caffeine effect refers to the difference between the average change in flow rate after caffeinated soft drink and the average change in flow rate after caffeine-free soft drink.

Results

Of the 38 subjects enrolled in the study, 3 did not return for the second appointment due to scheduling conflicts. Only 35

FIG. 1. Rampant caries in a patient who regularly consumed Mountain Dew. Cervical areas of all the teeth had bands of demineralization wrapped around the gingival area, with cavitated lesions and recurrent caries lesions present.

TABLE 1. DEMOGRAPHICS AND SEQUENCE OF SOFT DRINK CONSUMPTION OF STUDY PARTICIPANTS ($n=35$)

Age (mean $\pm$ SD)	27.7 $\pm$ 10.6
Gender (N, percentage)	
Male	18 (51%)
Female	17 (49%)
Ethnicity (N, percentage)	
African American	8 (23%)
Asian	9 (26%)
Hispanic	1 (3%)
White	17 (48%)
Sequence of soft drink consumption (N, percentage)	
Caffeine on first day	16 (46%)
Caffeine-free on first day	19 (54%)

completed the study. Table 1 reports demographic and soft drink sequences for the 35 participants.

Table 2 shows the salivary flow rates before and after each soft drink was consumed and the caffeine effects. Both unstimulated and stimulated flow rates slightly increased one hour after soft drink consumption, whereas labial minor salivary gland output slightly decreased regardless of the beverage types. The two-stage Grizzle model indicated no carry-over effect presented in the data. Since there was no carry-over effect, the caffeine effects were estimated using the linear mixed model applied to the salivary flow rates of both days. No significant difference was found between the changes in salivary flow rates after caffeinated or caffeine-free soft drinks (linear mixed model with significance level of 0.05).

Discussion

Caffeine is one of the most widely consumed dietary ingredients in the world. Approximately 80% of the world's population and 90% of adults in North America consume caffeine daily. Main sources of caffeine consumption are coffee (71%), soft drinks (16%), and tea (12%).²¹ These beverages each contain different amounts of caffeine. A standard 8 oz (240 mL) cup of brewed coffee contains 100–200 mg of caffeine, while instant coffee and tea contain ~90 and 50 mg of caffeine, respectively.²¹ Cola and many non-cola soft drinks contain about 40 mg in a 12 oz (355 mL) can. Mountain Dew contains relatively more caffeine (55 mg) than other soft drinks.²²

The alarming increase in dental caries seen in some young adults has caught the interest of the news media and has been named 'Mountain Dew Mouth'.²³ A recent study by Keast *et al.* demonstrated that caffeine suppresses sweetness in soft drinks resulting in the need for extra sugar to achieve an equivalent level of perceived sweetness.²⁴ However, commercial non-caffeinated sodas have a sugar concentration ranging from 3.1–3.6 g/oz, whereas caffeinated sodas range from 3.2–3.9 g/oz.²⁵ This small difference in sugar concentration would not be enough to explain the differences in caries rates seen between regular users of the two types of beverages.

The rapid progress of dental caries among caffeinated soft drink consumers might be a result of habitual consumption due to a physical desire for the caffeine in the beverages.²⁶ Based on the hypothesis that caffeine causes oral dryness leading to further beverage consumption, we investigated whether a caffeinated soft drink could be related to short-term oral dryness as a possible contributing factor in observed aggressive caries patterns.

The results of this study do not support the hypothesis that caffeine leads to oral dryness, as salivary flow rates did not decrease after consuming a caffeinated soft drink compared to a caffeine-free soft drink. Following consumption of a caffeine-containing beverage, peak serum levels of caffeine are attained in 15 minutes to 2 hours.²⁷ It would be expected that one hour after caffeine ingestion caffeine effects, if any, on saliva flow would be detectable. Rather, the flow rates of unstimulated and stimulated whole saliva slightly increased one hour after soft drink consumption regardless of the caffeine content. Minor salivary gland secretion slightly decreased, also regardless of the caffeine content. Any potential diuretic effect of caffeine in the amount consumed in the present study is not reflected in salivary flow rates.

The baseline flow rates measured before caffeinated and caffeine-free soft drink consumption (Table 2) closely resemble the values reported by Rudney *et al.*²⁸ and Eliasson *et al.*,^{17,18} and summarized by Dawes.¹¹ Some variation in the results was natural. Collection of stimulated and unstimulated whole saliva depended to some degree on participant cooperation. However, the participants had no control over their minor gland secretion. Therefore, this method of saliva collection may have been the most objective.

Degree of hydration is a factor that may influence salivary flow. Salivary flow rate decreases during dehydration.^{11,29} However, we found slightly increased flow rates for whole

TABLE 2. CAFFEINE EFFECT AND SALIVARY FLOW RATES BEFORE AND AFTER CAFFEINATED AND CAFFEINE-FREE SOFT DRINK CONSUMPTION ($n=35$)

Salivary flow rate	Caffeinated drink Mean (SD)			Caffeine-free drink Mean (SD)			Caffeine effect	95% CI Caffeine effect	p value
	Before	After	Δ	Before	After	Δ			
UW (mL/min)	0.34 (0.21)	0.45 (0.21)	0.10 (0.14)	0.38 (0.21)	0.42 (0.23)	0.05 (0.13)	-0.06	-0.12, 0.01	0.073
MG (μ L/cm ² ·min)	6.16 (2.20)	5.80 (2.61)	-0.34 (1.59)	6.23 (2.59)	5.61 (1.98)	-0.61 (1.66)	-0.23	-1.02, 0.55	0.55
SW (mL/min)	1.35 (0.63)	1.51 (0.69)	0.16 (0.37)	1.41 (0.66)	1.42 (0.62)	0.01 (0.44)	-0.14	-0.32, 0.04	0.11

UW, Unstimulated whole saliva, MG, Minor gland secretion, SW, Stimulated whole saliva.

Δ = difference in salivary flow rate before and after soft drink consumption. Positive values represent increased salivary flow rate after the consumption, negative values represent decreased salivary flow rate after the consumption.

Caffeine effect, 95% confidence interval (CI), and *p*-value were analyzed using linear mixed model. Caffeine effect is defined as the difference between the average change in flow rate after consuming caffeine-containing soft drink and the average change in flow rate after consuming caffeine-free soft drink.

saliva in both caffeinated and caffeine-free groups one hour after beverage consumption. Although it seems intuitive that caffeine would have a diuretic effect, this decrease may be balanced out by the fluid intake.¹¹ In addition, the high-fructose corn syrup, citric acid, sodium citrate, and flavoring agents of Mountain Dew may have increased the saliva flow rates. Interestingly, we found a slight decrease in the flow rate of the labial minor salivary gland in both caffeinated and caffeine-free soft drinks. Reduced minor labial salivary gland secretions have been reported among individuals with subjective oral dryness.¹⁷ Although it is conceivable that the sensation of "dry mouth" arising from decreased minor salivary gland secretion could drive individuals to consume more soft drink, in the present study the magnitude of the reduction was very small (5%–10%).

A review of the literature identified associations between low saliva flow and dental disease and between low saliva flow and dehydration, but it was not able to find a direct link between dehydration and dental disease.³⁰ Whether or not a state of dehydration can be caused by ingested caffeine has been questioned. A recent review concluded that the caffeine dose in standard servings of coffee or carbonated soft drinks does not have diuretic action.¹⁰ A short-term increase in urine volume was reported with large doses of caffeine intake (250–300 mg, equivalent to 2–3 cups of coffee), but the effect is confounded by higher tolerance in individuals who regularly consume caffeine-containing beverages. Caffeinated beverages consumed in moderation did not cause negative fluid balance, even for athletes and exercising adults.^{13,31} Our study result tends to support the concept that the amount of caffeine in a single carbonated beverage is not high enough to cause a diuretic effect. Recognizing that it is possible that caffeine could affect salivary flow by mechanisms other than diuresis and dehydration, such as by direct effects upon the salivary glands or through effects on the autonomic nervous system,⁶ we were still unable to demonstrate any significant effect of caffeine on saliva gland function.

The physiological effects of caffeine diminish with regular use as tolerance builds up.³² We did ask each study participant whether they considered themselves heavy "caffeine users." Six study participants reported that they were heavy caffeine users, while 26 reported that they were not heavy users. Assuming the self-report is accurate, it would be considered unlikely that the lack of effect of the studied beverage on salivary flow was caused by tolerance to caffeine among the study participants.

Manufacturers justify the addition of caffeine to soft drinks as a flavoring agent. A recent study of the effects of caffeine added to novel-flavored drinks found that, with repeated exposure, the caffeine increased subject preference for the beverages.³³ The results of our study do not support short-term oral dryness caused by caffeine. Therefore, caffeine is unlikely to contribute to cariogenesis via effects on salivary flow. How caffeine in soft drinks affects consumption patterns remains to be demonstrated. We did not evaluate the impact of caffeine consumed on a regular basis. A single dose of caffeine may affect the body differently than caffeine consumed daily, because the response may depend on tolerance level. We did not attempt to record subjective sensations of dry mouth after consumption of caffeinated soft drinks. The sensation of oral dryness, irrespective of actual salivary

parameters, could compel one to consume more of the caffeinated beverages.

Conclusions

Both caffeinated and caffeine-free soft drinks were associated with a slight increase in unstimulated and stimulated salivary flow rates and a slight decrease in the flow rate from labial minor salivary glands, however, these trends were not statistically significant. Any potential diuretic effects of caffeine in the amount found in a single soft drink were not reflected in salivary flow.

Acknowledgments

The project described was supported by Award Number UL1RR033183 from the National Center For Research Resources. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Center for Research Resources or the National Institutes of Health. Additional support was received from the University of Minnesota School of Dentistry Summer Fellowship program and a faculty start-up fund.

Author Disclosure Statement

No competing financial interests exist on behalf of any of the authors.

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Address correspondence to:
Gary H. Hildebrandt, DDS, MS

Director

Division of Operative Dentistry
Department of Restorative Sciences

School of Dentistry

University of Minnesota

515 Delaware St. SE

Minneapolis, MN 55455-0348

E-mail: hilde014@umn.edu