Review Article

A review of instruments used in evaluating wear in restorative materials

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ABSTRACT

Background: Increased patient demand for esthetic dentistry has generated interest in all-ceramic dental restorations. An overview of the types of wear simulating devices will allow us to better understand the multifactorial nature of wear. **Aim:** The aim of the review is to critically analyze the different wear simulators that are available in the market for dentistry and their capacity to mimic the wear conditions. **Materials and Methods:** A search on keywords highlights the most common *in vitro* wear simulators and their use in the laboratories for various simulation applications. **Results***:* Wear is a complex process, which cannot be simulated in total while controlling all variables. **Conclusion:** Even the most sophisticated wear simulator would have limitations.

KEY WORDS: Abrasion, Ceramic, Volume loss, Wear

INTRODUCTION

Increased patient demand for esthetic dentistry has generated interest in all-ceramic dental restorations. Better materials and innovative techniques have led many dentists to use all-ceramic crowns and inlays for the restoration of posterior occlusal surfaces. However, there has been a considerable concern as to how these materials, formulated for improved strength, as compared with respect to their tendency to abrade human enamel. Ideally, any restoration should not harm (wear) of the opposing tooth surface. Due to their strength, ceramics in general, is considered to be more abrasive to enamel than common restorative materials, such as gold or amalgam.

The excessive differential wear of teeth and restorative materials has significant deleterious effects on the biologic, functional, and esthetic condition of the masticatory system. It must be noted that controlled investigations of numerous factors that might influence tooth and restoration wear have been mainly laboratory studies. These findings need not correlate with either the physical properties of the substrates or clinical experience.

In restorative dentistry, the wear resistance of restorative materials is mainly evaluated with laboratory methods that use an electric device that puts a counterpart object (e.g., stylus) into contact with the material that is to be tested. Some devices simulate chewing movements that occur in the mouth,[1,2] and some methods use an abrasive medium.[3-5] The methods differ with regard to the applied force, the material type and movement of the counterpart, the number of cycles, etc.

The present paper compares the different wear simulators available that could be used for testing the wear properties of restorative materials used in dentistry.

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MATERIALS AND METHODS

Wear *In Vitro* Tests

Academisch centrum tandheelkunde amsterdam (ACTA) method

The ACTA method has been developed at the Dental College in Amsterdam (The Netherlands) (ACTA).[6] Two metal wheels rotate in different directions with about 15% difference in the circumferential speed while having near contact. The test specimens (n = 24

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and 28, resp.) are placed on the circumference of the wheel while the other wheel serves as an antagonist. The force with which the two wheels come together is adjusted to 15 N. The wheels are placed in a slurry of white millet seeds in a buffer solution. After 50,000, 100,000, and 200,000 cycles, the maximal vertical loss of the test specimens is measured with a profilometry device.

Alabama method

The Alabama wear method was developed at the University of Alabama (USA) by Leinfelder and Suzuki and is, therefore, also called Leinfelder wear method. The method has been first published in 1989[7] and is a modification of a device that has been originally designed by Roulet.[5] Several major modifications were made over the years. In the first publication in 1989, a polyethylene tape was used as intermediate substance, driven by a tape advancing system.[7] The tape was replaced by a slurry of poly(methyl methacrylate) (PMMA) beads 10 years later.[4] The original force was 55 N, which was increased to 75 N 10 years later. In the first publication, a stainless steel stylus with 2 mm radius hit the specimen without rotation. In the new method, an additional 30°clockwise rotation was integrated as soon as the stylus hits the surface of the specimen which was then called "localized wear" (Alabama loc.). In addition, with a new specimen, a flat stylus made of polyacetal is brought into contact with the flat specimen; the wear produced by this approach is called "generalized wear" (Alabama gen). The materials specimens are incorporated into extracted molars that are trimmed flat. The stylus for generalized wear is made of polyacetal; the one for localized wear is stainless steel. The original publication states that each spring is calibrated with a 200 kg load cell in conjunction with a universal testing machine before testing, but no data have been reported with regard to the deviations, the scattering of results and the time intervals of force measurements or the replacement frequency of the spring.

Ivoclar method

After processing and before testing, the specimens ($n = 8$) are kept dry at a temperature of 37°C for 24 h. The specimens are mounted in a chewing simulator that is commercially available (CS-4, SD Mechatronik, Germany). Antagonists are made by pressed IPS Empress ceramic (Ivoclar Vivadent) which is glazed 2 times at a temperature of 870°C. The diameter of the antagonist is 2.4 mm at the height of 600 m. A weight of 5 kg is put on each vertical bar. The sliding movement is fixed at 0.7 mm. The frequency of the antagonist movement is 1.6 Hz. A total of 120,000 cycles of unidirectional antagonist movements are carried out. Thermocycling with a frequency of 320/120,000 cycles is included in the wear setting with a temperature difference between 5°C and 55°C. After completing the wear generating procedure, replicas are made with white super hard plaster (Fuji Superhard Rock, GC Corporation, Japan). The plaster replicas are analyzed with a commercially available laser scanner device (Laserscan three-dimensional [3D] or etkones 1, Willytec, Germany) and the appropriate Match-3-D-software.[8] The volumetric (Ivoclarvol), as well as the maximal vertical loss (Ivoclar vert) (1% percentile), is calculated by the software.

Munich method

The Munich Method has been developed at the Maximilian University in Munich (Germany).[9,10] After processing the specimens (Ø 7.5 mm, $n = 8$) were kept in Ringer's solution for 24 h. After that period the specimens are mounted in a sliding wear tester (Munich artificial mouth) with pneumatic cylinders as an actuator. The wear tester is configured as a pin-on-block design allowing the test specimens to slide under permanent contact to the spherical antagonist (Degussit aluminum oxide and 5 mm diameter) at a linear distance of 8 mm and a vertical load of 50 N. During the chewing simulation, the specimens are rinsed with distilled water with a temperature of 37°C. At 6000, 10,000, 30,000, and 50,000 double cycles (bidirectional forth-and back-movement), replicas are made with white plaster (Fuji Superhard Rock, GC Corporation, Japan). The volumetric loss of the wear facet is quantified on the plaster models with the Laserscan 3D device (Willytec, Germany) described above and converted to vertical loss.

OHSU method

This method has been developed at the Oral Health and Science University (OHSU) in Portland (USA).[3] In principle, enamel cusps are forced into contact with the specimens through a layer of food like slurry (mixture of poppy seeds and PMMA beads). The enamel cusps are drilled out of human upper molars of similar shape giving them a spherical shape of a diameter of 10 mm. The enamel stylus is polished with 600 grit and 1000 grit silicon carbide and polished with 5 m aluminum oxide paste and then ultrasonically cleaned for 1 min. Before mounting the specimens ($n = 10$) in the wear simulator, they are kept in water for 24 h at 37°C. First the cusp is forced with a load of 50 N on the surface, sliding across a linear path of 8 mm producing abrasive wear. At the end of each path, a static load of 80 N is applied to produce localized attrition wear. For a whole test sequence, 100,000 cycles at 1 Hz with unidirectional movements are run. The mean vertical loss of the abrasion and attrition wear facets is measured with a profilometry device at 10 defined tracks. The values of tracks 4–6 correspond to the abrasion wear (OHUS ab) and the tracks 8–9 to the attrition wear facet (OHUS at).

Zurich method

The Zurich wear method has been developed at the University of Zurich (Switzerland).[2] With a load of 49 N and a frequency of 1.7 Hz the palatal cusps cut out of similar upper molars push against the surface of the specimens ($n = 6$) that are mounted on a rubber socket at 45° angle allowing the antagonist to glide over the surface of the test specimen. The test specimens are kept in water with exchanged temperature according to a thermocycling protocol (3000 × 5°C/55°C). After 120,000, 240,000, 640,000, and 1,200,000 cycles of loading the specimens are submitted to a tooth brushing device with a slurry of toothpaste for 30 min, 30 min, 100 min, and 140 min, respectively.[11] In addition, at the end of the first phase (120,000 cycles), the specimens are put into a solution of 75% ethanol for 20 h to simulate the chemical degradation. After each thermomechanical sequence, the maximal vertical loss of both the specimens (occlusal contact area OCA) and the antagonists, as well as the vertical loss in the contact-free area, are calculated using a computerized 3D-scanner.[12] The scanner is driven by step motors which scan the object in 1 m steps in the *z*-direction and 100 m steps in the *xy*-direction.[5,10,11]

Four variables were used in conjunction with the Zurich wear method: Phase 1 after 120,000 loading cycles, phase 2 after 240,000 cycles, phase 3 after 640,000 cycles, and phase 4 after 1,200,000 cycles. These values were claimed to correspond to 6 months, 1 year, 2.7 years, and 5 years of clinical wear, respectively.[11] For the Alabama method two variables had been included in the analysis: Generalized and localize wear; for the OHSU method two different wear zones were generated: Abrasion and attrition. For the Ivoclar method, the vertical, as well as the volumetric wear, was taken into consideration. A single variable was available for ACTA and Munich (vertical loss after completion of all cycles).

DISCUSSION

In the past, some efforts were made to correlate *in vitro* and *in vivo* data, but those studies were marred by a number of shortcomings related to an inadequate methodology of *in vivo* wear measurements, inadequate statistical methods, and/or a limited number of materials.[4,9-11] From the early seventies to the present date, the clinical wear of restorative materials was subjectively evaluated directly on the patient together with other clinical parameters using (modified) USPHS criteria. USPHS criteria, however, are by far not an adequate tool to measure wear.[13,14] In the eighties and early nineties, clinical wear used to be quantified by comparing cast replicas with a set of standards, known as scales. Two evaluators would compare the replica with the standards by means of loupes and assign a wear value. The scales were based on the concept that material loss at the restoration margin was indicative of the loss of material over the entire restoration surface. Mainly three different scales were propagated at that time. (1) The Leinfelder scale,[15] which used 6 calibrated die stone standards from clinical restorations, exhibiting approximately 100–500 m of occlusal loss; (2) the Moffa–Lugassy (M–L) scale; and (3) the Vivadent scale (modification of M–L scale developed by V. Rheinberger, Ivoclar Vivadent, Schaan), which used tooth sized dies with restoration-like incremental defects.

Factors that Affect *In Vitro* Wear Simulation

Standardization of the antagonist: Counter sample materials

Any laboratory investigation of the wear resistance of dental materials needs to consider oral conditions so that *in vitro* wear results can be correlated with *in vivo* findings. For differences among materials to be easily detected, low variation in *in vitro* wear tests is desirable. The choice of the counter sample is a critical factor in establishing the pattern of tribological wear and in achieving an efficient *in vitro* wear testing system.

A variety of factors including hardness, wear surface evolution and frictional coefficients have to be considered, relative to the tribology of the *in vivo* situation.[16-20] Assessment of potential counter sample materials should be based on the essential tribological simulation supported by investigations of mechanical, chemical, and structural properties.[21-25] Antagonists standardized for shape and size and according to materials should show mean values similar to those found in natural, non-standardized cusps. Krejci *et al*.[25] measured the shapes and sizes of palatal cusps of non-erupted human upper third molars. The cusp cupola was best described by the formula $y = 0.001\ \chi^2$ and was symmetrical around the axis of rotation. Up to 200 m of the *y*-axis, this parabola corresponded best to a ball radius of 0.6 mm. Natural enamel antagonists are preferable for the simulation of wear in the occlusal contact area.

Composition of the antagonist

The composition of antagonist may be either enamel, gold, ceramic, composite, stainless steel, annealed chromium or alumina ball with a diameter of 10 mm.

Shape of the antagonist

Flat, ball or rounded, flattened enamel surfaces, Enamel harvested from extracted human third molars and machined into cusps with a 5 mm spherical radius or hemispherically, standardized human enamel cusps with a uniform contact area of 0.384 mm^2.

Load/force

In the load/force diagram, several variations are possible.[26,27]

The load may be applied either as a static and/or sinusoidal cyclic and dynamic contact. The loads could range from 1 to 100 N with a chewing force of 53 or 75.6 N (maximum), abrasion load of 20 N and attrition load of 90 N.

Contact area size: Force per unit surface area

Facet area

The importance of the effect of contact area dimensions on the wear of composite specimens and their opposing enamel cusps was evaluated *in vitro* by Krejci *et al*.[23] Standardized contact area dimensions of 0.26, 0.38, 1.18, and 4.10 mm^2 were tested. The contact surfaces of the restorations and of the antagonistic enamel cusps were evaluated by scanning electron microscope. Increases in enamel contact areas after being loaded were measured by means of a digitizer and expressed in percent of the initial size before stress exposure. The wear of the composite specimens varied from 69.8 ± 19.9 to 9.5 ± 3.6 m, and that of antagonistic enamel cusps from 31.3 ± 3.4 to 8.8 ± 1.5 m. The increase in contact area varied between 27.8 and 0.1%.

Number of cycles

To compare results from different studies, one should take the number of cycles into consideration ranging from 5000, 10,000, 25,000, 50,000, 100,000 to 120,000.

CONCLUSION

There are certain advantages of *in vitro* models. These include controlled exposure time, nature of the agent to be studied individually or in combination, more defined substrate and tissue type, temperature, acidic environment and concentrations, larger numbers of samples can be examined over relatively short periods of time, a high level of standardization can be achieved, and possibility of controlling numerous variables. The *in vitro* models are extremely useful for demonstrating the wear propensity of a substance. The disadvantages of *in vitro* models include that they cannot replicate the oral environment with all its biological variations. Extrapolation to the oral environment is impossible to calculate. They show only trends and indications as to the true extent of wear can be obtained.

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