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Friction and wear behavior of human teeth under various wear conditions

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Abstract

Previous reports have described the differences in the friction and wear behavior between different zones of human teeth. The objective of this research was to study the friction and wear behavior of human teeth under different wear conditions to extend the understanding of the tooth wear process, as well as to provide a more rational explanation for wear mechanism of teeth. Two typical wear tests, namely two- and three-body wear, were conducted on human tooth enamel using a reciprocating apparatus. The effect of food particles was of particular interest. Three loads, 10, 20 and 40 N, were used. Wear was assessed by sample wear volume. The results show that human tooth enamel exhibits lower friction and smaller wear volume under three-body wear conditions than under two-body wear conditions. Under three-body wear conditions, although increasing normal load results in a progressive increase in the wear volume of enamel, the increasing rate is lower at high load than that under two-body wear conditions. Further analysis of wear surfaces indicates that human tooth enamel experiences different wear mechanisms under different wear conditions.

Keywords: Human teeth; Friction and wear; Food particles

1. Introduction

Wear of teeth, particularly on the occlusal surfaces, is considered a natural and physiological process. For most people, enamel serves as an occlusal surface whose morphology is shown in Fig. 1. Enamel uniquely consists of aligned prisms or rods, which run approximately perpendicular from the dentine–enamel-junction towards the tooth surface [1–3]. Each rod consists of tightly packed carbonated hydroxyapatite crystals, which are covered by a nanometer-thin layer of enamelin and oriented along the rod axis. The interfacial area between rods is termed inter-rod enamel, which is protein rich and mostly a result of the incoherence of combining crystals of different orientations in that area.

The wear of teeth has a multi-factorial aetiology involving the interplay of attrition, abrasion and erosion [4–7]. Attrition, also called as contact wear, describes tooth surface loss by tooth-to-tooth or tooth-to-restorative contact, and is often regarded as two-body wear. Abrasion, or generalized wear, is used for three-body wear caused by movement of food over both antagonizing teeth surfaces during mastication. Erosion is defined as loss of tooth structure attributed to chemical effects without the involvement of bacteria. Furthermore, in any tooth wear process involving physical and chemical agents, many factors such as contacting force, duration of contact, etc influence the wear [8].

Most of previous work has focused on the studies of two-body wear of human teeth [4,8–15]. However, only a few studies have investigated the wear of human tooth caused by food particles [16]. Mass [16] carried out compression tests to investigate the microscopic wear features on the occlusal surfaces of teeth caused by food particles. The results showed that large particles produced fewer, larger wear features than the small particles, and total wear area increased with particle size. Interestingly, wear seemed to be independent of load. But Eisenburger and Addy [8] found that load significantly influenced

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enamel wear by attrition both in acid and neutral conditions. Although such studies have taken the effects of food particles and normal load on tooth wear into account, they focused simply on the wear loss, rather than investigating the wear mechanism in detail.

In addition, the oral environment is very complex and has many variables so that a number of deficiencies exist with most of the test simulations of tooth wear. It is reported that the choice of testing machine and parameters influence the reliability of in vitro wear tests of human teeth to a greater extent [17]. Therefore, only representative laboratory tests would help the further understanding of tooth wear mechanisms and simplistic approaches would not. To better simulate mastication pattern, friction and wear tests on human teeth have been performed in a reciprocating sliding mode, instead of unidirectional sliding pin/disc mode, in our previous work [14,15]. Human teeth were tested against different dental restorative materials in the dry and artificial saliva conditions, for the friction and wear behavior of the enamel and dentin of a tooth.

In this study, more detailed research was performed on the friction and wear behavior of human teeth using a reciprocating apparatus, see Fig. 2. In vitro friction–wear tests under two- and three-body wear conditions have been conducted and compared on the occlusal surface of human teeth at different normal loads. Particular attention was paid to the effects of food particles and normal load on tribological behavior of teeth.

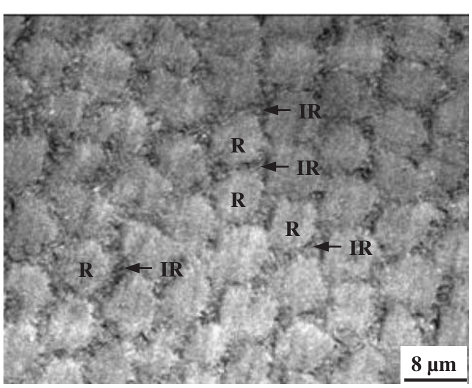

Fig. 1. Laser confocal scanning microscopic image of enamel rods obtained on an occlusal section. R = rod, IR = inter − rod.

2. Materials and methods

2.1. Sample preparation

Flat samples used in this study were freshly extracted human teeth without caries. The teeth were then placed in distilled water at 4 °C avoid dehydration before sample preparation. Thirty mandibular second permanent molars (M_2), which were obtained from different young people of 18–25 years old, were used in this study. Before testing, each of the 30 teeth was cut into two halves using a diamond saw, with the cut lying perpendicular to the buccolingual division line. The cutting was conducted under a water-cooling condition, aiming at mitigating local overheat which can result in dehydration and changes in microstructure and chemistry of human teeth. The half of lingual side was then embedded into a steel mold with self-setting plastic ($10 \times 10 \times 20$ mm in size) to obtain flat samples with the occlusal surface facing up. All the mounted samples were ground and polished under water-cooling conditions. Detailed preparation of teeth sample and microhardness characterization were done according to the methods that have been described in our previous work [15]. Only 0.2–0.3 mm was ground and polished off, aiming to keep the obtained surface similar to the original occlusal surface of teeth in mouth. After polishing, all the samples were stored in distilled water at 4 °C well.

The roughness of the flat samples was measured by means of a highly sensitive profilometer (TALYSURF6, England), with $R_a = 0.20\,\mu m$. The teeth were dehydrated partly during preparation, but efforts were made both to shorten the dry time and to keep the preparation time approximately the same for each sample. A titanium alloy ball (C 0.043%; Al 6.020%; H 0.011%; O 0.160%; V 4.100%; Fe 0.168%; Ti the balance) with a hardness of 350 HV and 40 mm in diameter was used as a ball sample. In terms of the evolution and stable value of the friction coefficient and the worn surface morphology and wear scar depth, our previous work found that the enamel/titanium alloy pair was similar to the enamel/ enamel pair [18]. All samples were cleaned by alcohol before testing.

2.2. Friction and wear test

In vitro friction–wear tests with bath lubrication were conducted in a ball-on-flat configuration using a reciprocating

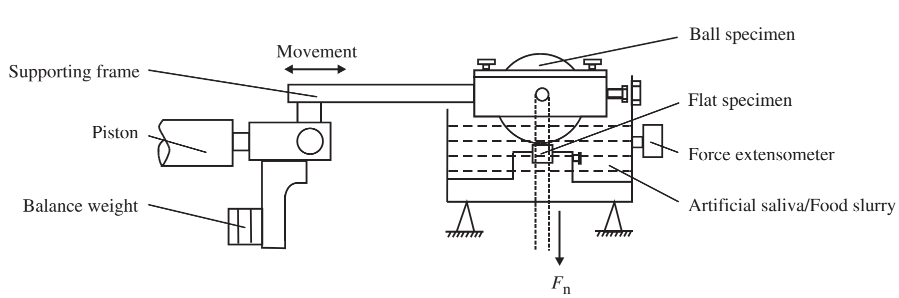

Fig. 2. Schema of friction and wear test rig.