Enhancement of Plaque Removal by Baking Soda Toothpastes from Less Accessible Areas in the Dentition

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Abstract

- **Objective:** To determine if baking soda toothpastes are relatively more effective than non-baking soda toothpastes in promoting plaque removal from less accessible sites in the dentition.

- **Methods:** Several single-brushing comparisons of baking soda and non-baking soda toothpastes for their overall ability to remove plaque have been published. In this study, individual comparisons of these published data, comparing the plaque removal performance of baking soda and non-baking soda toothpastes at various sites in the dentition, were examined to see if there were any site-dependant performance trends. The site-specific single-brushing data were then combined and analyzed in two ways. Meta-analyses of the clinical studies were performed to compare baking soda's relative plaque removal advantage at various sites in the mouth using paired t-testing at $p < 0.05$. Also, plaque index reductions at various sites due to brushing with baking soda toothpastes were graphically compared with plaque index reductions due to brushing with non-baking soda dentifrices. The percent relative plaque removal advantage for baking soda toothpastes at various sites were plotted against the reduction in plaque index due to brushing with non-baking soda toothpastes.

- **Results:** Individual comparisons showed that brushing with the toothpastes containing baking soda generally removed significantly more plaque from each site than brushing with toothpastes without baking soda. The relative efficacy advantage for baking soda toothpastes was consistently higher at sites where the non-baking soda toothpastes removed less plaque. Meta-analytical comparisons confirmed baking soda toothpastes to be relatively more effective in enhancing plaque removal from sites where less plaque was removed compared to brushing with non-baking soda toothpastes ($p < 0.05$). Graphically, the baking soda toothpastes' relative plaque removal advantage could be seen to increase hyperbolically with decreasing plaque removal by the non-baking soda toothpastes with which they were compared. We presuppose that the reason less plaque is removed by non-baking soda toothpastes at some sites than others is that these sites are less accessible to the toothbrush.

- **Conclusion:** These results show that baking soda toothpastes are relatively more effective in enhancing plaque removal from harder-to-reach areas of the dentition ($p < 0.05$), *i.e.*, from lingual than facial surfaces, from posterior than anterior areas, and from proximal than mid-surface sites.

Introduction

Adequate brushing of the teeth with a toothpaste is, of course, the key component of good oral hygiene. First of all, tooth brushing removes residual food deposits and some of the plaque biofilm which forms on teeth. Secondly, toothpastes themselves provide a useful delivery vehicle for therapeutic and cosmetic ingredients. The most important therapeutic ingredient added to toothpastes is fluoride, which helps to prevent dental caries and promotes the remineralization of incipient carious lesions. From a cosmetic standpoint, toothpastes contain mild abrasives which control stain and prevent yellowing of teeth. There are also many other useful agents which are optionally incorporated into toothpastes, including antimicrobials to inhibit plaque biofilm growth between brushings, tartar control agents to inhibit calculus mineral formation, and agents to relieve tooth hypersensitivity. Importantly, toothpastes also supply foaming agents, flavors, and sweeteners which make the brushing experience much more enjoyable and assure that both children and adults will regularly brush their teeth for an adequate period of time.

Since plaque biofilm is the etiological agent responsible for oral diseases such as dental caries, gingivitis, and periodontitis, the removal of plaque is of primary importance in the maintenance of oral health.[1-3] Though there are exceptions,[4] perhaps surprisingly, most clinical studies have shown that toothpastes themselves contribute little, if anything to the actual physical removal of plaque biofilm achieved by the toothbrush.[5-12] Furthermore, studies have also shown that most people are not able to effectively control plaque by brushing alone. Thus, De la Rosa, *et al.* found that on average 40–60% of the plaque present remained on the teeth after brushing for up to two minutes. On the other hand, these researchers did find that brushing with a dentifrice inhibited subsequent plaque regrowth by 27%.[13]

Providing a toothpaste with an ingredient that enhances plaque removal during brushing would thus seem to be highly desirable. Not only would such a toothpaste ingredient help reduce the amount of bacteria present on teeth, but, presumably, it would also promote the removal of the plaque matrix and other undesirable materials which are present therein. These include

potentially harmful metabolites of bacterial growth, such as gingival inflammatory agents, cariogenic or erosive acids, bacterial nutrients, and sticky polysaccharides which can help trap other undesirable substances in the mouth. It would also seem especially important to promote plaque removal from areas where the toothbrush has only limited access.

A series of recent studies has consistently demonstrated that brushing with toothpastes containing baking soda removes more plaque than brushing with non-baking soda dentifrices, indicating that this ingredient has a unique ability to physically promote plaque removal during brushing.[14-16] This paper presents additional analyses of the data from those previously published clinical studies, with a view to determining the relative effectiveness of baking soda toothpastes in areas of the dentition with varying toothbrush accessibility. In addition to the practical issues of effectiveness, it is thought that further examination of baking soda's performance in different areas of the mouth might provide a clue regarding its mechanism of action.

Materials and Methods

The data from six published, independent, randomized, controlled, blinded clinical studies, involving 14 comparisons of toothpastes containing baking soda with dentifrices that do not, were further analyzed for site specificity. Since the study designs and overall results have already been published, the following provides only a brief summary of the protocols used.

Five of the clinical studies were single-brushing crossover comparisons.[14] The sixth was a four-week, parallel-group plaque removal study, which included two sets of single-brushing measurements, one at baseline and one four weeks later at the completion of the study.[15] Subjects selected for the studies were required to meet a standard set of inclusion criteria. Prior to each visit, they refrained from oral hygiene for 24 hours and did not eat, drink, or smoke in the morning prior to their oral examination. At each visit, the subjects rinsed with erythrosine-red disclosing solution, and then received a pre-brushing plaque assessment using Soparkar's modification of the Turesky Modified Quigley-Hein Plaque Index as described by Lobene, *et al*.[17-19] Subjects then brushed their teeth under supervision for exactly one minute with a fixed quantity (1.5 g) of test toothpaste which had been pre-applied to a standard toothbrush. The subjects re-rinsed with disclosing solution and their plaque index was rescored. Between each leg of the study, subjects brushed at home for a fixed three- to five-day wash-out period using a non-baking soda dentifrice provided.

In each of the clinical studies included in these analyses, one or more toothpastes containing various levels of baking soda (between 20% and 65%) were compared for their ability to promote plaque removal with one or more toothpastes which did not contain baking soda. The non-baking soda toothpastes varied and were representative of some of the leading dentifrices available commercially. Table I lists the toothpastes used in each comparison study and summarizes the previously published whole mouth plaque index reduction results from these studies.

In this more in-depth look at the data, for each study comparison listed in Table I, a preliminary examination of the differences in plaque removal performance for baking soda and

Table I
Toothpastes Evaluated in Each Study and
Summary of Whole Mouth Findings

Dentifrice Group	PI Reduction	Overall PI Reduction Advantage
Study #1		
A—65% Baking Soda	0.73 ± 0.26	40% (A > K; p < 0.0001)
B—20% Baking Soda	0.64 ± 0.26	23% (B > K; p = 0.0001)
K—Triclosan/Copolymer	0.52 ± 0.20	
Study #2		
C—48% Baking Soda	0.72 ± 0.28	23% (C > K; p < 0.0001),
		21% (C > L; p < 0.0001)
B—20% Baking Soda	0.68 ± 0.27	17% (B > K; p < 0.0001),
		14% (B > L; p = 0.0002)
L—Stannous Fluoride/Silica	0.59 ± 0.26	
K—Triclosan/Copolymer	0.58 ± 0.25	
Study #3		
C—48% Baking Soda	0.78 ± 0.31	27% (C > K; p < 0.0001),
		34% (C > M; p < 0.0001)
D—27% Baking Soda	0.73 ± 0.32	18% (D > K; p = 0.0009),
		25% (D > M; p = 0.0001)
M—NaF/Silica	0.58 ± 0.24	
K—Triclosan/Copolymer	0.58 ± 0.25	
Study #4		
A—65% Baking Soda	0.80 ± 0.31	71% (A > N; p < 0.0001)
N—NaF/Silica	0.47 ± 0.23	
Study #5		
B—20% Baking Soda	1.07 ± 0.38	23% (B > K; p = 0.0014)
K—Triclosan/Copolymer	0.87 ± 0.37	
Study #6A (Baseline)		
B—20% Baking Soda	0.54 ± 0.26	88% (B > K; p < 0.001)
K—Triclosan/Copolymer	0.28 ± 0.18	
Study #6B (4-Week)		
B—20% Baking Soda	0.47 ± 0.21	108% (B > K; p < 0.001)
K—Triclosan/Copolymer	0.23 ± 0.15	

Baking soda-containing toothpastes:
A—Arm & Hammer® Dental Care®, Church & Dwight Co. Inc, Princeton, NJ, USA
B—Arm & Hammer® Advance White® Brilliant Sparkle, Church & Dwight Co. Inc, Princeton, NJ, USA
C—Arm & Hammer® Advance White® Baking Soda & Peroxide, Church & Dwight Co. Inc, Princeton, NJ, USA
D—Arm & Hammer® Liquid Gel, Church & Dwight Co. Inc, Princeton, NJ, USA

Non-baking soda toothpastes:
K—Colgate® Total® Clean Mint, Colgate-Palmolive Co., NY, USA
L—Crest® ProHealth™, Procter & Gamble Co, Cincinnati, OH, USA
M—Crest® Regular, Procter & Gamble Co, Cincinnati, OH, USA
N—Aim® Cavity Protection Gel, Church & Dwight Co. Inc, Princeton, NJ, USA

non-baking soda toothpastes in various areas of the dentition was made. The eight sets of sites selected for comparison were the anterior-facial/mid-surface sites (AFM), the posterior-facial/mid-surface sites (PFM), the anterior-facial/proximal sites (AFP), the posterior-facial/proximal sites (PFP), the anterior-lingual/mid-surface sites (ALM), the posterior-lingual/mid-surface sites (PLM), the anterior-lingual/proximal sites (ALP), and the posterior-lingual/proximal sites (PLP). By mid-surface is meant the mid-facial or mid-lingual areas between the mesial and distal (*i.e.*, proximal) sites. For each baking soda and non-baking soda toothpaste comparison, the differences in relative plaque removal performance were assessed at paired sets of areas in the mouth,

i.e., anterior and posterior teeth, facial and lingual surfaces, and mid-surface and proximal sites of the dentition.

Subsequently, for each baking soda and non-baking soda toothpaste comparison, the plaque index reduction at each site due to brushing with the baking soda toothpaste was graphed against the reduction due to brushing with the non-baking soda toothpaste. The percent plaque removal advantage for the baking soda toothpaste at each site was then calculated by subtracting the plaque index reduction due to brushing with the non-baking soda toothpaste (ΔPI_{NBST}) from the plaque index reduction due to the baking soda toothpaste (ΔPI_{BST}), and dividing the result by the plaque index reduction due to the non-baking soda toothpaste and multiplying the result by 100, as given in the formula:

$$\% \text{ Advantage for the Baking Soda-Toothpaste} = (\Delta PI_{BST} - \Delta PI_{NBST}) \times 100 / \Delta PI_{NBST}$$

The percent relative plaque removal advantage for each baking soda toothpaste versus absolute reductions in plaque index due to brushing with the corresponding non-baking soda toothpaste were then graphed.

Global meta-analyses of the data from all the studies were performed to compare the plaque removal advantage of baking soda toothpastes from the selected areas in the mouth using two-tailed Student's paired t-tests with $p = 0.05$ as a maximum for significance. In addition, 95% confidence limits for each pair of locations were determined.

A possible concern with the above meta-analytic Student's paired t-test is that some of the data used in the study were derived from multiple toothpaste comparisons in the same study and no modification in the alpha value was made to correct for this. Therefore, eight additional subsets of the data were re-analyzed for significance. The data incorporated into each of these subsets were randomly selected to include only one baking soda and one non-baking soda toothpaste from each multiple comparison study. Also, only the baseline single-brushing comparison from the four-week clinical study was included in these subsets to avoid affecting the results with any potentially lasting effects due to plaque growth inhibition by either toothpaste. In total, each data subset included six comparisons of baking soda with non-baking soda toothpastes.

The complete data set comparing the plaque index reductions at each site due to brushing with the baking soda toothpastes and non-baking soda toothpastes was graphed and regression analyses were performed. Additionally, plots of the percent relative plaque removal advantage for the baking soda toothpastes versus absolute reductions in plaque index due to brushing with the corresponding non-baking soda toothpastes were made.

Results

Table II summarizes the average percent relative plaque removal advantage found for the baking soda toothpastes over the non-baking soda toothpastes in each study comparison in each region of the dentition. Each comparison indicates a generally greater plaque removal advantage for baking soda toothpastes over non-baking soda toothpastes in areas where there are lower reductions in plaque index due to brushing with the non-baking soda toothpastes. Thus, in 11 out of 14 comparisons, baking

Table II
Individual Study Comparisons
Baking Soda Toothpaste's Percent Relative Plaque Removal
Advantage for More and Less Accessible* Areas of the Dentition

Area (Access)*	Anterior (Easy)	Posterior (Difficult)	Facial (Easy)	Lingual (Difficult)	Mid-Surface (Easy)	Proximal (Difficult)
Comp. 1	20.68	59.07	12.00	80.93	17.30	34.50
Comp. 2	41.93	119.13	21.00	154.87	36.67	51.67
Comp. 3	50.48	187.15	29.88	207.75	83.45	154.18
Comp. 4	36.70	52.08	14.80	73.78	36.10	52.68
Comp. 5	20.60	50.83	16.58	54.85	28.65	42.78
Comp. 6	32.60	31.78	9.28	55.10	30.33	34.05
Comp. 7	16.65	30.05	10.98	35.73	23.15	23.55
Comp. 8	56.98	70.15	25.80	101.33	50.23	76.90
Comp. 9	49.53	47.15	18.60	78.08	39.28	57.40
Comp. 10	33.95	41.10	22.48	52.58	35.06	40.00
Comp. 12	27.40	23.75	15.43	35.73	25.25	25.90
Comp. 13	30.43	32.38	15.65	47.15	25.63	37.18
Comp. 14	81.20	118.98	87.43	112.75	79.38	120.80
Comp. 15	118.45	217.30	77.98	257.78	123.85	211.90
Average	44.6	76.8	27.4	95.5	46.0	69.8
Std. Dev	38.7	96.0	28.8	89.5	51.8	83.9

*See Discussion

soda toothpastes were numerically relatively more effective in removing plaque from posterior than anterior teeth, in 14 out of 14 they were relatively more effective in removing plaque from lingual than facial areas, and in 14 out of 14 comparisons they were relatively more effective in removing plaque from proximal than mid-surface sites.

Figure 1 provides a plot of the data from Study 1 comparing the reduction in plaque index at various sites in the dentition resulting from brushing with a toothpaste containing 65% baking soda (A) with the reduction obtained due to brushing with a non-baking soda toothpaste (K). The results exemplify the linear relationship found in each of the 14 comparisons between baking soda and non-baking soda toothpastes. In all of the toothpaste comparisons, the baking soda toothpastes generally removed significantly more plaque ($p < 0.05$) than those not containing baking soda in most regions of the dentition.
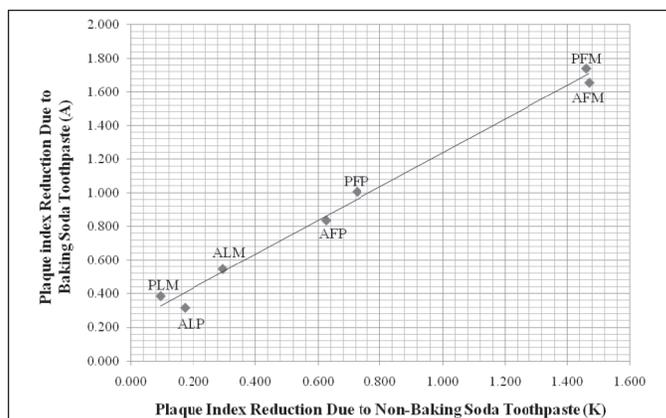

Figure 1. *Plaque index reduction due to baking soda (A) toothpaste versus a non-baking soda toothpaste (K). PFM = posterior-facial/mid-surface; AFM = anterior-facial/mid-surface; PFP = posterior-facial/proximal; AFP = anterior-facial/proximal; ALM = anterior-lingual/mid-surface; ALP = anterior-lingual/proximal; PLM = posterior-lingual/mid-surface; PLP = posterior-lingual/proximal.*

Figures 2, 3, and 4 provide graphs of the data from Studies 1, 2, and 3 listed in Table I, correlating the percent relative plaque removal advantage for baking soda toothpastes with plaque index reduction by the non-baking soda triclosan/copolymer toothpaste.
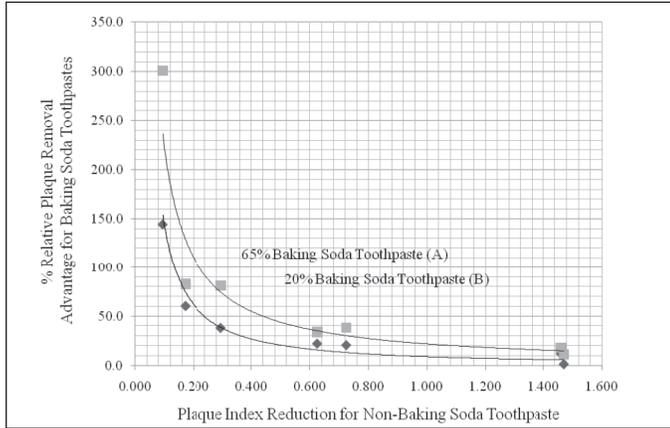

Figure 2. *Percent relative plaque removal advantage for baking soda toothpastes (A and B) over non-baking soda toothpaste (K).*
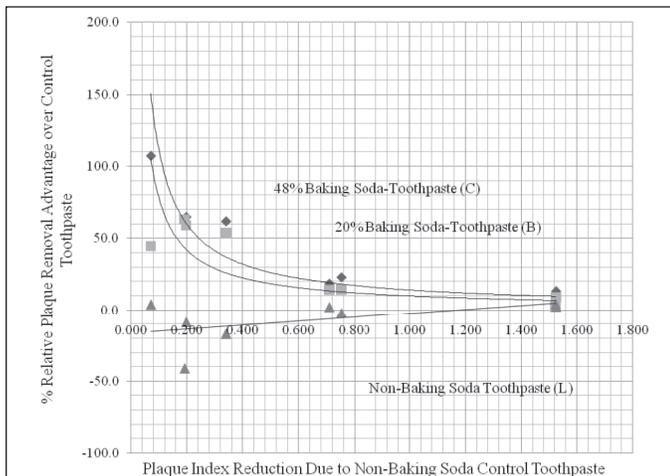

Figure 3. *Percent relative plaque removal advantage for three toothpastes (C, B, and L) over non-baking soda toothpaste control.*
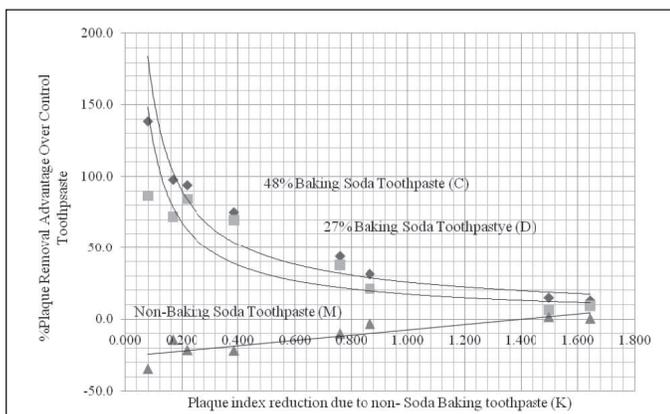

Figure 4. *Percent plaque removal advantage for three toothpastes (C, D, and M) over a non-baking soda toothpaste (K).*

Figure 2 shows the results from Study 1 comparing a toothpaste containing 65% baking soda (A) and a toothpaste con-

taining 20% baking soda (B) with a non-baking soda toothpaste (K). Clearly, both baking soda toothpastes show a hyperbolic increase in relative plaque removal advantage over the non-baking soda toothpaste in areas of decreasing plaque reduction due to brushing with the non-baking soda toothpaste. Statistical comparisons show that the 65% baking soda-containing toothpaste removed significantly more plaque at every site than the non-baking soda toothpaste (p < 0.05), while the toothpaste containing 20% baking soda removed significantly more plaque from six out of the eight areas analyzed (p < 0.05). The dentifrice containing 20% baking soda did not demonstrate statistical superiority at the anterior facial/mid-surface and anterior lingual/mid-surface areas. It may be noted that the toothpaste containing 65% baking soda significantly outperformed the toothpaste containing 20% baking soda at the posterior facial/proximal and posterior lingual/mid surface sites (p < 0.01), but not at the other sites.

Figure 3 shows the results from Study 2, which compared toothpastes containing 48% (C) and 20% (B) baking soda with two non-baking soda toothpastes. The relative plaque removal advantages for the two baking soda toothpastes and for one of the non-baking soda toothpastes (L) are plotted against the plaque index reduction due to brushing with the other non-baking soda toothpaste (K). Once again the baking soda toothpastes were seen to exhibit a hyperbolic increase in relative plaque removal advantage over the non-baking soda toothpaste (K) in areas of decreasing plaque removal by the non-baking soda toothpaste. Statistical analyses show that the 48% baking soda-containing toothpaste removed significantly more plaque from seven out of eight of the areas analyzed than the non-baking soda toothpaste (K; p < 0.01). Significance was not achieved at anterior-facial/mid-surface sites. The toothpaste (B) containing 20% baking soda removed significantly more plaque than the non-baking soda control (K) at five out of the eight areas analyzed (p < 0.05). In this study, plaque removal by the dentifrice containing 20% baking soda did not perform significantly differently than that of the control toothpaste (K) at the anterior-facial/mid-surface, posterior-lingual/proximal, and anterior-facial/proximal sites. None of the differences in plaque removal between the two baking soda toothpastes were statistically significant. Furthermore, no significant plaque removal advantage between the two non-baking soda toothpastes could be detected at any site in the dentition.

Figure 4 provides graphs of the results from Study 3 for toothpastes containing 48% (C) and 27% (D) baking soda, and two non-baking soda toothpastes. The relative plaque removal advantage for the two baking soda toothpastes and for one of the non-baking soda toothpastes (M) are plotted against the plaque index reduction due to brushing with the other non-baking soda toothpaste (K). In this study also, the baking soda toothpastes were seen to exhibit a hyperbolic increase in relative plaque removal advantage over the non-baking soda toothpaste in areas of decreasing plaque removal by the control toothpaste (K). Statistical analyses show that the 48% baking soda-containing toothpaste (C) removed significantly more plaque than the control toothpaste (K) at each of the eight areas analyzed (p ≤ 0.01). The toothpaste (D) containing 27% baking soda removed significantly more plaque from five of the eight areas analyzed (p < 0.05). In this study, the dentifrice

containing 27% baking soda did not perform significantly differently than the control dentifrice at the anterior-facial/mid-surface, posterior-lingual/proximal, and posterior-facial/mid-surface sites. The plaque removal differences between the two baking soda toothpastes were not found to be statistically significant. Also, no performance difference between the two non-baking soda toothpastes could be detected.

The graphs in Figures 2, 3, and 4 discussed above exemplify the results from each of the other studies listed in Table I. Thus, each comparison of baking soda toothpaste and non-baking soda toothpaste consistently showed a hyperbolically increasing plaque removal advantage for the baking soda toothpaste over the non-baking soda toothpaste with which it was compared.

The overall combined average relative plaque removal advantage for the baking soda toothpastes at each site is shown in Figure 5. For ready comparison, these results are shown side by side on a bar chart, with the overall mean plaque index reduction scores for the non-baking soda toothpastes at the same locations within the dentition. It can be seen that the average percent plaque removal advantage for the baking soda toothpastes generally increased with decreasing plaque removal from a site by the non-baking soda toothpaste.
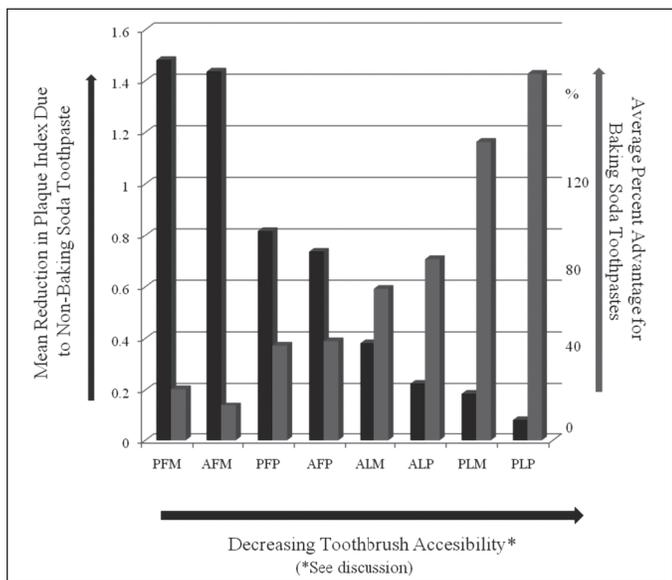

Figure 5. *Relative plaque removal advantage for baking soda toothpastes (gray) versus plaque index reduction due to non-baking soda toothpastes at each site (black). PFM = posterior-facial/mid-surface; AFM = anterior-facial/mid-surface; PFP = posterior-facial/proximal; AFP = anterior-facial/proximal; ALM = anterior-lingual/mid-surface; ALP =anterior-lingual/proximal; PLM = posterior-lingual/mid-surface; PLP = posterior-lingual/proximal.*

Table III provides the results of meta-analytical paired t-tests comparing the relative effectiveness of baking soda and non-baking soda toothpastes in removing plaque against areas where the non-baking soda toothpaste removed relatively more or less plaque. In each of the comparisons, the relative plaque removal effectiveness of the baking soda toothpastes was significantly greater in areas where the non-baking soda toothpastes removed less plaque. Thus, baking soda toothpastes were relatively more effective in removing plaque from posterior than anterior tooth surfaces ($p < 0.005$), from lingual than facial

Table III
Meta-Analysis Over All Comparisons
Plaque Reduction Advantage for Baking Soda Toothpaste

	Ant. (Easy)	Post. (Difficult)	Facial (Easy)	Lingual (Difficult)	Mid-Sf. (Easy)	Proximal (Difficult)
N	54		54		54	
Average	44.6	76.8	27.4	95.5	46.0	69.8
Std. Dev	38.7	96.0	28.8	89.5	51.8	83.9
SEM	5.3	13.3	3.9	12.2	7.0	11.4
Diff (S Dev)	− 32.2% (70.5)		− 68.1% (78.6)		− 23.8% (39.3)	
t-stat (Sig)	− 3.35 (p < 0.005)		− 6.37 (p < 0.0001)		− 4.4 (p < 0.0001)	
95% CL	− 51.4%, − 12.9%		− 89.6%, − 46.1%		− 34.5%, − 13.1%	

surfaces ($p < 0.0001$), and from proximal than mid-surface sites ($p < 0.0001$).

Table IV provides the results of additional meta-analytical Student's paired t-tests on subsets of the data used in Table III, further establishing the relative effectiveness of baking soda toothpastes in removing plaque at various areas of the dentition. These subsets include only a single comparison of a baking soda and non-baking soda toothpaste from each study, avoiding any questions concerning the need for adjustments to the alpha value used in the t-test due to multiple comparisons. It can be seen that in all but one of the 24 paired t-tests (*i.e.*, subset 3, Anterior versus Posterior), the baking soda toothpastes were confirmed to be relatively more effective in removing plaque from those areas where the non-baking soda toothpastes removed less plaque ($p < 0.05$). While seven of the eight data sets comparing anterior and posterior data clearly indicated a significantly greater relative plaque removal advantage for baking soda toothpastes in removing plaque from areas where the non-baking soda toothpaste removed less plaque ($p < 0.05$), the data comparison for the other data subset was at least suggestive of such a difference ($p = 0.06$).

Table IV
Meta-Analytical Student's Paired t-Test Results on Data
Subsets Without Multiple Comparisons. Mean % Plaque
Reduction Advantage for Baking Soda Toothpaste*

	Anterior	Posterior	Sig.	Facial	Lingual	Sig.	Mid-Surf.	Prox.	Sig.
SS1	47.2	87.8	p < 0.05	31.7	105.0	p < 0.001	50	81.3	p < 0.01
SS1	42.0	87.4	p < 0.05	31.4	100.0	p < 0.005	46.9	73	p < 0.05
SS3	45.2	80.3	p = 0.06	29.5	97.7	p < 0.001	44.1	74.7	p < 0.01
SS4	42.5	86.8	p < 0.05	31.7	99.5	p < 0.005	47.7	72.1	p < 0.05
SS5	44.8	87.6	p < 0.05	31.1	103.2	p < 0.005	48.2	74.7	p = 0.01
SS6	45.9	91.4	p < 0.05	32.0	107.3	p = 0.001	49.4	78.4	p < 0.01
SS7	43.1	83.6	p < 0.05	30.8	97.6	p < 0.005	46.8	76.2	p < 0.01
SS8	42.0	79.7	p < 0.05	29.9	93.6	p < 0.005	45.7	72.5	p = 0.01

*Each subset includes only single comparisons of baking soda and non-baking toothpastes from each study

Figure 6 provides a composite plot comparing the plaque index reductions due to baking soda toothpaste and non-baking soda toothpastes at each site in the mouth. The plot indicates that plaque removal due to brushing with the baking soda toothpastes increased as a linear ($R^2 = 0.99$) function of the increase in plaque removal due to brushing with the non-baking soda toothpastes. However, the line does not go through the origin, but
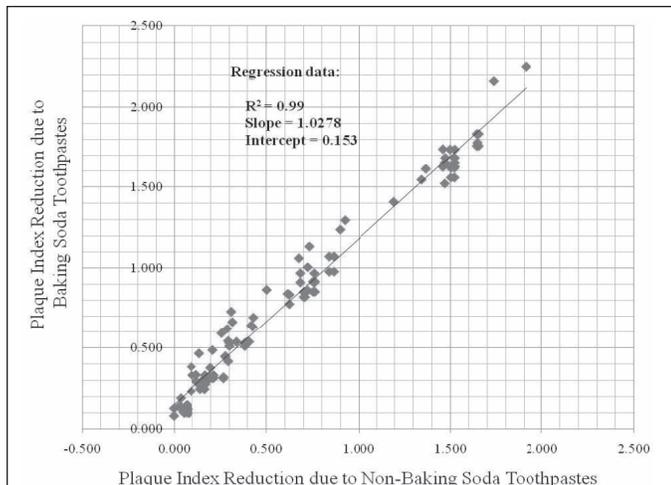
Figure 6. *Plaque index reduction due to baking soda toothpastes versus non-baking soda toothpastes.*

is displaced upwards indicating more effective plaque removal by the baking soda toothpastes where the non-baking soda toothpastes remove little or no plaque. Based on a meta-analytical linear regression analysis, the intercept with the y-axis is at 0.153, with a 95% CI of 0.128 to 0.179.

Figure 7 provides a composite plot of the percent relative plaque removal advantage found for the baking soda toothpastes over non-baking soda toothpastes versus plaque index reduction for the non-baking soda toothpaste at each area of the mouth. The plot indicates that baking soda toothpastes exhibited a hyperbolic increase in relative plaque removal advantage over the non-baking soda toothpaste in areas of decreasing plaque removal by the non-baking soda toothpaste.
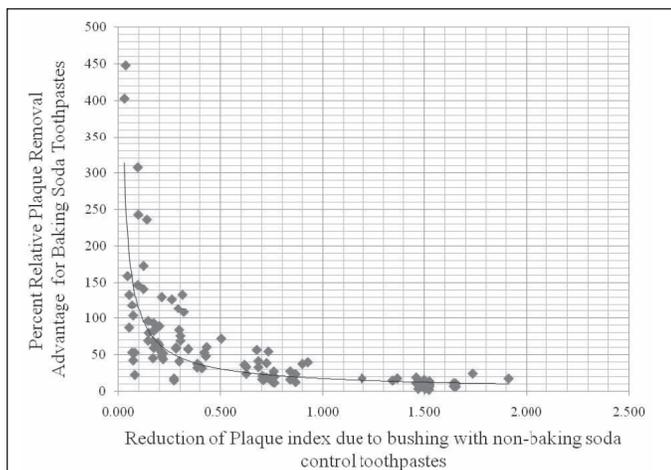

Figure 7. *Percent plaque removal advantage for baking soda toothpastes over non-baking soda toothpastes.*

Discussion

Based on the literature, there seems to be a preponderance of evidence that conventional toothpastes do not materially affect the toothbrush's ability to remove plaque during brushing.[5-12] It seems logical, therefore, to assume that any differences in plaque removal between sites due to brushing with a conventional toothpaste be attributed to differences in toothbrush accessibility at those sites. Hence, it appears reasonable to use plaque index

reductions by the non-baking soda toothpastes as a measure of site accessibility in this study.

The black bars in Figure 5 show the order of decreasing plaque removal due to brushing with non-baking soda toothpastes. This bar chart provides an indication of the relative accessibility of each site by the toothbrush. The figure indicates that the facial areas of the teeth are more accessible than the lingual areas. Also, the mid-surface sites are more accessible than the corresponding proximal sites. However, differences in the accessibility of the posterior and anterior teeth are less clear cut. There seems to be little, if any difference in accessibility between the corresponding posterior and anterior facial surfaces, while the anterior surfaces would appear to be more accessible than posterior surfaces in the corresponding lingual areas. The results of these comparisons would seem to be reasonably within expectation.

In this study, the data from each of 14 comparisons of toothpastes containing baking soda with those without baking soda were examined. Only a limited number of the comparisons have been shown graphically in this paper. However, the trends from all of these comparisons are surprisingly similar to the ones graphed in the figures. Thus, in each study the plaque removal performance of the baking soda toothpastes significantly exceeded that of the non-baking soda toothpastes at most sites in the dentition ($p < 0.05$). Furthermore, the relative plaque removal advantage for baking soda toothpastes increased hyperbolically with decreasing plaque removal by the non-baking soda toothpaste, and hence decreasing accessibility of the site by the toothbrush.

The data from each study was then combined into a single data set, and the relative performance of baking soda toothpastes with non-baking soda toothpastes was compared at each site in the dentition. The trend confirmed what was seen in the individual comparisons, which is that toothpastes containing baking soda are increasingly more effective in removing plaque than non-baking soda toothpastes as accessibility to the tooth site is decreased.

An initial meta-analysis across all studies confirmed that the relative plaque removal advantage for baking soda toothpastes is significantly greater in harder-to-reach areas of the dentition than easier-to-reach areas. Because of the concern that this meta-analysis included data from multiple comparisons without correction of the alpha value, additional meta-analyses were performed on eight subsets of the data. These data only included results from a single comparison of one baking soda and one non-baking soda toothpaste from each study, thus avoiding increasing the chances of seeing differences where there are none. It should be noted that there are approximately sixteen possible subsets that could have been chosen for these additional analyses. The eight subsets included in this study were chosen at random.

In all but one out of 24 resulting comparisons, the baking soda toothpastes were shown to be relatively more effective in areas with less access by the toothbrush ($p < 0.05$). The clearest significant differences in relative plaque removal were seen in comparing facial versus lingual areas with $p < 0.005$ for all eight data subset comparisons. The differences in relative plaque removal between mid-surface and proximal sites were also highly significant, with most comparisons being significant at $p < 0.01$.

While all but one of the anterior versus posterior comparisons achieved significance with a p-value < 0.05, the differences in relative plaque removal performance seemed less consistent between these teeth. The reason for this is probably that there are almost no differences, if any at all, in access to anterior and posterior sites on corresponding facial areas of the teeth. The differences in access to anterior and posterior teeth are largely limited to the less accessible lingual areas.

Finally, the complete data set was assessed graphically. A plot of plaque index reduction due to brushing with baking toothpastes versus plaque index reduction due to brushing with non-baking soda toothpastes provides a linear relationship (Figure 6) with an R^2 value of 0.99. This shows, as expected, that there is a strong correlation between plaque removal due to brushing with baking soda toothpastes and that due to brushing with non-baking soda toothpastes. However, when the percent plaque removal advantage for baking soda toothpastes is plotted against plaque index reduction due to brushing with non-baking soda toothpastes (Figure 7), a hyperbolic increase in relative advantage for baking soda toothpastes is seen with decreasing access to the tooth site.

The reason for this phenomenon can be understood by considering the linear graph comparing the plaque index reductions for baking soda and non-baking soda toothpastes. The line does not go through the origin. In fact, regression analysis shows that plaque index reduction due to the baking soda toothpastes is 0.153 ± 0.025 at the intercept with the y-axis, *i.e.*, where brush access to the site is zero. Hence, baking soda toothpastes are predicted to reduce plaque to some degree even in areas where the toothbrush cannot reach, and thus where no plaque is removed by the non-baking soda toothpastes. Therefore, as brush access tends toward zero, the relative plaque advantage for baking soda toothpastes tends toward infinity.

The evident efficacy of baking soda in removing plaque during brushing raises the intriguing question of its mode of action. Since baking soda reduces plaque even in areas where the toothbrush does not have access, as demonstrated above, there is a high probability that it is dissolved baking soda rather than the undissolved sodium bicarbonate particles that are responsible for baking soda's activity. That would rule out physical displacement, such as abrasion, as the mode of action. The fact that baking soda tends to be very low in abrasion further supports this hypothesis.[20,21]

It also seems highly unlikely that baking soda's effect on plaque could be due to its possible antimicrobial activity. Baking soda at high concentrations has been shown to exhibit slow acting, weak antimicrobial properties.[22] However, since it is quite soluble and not substantive to surfaces, it is lost from the mouth soon after brushing. Hence, the plaque reductions due to baking soda seen in this study are not likely due to direct attack by baking soda on oral bacteria.

It seems most likely that baking soda physically disrupts plaque in some way; for example, by disturbing the plaque matrix and reducing its viscosity. Alternatively, perhaps baking soda breaks the bonds between bacteria or the bonds between bacteria and the tooth surface. Rose, *et al*. suggested that sodium fluoride might detach plaque from teeth by just such a process.[23] They proposed that fluoride sequesters calcium, thereby breaking bonds mediated by calcium. Busscher, *et al.* provided evidence of this effect with sodium fluoride and sodium lauryl sulfate.[24] Because of the very low concentrations of these ingredients in toothpastes, any such effect would be fairly minimal, perhaps undetectable. Hence, toothpastes are not generally seen to enhance plaque removal. However, the baking soda content in all of the toothpastes evaluated in these studies is one or two orders of magnitude higher, and would be close to or above saturation during brushing. While baking soda is not a very powerful "sequestrant" of calcium, calcium carbonate can precipitate from aqueous baking soda solutions containing calcium ions.

One obvious question is whether there are any oral care benefits resulting from baking soda's ability to promote plaque removal especially from hard-to-reach areas. In sites where there is ready access of the toothbrush to the tooth site, the absolute plaque removal advantage for baking soda toothpastes over the non-baking soda toothpastes averaged about 10% after a single brushing. Presumably, after repeated regular twice-daily brushing, the net reduction in plaque would be higher since plaque regrowth is from a lower starting point. The baking soda advantage in less accessible areas is relatively larger. However, much less plaque is being removed in very inaccessible areas. Hence, it is difficult to assess whether the removal of such small amounts of plaque has a benefit.

That there is a greater reduction in plaque after repeated regular brushings is supported by the data shown in Table V, which is extracted from the published data from the four-week plaque study.[15] In this study, a single brushing with a toothpaste containing 20% baking soda resulted in global mouth plaque index reduction averaging 18.6%, whereas after a single brushing with a non-baking soda toothpaste the global mouth plaque index reduction averaged 9.7%. Four weeks after commencement of the study, prior to brushing, the plaque index was 12.1% below the initial baseline in subjects who brushed with the baking soda toothpaste, whereas it was 5.5% below the initial baseline in those who brushed with the non-baking soda toothpaste. After one additional brushing, the cumulative reduction in plaque reached 27.9% for the baking soda toothpaste and 13.1% for the non-baking soda toothpaste. As shown in the table, a similar trend is seen in the more difficult-to-access lingual area. The next steps will be to confirm the benefits in clinical studies.

Table V
Plaque Index Reduction in 4-Week Plaque Study

	Whole Mouth		
	After Single Brushing	Pre-Brushing After 4 weeks	Post-Brushing After 4 weeks
Baking Soda Toothpaste (B)	18.6%	12.1%	27.9%
Non-Baking Soda Toothpaste (K)	9.7%	5.5%	13.1%
	Lingual Sites		
	After Single Brushing	Pre-Brushing After 4 weeks	Post-Brushing After 4 weeks
Baking Soda Toothpaste (B)	8.1%	7.8%	17.6%
Non-Baking Soda Toothpaste (K)	4.0%	3.7%	7.0%

Conclusions

While several dentifrice ingredients, especially those which exhibit antimicrobial activity, have been shown to inhibit plaque regrowth, baking soda is the only ingredient which has actually been demonstrated to promote the removal of plaque already present on tooth surfaces. Analyses in this paper show that baking soda toothpastes consistently provide a progressively increasing relative plaque removal advantage over other toothpastes as accessibility by the toothbrush is decreased.

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