Predictability of clinical wear by laboratory wear methods for the evaluation of dental restorative materials
Heintze, Siegward Dietmar

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Chapter 8

Summary and future perspectives
In technical engineering, wear is the progressive loss of material from an operating surface of a body as a result of relative motion on the surface area. The friction of the materials involved, the lubrication of the material surfaces and the applied load stresses are the influencing factors that affect the wear rate. A similar definition can be adopted for the wear of dental materials in the oral cavity. The restorative material in its anatomical form is the body against which other artificial materials or enamel slide, the motion is generated by the movement of the lower jaw, the lubricant is saliva and the loads are generated by the masticatory muscles.

Wear as such is a physiological process that occurs with time and affects more or less all natural teeth as well as artificial materials that are incorporated in the tooth or in a prepared tooth. The dental hard tissues are the only tissues that are replaced only once during the lifetime of a human being, i.e. when the deciduous teeth are replaced by permanent teeth between 6 and 11 years after birth. Excessive wear can be seen in patients that suffer from bruxism, parafunctional habits and regurgitation refluxes. However, as the stomatognathic system is very adaptive even extreme wear of natural or restored teeth generally does not lead to diseases of the temporo-mandibular joint or periodontal diseases. Also elongation of antagonists due to wear is limited and does not cause biological problems. Therefore, wear as such is an aesthetical problem in the first place, especially when it occurs in visible areas like anterior or premolar teeth.

As the measurement of clinical wear is complicated and time-consuming and as the results vary largely amongst patients, different wear simulating methods were developed in conjunction with electro-mechanical devices that try to mimic some elements of physiological masticatory movements and load mechanisms. Devices to test dental materials have to be qualified for the intended purpose. The test equipment has to operate within acceptable and reproducible limits and tolerances. With regard to chewing simulators, force, speed of movement and frequency are decisive factors that have to be controlled as was pointed out in chapter 2. Some of the methods, however, do not allow to generate reproducible results. In a systematic review, the wear rate results for the same composite resin varied between 30% and 70% for some methods, when the same wear generating parameters were used. This variation is most probably attributable to the fact that devices, which were not appropriate for the intended use, were employed. The Alabama and ACTA methods are the methods most frequently cited in the dental literature. Only two devices, which are designed to be used as chewing simulators with two axes, allow the force and distance applied to the test samples to be controlled (MTS, BOSE
ElectroForce); however both devices are very expensive and feature one chamber only. The two-axis Willytec chewing simulator is a good compromise with regard to reproducibility of results, flexibility, costs and maintenance. This simulator uses dead weights, which are descended and lifted with computer-controlled stepping motors. Some Willytec simulators are designed to produce simultaneous thermocycling with sequential flooding and evacuating of the chambers. According to a survey, a Willytec chewing simulator with 8 chambers is used by 15 dental universities and 3 dental companies; all together 23 such devices are in use. The chewing simulator can be used for both wear testing and loading of prosthodontic reconstructions or fillings placed in extracted teeth.

Some of those methods are part of an ISO Technical Specification on two-body and three-body wear. The different methods follow different wear concepts and approaches and therefore vary widely with regard to the main wear-influencing factors, such as load, abrasive medium, shape and material of stylus, number of cycles, force actuator, etc. Therefore, the results cannot be directly compared as the blind round robin test on 10 materials (8 composite resins, 1 ceramic, 1 amalgam) tested with 5 different methods (ACTA, Ivoclar, Munich, OHSU, Zurich) has shown (chapter 6); the test centres did not know which material they tested. The variability of the test results varied tremendously between the methods. Of all five test methods, the Ivoclar method showed the lowest coefficient of variation in relation to the number of specimens tested.

Intraoral wear can only reliably be measured with sophisticated equipment and after taking replicas. The quality of the replicas is crucial for any wear quantification. Impression taking and pouring with improved stone or epoxy resins have to follow a strict protocol. Optical sensors (laser, white light interferometry) and mechanical sensors (profilometry) provide similar results with regard to precision and accuracy, as a comparative study of the wear facets of 126 specimens from 12 dental materials showed (chapter 4). In this study, the materials were subjected to the Ivoclar wear method, which involves 120,000 cycles of loading with 5 kg weight, 0.7 mm lateral movement, and simultaneous thermocycling. However, optical sensors should be preferred over mechanical sensors because of their efficiency and ease of use.

The type of antagonist is another element that plays a crucial role in wear testing methods. Enamel should be the material of choice due to its relevance. However, it is not possible to standardize a biological substrate as far as its composition is concerned. Furthermore, there is a shortage of extracted teeth making it necessary to look for alternative materials. Different materials have been proposed as enamel substitute. The pressable leucite-reinforced ceramic IPS Empress is a suitable material for this purpose. The OHSU wear
method showed that this material generates a similar wear rate as an enamel stylus of the same shape (chapter 3). However, when the lithium disilicate material e.max Press, which features a higher strength than IPS Empress, was used, the wear rates were different both for the OHSU and the Ivoclar method.

The correlation of the physical parameters of 24 different composite resin materials, including 11 experimental materials, was analyzed in a systematic investigation. This study revealed that it was possible to create a wear formula for the Ivoclar method as shown in chapter 5. The wear formula is based on the volumetric percentage of all fillers and the volumetric percentage of the largest filler, the fracture toughness, modulus of elasticity, and Vickers hardness. The lowest wear for composite resins to be tested with the Ivoclar method can be expected for a material with small fillers, high fracture toughness, high filler volume, high modulus of elasticity and relatively low Vickers hardness. The good correlation between the physical parameters and the actual wear rates is indicative of the fact that the Ivoclar wear method is based on the physical properties of resin materials. This formula enables research developers to construct composite resins that show low wear in the chewing simulator.

A wear method should not only be internally valid, which means that the results for the same material tested at two different points in time are similar, but the wear method should also be externally valid, which means that the results correlate with in vivo findings. The raw data on clinical wear of restorative materials (21 composite resins for intra-coronal restorations, 20 direct and 1 indirect; 5 resin materials for crowns; 1 amalgam; enamel) which was provided by the Technologies in Restorative and Caries (TRAC) Research Foundation (formerly Clinical Research Associates CRA) in Provo, USA, was used to correlate the clinical wear results with those of the most frequently cited wear methods, namely Alabama (localized/generalized), ACTA, OHSU (abrasion/attrition), and Zurich method. Additionally, the results of the Ivoclar and Munich wear method were investigated. The best and most significant correlation was found for OHSU (abrasion). For the methods Zurich, ACTA, Alabama generalized wear, Ivoclar (volume) and Munich, the correlation was weak with correlation coefficients between 0.3 and 0.5 (chapter 7). Alabama localized wear did not correlate with the in vivo findings at all. The combination of different methods did not improve the correlation. Therefore, wear simulation methods cannot reliably predict the wear of restorative resin materials after the insertion into the oral cavity. However, some of them have the potential to provide a rough indication of whether a material might be wear resistant or show excessive wear in vivo. The clinical wear data showed that to date no composite resin is as wear resistant as amalgam.
Future perspectives
Wear can efficiently and adequately accurately measured with modern laser technology both in vitro and in vivo. The different laboratory methods to test the wear rate of dental materials follow different concepts and the results can therefore not be compared with each other. Most of the laboratory methods to test the wear of dental materials are not validated and operate with a device that is not qualified for this purpose. Low reproducibility and high variability of test results as well as low correlation with clinical results are the consequences. Mimicking the entire masticatory cycle with all possible movements of the lower jaw is not the correct approach and is not necessary to test the wear rate of materials. However, a machine that applies a force in only one direction is equally inadequate. Instead, the device should have computer-controlled force actuators, bi-axial motion and water exchange in the test chamber. The device should be simple, robust and efficient and require only low maintenance efforts. There is no need to cut enamel from extracted teeth and use it as stylus material. A pressable or machinable ceramic material of low strength is an adequate substitute. It is time to define an adequate standard wear testing device that qualifies for the purpose and to adopt a wear method that is validated. An indication for a valid wear simulation concept is that the variation of physical parameters of different composite materials can explain the wear of those composite materials thus making the method internally valid. The clinical wear results can be used to externally validate the wear method.

It is desirable that more wear-resistant composite materials are developed so that composite resin materials maintain their anatomical shape over longer time periods than it is currently the case. Possible directions of future research include (1) better and stronger monomers, (2) better polymerization kinetics and higher conversion rate, (3) intelligent filler technologies with optimal filler distribution and dimensions as well as stable bonding between filler and matrix, (4) “self-repairing” composites with microspheres that liberate a polymer that repairs possible cracks in the material.