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A comparison of two-dimensional and three-dimensional measurements of wear in a laboratory investigation

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ABSTRACT

Objectives. The aim of this research was to compare two-dimensional (2D) and three-dimensional (3D) tooth measuring techniques after subjecting enamel samples to tooth wear *in vitro* on an erosion–abrasion model.

Method. 80 polished mid-coronal enamel sections were subjected to 10 wear cycles. Each cycle consisted of remineralization for 2 h in artificial saliva, followed by 10 min immersion in one of four acidic fruit drinks or distilled water and finally toothbrush abrasion with a non-fluoridated tooth paste. The resulting wear scars were measured using 2D and 3D techniques using surface matching software.

Results. The 2D step heights measurements from the exposure to the four acidic drinks showed no statistically significant differences (median wear range = 22.4–32.5 μm) between them ($p = 0.99$) but there were differences with distilled water (median wear = 10.0 μm) ($p = 0.01$). The 3D measurements showed that two drinks produced more wear compared to the others and water when the whole surface and volume exposed to wear was accounted for ($p = 0.01$).

Significance. The difference in data from the two techniques showed that 3D measurements gave a more accurate assessment of the impact of the wear regime.

1. Introduction

The measurement of wear using contacting or non-contacting profilometers has been reported by a number of authors both for *in vitro* and *in vivo* measurements [1–3]. Most research groups report wear data as two-dimensional (2D) step height measurements recorded from individual profiles from the teeth subjected to wear [4,5]. A potential problem with 2D measurements is that measuring exactly the same profile before and after the wear episodes is prone to variation as areas have to be visually identified and this relies on the operator's judgement. For very small dimensional changes the ability of the operator to choose exactly the same location may reduce the repeatability of the measurements. Added to this, measuring wear from single profiles does not give an indication of the total activity of the wear over the whole surface area which may shed more light on the complex interactions of abrasive three-body wear and erosive wear. To counteract this, researchers may obtain various single step height measurements which are then averaged to obtain a mean step height over the number of profiles evaluated.

Increased availability of surface metrology software has made three-dimensional tooth wear measurement methods possible; either reported as volumetric loss [6–8] or mean step height loss over the whole surface area exposed to the wear [9], also called three-dimensional (3D) step height. Another way of measuring tooth wear is to 'normalize' measurements

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Table 1 – Constituents, pH, titratable acidity of the drinks.

Experimental drinks	Constituents	pH	Titratable acidity
Packaged orange juice (POJ)	Pasteurized orange juice	3.8	25.3 ml
Freshly squeezed orange juice (FOJ)	Freshly squeezed orange juice	3.6	36.5 ml
Strawberries and bananas juice (SB)	Pasteurized juice of strawberries, apples, bananas, oranges, grapes and limes	3.5	20 ml
Mangoes and passion fruit juice (MP)	Pasteurized juice of apples, mangoes, bananas, oranges, passion fruit and limes	3.5	22.4 ml
Control	Distilled water	7.0	n/a

by dividing the 3D step height by the surface area of the sample subjected to the wear. This method was described by Vieira et al. [9] but the authors did not compare normalized to non-normalized data. It is believed three-dimensional measurements provide a more accurate representation of the activity of the wear over the whole surface area but the differences between 2D and 3D tooth wear measurements have not been reported in the literature.

The aim of this research was to compare two-dimensional (step height from single profiles) and three-dimensional (mean step height over the surface area exposed to the wear and volumetric data) tooth wear measurements on human enamel subjected to an *in vitro* erosion–abrasion regime. The null hypothesis was that there were no differences in two-dimensional and three-dimensional tooth wear measurements.

2. Materials and methods

Twenty intact human third molars were randomly chosen from a pool of extracted teeth of unknown origin stored in saturated aqueous thymol solution. Ethical approval was obtained from Guy's Research Ethics Committee (REC reference number: 04/Q0704/57). Mid-coronal enamel sections from the buccal, lingual, mesial and distal surfaces were obtained using a diamond blade (Diamond wafering blade XL-12205, Extec. UK) on a low speed sectioning machine (Isomet 11-1180 Low Speed Saw, Buehler Ltd., USA) and individual sections imbedded in a brass block using cold cure acrylic resin (Forestacryl® – Forestadent. UK, Lot No.: 202405 – Exp March/2010). Samples were mounted with a 300 μm ring of aluminum on top. After 24 h and after the acrylic resin had set, the aluminum ring was removed and the samples were polished sequentially and carefully with silicone carbide paper of 800, 1200, 2400 and 4000 grit (Silicon Carbide paper, Struers A/S, Denmark) on a rotating polishing machine (Struers Labopol-1, Denmark) under constant water irrigation until the sample was flush with the mark left by the aluminum ring, indicating that 300 μm had been removed. After this, three dimples were made into the acrylic resin in a triangular pattern surrounding the sample with a fast hand-piece and a small round diamond bur. The dimples served as reference areas to aid the superimpositional procedure to measure wear three-dimensionally. The samples were examined for defects under an optical microscope (EMZ TR, Meiji, Japan) and were randomly allocated to one of the four experimental groups or to the control group. Each group contained 16 enamel samples.

Table 1 shows the contents of the experimental drinks. The pH of the experimental drinks and the control were measured with a previously calibrated pH meter (Hydrus 100, Fisherbrand, UK) and the titratable acidity, the volume of 0.1 mol solution of sodium hydroxide required to raise 20 ml of the experimental drink to pH 7, was measured after agitation and equilibrium (2 min) at 20 °C. These measurements were repeated on three occasions.

The enamel sections were subjected 10 wear cycles in an abrasion–erosion model using methods similar to those described in [8,10]. Each cycle consisted of initial immersion of the enamel sample in artificial saliva in an agitating machine (Titertek, Flow Laboratories, Germany) and after 2 h they were removed, washed under tap water and gently dried using paper towels. Samples were then immersed in the experimental drinks or control for 10 min under gentle agitation at room temperature (20 ± 3 °C) and then washed under tap water and gently dried using paper towels. Following this, samples were subjected to 200 strokes on a toothbrushing machine (Abrasion testing machine No. 8. The Pepsodent Co. USA). The machine consisted of four reciprocating arms each holding a standard Oral-B® Plus Size 40 soft-bristled head from a toothbrush (Oral B, UK) under a load of 200 g using a slurry of fluoride free toothpaste (Kingfisher natural toothpaste, Kingfisher, UK, Lot BN 023) and artificial saliva (1:3 ratio by weight). The enamel samples were firmly secured in acrylic wells. The toothbrush heads were changed for new ones every 2000 cycles.

The artificial saliva was prepared according to a protocol described in [11] and contained the following chemicals in 1 l of distilled water: calcium chloride: 0.7 mmol/l; magnesium chloride: 0.2 mmol/l; potassium hydrogen phosphate: 4.0 mmol/l; HEPES buffer (acid form) 20.0 mmol/l and potassium chloride 30.0 mmol/l. The pH was adjusted to 7 by titration using 0.1 mol sodium hydroxide. Artificial saliva was prepared freshly every day.

Before the first wear episode and after the final wear episode the samples were washed with tap water and gently dried with compressed air and an impression taken using Extrude™ light bodied addition silicone impression material (Kerr Corporation, Romulus, MI, USA). Impressions were taken under a Perspex table weighted with 1 kg to ensure even thickness of individual impressions. The impressions were left to rest for 24 h and scanned on the non-contacting laser profilometer (Taicaan™ Technologies, Southampton UK) at medium precision and using a step-over distance of 15 μm. Digital scans from each paired set of impressions (before and after wear cycle) were superimposed using surface matching software with a superimpositional feature (Boddies® v1.92. Taicaan™. Technologies, Southampton, UK). The superimpositional feature of this software required the user to relocate three unchanged reference points, in our case the dimples cre-