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The Effect of Previous Diet on Plaque pH Response to Different Foods

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In this study we investigated the effect of previous diet on the response of plaque pH to three test foods. The study population consisted of 11 dental students. Plaque pH was measured, by means of the touch electrode method, on the first two upper molars. The study was conducted at two sessions, one week apart. Subjects followed a 48-hour high-sugar diet before the first test session and a 48-hour low-sugar diet before the second test session. During both 48-hour periods, students refrained from all oral hygiene practices and fluoride utilization. At each session, three foods were ingested at one-hour intervals: cola, beer, and chocolate bar. pH measurements at baseline and at selected times after food ingestion were recorded and analyzed. Multivariate analysis of variance revealed significant independent effects of food, previous diet, and their interaction on plaque pH. After the same foods were ingested, plaque pH response after a previous high-sugar diet was significantly more acidic than after a previous low-sugar diet.


Introduction.

The development of dental caries is based on dynamic demineralization and remineralization activity at the enamel-plaque interface (Kleinberg et al., 1983; Nikiforuk, 1985). Acidic plaque, rich in an acidogenic microflora, is likely to facilitate demineralization, whereas plaque at neutral pH, which is relatively supersaturated with calcium phosphate, is capable of a remineralizing response.

Measurements of plaque pH after food ingestion offer a valuable means of predicting caries risk (Kleinberg, 1978). Studies have proposed that the decrease in plague pH and the subsequent return to the original resting pH level, or the "Stephan curve", reflect the cariogenic challenge to the tooth imposed after the ingestion of fermentable carbohydrates (Stephan, 1944).

Human studies, measuring the acidity of human plaque, have attempted to rank the cariogenic potential of different foods (Schachtele and Jensen, 1984). Previous dietary content has been controlled by specification of a "normal" diet, which has not been defined or characterized. The possible effect of previous dietary content on the immediate pH response within plaque to a given food may therefore not have been adequately investigated. To test the hypothesis that a previous diet, high in readily fermentable sugars, would increase the acidogenic potential of the plaque and microflora, we compared the effects of selected foods on plaque pH in subjects who had previously consumed either a low-sugar or a high-sugar diet.

Materials and methods.

The study population consisted of 11 healthy volunteer dental students. All subjects had at least 28 teeth present, with no orthodontic or prosthetic appliances. The ages of the five males and six females ranged from 22 to 25 years. All had upper molars free of buccal restorations or caries. To be included, subjects were prescreened, by use of the criteria described by Harper et al. (1986), and were found suitable for the experiment if, after fasting overnight and then rinsing for one minute with a 10% solution of sucrose, they exhibited a plaque pH of 5.5 or below.

The study was conducted in two sessions, one week apart. Subjects were instructed to follow a 48-hour high-sugar diet before the first test session, and a 48-hour low-sugar diet before the second test session. The high-sugar diet consisted of the sucking of seven sweets (sucrose) daily at regular intervals (8.00, 10.00, 13.00, 16.00, 18.00, 21.00, and 24.00 hours) during the 48-hour period. Besides this stipulation, students were instructed to follow their regular dietary patterns with no changes. During the low-sugar period, students were instructed to refrain from ingesting most sweet dietary carbohydrates, including sugar, sweetened foods, or fruit. They were directed to eat predominantly meat, fish, eggs, milk products, and vegetables. Throughout the study, personal contact was maintained with the participants, and dietary regulations were monitored. During both 48-hour periods, students refrained from all oral hygiene practices and from using any therapeutic agents containing fluoride or other mouthrinses. Test sessions took place in the mornings after an all-night fast. At each of the two sessions, three test foods were consumed at one-hour intervals: 25 mL of cola drink (content: water, sucrose, flavors, CO2, caramel), 25 mL of beer (content: water, hops, maize, glucose, barley, 4.9% alcohol), and a 20-g chocolate bar (content: sucrose, glucose, milk powder, nuts, vegetable shortening, cocoa butter, 28% cocoa mass, whipping agent, salt, lecithin, vanillin). These items were selected as examples of foods commonly consumed between meals. The two drinks were rinsed in the mouth for one minute and the chocolate bar was chewed for one minute, before being swallowed.

Plaque pH was measured by the touch electrode method (Schachtele and Jensen, 1982). An antimony electrode (Settler Medical Electronics, Inc., Winnipeg, Manitoba, Canada) designed for plaque pH measurement was employed. Electrodes were calibrated prior to each session, and baseline resting plaque pH was then determined. At the start of each test session, subjects ingested the test foods as instructed. The plaque pH was measured immediately afterward (time "0") in the buccal/mesial/interproximal regions of each of the four upper molars. Measurements were then conducted after two, five, 10, 20, 30, 45, and 60 minutes, or until pH returned to the baseline level. These time intervals — the 48-hour period of refraining from oral hygiene prior to the experiments, the morning test sessions after an all-night fast, and the position of plaque pH determination at the buccal/interproximal surfaces of four posterior teeth — are according to the protocol recommended by the Scientific Consensus Conference on Methods for Assess-
TABLE 1
PLAQUE pH LEVELS AFTER INGESTION OF THREE FOODS, AFTER HIGH- AND LOW-SUGAR DIETS, BY TIME

<table>
<thead>
<tr>
<th>Food in Diet</th>
<th>N = 11</th>
<th>Baseline</th>
<th>0</th>
<th>2</th>
<th>5</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>45</th>
<th>60</th>
<th>75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chocolate</td>
<td>Low mean</td>
<td>7.32</td>
<td>8.29</td>
<td>7.35</td>
<td>6.11</td>
<td>5.90</td>
<td>5.97</td>
<td>6.52</td>
<td>7.12</td>
<td>7.31</td>
<td>7.37</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>0.18</td>
<td>0.48</td>
<td>0.55</td>
<td>0.48</td>
<td>0.36</td>
<td>0.43</td>
<td>0.35</td>
<td>0.30</td>
<td>0.11</td>
<td>0.16</td>
</tr>
<tr>
<td></td>
<td>High mean</td>
<td>7.29</td>
<td>8.52</td>
<td>7.68</td>
<td>6.38</td>
<td>5.77</td>
<td>5.56</td>
<td>5.61</td>
<td>6.30</td>
<td>6.98</td>
<td>7.23</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>0.48</td>
<td>0.58</td>
<td>0.98</td>
<td>0.72</td>
<td>0.35</td>
<td>0.44</td>
<td>0.54</td>
<td>0.39</td>
<td>0.49</td>
<td>0.15</td>
</tr>
<tr>
<td>Beer</td>
<td>Low mean</td>
<td>7.26</td>
<td>5.50</td>
<td>6.05</td>
<td>6.37</td>
<td>6.73</td>
<td>6.96</td>
<td>7.32</td>
<td>7.38</td>
<td>7.38</td>
<td>7.38</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>0.20</td>
<td>0.42</td>
<td>0.41</td>
<td>0.51</td>
<td>0.58</td>
<td>0.44</td>
<td>0.22</td>
<td>0.21</td>
<td>0.17</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High mean</td>
<td>7.44</td>
<td>5.15</td>
<td>5.70</td>
<td>5.89</td>
<td>5.98</td>
<td>6.49</td>
<td>6.86</td>
<td>7.39</td>
<td>7.46</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>0.35</td>
<td>0.37</td>
<td>0.36</td>
<td>0.30</td>
<td>0.37</td>
<td>0.36</td>
<td>0.55</td>
<td>0.55</td>
<td>0.24</td>
<td></td>
</tr>
<tr>
<td>Cola</td>
<td>Low mean</td>
<td>7.45</td>
<td>5.54</td>
<td>6.19</td>
<td>6.13</td>
<td>6.33</td>
<td>6.83</td>
<td>7.29</td>
<td>7.49</td>
<td>7.49</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>0.24</td>
<td>0.31</td>
<td>0.17</td>
<td>0.50</td>
<td>0.46</td>
<td>0.34</td>
<td>0.33</td>
<td>0.20</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High mean</td>
<td>7.34</td>
<td>5.20</td>
<td>5.60</td>
<td>5.36</td>
<td>5.64</td>
<td>6.03</td>
<td>6.34</td>
<td>6.95</td>
<td>7.41</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>0.42</td>
<td>0.60</td>
<td>0.62</td>
<td>0.32</td>
<td>0.64</td>
<td>0.82</td>
<td>0.71</td>
<td>0.56</td>
<td>0.41</td>
<td></td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>0.59</td>
<td>123.5</td>
<td>26.0</td>
<td>5.9</td>
<td>7.8</td>
<td>13.1</td>
<td>20.3</td>
<td>13.5</td>
<td>4.2</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>0.71</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.002</td>
<td></td>
</tr>
</tbody>
</table>

Results.

A within-subjects multivariate analysis of variance for repeated measures revealed significant independent effects of food (F = 21.04; p = 0.001), previous diet (F = 5.44; p = 0.001), and their interaction (F = 2.36; p = 0.004) on plaque pH levels at selected times after test food ingestion. Post hoc multiple comparison analyses were therefore applied to the separate effects of food and previous diet at each point of time.

As a demonstration of the influence of previous diet on plaque pH response to individual foods, mean plaque pH levels for the 11 subjects for each of the three test foods, separated by previous high- or low-sugar diets, at each measurement time are presented in Table 1 and the Fig. At baseline, no significant differences were detected in plaque pH values of the 11 subjects. At time "0" and the second minute, most foods after both diets caused pH decreases, except chocolate, which, after both diets, still demonstrated significantly higher pH values. At the fifth minute, all foods produced decreases in pH, with beer and cola after the high-sugar diet causing significantly lowest pH levels. At the 10th minute, most combinations of food item and previous diet caused plaque pH values to remain at low levels, except both beer and cola after the low-sugar diet, for which plaque pH started returning to significantly higher levels. At the 20th minute, chocolate after both diets and cola after the high-sugar diet caused the significantly lowest plaque pH values. Other values were higher, as the curve returned to baseline. At the 30th minute after ingestion, beer and cola following the low-sugar diet caused the significantly highest pH levels, close to baseline, while chocolate after the high-sugar diet still caused a significantly lower plaque pH level. At the 45th and 60th minutes, for all foods, after both diets, plaque pH had returned close to baseline, except with chocolate after the high-sugar diet, when a significantly lower pH value was obtained, which returned to baseline only after 75 minutes.

Mean time-hydrogen ion areas of the Stephan curves for different food items by previous diet are presented in Table 2 and are evident in the Fig. As is demonstrated, a ratio of approximately 2:1 was apparent between high- and low-sugar curve areas for all three foods. Univariate analysis of variance showed this to be statistically significant (p<0.001).

Discussion.

The cariogenic potential of diet has been extensively studied by measurement of plaque pH. The aim of this research has been either to identify non-cariogenic foods as "safe for teeth" (Firestone, 1982) or to rank foods according to their potential cariogenicity (Edgar, 1985; Newbrun, 1982a). Investigators have also studied the effect on plaque pH of the sequence of sugary foods within the dietary pattern and the combination of different foods. The effect on plaque pH was considerably modified when a sugary food was consumed in combination with a non-sugary food in the same meal (Rugg-Gunn et al., 1981). The interaction between oral food clearance and plaque pH has also been investigated. Retention of sugary-starchy...
measured pH changes after ingestion of various foods. Figure 1 shows the pH levels for chocolate, beer, and cola. The pH levels were recorded at different time intervals after consumption.

The pH levels for chocolate were lower than for beer and cola, indicating that chocolate has a more acidic effect on plaque pH. The pH levels for beer were higher than for cola, suggesting that beer has a more alkaline effect on plaque pH.

Table 2 summarizes the mean time-hydrogen ion areas of stephan curves for different food items, by previous diet.

<table>
<thead>
<tr>
<th>Food item</th>
<th>High-sugar</th>
<th>Low-sugar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cola</td>
<td>7952</td>
<td>3872</td>
</tr>
<tr>
<td>Beer</td>
<td>5350</td>
<td>2790</td>
</tr>
<tr>
<td>Chocolate</td>
<td>10985</td>
<td>5250</td>
</tr>
</tbody>
</table>

*Area units = equiv/liter H+ x 10^-6 x time

The table shows that the pH levels for high-sugar foods were higher than for low-sugar foods. The pH levels for chocolate were higher than for beer and cola, indicating that chocolate has a more acidic effect on plaque pH.

One study has investigated the effects of previous ingestion of sugary foods on plaque pH response. Following a high-sucrose diet, a starch rinse significantly lowered the plaque pH more than after a low-sucrose diet (Dodds and Edgar, 1986). However, unlike our findings, the baseline pH measurements differed with the two diets, so that the pH areas after the starch rinse were not significantly different. In our study, the different plaque pH responses to cola and beer (as compared with chocolate) were assumed to be related to diffusion and clearance. In the absence of plaque, numerous foods and beverages are capable of lowering the intra-oral pH. For example, cola and beer lowered the pH at the surface of the tongue to 4.7 and 5.18, respectively (Meurman et al., 1987). However, such pH depression is short-lived, rapidly returning to baseline within two to three minutes. In plaque, cola and beer depressed the pH for from 20 to 40 min, depending on the preceding diet, and chocolate depressed the pH for from 60 to 75 min.

The cariogenic process initiated on the tooth-plaque interface involves many causal, modifying, interacting, synergistic, antagonistic, and other associated variables. A sucrose-rich diet favors an acidogenic and aciduric type of flora, which potentially is more capable of producing an acidic plaque (de Stoppelaar et al., 1970; Staat et al., 1975). Once a more acidic environment has been achieved, this too will favor a shift in the plaque flora to one containing a higher level of cariogenic organisms. This continuing cycle of events is further enhanced by the fact that the more acidic condition will inhibit salivary replenishment of calcium phosphate — the process that induces remineralization.

Epidemiological research on the association between diet and dental caries has often been confronted with the problem of “background noise” (Newbrun, 1982b). Urban Western civilization has been saturated with diets high in readily fermentable carbohydrates, to such an extent that the effects of specific potentially cariogenic dietary items have been extremely difficult to establish (Bagramian et al., 1974).

In the present study, we hypothesized that a previous sugary diet would increase the acidogenic potential of the plaque and microflora, thereby enhancing the immediate ability of a specific food item to influence plaque pH. To control for the possible synergistic effect between particular food items and previous diet, we developed a study design in which the effect of food on plaque pH after a sugary diet was compared with the effect after a specially constructed low-sugar diet.

The three food items were consumed at hourly intervals. Resting pH values were re-established after the previous food’s ingestion, but the metabolic state of the plaque could have differed for the second and third foods as compared with the first. Due to the constant sequence of food items, it is unlikely that this factor could influence the comparisons between the effects of previous diets.

The data demonstrated a highly statistically significant difference between the two test periods. After the sugary diet, plaque pH response was more acidic than after the low-sugar diet. This result supports our hypothesis that a synergistic relationship exists between the immediate response of plaque pH to specific sugary foods and the accumulated past experience.

**Table 2**

<p>| Mean Time-Hydrogen Ion Areas of Stephan Curves for Different Food Items, by Previous Diet |
|---------------------------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>Food item</th>
<th>High-sugar</th>
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<td>Chocolate</td>
<td>10985</td>
<td>5250</td>
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</tbody>
</table>

*Area units = equiv/liter H+ x 10^-6 x time

**Figure 1**

Mean pH levels (and S.D.) of 11 subjects after previous high- or low-sugar diets, by time, in response to ingestion of chocolate, beer, or cola.
of sugary challenges that might have modified the composition of plaque and microflora toward a higher acidogenic potential. A more independent estimate of the contribution of a specific test food to cariogenic potential is therefore obtained after a low-sugar diet, eliminating the accumulated past experience of sugary challenges and thereby the possible synergistic influence of previous diet. This should be considered in future attempts to rank foods according to their cariogenicity. Further research should also investigate the role of microflora and saliva in this multifactorial process.

Acknowledgment.

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REFERENCES


