**Effect of Kibble Size, Shape, and Additives on Plaque in Cats**

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**Summary:**

Forty mixed-breed cats completed a parallel-group, clinical study to compare supragingival plaque accumulation using a triangular or rectangular shaped dry-expanded diet, with or without an anti-calculus agent (sodium tripolyphosphate) or an anti-plaque agent (plaque-reducing nutrient). The cats were divided into 4 equal groups based on plaque scores. Results showed that coating the kibble with sodium tripolyphosphate had no effect on plaque accumulation. Increasing the surface area and volume and changing the shape of the kibble was associated with a reduction in plaque accumulation, and coating the kibble with a plaque-reducing nutrient further reduced plaque accumulation. The importance of a combination of both mechanical abrasion (chewing) and chemical interference (plaque-reducing nutrient) was demonstrated in this study.

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**Introduction**

Periodontal disease is a significant problem in client-owned cats. While there are many factors that contribute to its prevalence, bacterial plaque is the primary cause of periodontal disease and thus plays a key role in its pathophysiology. Dental plaque is the term that is universally used to describe the bacteria associated with tooth surfaces. Plaque is actually an organic, transparent, adhesive biofilm consisting of salivary glycoproteins, oral bacteria, and extracellular polysaccharides that adhere to the tooth surface and oral tissues. The extracellular organic matrix of supragingival plaque consists of approximately 30% carbohydrates, 30% proteins, 15% lipids, and 25% varied or undefined material. The inorganic components, principally calcium and phosphates, are provided by foodstuffs and saliva.

Dental plaque is not a food residue. It forms within minutes of cleaning a tooth surface and continues to form even while eating and sleeping. The bacteria usually comprise the resident flora of the mouth which is predominantly aerobic, gram (+), colony-forming, non-motile cocci during the initial stages of plaque formation.

Plaque begins to calcify, forming dental calculus within 72-hours. Calculus is not the primary cause of periodontal disease, but once formed it is invariably covered with newly-formed dental plaque, promoting the disease process. Plaque initiates an inflammatory response upon contact with the gingival margin. This often results in edematous gingiva and increased periodontal sulcus depth that further serve to trap dental plaque subgingivally. The resultant inflammatory response may lead to periodontitis and ultimately tooth loss if not treated.

Regardless of the disease stage, plaque control is critical to therapeutic success. Numerous methods have been proposed for mechanical and chemical plaque control. Although toothbrushing is considered the most effective method of plaque removal for humans, it is not a practical therapeutic method for cats since few owners are diligent in brushing their cat’s teeth and many cats will not allow foreign objects to be placed in their mouth. The few published studies demonstrating effective plaque reduction in cats have used diets, dental chews, toothbrushing, gels, and a drinking water additive. For many cats, dental prophylaxis requiring owner participation and compliance as well as cat acceptance is rarely performed, and treatment is often initiated when problems are identified.

The purpose of the current study was to determine if the size and shape of dry-expanded kibbles, as well as the addition of an anti-calculus agent (sodium tripolyphosphate, STPP) and an anti-plaque agent (plaque-reducing nutrient, PRN), would result in significant plaque reduction in cats.

**Materials and Methods**

Forty mixed-breed cats, age 1.5 to 7.2-years (mean = 2.9-years), and weighing 2.9 to 5.8 kgs (mean = 4.2-kgs) participated in the study. The 24 male cats were not neutered and the 16 female cats were spayed. Each cat had full dentition, normal occlusion, no grossly visible pathology on oral and periodontal examination, and was clinically healthy based on a complete physical examination, CBC, serum chemistry panel, and urinalysis. Each tooth was examined using a Williams periodontal probe to ensure that normal periodontal sulcus depths were present. The subjects were housed in 4 groups of 10 cats, and were provided their respective diet and water *ad libitum*. Each cat had been vaccinated against feline rhinotracheitis, calicivirus, and panleukopenia using a modified live vaccine. Feline leukemia and feline immunodeficiency viruses have not been detected in the colony since its establishment in 1976. The study was conducted in an approved animal care facility (Massey University’s Centre for Feline Nutrition) and the protocol was approved by, and followed the requirements of Massey University’s Animal Ethics Committee.

The cats were exclusively fed dry-extruded diets throughout the 49-day study. No treats, chews, toys, or dental hygiene products were provided to the cats for the duration of the study. Four different dietary regimens were compared (Table 1). All diets were formulated to meet the nutritional requirements established by the Association Of American Feed Control Officials (AAFCO) for adult maintenance. All diets were assessed for kibble thickness, penetration, hardness, and Fmax using a texturometer to ensure consistency and comparison (Table 1).

At the beginning of the study (day -21), all cats were fed diet A for 14 days to accustom them to a dry diet (Fig. 1). At the end of this pre-study phase (day-7), all cats were anesthetized using ketamine *hydrochloride* (5.0 mg/kg) and medetomidine *hydrochloride* (80.0 mg/kg) IM and their teeth thoroughly scaled (subsonically) and polished with a fine grade paste. The anesthetic was reversed using atipamezole *hydrochloride* (40.0 mg/kg) IM. Each cat was allowed to recover in an individual cage

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Table 1
Characteristics of the four experimental dry-kibble diets.

<table>
<thead>
<tr>
<th></th>
<th>Diet A</th>
<th>Diet B</th>
<th>Diet C</th>
<th>Diet D</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Shape</strong></td>
<td>Triangle</td>
<td>Triangle</td>
<td>Rectangle</td>
<td>Rectangle</td>
</tr>
<tr>
<td><strong>Size (mm)</strong></td>
<td>9 x 9 x 5</td>
<td>9 x 9 x 5</td>
<td>13 x 13 x 9</td>
<td>13 x 13 x 7</td>
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<tr>
<td><strong>Additive</strong></td>
<td>None</td>
<td>STPP</td>
<td>None</td>
<td>STPP, PRN</td>
</tr>
<tr>
<td><strong>Surface Area (mm²)</strong></td>
<td>216</td>
<td>216</td>
<td>806</td>
<td>702</td>
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<tr>
<td><strong>Volume (mm³)</strong></td>
<td>202.5</td>
<td>202.5</td>
<td>1421</td>
<td>1183</td>
</tr>
<tr>
<td><strong>Thickness (mm)</strong></td>
<td>5.3</td>
<td>5.3</td>
<td>9.1</td>
<td>7.3</td>
</tr>
<tr>
<td><strong>Penetration (mm)</strong></td>
<td>1.6</td>
<td>1.5</td>
<td>3.3</td>
<td>2.6</td>
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<tr>
<td><strong>Fmax (N)</strong></td>
<td>44.7</td>
<td>42.8</td>
<td>57.4</td>
<td>55.1</td>
</tr>
<tr>
<td><strong>Hardness (N/mm)</strong></td>
<td>56.3</td>
<td>59.1</td>
<td>31.3</td>
<td>72.5</td>
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<td><strong>Work (Fmax)</strong></td>
<td>38.3</td>
<td>37.2</td>
<td>89.2</td>
<td>37.2</td>
</tr>
</tbody>
</table>

* = measured using a texturometer; STPP=sodium tripolyphosphate; PRN=plaque-reducing nutrient.

Figure 1
Study overview including diet allocation and dental examinations.

before being returned to group housing. Water and diet A were provided *ad libitum*.

After 7 days (day 0), evaluation of plaque on the target teeth was performed under general anesthesia as described previously. Tooth surface area covered by plaque was scored as 0 = no observable plaque; 1 = < 25 % plaque coverage; 2 = between 25 and 50 % plaque coverage; 3 = between 50 and 75 % plaque coverage; 4 = between 75 and 100 % Plaque staining intensity was scored as 1 = pink to light red; 2 = red; 3 = dark red. Following plaque evaluation and scoring, each cat again had its teeth thoroughly scaled and polished as described previously. Cats were designated to begin the study according to the “clean tooth model” following confirmation of the absence of plaque with a disclosing agent (2 % erythrosine). After recovery in individual cages, the cats were allocated to 4 groups of 10 based on their total mouth plaque scores, such that each group had an identical baseline mean total mouth plaque score. The 4 diets to be evaluated were assigned randomly on day 1 (group 1 received diet A, group 2 received diet B, group 3 received diet C, and group 4 received diet D). On days 7 and 28, plaque accumulation was evaluated and scored under general anesthesia. The same scorer (DEC) was used at both evaluations and was blinded to the feeding regimens and the scoring order. Cats presented to the scorer were randomly selected from each group at each evaluation.

Plaque evaluation scores were determined based on visual assessment of plaque thickness and coverage on the buccal surface of the target teeth. Scoring was aided by applying 2 % erythrosine to the teeth followed by rinsing with water and gently drying the tooth with air. The 14 target teeth were the maxillary canines (104/204), maxillary third premolars (107/207), maxillary fourth premolars (108/208), mandibular canines (304/404), mandibular third premolars (307/407), mandibular fourth premolars (308/408), and the mandibular first molars (309/409).

The tooth crown was divided horizontally into gingival and coronal halves and each half assigned a numerical score for both plaque coverage (Table 2) and plaque thickness (Table 3). The individual coverage and thickness scores from the gingival half of the tooth were multiplied to obtain the “gingival half score.” The
coverage and thickness scores from the coronal half of the tooth were multiplied to obtain the “coronal half score.” The gingival and coronal half scores were added to obtain the total tooth score. The sum of the 14 gingival half tooth scores was divided by the number of target teeth (n = 14) to obtain a “mean gingival score” for each cat. The sum of the 14 coronal half tooth scores was divided by the number of target teeth (n = 14) to obtain a “mean coronal score” for each cat. The sum of the 14 total tooth scores was divided by the number of target teeth (n = 14) to obtain a “mean mouth score” for each cat.

Data were confirmed to have a Gaussian distribution. A repeated-measures design was used to derive F-tests for significant differences between treatments. The Bonferroni procedure was used for post hoc analysis. F-values with P < 0.05 were considered significant. All analyses were performed using the General Linear Model procedure. Data are expressed as mean ± SEM.

**Results**

The day 7 mean mouth whole tooth plaque scores for cats receiving diets A and B were the same (11.8) and there was no significant difference between mean gingival half of tooth plaque scores for diet A (7.1) and diet B (7.4) [Figs. 2 and 3]. The mean mouth whole tooth plaque score for cats fed diet C (9.2) was 22.0% less than for cats fed diet A or B (P < 0.05). The mean gingival half of tooth plaque score for cats fed diet C (5.7) was 19.4% less than diet A (P < 0.05) and 22.9% less than diet B (P < 0.05). The mean mouth whole tooth score for cats fed diet
D (8.5) was 8.1 % less than diet C (P < 0.05), while the mean gingival half of tooth score for diet D (5.2) was 9.9 % less than diet C (5.7) (P < 0.05). The mean mouth whole tooth score for cats fed diet D was 28.3 % less than for cats receiving diets A or B (P < 0.05), and the mean gingival half of tooth score was 27.3 % less for diet A (P < 0.05) and 30.5 % less for diet B (P < 0.05).

The day 28 mean mouth whole tooth scores for cats fed diet A or B were the same (12.0) and there was no significant difference in mean gingival half of tooth scores of the cats fed diet A (7.0) or diet B (6.8) [Figs. 4 and 5]. The mean mouth whole tooth score for cats fed diet C (9.4) was 21.0 % less than for cats fed diet A or B (P < 0.05). The mean gingival half of tooth score for diet C (5.5) was 21.5 % less than diet A (P < 0.05) and 18.6 % less than diet B (P < 0.05). The mean mouth whole tooth score for cats fed diet D (8.4) was 11.6 % less than the cats fed diet C (P < 0.05), and the mean gingival half of tooth score for diet D (4.8) was 12.9 % less than for diet C (P < 0.05). The mean mouth whole tooth score for cats fed diet D was 30.0 % less for the cats fed diet A or B (P < 0.05), and the mean gingival half of tooth score was 31.7 % less than diet A (P < 0.05) and 29.2 % less than diet B (P < 0.05).

Discussion

Periodontal disease is a significant problem in client-owned domestic cats and has been reported to occur in up to 85 % of cats older than 6-years of age. Dental plaque and bacteria play a key role in the pathogenesis of this disease. Although plaque accumulates over the entire tooth surface, it is the direct contact of
the plaque biofilm with the gingival margin and the periodontal sulcus that results in gingivitis, periodontitis and, ultimately, tooth loss and adverse systemic effects. Therefore, decreasing plaque accumulation on the gingival half of the tooth could result in an improvement in feline oral health.

Cats eat everyday justifying the rationale that a diet that provides genuine dental losses and expanded diets provide dental cleaning as the cats eat. However, to the authors' knowledge, there are no published long-term studies to confirm this theory.

In this study, cats fed a diet (diet B) containing an anti-calculus agent (STPP) had no significant reduction in plaque accumulation when compared with cats fed the same diet (diet A) without STPP at the day 7 and 28 evaluations. These results confirm that STPP does not reduce plaque accumulation. Polyphosphates, such as STPP, are mineral chelators and mineralization inhibitors. These agents bind salivary calcium, making it unavailable for calcification into the plaque biofilm to form calculus.

The present study showed that at both the day 7 and 28 evaluations, the cats fed diets A or B accumulated significantly more plaque, both on the gingival half of the tooth and the whole tooth, compared with cats fed diet C. At the day 7 evaluation, the cats fed diets A or B had accumulated an additional 28.2% plaque over the whole tooth, and 24.6% and 29.8% over the gingival half of the tooth, respectively. At the day 28 evaluation, the cats fed diets A or B accumulated an additional 27.7% more plaque over the whole tooth, and 27.7% and 23.6% over the gingival half of the tooth, respectively. These plaque reductions with Diet C can be explained by the larger kibble size and shape compared with the triangular kibble shape of Diets A and B. Diet C was rectangular and had a greater surface area (273%) and volume (651%) compared with diets A and B. The rectangular shaped diet C also had a greater kibble thickness (9.1 mm) compared with the kibble thickness (5.3 mm) for diets A and B leading to an enhanced penetration value (1.6-mm and 1.5-mm respectively, compared with 3.3-mm for diet C). We conclude that the shape and size of the kibble allowed better prehension with an increase in tooth penetration into the food, causing a proportional increase in mechanical abrasion and a reduction in plaque accumulation.

The results of this study also showed that, at both evaluations, cats fed diets A or B accumulated significantly more plaque, both on the gingival half of the tooth and the whole tooth compared with cats fed diet D. At the Day 7 evaluation, the cats fed Diets A or B had accumulated an additional 38.8% plaque over the whole tooth and 36.5% and 42.3% over the gingival half of the tooth, respectively. At the Day 28 evaluation, the cats fed Diets A or B had an additional 42.9% more plaque over the whole tooth and 45.8% and 41.7% over the gingival half of the tooth, respectively. Diet D was rectangular compared with the triangular-shaped diets A and B, increasing the diet D kibble surface area (225%) and volume (484%). The kibble thickness (7.3 mm) and penetration value (2.6 mm) for diet D was greater compared with diets A and B for thickness (5.3 mm) and penetration value (1.5 mm).

The anti-plaque agent (PRN) used in this study was coated onto the surface of diet D after manufacture of the kibble. PRN belongs to the sodium ascorbyl phosphate group of products, of which ascorbic acid (Vitamin C) is related. Ascorbic acid is commonly known as a water-soluble vitamin, which promotes wound healing, helps maintain normal connective tissue, and aids in the promotion of healthy teeth and gums. The exact relationship between plaque-induced periodontal diseases and ascorbic acid deficiency is not known. The best characterized function of ascorbic acid is in the synthesis of collagen connective tissue protein at the level of hydroxylation of prolyl and lysyl residues of procollagen. Several studies in humans have shown that a reduction in ascorbic acid intake has a direct effect on gingival inflammation, gingival bleeding, the severity and risk of periodontal disease, and amounts of visible plaque and numbers of decayed tooth surfaces.

Diet D had 12.9% less surface area, and 22.2% less volume than Diet C. Although we hypothesized that the cats fed Diet D should have accumulated slightly more plaque than the cats fed Diet C because the kibble was slightly smaller in surface area, volume, and tooth penetration, the opposite was found. When the cats were fed diet C compared with diet D, the whole tooth plaque scores revealed significantly greater accumulation of plaque, with 8.2% and 11.9% greater accumulation at the 7 and 28-day evaluations, respectively. This was also observed for gingival plaque scores, with 9.6% and 14.6% greater accumulation at the 7 and 28-day evaluations, respectively. These results confirmed that over the longer time frame there was an increasing difference between the two foods when both whole tooth and gingival half plaque scores were compared. The significant difference in plaque accumulation cannot be attributed to the physical attributes of the kibble since more plaque did not accumulate when the cats were fed the smaller kibble. Therefore, although it cannot be stated with absolute certainty, we hypothesize that the PRN was responsible for the additional reduction in plaque accumulation in the cats fed diet D.

This trial has shown that a larger kibble size with enhanced textural characteristics, producing increased abrasion and greater tooth penetration, results in a significant reduction in plaque accumulation in the early stages after teeth cleaning. It also showed that the size of the kibble was not the only characteristic which determined plaque accumulation. Thus, a significant factor in reduction of plaque accumulation over the longer term after teeth cleaning can be attributed to the addition of the PRN. Therefore, while the shape of the food enhanced its mechanical action, we hypothesize that the PRN contributed to a reduction in plaque adhering to the tooth surface, allowing it to be effectively brushed away by the action of the food as the cat chewed.

1. Felocell CVR, Norden Laboratories, München, Germany
2. Ketamine, Parnell Laboratories, Alexandria, New South Wales, Australia
3. Domitor, Novartis, North Ryde, New South Wales, Australia
4. NSK Sonic scaler, Oceanica Ltd, Waterloo, New South Wales, Australia
5. Antisedan, Novartis, North Ryde, New South Wales, Australia
6. Plaque disclose gel, Professional Dentist Supplies, Bayswater North, Australia
7. Royal Canin Indoor cat food
8. Royal Canin Indoor cat food
Hills t/d prescription diet
Royal Canin Dental s/o prescription diet

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References