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Influence of different tribological mechanisms on in-vitro wear simulation results of composites

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Abstract

The aim of this study is to explain the different wear rate of composite samples in areas involved in direct tooth contact with the antagonists and areas free of direct contact depending on the various tribological mechanisms (two-body and three-body wear) that act in these areas. Materials and methods: A novel chewing simulator - “Sofia” was used in order to mimic the dynamic masticatory forces according to the functional occlusal concept of Le Gall and Lauret (1). Twelve composite samples (Herculite HRV) were produced, divided in two groups and subjected to in vitro chewing simulation. In order to compare the influence of different tribological mechanisms on the overall wear the only difference between the two testing groups was the environment - distillated water (for two-body wear tests) or an artificial food medium (for three-body wear tests). Results: A significant difference has been recorded between the two testing groups – the overall wear of the samples in the two-body wear group was two times higher than the three-body wear group. Conclusion: Much more aggressive tribological mechanisms are related with the two-body wear and occur clinically in the area of the direct occlusal contact in comparison to the free of contact occlusal area where three-body interaction exists. Clinical significance: The outcomes of this research aim to help the clinician choose from the variety of restorative materials in order to achieve extended longevity of their restorations. On the other hand the accumulation of clinical and in vitro data regarding the properties of the currently used restorative materials helps scientists improve the quality of new materials.

Keywords: Wear, two-body wear, three-body wear, wear simulator, composite

Background

Wear of dental materials is a problem, greatly exceeding the borders of dental medicine. Wear can occur wherever there is friction between different particles and it might represent a substantial engineering problem in many different areas. In dentistry, wear resistance of restorative materials is a factor of utmost importance and determines to a great extent the clinical longevity of the treatment results.

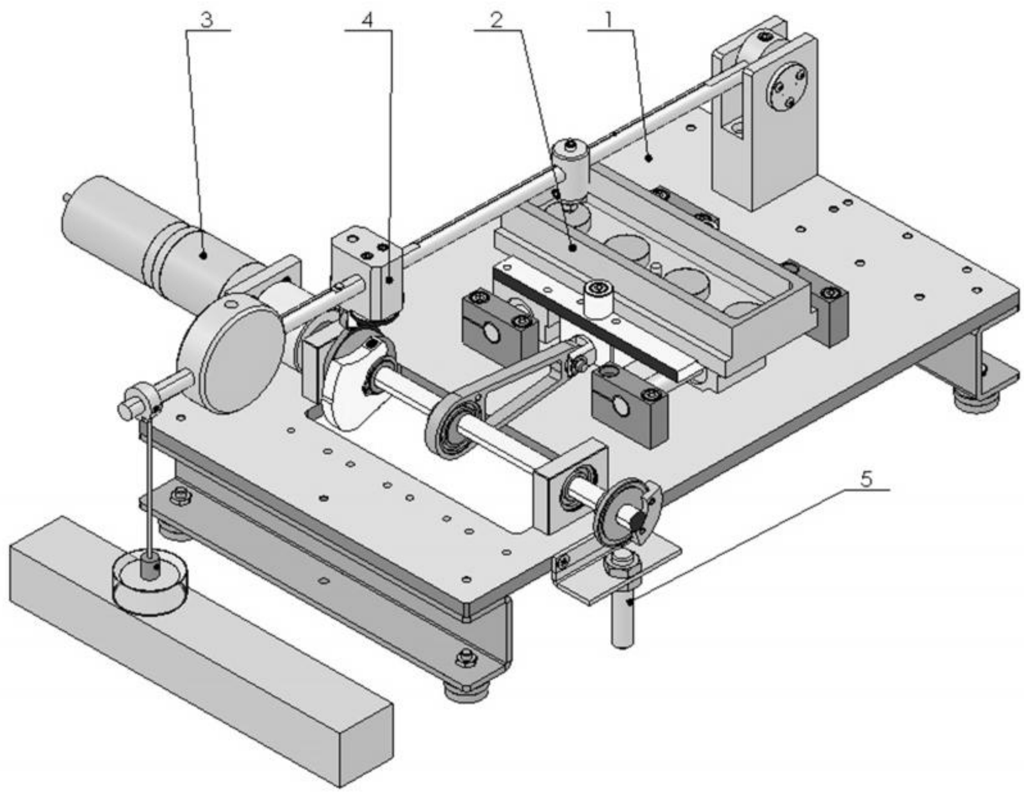
It has been recognized that clinical wear is the result of the accumulative effect of several simultaneously occurring wear mechanisms, named also “tribological mechanisms” by engineering science, which studies the wear phenomenon. The parallel existence of clinical and tribological classification of dental wear can be found in the relevant literature (2). While the former focuses on the localization and the degree of advancement of the wear process, the tribological classification emphasizes the intimate physical and chemical processes leading to loss of substance from the surface of a body. From a practical point of view the clinical classification of wear is extremely valuable since it leads to a different treatment strategy according to the severity of the wear. On the other hand tribological classification is an important consideration when discussing the choice of restorative material and the improvement of the wear resistance of dental restorative materials.

Among the first to provide extensive data on the in vivo wear rate of enamel was Lambrechts (1984) (3). A notable difference in wear was found to exist within the same occlusal surface between the areas involved in direct tooth contact with the antagonists (OCA-occlusal contact areas) and the areas free of direct contact (CFOA – contact-free occlusal areas). This difference (39µm instead of 20µm) was later explained with the much more aggressive mechanisms acting in the area of direct occlusal contact. Three-body wear as well as tribochemical wear are supposed to act in the CFOA, while in the OCA their effect is combined with two-body abrasion, adhesive wear and fatigue (4). Since the contribution of each of the mechanisms for overall wear remains unknown and is difficult to determine, it is more practical to speak about a three-body mechanical system (presence of a third body as a mechanical mediator between the antagonistic teeth) and a two-body mechanical system (contacts without the presence of another body between the arches). During normal chewing a three-body interaction with the food bolus is mostly observed serving as a mechanical mediator, while two-body interaction occurs in bilaterally balanced dentitions as well as in patients with bruxism (5). Occlusion plays a key role in determining the type of tooth contacts and thus the main tribological mechanisms involved. However it is difficult to estimate its practical impact since many micro-varieties exist even within Class I Angle occlusion, which we consider as “normal occlusion” (6).

Materials and methods

In order to mimic the clinical wear of dental composites a novel chewing simulator “Sofia” was used. It was developed in the Faculty of Dental Medicine Sofia as part of a PhD work (6). The device was designed to reproduce the dynamic masticatory forces according to the functional occlusal concept of Le Gall and Lauret (1).

Figure 1. Simplified presentation of the chewing simulator "Sofia". The major modules are as follows: (1) base, on which the chariot is mounted (2), with a fixed container housing 1-4 standardized flat samples of the investigated restorative material in an environment that might be distilled water (for two-body wear tests) or an artificial food medium (for three-body wear tests; (3) Electric gearmotor module and the (4) rocker arm module.



To achieve the dynamic force profile necessary to mimic the complexity of the forces during one chewing cycle a combination of a permanent magnet and a rotating laser-cut ferromagnetic cam were used. A second cam rotating simultaneously provides for the ascending and descending movement.

Materials and sample preparation

The experimental samples were made out of a composite material (Herculite HRV, Enamel A2, item number 7733860, Kerr Italia Srl.) In order to house the material twelve metal rings were fabricated and calibrated to the size of 25 mm external diameter, 24 mm – internal diameter and height – 8mm. The rings were placed in a special holder device, fixing the ring against a glass slab. A bulk of 2-2,5gr composite was placed on the inner side of the ring in contact with the glass surface and gently adapted to the surface until a uniform layer of about 1-2mm thickness was achieved. The light curing of the material was done using a 2000 mW/cm2 light curing lamp. The surface was divided into 9 areas (with a size corresponding approximately to the tip of the lamp. Polymerization was performed using two different modes of polymerization –a “soft start” mode (starting with a low intensity of the light and a subsequent increase to the maximal light intensity) for about 20 s, and a second “pulse” polymerization mode for another 20 s. The rest of the volume of the metallic ring was filled with self curing acrylic resin (Duracryl, Spofa). The samples were divided into two groups. Six chewing simulation tests were performed for each sample. The experiments with the first group were made in a medium of distilled water, and the second group was tested in an artificial food medium (equal parts water and PMMA beads (powder of Unifast, GC).

Antagonists

As antagonists in the chewing simulation experiments, spherical pearls made of silicon nitride were chosen with a diameter of 4 mm. The antagonists were fixed in a special holder. The choice of the antagonists was determined by the high degree of standardization in terms of shape, hardness and surface roughness which greatly reduces the experimental variation related to non-material dependant factors.

Results measuring

As a result of the chewing simulation tests, areas of wear were formed on the sample surfaces. The wear grooves presented different depth according to the variety of the forces applied during the same chewing cycle. The measurements were performed using contact profilometer (precision of 1µm), following a predetermined mesh. Each wear groove was measured in 10 sections using 3 point measurement per section – or 30 measurements per groove.

Results

The results of the wear in water and in artificial food medium of Herculite HRV are displayed in table 1.

Table 1. Comparison between the wear of Herculite HRV in water and in an artificial medium

Material	Number of experiments	$\overline{X}$	SD	V
Herculite 3-body	379	67,55a	24,63	36,46
Herculite 2-body	168	112,21b	19,77	17,62

* same letters show lack of significant difference, whereas different ones stand for significant difference ($p<0.05$)

According to the data the wear of the testing samples in water is higher. The statistical analysis shows statistically significant difference between the two testing groups.

Statistical methods

The data was analyzed by IBM SPSS Statistics 19.0.0 through the following methods:

1. Descriptive analysis
2. Variational analysis
3. Nonparametric Kolmogorov-Smirnov test and Shapiro-Wilk test
4. Nonparametric Kruskal-Wallis test
5. Nonparametric Mann-Whitney test

Discussion

The subject of the perfect food medium for wear experiments has interested scientists for decades. Tests have been run with flour, poppy seed, millet and rice, PMMA, silicon carbide (SiC), calcium carbonate (CaCO3). For our experiment we chose 44-millimeter PMMA beads, which conforms with Leinfelder's opinion (1999) (7). PMMA is a favorable food medium because it is stabile in water unlike organic food mediums. The plasticizerin PMMA i.e. dibuthyl phthalate, absorbs the greater part of the masticatory forces instead of letting them act on the sample's surface, therefore PMMA without dibutyl phthalate is preferable. Another desirable PMMA's characteristic is the fact that in comparison to other food mediums PMMA is less abrasive, which corresponds well to contemporary processed foods, which have more lubricating than abrasive effect on the tooth's surface.

Antagonists

Ceramic silicon nitride (Si3N4) pearls designed for ceramic bearing manufacture were used as antagonists. The pearls meet ISO 3290 – issue 2001/12/01 standards, with variation in the diameter up to 0.13 μm and in the surface roughness - up to 0,014μm.

Comparison between two-body and three-body abrasion results

Two-body wear includes tribological mechanisms such as two-body abrasion, adhesive wear and fatigue (4), as well as three-body wear and tribochemical wear. Since the contribution of each of the mechanisms for overall wear remains unknown and is difficult to determine, it is more practical to speak about a three-body mechanical system (presence of a third body as a mechanical mediator between the opposing teeth) and a two-body mechanical system (contacts without the presence of another body between the arches). During chewing the food bolus does not allow a direct contact between antagonistic teeth so the final wear is mostly determined by the tribochemical wear and the three-body abrasion, which are less aggressive. Therefore milder wear rates are observed. In addition to that, by the three-body interaction the masticatory forces are distributed on a greater surface through the food medium, which reduces the masticaroty pressure and the coefficient of friction (8).

The ability of the chewing simulator "Sofia" to reproduce different wear mechanisms has already been proven (9).Our experiment has established that in the presence of equal other variables (force, contact time, material, form and antagonist roughness)only the switch from three-body to two-body wearcan cause two times higher wear rate. Our result concurs with Lambrecht's 2006 (10), who found 2,5 times higher wear rate in the areas involved in direct tooth contact with the antagonists (OCA-occlusal contact areas) than in the areas free of a direct contact (CFOA – contact-free occlusal areas). Other studies show different outcomes depending on the different materials, forces, antagonists (4).

Our experiment shows the same results as those of Lasserre 2003 (2), who compared the wear rate of 17 materials in water and artificial food medium. Significantly higher wear was found to exist in most of the samples in water. The only exception came out to be dentin's wear rate, which is approximately the same in water and in artificial food medium.

The opposite results can also be found in the literature for some materials. Al-Hiyasat (11) makes a comparison between in-vitro wear rate in water and artificial food medium (cornmeal grit and whole meal flour) of several dental ceramics. While Vita Mark II and Vitadur Alpha mark milder wear by three-body interaction, the low-fusing Duceram LFC shows the opposite results. As a possible explanation the author points out that the formation of the characteristic passivation "hydroxide" layer on the surface is prevented due to the action of the food particles. The incorporation of the hydroxyl groups in the chemical structure of this ceramic is achieved by a special treatment with high temperature and steam. The presence of the hydroxyl groups explains some important properties of the ceramic like the low fusing temperature, which has become the reason for this material to be called "hydrothermal ceramic" Komma 1993 (12), Mattmuller 1996 (13). Harrison (14) also emphasizes the correlation between the food medium's abrasive effect and the material's wear.

Conclusion

The wear rate of the tested materials in water proved to be significantly higher compared to the wear rate in artificial food medium, which supports the results found by other authors studying different materials. Much more aggressive mechanisms (two-body abrasion, adhesive wear and fatigue combined with three-body wear and tribochemical wear) acting in the area of the direct occlusal contact explain the more intensive wear of those areas, while within the same occlusal surface the areas free of direct contact remain intact longer due to less aggressive mechanisms (three-body wear and tribochemical wear) acting in these area.

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