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An *in vitro* study of the wear behaviour of dental composites

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Abstract

Use of dental resin composites in restorative dentistry has increased significantly in recent years. While wear may be of minimal importance for small to medium size composite restorations, failure rates are higher for large restorations. Moreover, wear is a significant mode of posterior restoration failure for patients with bruxing and clinching habits. However, in spite of previous *in vitro* studies, the mechanisms associated with the wear of these composites are not yet clearly identified. Accordingly, the wear behaviours of three different glass-polymer dental composite materials were studied *in vitro* and the associated mechanism(s) were investigated in-depth.

Reciprocating sliding wear tests were carried out using these composites where a self-mating composite cusp was sliding on a flat-surface sample. The wear loss was quantified using profilometry and the wear scar surface and subsurface were analysed using electron microscopy techniques to reveal the underlying wear mechanisms. The composites' mechanical properties were assessed using nanoindentation.

The results revealed that two different wear mechanisms were dominant for the composites tested: fatigue wear for the anterior/posterior composites and, abrasion due to lateral crack formation and filler particle pull out for the anterior composite.
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Keywords: Wear mechanism; Electron microscopy; Dental composite

1. Introduction

Dental resin composites containing filler particles (e.g., borosilicate glass, colloidal silica, etc.) in a polymer matrix (e.g., bisphenol A glycidyl methacrylate (BisGMA), triethylene glycol dimethacrylate (TEGDMA), etc.) are commonly used to restore cavities and non-carious cervical lesions (NCCLs) and to replace the missing tooth tissue that has been worn away by grinding [1–3]. The functions of filler particles are to reduce the polymerisation shrinkage on setting and to improve the composite's wear resistance. Use of these composites in restorative dentistry has increased significantly in recent years due to their good aesthetics, the ability to bond to tooth structures and the need for an amalgam alternative.

Early dental resin composites in the 1970s which contained large filler particles (above 10 μm diameter) showed rapid wear when used on the biting surfaces of posterior teeth [2]. Significant improvements have been made with the introduction of composites with medium size filler particles (e.g., 2.5 μm) in the mid-1980s and more recent micro/nano-hybrid composites, and wear of dental composites has been substantially reduced. While wear may be of minimal importance for small to medium size restorations, failure rates are higher for large restorations, particularly, those involving the replacement of functional cusps, which are routinely performed [4]. Moreover, wear is a significant mode of posterior restoration failure for patients with bruxing and clinching habits [5,6].

Since bruxism and erosion are often associated with severe tooth wear, restorations placed on worn teeth are also considered to subject to same wear processes [7]. However, the available evidence on the longevity of restorations originates from studies in which severe tooth wear was usually an exclusion criterion and hence the results of these studies do not reveal the restoration longevity of severe wear cases. In addition, the available literature on restorative treatment of patients with severe tooth wear is also very limited [7]. One recent study has revealed that, despite considerable restorative wear observed, improved retention of

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Table 1
Details of the three dental composites and the average specimen surface roughness values.

Composite	Intended application	Filler particles, %	Particle size (nm)	Specimen surface roughness (R_a, μm)	
				Ground	Polished
DC-1	Anterior/Posterior	Alumino silicate glass, 61 %vol	50–1000	0.043 ± 0.009	0.022 ± 0.004
DC-2	Anterior/Posterior	Strontium glass, 61 %vol	50–2000	0.055 ± 0.008	0.015 ± 0.001
DC-3	Anterior	Silica, 51 %wt	20–100	0.034 ± 0.006	0.049 ± 0.01

hybrid composite restorations compared to micro-filled composite ones [8].

From the above discussion, it is clear that there is a requirement for further improvement of wear behaviour of dental composites through qualitative/quantitative assessment and identification of the associated wear mechanisms. Investigators in previous studies have stated that the dominant wear mechanism(s) of these composites are abrasion and fatigue [9] or fatigue [10,11] or abrasion due to microcutting or microcracking [12] or delamination [13]. Another study has concluded that delamination is dominant for more brittle composites under higher loads [14]. These indicate that the mechanisms associated with the wear of dental composites are not yet clearly understood. The reasons for this can be summarised as follows: while some researchers have assumed the dominant wear mechanism [9–12], others [13,14] have restricted their study to the analysis of wear surface topography by scanning electron microscopy (SEM). It appears that only one study carried out in early 1980 [11] analysed the wear scar subsurface damage of dental composites using silver staining process and optical microscopy.

The present study attempts to overcome the aforementioned disadvantages by carrying out an in-depth analysis of composites' wear surface and subsurface by SEM and transmission electron microscopy (TEM) to reveal the underlying wear mechanism. Additionally, the observed tribological behaviour of these composites will also be related to their fracture behaviour. The findings of this research should in turn facilitate the development of novel composite materials with improved wear properties.

Previous *in vitro* dental composite wear studies have used various tooth wear simulators (e.g., Oregon Health Sciences University wear simulator [15]) and standard tribometers (e.g., pin-on-disc, reciprocating). However, simple pin-on-disc tests are not considered to be representative of the wear processes that occur in the oral environment [16]. Although wear simulators seem more representative of the processes *in vivo*, they are not widely available, possibly due to the high initial cost [14]. Moreover, a carefully controlled round-robin test [17] that used five different wear simulators revealed 'tremendous' variations in the wear ranks of tested materials among different simulators although publications relating to three of these simulators attempted to establish clinical correlations. Thus no universally accepted in vitro method is currently available for evaluating the wear of dental materials which totally simulated the clinical behaviour [18]. Conversely, even though a reciprocating tribometer does not provide a replica of *in vivo* loading, it facilitates similarities in the wear process, isolates a more relevant range of factors and provides excellent repeatability. It was hence chosen for the present experiments.

Use of various antagonist materials for *in vitro* wear testing of composite dental materials has also been reported in literature. These materials include stainless steel, chromium steel, human enamel, dental ceramic, common ceramic, e.g., alumina [11–14]. All these materials are known to have disadvantages [13]: steels and ceramics having properties considerably different to those of human enamel; human enamel with size limitations, irregular shape, variable structure and properties. Accordingly, in the present work, self-mating dental composite specimens (i.e., both sliding partners made of same composite material) will be used. It can be argued that such self-mating dental composite specimens in sliding contact have clinical relevance since a composite cusp sliding on a composite fossa can occur in the oral environment.

2. Materials & methods

The dental composite specimens required for the tests DC-1, DC-2 and DC-3 (Table 1) were prepared in teflon moulds and were cured using blue light: 20 s per 2 mm thickness (Radii plus, SDI Limited, Bayswater VIC, Australia). Prior to the *in vitro* wear tests, nanoindentation tests were carried out to obtain the mechanical properties, in particular, hardness and elastic modulus.

2.1. Dental composite specimen preparation

2.1.1. Nanoindentation

For these tests, short cylindrical composite specimens (4 mm height and 4 mm diameter) were used. In order to obtain the final geometry, a flat surface of an original specimen was first ground using 2500 grade SiC paper to improve its flatness. It was then used to glue the specimen on to a perspex pin using commercial superglue with 20-24 hours allowed for adequate curing of superglue and to obtain a stronger bond.

The free/exposed flat surface of each cylindrical specimen was then prepared for nanoindentation testing. It was initially ground using 1200, 2500, 4000 grades SiC paper followed by polishing with 1 μm diamond suspension. For these tests, six specimens in total (2 specimens per composite) were prepared.

2.1.2. Wear tests

For these tests two sample geometries suitable for *in vitro* reciprocating wear testing were prepared: short cylindrical samples (4 mm height and 4 mm diameter) as flat surface

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