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Tooth wear prevention: A quantitative and qualitative *in vitro* study

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Abstract

Background: Management of tooth wear from grinding presents a significant clinical challenge. Acrylic nightguards are often used to protect the teeth, but many patients still grind with these appliances. This study aimed to test the effectiveness of three lubricants in reducing enamel wear by using an electro-mechanical machine under controlled conditions, with a view to undertaking a subsequent longitudinal clinical study.

Methods: Sectioned tooth specimens were worn against each other under different loads and with the addition of three different lubricants: calcium fluoride (CaF) powder, olive-oil, and a combination of calcium fluoride with olive-oil in the form of a slurry. Wear rates of enamel only were quantified by weighing the specimens, and resin replicas of the worn tooth surfaces were made for examination under a scanning electron microscope.

Results: All three lubricants reduced the amount of enamel wear significantly compared with wearing specimens without adding lubricants. Wear rate was influenced by the type of lubricant and the load applied. Wear rates were significantly less for olive-oil and the olive-oil/CaF slurry compared with CaF alone. The microwear detail differed between the three lubricants.

Conclusions: This study has shown that enamel wear can be reduced using dry or wet lubricants between opposing teeth that are worn under controlled conditions. Further research is required to clarify their possible clinical applications.

Key words: Attrition, lubrication, enamel, tooth grinding.

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INTRODUCTION

It is currently acknowledged that there are several mechanisms that contribute to tooth wear. These include abrasion resulting from the friction of exogenous material forced over tooth surfaces (e.g., masticating food) or the use of teeth as "tools"; erosion (or more correctly corrosion) resulting from the chemical dissolution of tooth surfaces (e.g., effects of acid from various eating disorders or from a highly acidic diet), and attrition from tooth-to-tooth contact (e.g., night grinding). These mechanisms most often occur together, each acting at different intensity and duration in a continuously changing salivary medium, producing immensely variable patterns and degrees of wear.

This *in vitro* study focuses on attrition of enamel resulting from tooth grinding. Explanations about the aetiology of tooth grinding range from sleep disorders, stress, occlusal discrepancies and physiological function.[1] It is generally agreed that stress is the common associated factor that seems to contribute to this behaviour. When in excess, tooth grinding can cause extensive wear and fracture damage to both teeth and restorations and may contribute to various craniomandibular disorders, such as myofascial pain of masticatory muscles and forms of temporomandibular joint pathology.[1,2] Treatments are expensive and may be compromised because the behaviour is often uncontrolled. Clinicians commonly use acrylic nightguards of different designs to protect the teeth from tooth grinding, but ways to reduce stress seem to fall outside the general dental practitioner's capabilities and training. Furthermore, no-one knows the effects of the long-term use of nightguards.[3] It seems that patients still grind on these appliances[4] and that they serve mainly as physical barriers to protect tooth structure.

Recent *in vitro* studies indicate that wear rates of enamel follow two phases: an initial fast "primary phase" and a slower consistent "secondary phase" (Fig 1). Wear rates of enamel and dentine are also determined by a number of extrinsic variables including load, pH of the oral environment, and the nature and type of lubricant.[2,5] Within the oral environment saliva is an excellent lubricant. However, its quality and quantity varies extensively both between and within individuals. The combination of hyposalivation, especially at night, and superimposed tooth grinding may lead to excessive tooth tissue loss.

Lubricants in nature, whether they are liquids or in solid state (dry), function by acting as separating media between opposing surfaces. By keeping the wear

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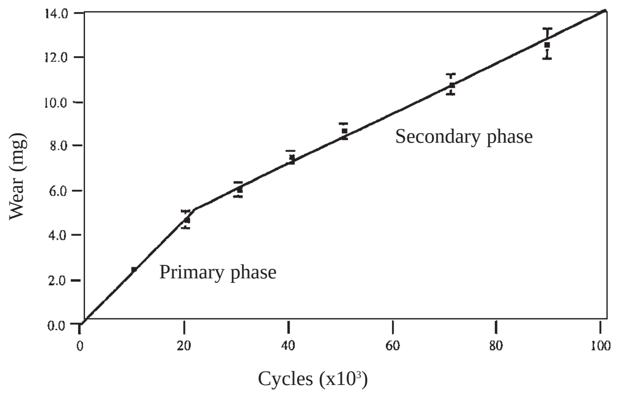

Fig 1. The two typical wear phases of enamel observed in previous *in vitro* wear studies (Error bars represent ±1SE).

interfaces 'apart', wear is reduced. Dry lubricants (e.g., graphite) when used between loaded opposing surfaces will reduce wear considerably. However, the graphite can also be interpreted as a 'third body' in a 'three-bodied abrasion' model (if tribological terms are used). Over time the graphite, though a lubricant, will also eventually cause some wear on the opposing surfaces with characteristic microwear detail.

This investigation aimed to extend previous studies by testing three lubricants in the laboratory and comparing results with base-line data already collected and published.[5] The long-term objective is to find a simple approach to control tooth wear as an alternative to the use of nightguards as prophylactic devices.

MATERIALS AND METHODS

An electromechanical wear machine specifically designed, constructed and tested to wear natural teeth under controlled conditions was used in this study.[5] Variables that were controlled included the load imparted upon opposing surfaces; the relative direction of movement; the duration of contact between opposing surfaces; the number of cycles; the relative speed of each cycle; as well as the quality, quantity, and flow rate of various lubricants.

Freshly extracted, non-carious human teeth were obtained following routine dental treatment at the Dental School, the University of Adelaide (Ethics Approval H/27/90). The teeth were cleaned in water, sectioned longitudinally and dried in air for two days in a constant environment, so that each specimen consisted of a buccal or lingual half-crown with a root portion. Each half-crown was attached to a specimen holder (a scanning electron microscope (SEM) stud attached to a plastic cylinder) that fitted onto the tooth wear machine so that that buccal and lingual surfaces of the same tooth were opposed. Facets were then worn on these enamel surfaces during grinding. The teeth were covered in varnish to prevent the ingress and egress of water, leaving only facets exposed. Previous studies confirmed that the weights of cylinders were not affected by moisture.[5]

Three different lubricants were used in the experiments. The first was the dry lubricant calcium fluoride (CaF) (powder), which is recognized by tribologists to be one of the best found in nature,[6] the second was olive-oil, while the third was a combination of both a calcium fluoride/olive-oil slurry. It was anticipated that if a powder lubricant were to be applied to teeth *in vivo,* it would need to be maintained on occluding surfaces to have any effect. As a result, olive oil was selected to form the slurry, acting as a neutral (non-reactive) 'carrier' for the calcium fluoride. To assess possible confounding lubricating effects of olive oil, it was also tested alone.

Quantification of wear involved weighing specimens to an accuracy of 0.1mg using a calibrated A and D, ER-182A Electronic Analytical Balance. To correct for moisture fluctuations, control specimens were weighed at the same time and under the same conditions as the experimental specimens. Preliminary tests confirmed that there was no measurable olive oil penetration within the cylinders.

Mean wear rates of opposing pairs of dried teeth were determined in the presence of each lubricant at loads of 8.2 and 13.2kg, and then comparisons made with data already collected.[5] Each pair of specimens was worn for 20000 cycles to ensure that the facets produced were well into the secondary phase of wear. After weighing the specimens a lubricant was included and the wear continued for a further 20000 cycles. The teeth were then cleaned of lubricant using water, dried and re-weighed. Wear rates were quantified in terms of mg/l000 cycles by comparing the initial and final weights of specimens.

The statistical package SPSSX (Version 10, SPSS Inc, Chicago, Illinois, USA) was used to analyse results.

Table 1. Comparison of enamel wear rates (mg/1000 cycles) between the three lubricants and that of a previous study[5] where enamel was worn with no added lubricant

Load kg	Enamel wear with no added lubricant[5]			CaF			Olive-oil			CaF + Olive-oil slurry		
	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE
1.7	6	.041	.02									
3.2	24	.063	.01									
8.2				21*	.061	.007	12	-.0464	.05	8	-.498	.05
9.95	14	.135	.02									
13.2				6	-.023	.05	4	-.309	.05	4	-.272	.04
16.2	11	.196	.06									

*one specimen fractured
($p < 0.05$)

Analysis of variance (ANOVA) was performed between selected experimental groups to determine whether there were any statistically significant differences between mean wear rates under various conditions. *Post hoc* comparisons of mean values were made using the Student-Neuman-Keuls method. Statistical significance was set at the 0.05 probability level.

The wear machine had been tested previously and shown to produce consistent results under controlled conditions after using specimens prepared as above.[5] Finally, positive resin replicas were made from polyviny-siloxane impressions of the wear interface of all specimens. These were studied under the SEM and a qualitative comparison made between lubricants.

RESULTS

Quantitative analysis

ANOVAs performed between data for lubricants and load showed that the wear rate was significantly influenced by the type of lubricant and the load ($p<0.05$).

A comparison between the three test lubricants (Table 1) showed that the wear rates of enamel with the olive-oil and the olive-oil/CaF slurry were significantly less than with the CaF alone at both loads (8.2 and 13.2kg). The enamel wear rates with olive-oil and the olive-oil/CaF slurry were not significantly different at both loads.

A comparison between the loads indicated that the enamel wear rates were significantly less at 13.2kg for all three lubricants except for olive-oil where no significant difference was found.

When compared with the findings of a previous study, where enamel was worn without added lubricant, the three lubricants all produced considerably less wear. Enamel wear rates using both olive-oil and the olive-oil/CaF slurry were significantly different to the base-line data, while the wear rate using CaF at 8.2kg was significantly different to the base-line data at 9.95kg and above. At 13.2kg, the wear rate with CaF was not significantly different to the base-line data at 3.2kg and below.

Qualitative analysis

There was a qualitative difference in microwear detail between the three lubricants. However, load did not affect the microwear detail for each of them. Dry CaF powder produced a facet surface showing generalized breakdown and cratering (Fig 2a, b), while olive-oil produced very smooth polished surfaces (Fig 3a, b, c). Figure 3a shows severe breakdown in close proximity to a fracture line that transverses the tooth surface. At higher magnification there is some evidence of olive-oil being impregnated into the enamel – depicted by black areas of differing size and shape (Fig 3b, c).

The olive-oil/CaF slurry produced microwear detail almost identical to the olive-oil alone, showing areas of high polish (Fig 4a). At higher magnification (Fig 4b), the CaF/olive oil slurry tended to produce directional striations (following the direction of movement of the machine).

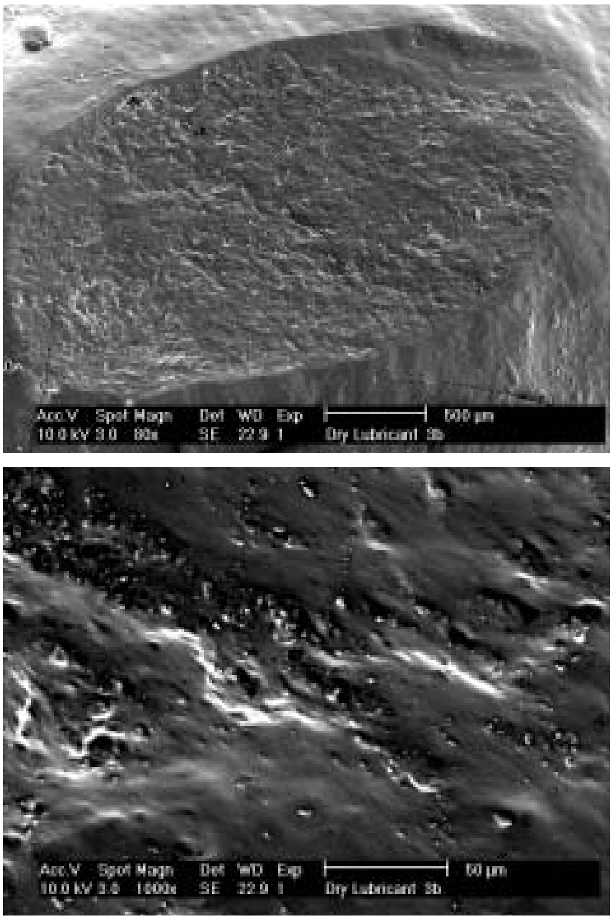

Fig 2a, b. Scanning electron micrographs of an enamel facet using CaF powder as a dry lubricant showing generalized breakdown and cratering in an otherwise smooth enamel surface.

DISCUSSION

Problems experienced in this project included fluctuations in specimen weight due to variations in moisture and machine failure which did not allow wear rates to be tested at 16.2kg. Table 1 shows the mean wear rates of the olive-oil and the olive-oil/CaF combination yielded negative values, indicating an overall increase in weight reflecting the ingress of water resulting from fluctuations in humidity and temperature within the immediate environment. This problem did not detract from the value of the study in that comparisons between the different lubricants were still possible. It was confirmed that each of the three lubricants reduced the wear rate of enamel substantially during tooth grinding when compared with previously published wear rates of enamel without the inclusion of lubricants.

Of the three lubricants, olive-oil and the olive-oil/CaF slurry were significantly more effective than CaF alone and especially when compared with the previously published base-line data. The enamel wear

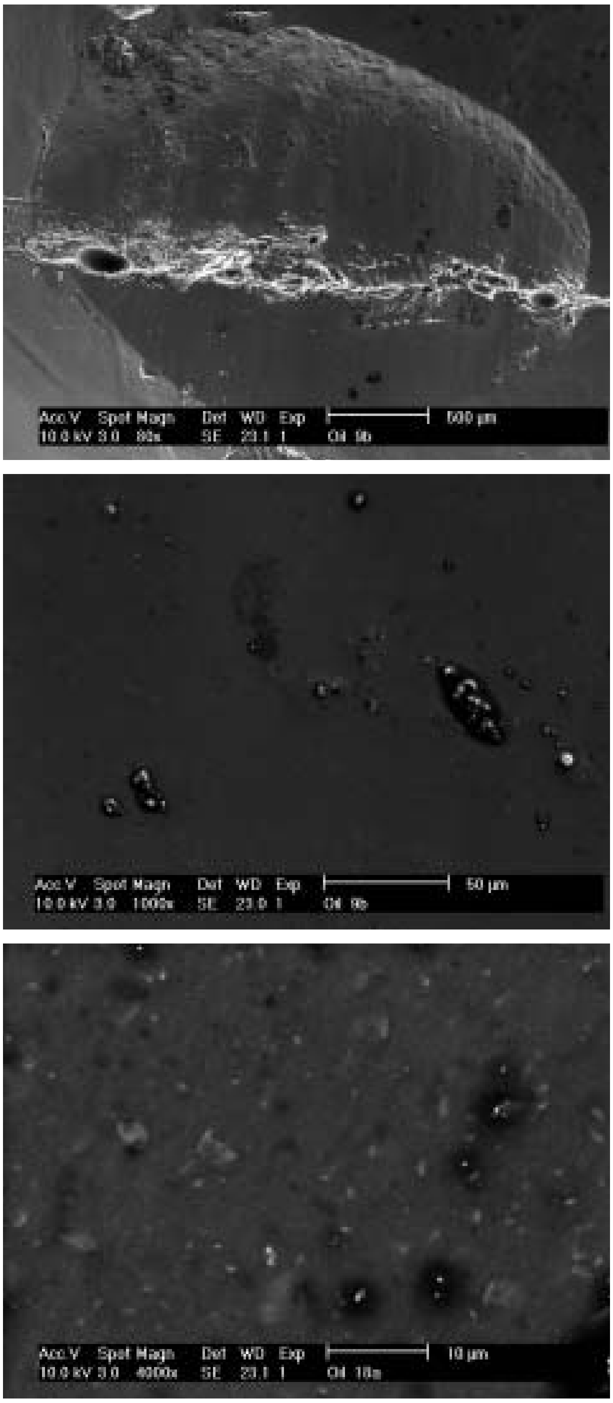

Fig 3a, b, c. Scanning electron micrographs of a facet using olive-oil as a lubricant at progressively increasing magnification. Fig 3a shows severe breakdown in close proximity to a fracture line that transverses across the tooth surface. At higher magnification there is some evidence of olive-oil being impregnated inside the surface – depicted by black areas of differing size and shape.

rate with CaF at 8.2g was significantly less than when enamel was worn without lubricant at loads of 9.95kg or above, while the wear rate with CaF at 13.2kg was significantly greater than when enamel was worn below 3.2kg. At low loads, it seems that the wear rate of enamel with the CaF lubricant is similar to the wear rate of enamel without a lubricant, while at high loads the wear rate with CaF becomes significantly less.

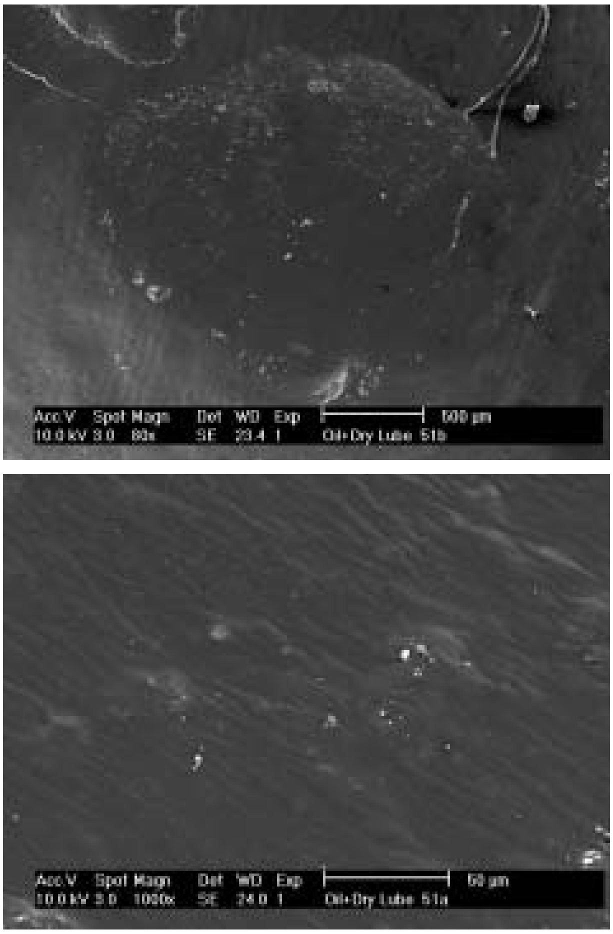

Fig 4a, b. Scanning electron micrographs of a facet using a combination of olive oil/CaF as a lubricant. The surface is highly polished with some evidence of striations.

Further research is required to determine if indeed a load threshold exists at which CaF is most effective. Interestingly the microwear detail of enamel worn against enamel is very similar to the detail produced using CaF as a lubricant (Fig 2a).

We postulate that the dry lubricating properties of CaF are similar to enamel powder produced during wear without lubricant, hence the similar microwear detail observed on facets. However, the anisotropic characteristics of enamel prisms, even in the form of a powder between surfaces, may tend to produce more wear when compared with CaF powder. This may explain why CaF lubricant leads to a lower enamel wear rate at relatively higher loads.

Both the CaF and the olive-oil/CaF slurry produced a significant reduction in wear rate with increasing load. Although this needs to be investigated further, it is postulated that an increasing degree of compaction of CaF at the wear interface with increasing load adds to the lubricating effect by maintaining the opposing surfaces apart for a longer period of time.

This study also confirmed that olive-oil alone, was a very effective lubricant. This was substantiated qualitatively, with the facet detail produced by olive-oil being consistently very smooth and polished. In addition there was qualitative evidence that there was some uptake of olive-oil within the enamel structure which may help sustain its effectiveness. This needs to be substantiated with further studies.

Some weight gain may have been due to the uptake of olive-oil. However, this could not be quantified using our experimental system. Control specimens treated with olive-oil, then washed and dried after the phase 1 facet was formed, did not show any significant differences to specimens that were only washed and dried.

The combination of olive-oil and CaF showed positive results and confirmed that the CaF powder could be incorporated effectively into the oil to form a slurry. The fact that the wear rate with this combination was not significantly different to olive-oil alone, implies that olive oil is the predominant agent in reducing wear.

This study also showed that with olive-oil, there was no significant difference in the wear rate with different loads. Previous studies[5] using various liquid lubricants at different loads have indicated that progressively increasing load makes little difference to the wear rate of enamel until a threshold is reached. At this threshold, liquid lubricants are displaced and rendered relatively ineffective.

Thereafter, the enamel undergoes substantial breakdown, almost at a catastrophic rate. This threshold varies between lubricants and may explain the results obtained in this study.

It is well established that calcium and fluoride concentrations within the oral environment prevent demineralization; promote remineralization, and protect against caries and erosion.[7] Similarly, a fluoridated tooth is more resistant to erosion and breakdown from superimposed attrition: the tooth surface is not easily 'softened' and made susceptible to the superimposed wear.[8] The findings of the present study now indicate that the physical effects of a dry powder such as calcium fluoride can also reduce wear, purely in a mechanical manner, provided the powder can be applied and maintained on occluding tooth surfaces.

It is interesting that previous *in vitro* studies quantifying wear rates of enamel without the addition of any lubricant, showed that the enamel powder produced during the wear process was responsible for the surface breakdown (e.g., observed striations) yet simultaneously protected the surface from wear by acting as a dry lubricant. However, when the dry lubricant was washed away, catastrophic tooth wear resulted even at low loads.[5]

CONCLUSION

This study has shown that enamel wear can be reduced significantly using various lubricants between opposing teeth that are worn together under controlled conditions. The use of CaF as a dry lubricant significantly reduced enamel wear, as did olive-oil or the combination of olive-oil and CaF in the form of a slurry. Further *in vitro* and *in vivo* research is required to answer questions that have arisen from this research. These include: how can the lubricating potential of calcium fluoride be used while still incorporating the chemical nature of the fluoride for protection? could calcium fluoride be applied to the dental tissues in the form of a slurry before bedtime and be effective in reducing wear? what other lubricating media apart from olive-oil may significantly reduce tooth wear? if it can be substantiated that olive-oil is absorbed by worn tooth surfaces, could this agent alone provide protection from wear?

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