Supragingival calculus predisposes to the development of periodontal disease by providing a retentive surface for plaque bacteria and impeding attempts to maintain an effective level of plaque control (47). Although the presence of calculus and gingival inflammation, as evidenced by bleeding on probing, are not always coincident (1) the close proximity of supragingival calculus to the gingiva ensures that its superficial layer of plaque bacteria is maintained in contact with the gingival tissues. The finding that oral hygiene instruction alone resulted in significant improvements in the gingival health of individuals with large amounts of calculus supports the primary role of plaque bacteria (21).

Recent studies have investigated the relationship between supragingival calculus and gingival recession (59). A selected sample of Thai children and adolescents were examined, and the amount of supragingival calculus and gingival recession was measured on the six lower anterior teeth. A significant association was observed between total calculus levels and the presence and extent of gingival recession. Two clinical studies, again involving Thai children and adolescents, demonstrated that subjects who used an anticalculus dentifrice for 1 year had significantly less supragingival calculus and gingival recession than those who used a placebo dentifrice or continued to use their customary oral hygiene procedures (60, 81).

Supragingival calculus is relatively porous and becomes stained by dietary constituents and tobacco, and its removal is generally appreciated by the individual. Although toothbrushing with a conventional toothpaste containing abrasives and detergents may interfere with its formation, the widespread prevalence of supragingival calculus clearly indicates that such measures are not generally very effective.

The dental profession spends a considerable amount of time removing supragingival calculus. In England and Wales periodontal treatment comprises approximately 23% of the treatment provided by the National Health Service (NHS) general dental services. In 1988–1989, single-visit scale and polishes cost GBP 120 million, approximately 12% of the total costs. The professional removal of supragingival calculus is frequently undertaken as part of a more comprehensive program to remove tooth deposits and provide instruction and advice regarding the maintenance of effective oral hygiene. Many factors influence how often supragingival calculus is removed, including the rate of supragingival calculus formation and whether the costs are borne by the patient or some other form of health care system. The implications of scaling and polishing have been considered in a previous review (2).

Since supragingival calculus is a predisposing factor in the development of gingivitis and recession, the development of clinically proven products that reduce its formation benefits both the profession and consumers. Anticalculus products comprise a significant sector of the oral hygiene market in many countries. For example, in the United States, anticalculus toothpaste accounted for approximately one quarter of total toothpaste sales in 1995.

Prevalence

Although calculus is prevalent in populations throughout the world, the widespread use of indices, such as the Community Periodontal Index of Treatment Needs, that do not discriminate between supragingival and subgingival calculus means that there is relatively little detailed information on the prevalence, extent and intraoral distribution of supragingival calculus per se.

Two national surveys have provided data on the prevalence of calculus in children. In the United
Kingdom, the proportion of children with calculus increased gradually from 5% among 5-year-olds to 32% of 15-year-olds (52). In the United States 34% of children aged 14–17 years had only supragingival calculus, and 23% had subgingival calculus with or without supragingival calculus (9). The prevalence of supragingival calculus only and the mean proportion of teeth affected did not increase with age. In contrast, the prevalence of subgingival calculus, with or without supragingival calculus, showed a slight but consistent increase with age for both sexes. The prevalence of both types of calculus was approximately 3% higher in boys than girls, and a higher proportion of non-white children had calculus across all age groups. Approximately 8% of teeth had supragingival calculus only and 4% had subgingival deposits. In all age groups males had approximately twice as many teeth with supragingival and subgingival calculus as females. Both types of calculus were distributed symmetrically around the mouth and were observed most often on maxillary molar and mandibular incisor teeth.

A study comparing the prevalence of calculus in adult males, aged 19–30 years, was undertaken in the United States, Norway and Sri Lanka (4). All subjects were from the higher socioeconomic strata in each country. Despite differences in geography, race and previous dental care, calculus accumulated most frequently on lower incisor and maxillary molar teeth in all three young adult populations. The lowest calculus scores were found in Norwegians, who sought more frequent dental care than the groups in Sri Lanka and the United States. The frequency of supragingival calculus alone remained constant with age, whereas the percentage of surfaces with subgingival deposits, with or without supragingival deposits, increased with age.

A recent adult dental health survey in the United Kingdom reported that 88% of dentate adults had calculus, with values ranging from 73% in 16- to 24-year-olds to over 90% in those aged ≥35 years (79). No distinction was drawn between suprag- and subgingival deposits. In the United States 87% and 80% of employed men and women had calculus; 30% had only supragingival deposits and a further 54% had subgingival calculus or a combination of both (50). In most age groups a greater percentage of women than men had only supragingival calculus although men had greater amounts.

Data from a longitudinal study involving two contrasting populations are of particular interest (5). The two populations comprised a group of Sri Lankan tea workers with no access to dental care and practicing no oral hygiene and a group of Norwegians who performed twice-daily toothbrushing and received regular dental care. All Sri Lankans and most Norwegians (93%) had some calculus (Table 1). However, only 6% of teeth were calculus free in Sri Lankans compared with 74% in Norwegians. Fewer than 1% of Sri Lankans had only supragingival calculus compared with 56% of Norwegians. However, the Norwegians had a greater percentage of teeth (17%) with only supragingival calculus than Sri Lankans (6%). All Sri Lankans had subgingival calculus on almost all teeth, whereas only 36% of Norwegians had subgingival deposits involving an average of 9% of teeth.

In the youngest Sri Lankan group, aged 14–17 years, supragingival calculus only was found on 8.5% of surfaces, and 80–90% of the lower anterior teeth had supra- or subgingival calculus or both.

Almost 20% of 16- to 20-year-old Norwegians had no calculus. Approximately a third of 16- to 17-year-olds had supragingival calculus, which was 6 times more prevalent on mandibular incisors than maxillary molars and was rarely seen on other teeth. Throughout 30 years of adult life (16–50 years) supragingival calculus did not increase significantly in Norwegians.

**Rate of formation**

The rate of supragingival calculus formation varies between individuals. A total of 908 adults were given a prophylaxis (8), and the amount of supragingival calculus that formed on the lingual aspect of the lower anterior teeth during the subsequent 6 months was measured using the Volpe-Manhold Index (84). The results showed that males (Volpe-Manhold score 11.15) had a greater incidence of supragingival calculus than females (Volpe-Manhold score 8.19), and this difference persisted across all age groups. Approximately 5% of males and females had zero calculus scores, 60% had Volpe-Manhold scores of <10 and 85% had Volpe-Manhold scores <20. A small minority formed very large amounts of calculus, with Volpe-Manhold scores ranging from 40 to 55.

The rate of supragingival calculus formation has been found to vary between different populations (20). A group of Norwegian students and Indonesian soldiers received prophylaxis, and the amount of supragingival calculus that formed after 5–6 months was measured using the Volpe-Manhold Index. The Indonesians formed much more calculus than the Norwegians. The Indonesians had a total of 361
Table 1. Percentages of people, teeth and surfaces with calculus in Sri Lanka and Norway

<table>
<thead>
<tr>
<th>Calculus</th>
<th>People</th>
<th>Teeth</th>
<th>Surfaces</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sri Lanka</td>
<td>Norway</td>
<td>Sri Lanka</td>
</tr>
<tr>
<td>None</td>
<td>0.0</td>
<td>7.5</td>
<td>6.0</td>
</tr>
<tr>
<td>Supragingival only</td>
<td>0.1</td>
<td>55.8</td>
<td>5.3</td>
</tr>
<tr>
<td>Subgingival+supragingival</td>
<td>58.0</td>
<td>36.5</td>
<td>82.0</td>
</tr>
<tr>
<td>Abundance of subgingival+supragingival</td>
<td>41.9</td>
<td>0.1</td>
<td>5.9</td>
</tr>
</tbody>
</table>

(52%) mandibular teeth with supragingival calculus compared with 14% in the Norwegians. The Norwegians rarely had supragingival calculus extending beyond the lower six anterior teeth, whereas the Indonesians had calculus on all lingual surfaces in the lower jaw.

**Intraoral distribution**

Supragingival calculus has a very distinctive distribution around the mouth, being localized primarily to the lingual aspects of the lower anterior teeth and the buccal surfaces of the upper molars (3, 5, 83). A recent study has also reported that the amount of supragingival calculus deposited on the lingual surfaces of the six lower incisor teeth decreased the further the distance from the midline (45). When expressed as a percentage of the amount of calculus formed on the lower central incisors the mean amount on the lower lateral incisors varied from 58% to 71% and that on the lower canines varied from 42% to 46%.

The distribution of supragingival calculus within the mouth is usually explained on the basis that the surfaces affected are located in close proximity to the openings of the submandibular and parotid glands. The fact that such sites have a low prevalence of dental caries prompted a study that examined the intraoral distribution of saliva and sucrose and it was found that saliva provides a series of distinctly different fluid environments, some with cariogenic and others with calculogenic potential, in different regions of the mouth (14).

**Formation**

The formation of supragingival calculus is complex and involves both biological and physical-chemical processes. Since supragingival calculus is essentially mineralized plaque, the initial stages in its formation involve the selective adsorption of salivary proteins on the tooth surface and the subsequent attachment and colonization of the pellicle by bacteria. This biofilm of pellicle, bacteria and interbacterial matrix provides an environment within which mineralization may occur with the resultant formation of calculus.

Both parotid and submandibular saliva are supersaturated with respect to various calcium phosphates (31) but show little tendency for spontaneous precipitation of mineral during the short time that saliva would be in contact with plaque on the lingual surfaces of the lower incisors and the buccal surfaces of the upper molars. However, in these locations the abundant supply of urea from the saliva and the high salivary film velocity tend to promote base formation in plaque and calcium phosphate precipitation. It has been proposed that the lower anterior lingual and upper posterior buccal surfaces may be most susceptible to calculus formation because of the low sucrose concentration in saliva in these regions, the high salivary film velocity, which promotes clearance of salivary sugar and acid from plaque, and the higher resting plaque pH because of better access to salivary urea (14).

Initially the process of mineralization commences in the interbacterial matrix (69), which contains mineral-nucleating proteolipids (16). However, as plaque accumulates, the deeper layers of organisms increasingly enter a stationary or death phase and mineralization occurs both within and between bacteria. The rapidity of this phase probably reflects the fact that the local environment is supersaturated with calcium and phosphate ions, and inhibitors diffuse slowly through the biofilm (71). The mineral appears to be deposited in layers, which suggests that the process of mineralization is phasic with periods of mineralization being interspersed with periods during which further deposits of salivary protein and bacteria accumulate on the surface (88).
The process of mineralization is not fully understood but involves localized supersaturation, nucleation, crystal growth and the transformation of precursor phases such as dicalcium phosphate dihydrate, octocalcium phosphate and amorphous calcium phosphate into more stable, crystalline deposits of hydroxyapatite and whitlockite (87). The calcium phosphate that forms during mineralization depends on the degree of supersaturation with respect to the different phases. There is, however, considerable variation in the relative proportion of these different minerals between and within samples of calculus (34).

Saliva contains a number of crystal growth inhibitors, notably statherine and proline-rich peptides (30) whose biological function is to maintain supersaturation with respect to tooth enamel and prevent loss of mineral by dissolution. Within plaque, such inhibitors adsorb rapidly to crystalline surfaces and inhibit or retard crystal growth and calculus formation. However, the effectiveness of these inhibitors is limited by a number of factors, notably their ability to diffuse into plaque and the fact that, once adsorbed, conformational changes may result in surfaces that catalyze the nucleation of mineral phases (49). Nevertheless, studies involving such endogenous crystal growth inhibitors have provided the impetus to develop products that inhibit or reduce calculus formation by incorporating inhibitors of crystal growth.

Inhibition of formation

In theory, the formation of supragingival calculus may be prevented or controlled by i) reducing the amount of plaque available for mineralization using antimicrobial agents and enzymes, ii) modifying the attachment of plaque by antiadhesive agents and iii) inhibiting the process of mineralization by crystal growth inhibitors. All these approaches have been investigated, and many agents have been shown to be clinically effective. However, the most effective and successful products and those currently dominating this sector of the oral hygiene market, contain crystal growth inhibitors.

Mineralization inhibitors include chemicals such as pyrophosphates, diphosphonates and zinc salts that adsorb to the surface of crystals, thereby reducing the rate of crystal growth and phase transformations of calcium phosphate salts (24, 87). In addition to coating the surface of crystals at the time of application, it is important that the inhibitors be retained within the plaque fluid to provide a reservoir that sustains activity between applications.

Pyrophosphate is an effective inhibitor of hydroxyapatite formation in vitro (15), but early studies in vitro indicated that its activity was short-lived due to its hydrolysis by phosphatases in saliva and plaque. Several approaches have been used to minimize this problem.

Increasing the concentration of pyrophosphate has been shown to increase its retention and enhance clinical efficacy (87). In vitro studies demonstrated that the uptake and retention of pyrophosphate from a dentifrice containing 5% pyrophosphate was greater than from a formulation containing 3.3% pyrophosphate (61), and the positive impact of this reservoir has been substantiated in clinical studies (44).

The incorporation of a copolymer of polyvinylmethyl ether and maleic acid also enhances the efficacy of pyrophosphate by inhibiting alkaline phosphatase and pyrophosphatase activity (22). This has enabled a lower concentration of pyrophosphate (1.3%) to be used and yet maintain an effective level of calculus inhibition (23).

Pyrophosphate exerts its effect by inhibiting or delaying the transformation of the amorphous, precrystalline phase to hydroxyapatite. Evidence to support this hypothesis is provided by electron micrographs of calculus formed in vitro. In the absence of inhibitor the crystals are larger and needle-like, closely resembling apatite crystals (25). In the presence of inhibitor the crystal size was small and had the morphology of amorphous calcium phosphate. A recent clinical study also showed that brushing with a pyrophosphate dentifrice resulted in stabilization of precursor phases within calcifying plaque (18).

Zinc has also been shown to inhibit the growth of hydroxyapatite crystals in vitro and possesses the additional benefit of inhibiting plaque formation (29, 63, 73). Unlike other crystal growth inhibitors, it is cationic and is consequently retained within the oral cavity (26, 27). Following brushing with a 0.5% zinc citrate dentifrice, the oral retention varied from 24–38% (27). Reasonable plaque levels of zinc were found 4 hours after brushing and concentrations were elevated in both plaque fluid and plaque residue. The levels of zinc in calculus from individuals who had used dentifrices containing 0.5% or 1.0% zinc citrate for 3 months were well in excess of those shown to inhibit crystal growth in vitro (28). Studies have generally reported only small and mostly nonsignificant reductions in calculus using formulations
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containing 0.5% zinc citrate (38, 70, 82) unless combined with triclosan (75, 77).

Although antimicrobial agents that exert an anti-plaque effect might logically be expected to reduce supragingival calculus, this has not always proved to be the case (7, 42). A notable example is chlorhexidine which, when used as a mouthrinse, promotes the formation of supragingival calculus despite inhibiting plaque formation. A toothpaste containing 1% chlorhexidine has also been found to increase calculus formation compared with placebo after 6, 12 and 24 weeks (89). However, a formulation containing 0.4% chlorhexidine and 0.34% zinc did not promote significantly more calculus than the control group (62). Triclosan, a nonionic antimicrobial agent, has also been incorporated into dentifrices containing either pyrophosphate, zinc citrate or a copolymer, and these formulations have been shown to reduce the formation of supragingival calculus.

Clinical efficacy of anticalculus agents

Clinical trials of anticalculus toothpaste formulations have been reviewed in a number of publications (76, 86). To facilitate a meaningful comparison of clinical studies, this chapter only considers those published in full that compare an active product to a placebo (control). In addition, 3-month results are presented wherever possible.

In general, clinical trials of anticalculus formulations have followed a fairly standard format. They are randomized, double-blind studies 3–6 months in duration with predominantly parallel groups. The participants are invariably heavy calculus formers and are rendered free of deposits at the commencement of the trial period. Subjects are requested to use toothpaste twice a day, unsupervised, and a fluoride dentifrice is usually included as a control.

Pyrophosphate

The most widely available types of anticalculus toothpaste incorporate pyrophosphate salts. Formulations may contain tetrasodium, tetrapotassium or disodium dihydrogen pyrophosphate, either singly or in combination, and in various concentrations. The range of pyrophosphate formulations available makes it difficult to compare studies in a meaningful way. In this review, as with others (86), the percentage of soluble pyrophosphate rather than the concentration of individual salts has been used as the common denominator.

Toothpaste formulations containing soluble pyrophosphate concentrations ranging from 1.25% to 5%, with and without other active ingredients, have been investigated in many clinical trials (Fig. 1). The efficacy of toothpaste containing low concentrations of soluble pyrophosphate (<1.5%) have resulted in somewhat contradictory conclusions. A study initially designed as a two-period crossover investigation (57) indicated that subjects using a dentifrice containing 1.25% soluble pyrophosphate had 45% less calculus than a control group. In contrast, two other studies (68, 72) were unable to demonstrate a statistically significant effect for formulations containing these low concentrations of soluble pyrophosphate.

Fig. 1. Three-month results of studies comparing the relative efficacy of toothpaste formulations containing pyrophosphate (Pyro) salts. PVM/MA: copolymer of polyvinylmethyl ether and maleic acid.
A number of studies have assessed 3.3% soluble pyrophosphate formulations without the addition of other active agents, and most have reported positive benefits. One study (65) observed a significant 35% reduction in calculus formation relative to a placebo after 3 months. Schiff (66) also found a statistically significant 29% reduction in mean calculus scores relative to a placebo after 3 months of use. A further 3 studies (35, 36, 39) reported statistically significant reductions in mean calculus scores ranging from 38% to 48%. Juliano et al. (32) and Rustogi et al. (58) reported 40% and 32% reductions, respectively, both of which were statistically significant compared with a control formulation. However, another study (56) reported nonsignificant reductions in mean calculus scores relative to a placebo after 3 months and 6 months. Another study (33) reported a nonsignificant difference of 6% after 3 months but a significant difference of 21% after 6 months. The results of two other studies (46, 90) are not included in Fig. 1 because 3-month results were not available. A 2-month study (46) found a statistically significant reduction of 26% in mean calculus scores relative to a placebo. The other study (90) reported a statistically significant 32% reduction after 6 months.

The clinical efficacy of a formulation containing 5% soluble pyrophosphate was investigated (53) and a statistically significant 44% reduction relative to a placebo was found. A formulation containing 5% soluble pyrophosphate but combined with 0.3% triclosan was also tested (85), and a statistically significant 24% reduction in mean calculus scores was observed compared with placebo. However, another study (78) failed to demonstrate a significant effect for this formulation during the course of a 7-month study.

Three studies investigated the effect of the addition of a copolymer (polyvinylmethylether and maleic acid) to formulations containing low concentrations of pyrophosphate (less than 1.5%) and found statistically significant reductions in calculus formation (Fig. 2) of about 35% relative to a placebo after 3 months (53, 67, 72). More recently, a clinical trial of this formulation resulted in a calculus reduction of 55% relative to a placebo (6). Another study tested the efficacy of a similar formulation containing 1.3% soluble pyrophosphate and 1.5% polyvinylmethylether and maleic acid but with the addition of 5.0% potassium nitrate, a desensitizing agent (13). A 54% reduction in mean calculus scores relative to a placebo was observed. The addition of polyvinylmethylether and maleic acid to formulations boosts the efficacy of dentifrices containing lower concentrations of soluble pyrophosphate.

Many clinical studies of toothpaste containing 3.3% soluble pyrophosphate supplemented with polyvinylmethylether and maleic acid (1.0%) have been undertaken (12, 37, 53, 66, 80, 81). With one exception (12), all have shown statistically significant reductions in mean calculus scores after 3 months (Fig. 2). Two 6-month studies (56, 82) have also reported statistically significant reductions in calculus of approximately 40%.

Two studies compared 3.3% soluble pyrophosphate toothpaste with and without added 1.0% polyvinylmethylether and maleic acid (56, 66). Both studies showed a significant improvement in efficacy for the combination formulation relative to the positive control although for one study (56) this was only achieved after 6 months use of the products.
The anticalculus efficacy of zinc salts has also been considered in a number of clinical trials. These can be broadly divided into those investigating the efficacy of 0.5% and 2% zinc citrate and those considering 2.0% zinc chloride (Fig. 2).

The results of clinical trials of formulations containing 0.5% zinc citrate have been inconclusive. Only one large study (70) demonstrated statistically significant reductions (14%) in mean calculus scores relative to a placebo toothpaste. Two other studies (38, 82) did not result in statistically significant reductions. A further study (19) suggested some efficacy in calculus formers. A toothpaste containing 2% zinc citrate has also been shown to be effective in reducing calculus (33) in a 6 month study.

Two studies of 3 months’ duration (38, 58) resulted in percentage reductions in mean calculus scores of about 50% for formulations containing 2% zinc chloride.

Two studies investigating the combination of 0.2% triclosan and 0.5% zinc citrate in a dentifrice have demonstrated efficacy. In the first study (75) statistically significant percentage reductions in mean calculus scores of 44% after 3 months and 50% after 6 months were reported. In the second study (77) statistically significant reductions of 54% and 52% after 3 and 6 months, respectively, were found relative to a control dentifrice. A recent study (6) found a statistically significant 39% reduction in mean calculus scores relative to a placebo for a formulation containing 0.3% triclosan and 0.75% zinc citrate. A 0.3% triclosan and 0.75% zinc citrate formulation also produced a significant reduction in calculus (78).

Another agent that has been demonstrated to have anticalculus efficacy is azacycloheptane-2,2-diphosphonic acid. A toothpaste containing 1.15% azacycloheptane-2,2-diphosphonic acid was compared with a placebo; after 2 months’ use of test products mean calculus scores declined by 23% (statistically significant) relative to a placebo toothpaste (11). In another study (51) a 1.0% azacycloheptane-2,2-diphosphonic acid formulation tested over 4 months resulted in a 30% reduction in mean calculus scores relative to a placebo.

The anticalculus efficacy of formulation containing triclosan (0.3%) and polyvinylmethyl ether and maleic acid (2.0%) has also been evaluated in a number of clinical trials. Both silica and alumina abrasive-based formulations produced similar, statistically significant, reductions in mean calculus scores compared with a silica based control (67). The percentage reductions were 23% and 26% for the silica and alumina formulations, respectively. A further study (40) reported a 26% reduction relative to the placebo after 3 months and a 36% reduction after 6 months (41). Significant reductions in calculus for the triclosan-copolymer formulation of 36% (85) and 55% (6) after 3 months have also been demonstrated. Only one study (78) did not demonstrate significant efficacy for this formulation when compared with a placebo toothpaste.

Calcium lactate has been shown to possess some anticalculus activity although its mechanism of action is unclear. One study (64) suggested reductions in calculus scores of approximately 45% relative to a control dentifrice after 3 months use of the product.

Although there has been some concern that crystal growth inhibitors, such as pyrophosphate, might negate the remineralization of early carious lesions by fluoride (10, 17, 54), long-term clinical studies reject this hypothesis. Three clinical studies of caries (43, 55, 75) have clearly demonstrated that anticalculus dentifrices containing fluoride maintain anticaries efficacy. One possible explanation as to how crystal growth inhibitors and fluoride exert their respective effects is that the pellicle allows the selective transport of fluoride into the subsurface region of enamel, whereas the crystal growth inhibitors are retained on the tooth surface (48, 87).

Supragingival calculus is a predisposing factor in causing periodontal disease. A wide range of clinically proven anticalculus dentifrices are now commercially available. They have been shown to reduce
the formation of supragingival calculus providing desirable benefits for the dental profession and consumers.

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