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A new tribometer for friction and wear studies of dental materials and hard tooth tissues

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Abstract

This paper presents a new tribometer developed for a study of the tribological behaviours of dental materials and hard tooth tissues. The device simulates oral kinematic conditions and the loading produced during masticatory process. The tribometer is similar to the existing devices regarding the kinematic features, i.e. it produces an adjustable oscillating movement. However, the device machine is equipped with a unique pneumatic system of loading controlled via computer by special software called TOOTHY. The programmable system allows easy adjusting of the loading parameters such as the magnitude of normal force and its amplitude or pattern of cyclic loading. In this way different combinations of loads can be applied thus making the investigation of different wear situations possible. The device has two full bridge strain gauges for the measurement of loading and friction forces, by which the coefficient of friction is determined.

The use of the tribometer is illustrated by a comparative study of tribological behaviour of human enamel subjected to two- and three-body friction, and to two different loading patterns as well. The obtained results are discussed.

Keywords: Tribometer; Friction and wear test; Tooth enamel; Dental materials

1. Introduction

Up to now a wide range of devices for tribological testing of dental materials has been employed. It is understandable that simple wear-producing machines such as pin-on-disc cannot duplicate the complexity of intra-oral conditions. However, even more sophisticated simulators like the ones developed by De Long and Douglas [1] or by Yap et al. [2] have only partially been successful at predicting clinical performance of restorative dental materials or tooth enamel. The main reason for this situation is that while developing a new design a lot of effort has been concentrated on obtaining a similarity to the physiological movements or force patterns existing in the mouth, whilst there is no standard pattern of intra-oral conditions. Kinematics as well as loading of teeth has a strong stochastic nature, different for each individual [3] and it depends, for instance, on the kind of food subjected to reduction, and as a consequence substantial scatterings of the tooth wear is observed [4]. It follows from the above that the methodology of tribological investigations of dental materials or hard tooth tissues as well as designed apparatus should be covering main oral features (in terms of tribology) with a possibility of their controlling rather than fixed "the most probable" oral conditions. This approach gives us also a possibility to carry out more fundamental investigations instead of a simple wear assessment after tests. Moreover, it is also very important to record the friction force as a function of test time (usually skipped in oral simulators). This allows us to obtain kinetic characteristics, which are helpful to interpret wear mechanisms and utilize energy criteria to evaluate wear resistance of the investigated materials [5].

On the basis of the literature study and the authors' own experimental experience, it is postulated here that a

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tribometer for testing of dental materials and hard tooth tissues should possess the following main features:

- cyclic loading of testing samples;
- "to and fro" movement of testing samples with a separation of the contacting surfaces during a backward motion;
- force-movement timing;
- controlled ambient conditions.

The type of loading has a great impact on the wear process, and as it has been stated in the author's previous work [6], the wear behaviour of human enamel at cyclic loading is substantially different from the one that occurs at a constant load value. The effect and the type of loading used was also confirmed during testing a dental material [7]. As regards the required form of movement, the bidirectional one is not only similar to the physiological motion, but it can also produce a more severe wear than the one that might take place during the unidirectional movement. For example, when testing steel, Bill found [8] that the wear rate for unidirectional sliding was about 10 times lower than the one noticed during bidirectional sliding. The next important feature of the tribometer is the manner in which the force is coupled with the movement. Usually when cycling loading is used it is also assumed that the maximum of the loading force corresponds to the middle of the sliding stroke [1,7]. However, according to Condon and Ferracane [9] in the mouth the chewing force is increased at the end of the chewing stroke. As a consequence this produces different wear mechanisms along contact tooth areas. Apart from the requirements listed above, a possibility of using different environments, including natural and artificial saliva, is obvious as numerous studies have shown substantial influence of environmental parameters on the wear of hard tooth tissues and dental materials as well.

The goal of the research reported in this paper was to design a tribometer that could be used for a comprehensive study of wear and friction behaviour of hard tooth tissues and dental materials. The authors believe that the employment of the presented design will be helpful for a better understanding of tribological processes taking place in the human mouth.

2. Parameters of chewing cycle

Chewing is a complex and compound process. Parameters which characterize mastication such as bite forces, speed and acceleration of the mandible vary widely and depend on kind of food, size of a food bolus, chemical and physical action of saliva or psychological factors. The knowledge of a great variety of oral situations is indispensable in order to make appropriate selection of parameters of the developed tribometer.

There are several somewhat different descriptions of the chewing cycle [10–12], nevertheless it can be accepted that the whole cycle is divided into two main phases: Phase I (closing phase), when the teeth are brought into occlusion, and Phase II (opening phase), when the teeth are being separated from each other. During Phase I the food is compressed, crushed then grinding occurs either with direct or tooth–food–tooth contacting of opposite teeth surfaces. The motion of the jaw preceding grinding varies widely and depends on kind of the food undergoing the chewing process, whereas during grinding it is strictly defined by the shape of the dentition. Upper and lower posterior teeth of mammals are developed into the so-called tribosphenic molars which have complex surfaces and cusps that fit together in a dynamic way during the chewing process [13]. A simplified drawing of the chewing cycle is displayed in Fig. 1. It is worth noting that the teeth can be brought in direct contact and relative movement not only in order to process food, but also because of some masticatory habits (thegosis, bruxism) [14]. They (especially bruxism) are treated as some extreme processes, causing excessive wear of teeth.

It is well known that the load applied to the teeth during mastication has no constant value. On the basis of numerous works [15–18] one can assume that the shape of the force curve is similar to the positive half of a sine curve [1,7]. However, as it was shown by the measurements performed by Kohyama et al. [19,20] in order to obtain the kinetics of the chewing force, the force curve is asymmetric, and the time to reach the peak force equals 59–67% of the whole occlusion time. Furthermore, it seems reasonable to assume that the real force curve is less regular than the sine one because of the irregularity of some foods [21].

The magnitude of the force produced during mastication depends mainly on the physical properties of food. As there is a great variety of foods, various forces can be expected. It has been confirmed by the experimental data presented in the literature. Kohyama et al. found in their study [19] that the mean of the peak force during chewing silicon rubber ranged from 33 to 37 N for incisors and from 100 to 127 N for molars. Substantially higher values were reported

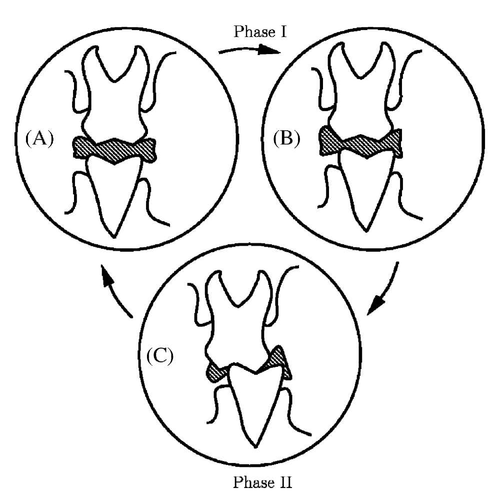

Fig. 1. Schematic drawing of the chewing cycle.