Original Article

Acidic Soft Drinks Effects on the Shear Bond Strength of Orthodontic Brackets and a Scanning Electron Microscopy Evaluation of the Enamel

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Abstract: This study investigated the effects of acidic soft drinks on the resistance of metal brackets to shear forces in vitro and in vivo. Thirty noncarious maxillary premolar teeth, scheduled for extraction for orthodontic purposes, were used in the in vivo group. Thirty other noncarious maxillary premolar teeth, already extracted for orthodontic purposes, were used in the in vitro group. The teeth in both groups were divided equally in three subgroups, ie, the Coca-Cola®, Sprite®, and control subgroups. Brackets were bonded using conventional methods. Teeth in the in vivo group were rinsed with the acidic drink three times for five minutes daily and extracted after three months. Teeth in the in vitro group were kept in the acidic drink for five minutes on three equal time intervals within 24 hours. The brackets from both groups were subjected to shearing forces using a Universal test machine. After the shearing tests, a scanning electron microscope was used to determine the amount and the localization of erosion. The results indicated that both acidic soft drink subgroups had a reduced debonding resistance in vivo and in vitro compared with their control subgroups. No statistical difference in debonding resistance was found between the in vivo and in vitro groups. Areas of defect due to erosion were observed on the enamel surface around the brackets in both the in vitro and in vivo groups. Acidic soft drinks such as Coca-Cola® and Sprite® have a negative effect on bracket retention against shearing forces and enamel erosion. (*Angle Orthod* 2005;75: 247–253.)

Key Words: Acidic soft drinks; Shear force; Scanning electron microscopy

INTRODUCTION

Many factors affect the retention of the brackets during fixed orthodontic treatment.[1] Healthy enamel surface is also needed for the retention of the bracket, and an altered enamel surface may affect the retention.[2]

Dental caries and dental erosion both result in the loss of the mineral component of teeth. Dental caries involves mineral loss from the subsurface region of enamel and dentine because of exposure to weak acids from plaque. Dental erosion is a loss of surface tissue because of exposure to a variety of acids.[3] The most important factors affecting the development of erosion during orthodontic treatment are oral hygiene, nutrition, and orthodontic bonding techniques.

Sweets, carbonated fruit drinks, and other dietary acids lowers the intraoral pH value below 5.5.[2–4] However, factors other than pH, such as type of acid, pKa, titratable acidity, buffering capacity, and temperature influence the dental erosive capacity of acidic liquids.[5] The acidic properties of acids are determined by the amount of acid available (the titratable acidity) and the amount of acid actually present (concentration of H+ ions—pKa), and all these factors contribute to the erosive potential of a specific acid. In a beverage matrix there are further complex interactions between solid and soluble components of the beverage, such as the acid/hydroxyapatite reaction, again affecting the erosive potential.[6]

Gedalia et al[7] determined the softening of the enamel surface after an hour of Coca-Cola application. The decrease of the pH value of the mouth to below 5.5 creates a medium for enamel erosion. A recent article showed that approximately half of all 14-year-old children have appreciable tooth wear and significant erosion and that this phenomena is more prevalent in lower socioeconomic groups.[4,8]

Investigators have demonstrated that the erosive potential

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of soft drinks depends on the initial pH and the buffering capacity of the drink. The buffering capacity is assessed either by the total content of acid in the drink or by the slope of the titration curve at a predefined pH.[9–11] Carbonated soft drinks are potentially more erosive than noncarbonated beverages because of the additional carbonic acid present.[12] In developed countries Coca-Cola has the largest segment within the carbonated sector with a share approaching 50%, followed by lemon flavor (22%) and orange flavor (7%).[13]

Acidic soft drinks include citric acid and phosphoric acid, and citric acid is far more effective than phosphoric acid in producing enamel erosion.[8] In addition, during fixed orthodontic treatment, the excess adhesive around the brackets causes a gathering of dental plaque that increases the risk of decalcification.[2]

O'Reilley and Featherstone[14] analyzed the amount of demineralization and remineralization around fixed orthodontic appliances. They stated that the demineralization did not occur because of the etching effect of the acid but because of dental plaque activation in the mouth. Hall et al[3] and Meurmann et al[15] indicated that saliva forms an important defense mechanism against erosion. They demonstrated that all samples exposed to an erosive solution that were stored in saliva showed less erosion.

The purpose of this study was to study the in vivo and in vitro effects of acidic soft drinks on the resistance of metal brackets to shearing forces and to evaluate the enamel surface after debonding using a scanning electron microscope (SEM).

MATERIALS AND METHODS

This study investigated the effects of acidic soft drinks on the resistance of metal brackets to shear forces in vitro and in vivo. Thirty noncarious maxillary premolar teeth, scheduled for extraction in 12- to 16-year-old orthodontic patients, were used in the in vivo group. All subjects were provided with verbal and written information concerning the study and signed and witnessed consent to participate. Thirty other noncarious maxillary premolar teeth, already extracted from 12- to 16-year-old orthodontic patients, were used in the in vitro group. The teeth in both groups were divided equally in three subgroups, ie, the Coca-Cola, Sprite, and control subgroups.

Brackets were identically bonded on all 60 teeth. In the in vivo group, brackets were placed only on the teeth to be extracted and not on any other teeth in the mouth. The buccal surfaces of all teeth were brushed with fluoride-free pumice, etched with 37% phosphoric acid, and washed with an air-water spray for 15 seconds. After air-drying each tooth surface, brackets were bonded (3M Unitek, Unitek Bonding Adhesive, Monrovia, Calif).

The patients in the Coca-Cola and Sprite subgroups were told to rinse their mouth with their respective room temperature drink for five minutes, three times a day, ie, in the morning, noon, and at night. They were told not to drink any acidic soft drinks apart from these. The patients in the in vivo control group were told not to consume any acidic soft drinks during these three months. All volunteers who participated in this study brushed their teeth twice a day for three minutes. At the end of three months, the premolar teeth were extracted without damaging the brackets.

Teeth in the in vitro group were placed in an apparatus providing an artificial oral environment[16] (Figure 1). Acidic soft drinks were placed in the first section of the apparatus and kept at room temperature. The artificial saliva was placed in the second section, and it was kept at 37°C. During the day, the teeth of the Coca-Cola and Sprite groups were placed in the acidic drinks for three sessions of five minutes with equal intervening intervals. The rest of the time they were kept in the artificial saliva. This process was continued for three months. The pH value and acidic values are provided in Table 1.

The in vitro control group teeth were kept in the artificial saliva at 37°C. for three months The artificial saliva was prepared from 0.4 g NaCl, 1.21 g KCl, 0.78 g $NaH_2PO_4 \cdot 2H_2O$, 0.005 g $Na_2S \cdot 9H_2O$, 1 g $CO(NH_2)_2$, and 1000 mL of distilled and deionized water in the laboratory. Then, 10 N sodium hydroxide was added to this mixture until the pH value was measured electrometrically as 6.75 $\pm$ 0.15. Later this mixture was sterilized in the autoclave.

Shear testing

All teeth in the in vitro and the in vivo groups were mounted vertically in acrylic blocks up to the clinical crown level. A shear test with a steady speed of 0.5 mm/minute was applied to the samples in the Universal test apparatus (Lloyd Instruments LR5K, Segenoworth Farcham, UK). The two jaws consisted of a vertically stationary lower jaw and a mobile upper jaw. The modified piece attached to the lower jaw enabled the fixed samples to move left, right, forward and backward, achieving total adaptation of the force from the upper jaw to affect the bracket and the tooth enamel. After making sure the force was correctly positioned, the apparatus was turned on, and a constant downward movement with a speed of 0.5 mm/minute was obtained. When the bracket detached from the tooth, the apparatus automatically stopped, and the force value recorded on a force meter fixed to the upper jaw. The values gained from the tests were evaluated with the Student's *t*-test using group and intergroup comparisons.

Scanning electron microscopy

The determination of the amount and localization of erosion was performed after the teeth were separated from their roots at the crown level and the crowns of teeth separated leaving only the buccal surface. These sections of teeth with brackets were left on brass supports in the de-

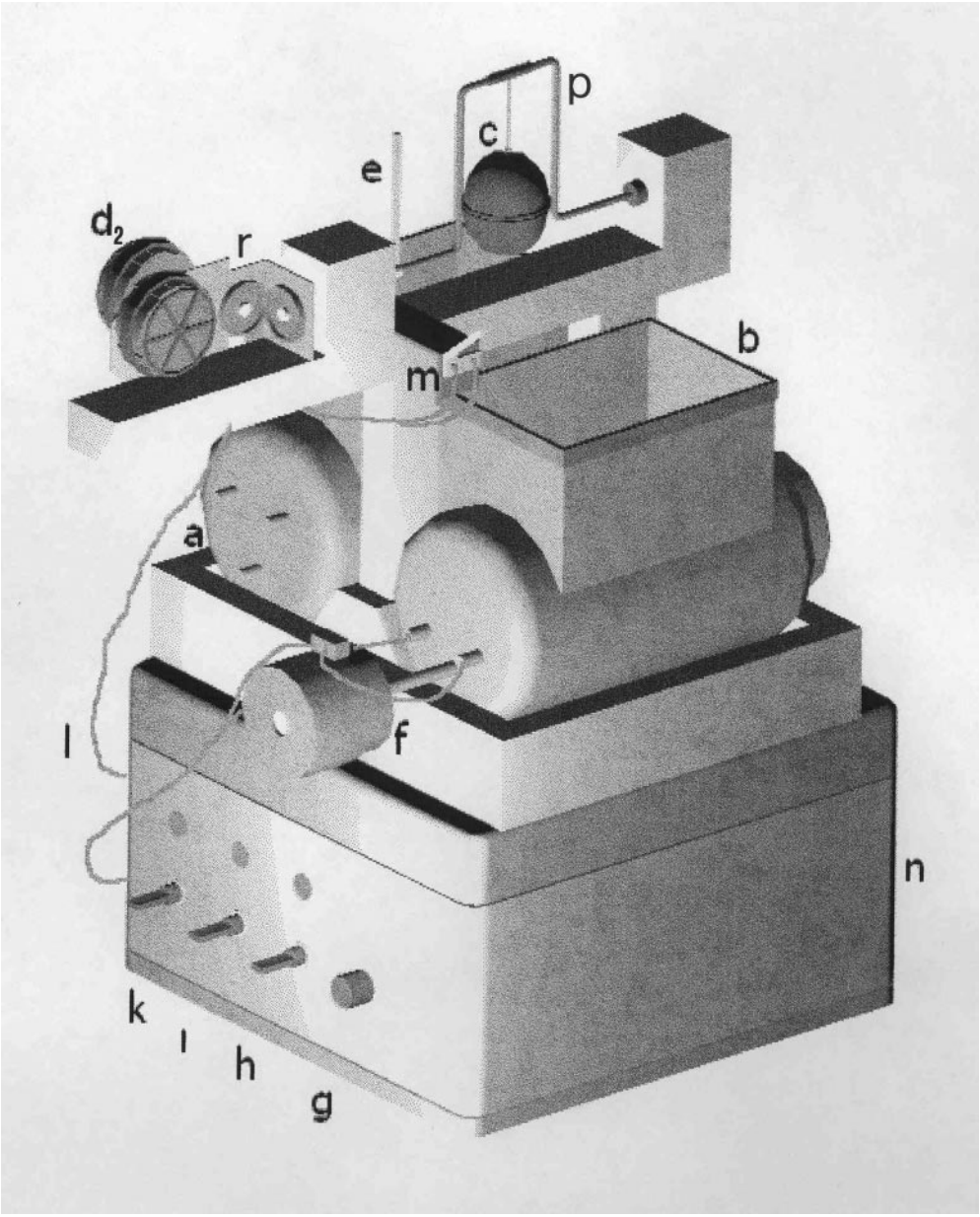

FIGURE 1. Schematic of thermocycling apparatus: (a) indicates soft drink tray; (b), artificial saliva tray; (c), tooth-carrying ball; (d), electric engine; (e), stop; (f), heater; (g), fuse switch; (h), main switch; (i), heater switch; (k), engine switch; (l), electric cable; (m), stop switch; (n), electric panel; (p), time-controlled handle; and (r), gear group.

TABLE 1. Acidic Properties Used in the Study

	pH Value	pKa Value	Titration Value	Buffering Capacity
Coca-Cola				
Phosphoric acid	2.44	2.12	3.20	0.42
Sprite				
Citric acid	2.90	3.12	2.31	0.50

cinator containing $CaCl_2$ for three days. They were then covered with gold and analyzed at different magnifications, using a JEOL JSM-5200 SEM. Photographs were also taken at this stage.

RESULTS

The means and standard deviations obtained from the shear test are shown in Table 2. In the in vivo group, the mean shear force was 7.16 kg/mm^2 in the Coca-Cola group, 8.68 kg/mm^2 in the Sprite group, and 14.12 kg/mm^2 in the control group. In the in vitro group, the mean shear force

TABLE 2. The Mean Force and Mean Deviation of the In Vitro and In Vivo Groups

	Mean Shearing Force (kg/mm²)	Mean Deviation
In vitro Coca-Cola	6.14	1.288
In vitro Sprite	7.06	2.032
In vitro control	12.12	1.424
In vivo Coca-Cola	7.16	0.888
In vivo Sprite	8.68	0.824
In vivo control	14.12	3.091

TABLE 3. The Comparative Variations Intragroups

	Mean Shearing Force (kg/mm²)	*P* Value
In vitro Coca-Cola/in vitro control	6.14/12.12	.0003***
In vitro Sprite/in vitro control	7.06/12.12	.0037**
In vitro Coca-cola/in vitro Sprite	6.14/7.06	.2549
In vivo Coca-Cola/in vivo control	7.16/14.12	.0027**
In vivo Sprite/in vivo control	8.68/14.12	.0091**
In vivo Coca-Cola/in vivo Sprite	7.16/8.68	.1359
In vivo Coca-cola/in vitro Coca-Cola	7.16/6.14	.1440
In vivo Sprite/in vitro Sprite	8.68/7.06	.1122
In vivo control/in vitro control	14.12/12.12	.1703

*** $P < 0.001$.
** $P < 0.01$.

was 6.14 kg/mm² in the Coca-Cola group, 7.06 kg/mm² in the Sprite group, and 12.12 kg/mm² in the control group.

The in vitro Coca-Cola subsample showed a statistically significant reduced bond strength compared with its control ($P < .001$). There was also significant statistical reduction in bond strength between the Sprite and its control ($P < .01$). There was no significant difference between the Coca-Cola and Sprite samples.

The in vivo group Coca-Cola sub sample showed a statistically significant reduction in bond strength compared with its control ($P < .01$). There also was a significant statistical reduction in bond strength between in vivo Sprite and its control ($P < .01$). There were no significant differences between the in vitro and in vivo groups (Table 3).

SEM result

The enamel surfaces and the adhesive-enamel borders of the teeth in the three subgroups were analyzed with SEM. In Figure 2, areas of enamel defect that were caused by erosion were seen on the samples taken from the Coca-Cola group (in vitro study) (1000× magnification). Areas of enamel defects of the Sprite group were not as extensive as those of the Coca-Cola group (Figure 3) (500× magnification). The control group showed a healthier enamel surface compared with both the Coca-Cola and Sprite groups (Figure 4) (1000× magnification).

The SEM study in the in vivo group showed extensive areas of defect caused by erosion around the adhesive on the enamel surface of the gingival region in the Coca-Cola group (Figure 5) (1000× magnification). The enamel surface of the incisor area was less affected when compared with the gingival area (Figure 6) (1000× magnification). In the Sprite group, wide enamel defects similar to the ones

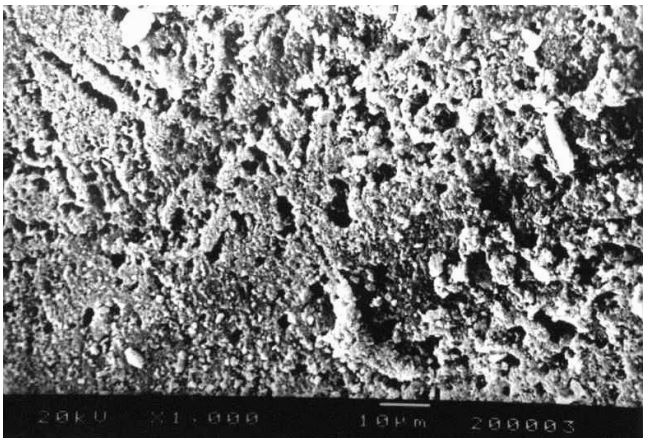

FIGURE 2. The demineralization areas of enamel surface in the in vitro Coca-Cola group (1000× magnification).

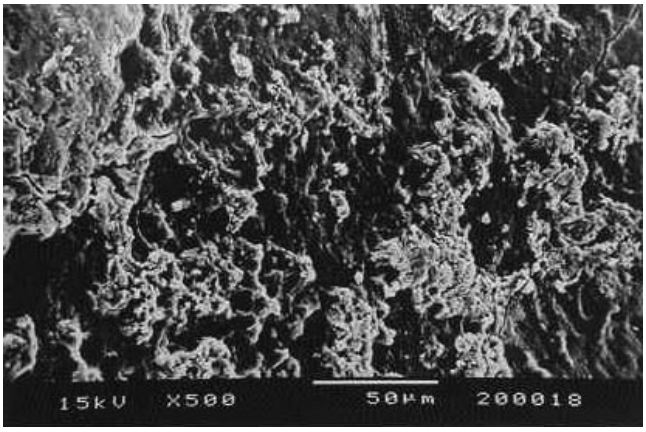

FIGURE 3. The demineralization areas in enamel surface in the in vitro Sprite group (500× magnification).

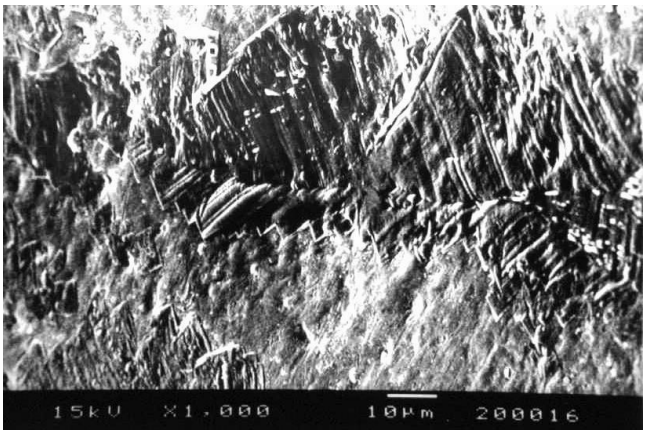

FIGURE 4. The enamel surface in the in vitro control group (1000× magnification).

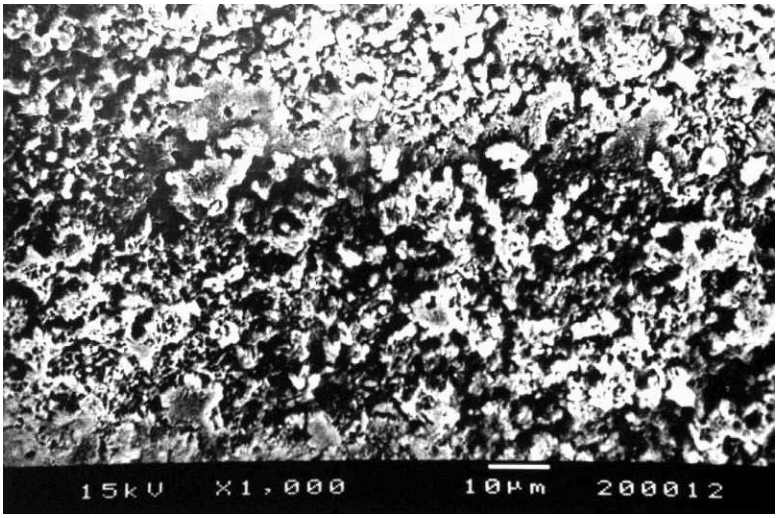

FIGURE 5. The demineralization in enamel surface in the in vivo Coca-Cola group (1000× magnification).

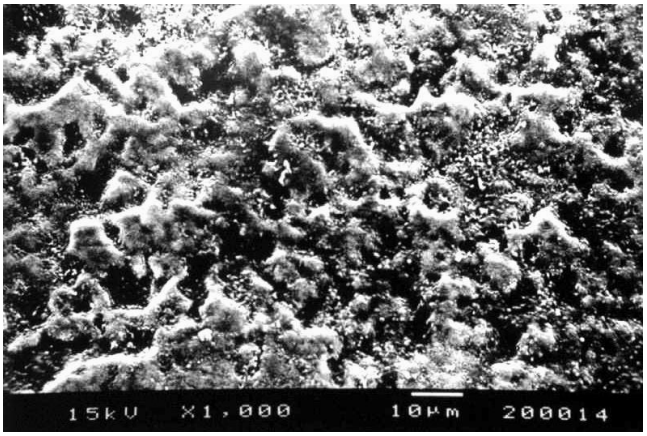

FIGURE 6. The incisal area enamel surface in the in vivo Coca-Cola group (1000× magnification).

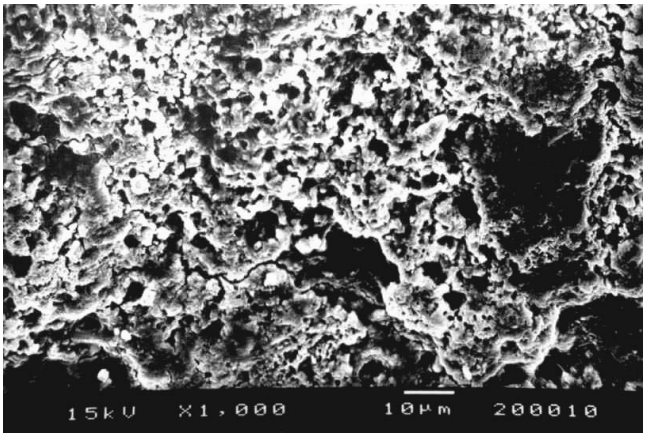

FIGURE 7. The demineralization in enamel surface in the in vivo Sprite group (1000× magnification).

seen in the Coca-Cola group were seen (Figure 7) (1000× magnification). The control group showed a healthier enamel surface compared with the Coca-Cola and Sprite groups (Figure 8) (750× magnification).

DISCUSSION

Acidic soft drinks have a low pH value (Coca-Cola 2.44 and Sprite 2.90), which lowers the pH of the oral cavity. The acidity of both drinks has a high erosive character on enamel.[8] The erosive character depends on the acidic properties, which is the amount of the acid available (titratable acidity) and the amount of the acid actually present (concentration of H+ ions—pKa). All these factors contribute to the erosive potential of a specific acid. In a beverage matrix there are further complex interactions between solid and soluble components of a beverage, such as the acid/hydroxyapatite reaction, which again affect the erosive po-

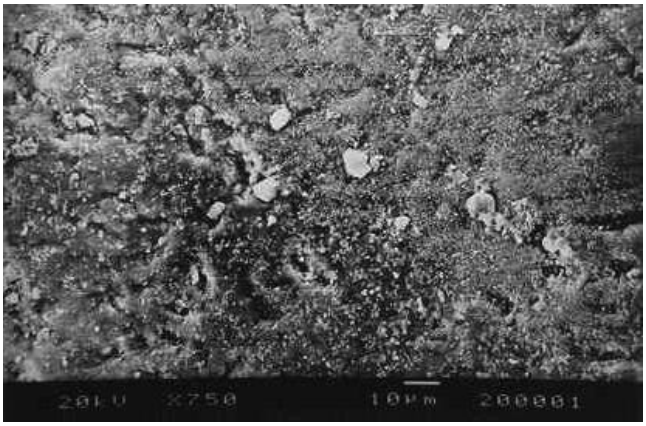

FIGURE 8. Enamel surface in the in vivo control group (750× magnification).

tential.[6] In addition, these beverages were consumed largely by young people.[13]

During an orthodontic treatment with fixed appliances, frequent intake of soft drinks increases the risk of erosion. Erosion is a defect on the enamel surface, which can decrease the retention of the brackets.[2,17,18] Considering the effects of soft acidic drinks on the enamel surface, this in vitro and in vivo study focuses on the resistance to shearing forces.

Hall et al[3] and Meaurman et al[15] determined a remineralizating effect of saliva on the enamel. For in vitro study samples, we used the artificial saliva used by Barrett et al[19] with a stable temperature of 37°C degrees in the artificial mouth environment that we created.

We performed the shearing test in the Universal apparatus similar to others.[20–22] Gillis and Redlich[22] and Mascia and Chan[23] also applied the shearing to their samples with a stable speed of 0.5 mm/minute in the Universal test apparatus. In both the in vitro and in vivo groups, the Coca-Cola group showed the lowest mean resistance to shearing forces. In the in vitro study, significant statistical differences were established between the Coca-Cola/control samples and Sprite/control samples. We believe the area of defect caused by Coca-Cola and Sprite's erosive effect on enamel (which was shown by SEM) has a negative effect on bracket retention. There were no significant statistical differences between the Coca-Cola and Sprite samples.

When the Coca-Cola and Sprite groups were compared with SEM, the enamel defects in the Coca-Cola group were more extensive and noticeable than in the Sprite group. We believe that the reason for this was the enamel erosive effect of the phosphoric acid in Coca-Cola. Rugg-Gunn et al[6] compared the erosive capabilities of a citric acid–based orange juice drink and a phosphoric acid–based diet cola drink. They determined that the phosphoric acid–based diet cola had more erosive potential than the citric acid–based orange juice drink. This supports this study's results. Our findings, evaluated by the SEM, were parallel to the results of Gedalia,[7] Dinçer et al,[16] Steffen,[18] and Grando et al.[24] Many others have also stated that acidic soft drinks like Coca-Cola and Sprite cause erosive defect areas on the enamel.[8,16,18,25]

There were significant statistical differences between the in vivo Sprite/Control group and in vivo Coca-Cola/control group in the shear test. However, there were no differences between the in vivo Coca-Cola and in vivo Sprite groups. These results were parallel to the results of the in vitro group.

Under SEM, enamel defects were more common in the Coca-Cola and Sprite groups than in the control group. The enamel defects of the in vitro Coca-Cola group were more noticeable than the in vitro Sprite group. In these samples where adhesive was left on the enamel, the adhesive was noticeable closer to the periodontal tissues than the occlusal edge. The probable reason for this was that plaque retention in the gingival area could not be cleaned very well. Sukontapatipark et al[26] demonstrated that excess composite around the bracket base was the critical site for plaque accumulation attributable to its rough surface and the presence of a distinct gap at the composite-enamel interface. These records supported our argument.

There was no significant statistical difference in the in vivo Coca-Cola/ in vitro Coca-Cola, in vivo Sprite/in vitro Sprite, and in vivo control/in vitro control samples tested for shearing. There was no significant experimental difference in the bracket retention against shearing force between the artificial and original mouth environment. In the SEM comparison of Coca-Cola and Sprite samples, the enamel defects were more extensive in the in vivo group, but this was not statistically significant. The reason for the difference between the in vitro and in vivo group was the bacterial functions of the oral environment. Steffen[18] stated that the bacteria in the mouth with the acidic soft drinks accelerate the erosion.

In both the in vitro and in vivo groups, the enamel defects were dense and approximately 50 μm from the adhesive-enamel border under SEM. This may be due to the protective quality of the adhesive at the enamel-adhesive border. Also, the enamel surfaces of the control groups were healthier than that of the Coca-Cola and Sprite groups, except for some areas near the adhesive-enamel border where the erosive areas were believed to be caused by the acid etching. In the in vivo Control group there were less erosive areas compared with the Coca-Cola and Sprite groups. These limited erosive areas may have been caused by bacterial plaque functions on the acid-etched enamel surface.

CONCLUSIONS

- In this study, Coca-Cola samples have the lowest shear resistance in both the in vitro and in vivo groups.
- Intragroup comparisons of both of the in vivo and in vitro groups show that the Coca-Cola and Sprite group samples have statistically more significant differences compared with the control group samples.
- In vitro and in vivo groups have no statistically significant experimental differences.
- Areas of defect, which were caused by the erosion related to soft acidic drinks on the enamel surface around the adhesive, were seen in the in vitro study.
- Because of the bacterial effects in the mouth, the effects of the soft acidic drinks were more severe on the in vivo samples compared with the in vitro samples.
- The control groups, in both the in vitro and in vivo groups, show a healthier enamel structure. However, in both control groups, demineralized areas caused by the acid-etching effect were noticed.
- This study results show that the patients who were undergoing fixed orthodontic treatments should be advised

not to consume any soft acidic drinks, which can increase the risk of erosion.

- Soft acidic drinks such as Coca-Cola and Sprite have a negative effect on the bracket retention against shearing forces.

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