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Technical Note

A multifunctional device to simulate oral ageing: the "Rub&Roll"☆

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ABSTRACT

This article describes an in vitro fatigue and/or wear simulator enabling controlled application of force, speed, type of liquids and duration, to mimic challenges representative for the human oral environment.

The device consists of a container in which a cylinder with specimen holder is placed which drives another cylinder (rod). The rod rotates in an opposite direction to the rotation of the stirring motor, rolling over the specimens mounted in the cylinder. When the rod contacts the specimen a force is applied to mimic processes in the oral environment. The design, working and construction principles of a new device, the Rub&Roll, and some of the possible applications are described Four different application examples are presented: occlusal wear in an low acidic abrasive slurry; combined erosive and abrasive wear of enamel exposed to apple juice or apple pulp; the wear of sealant material in natural teeth in an abrasive slurry; and the influence of mechanical loading cycles on micro tensile bond strength of an adhesive system to dentin Application of the "Rub & Roll" device showed results which are clinically relevant, reproducible and in accordance with existing literature.
Conclusions: The Rub&Roll enables controlled application of chemical and mechanical loading, allowing variation of force, sliding distance, velocity, number of cycles, and frequency, and a combination with erosive and abrasive challenges representative of those in the oral environment.

1. Introduction

The oral human cavity is a complex environment where teeth, restorations and dental appliances are subjected to mechanical (tooth-tooth or tooth–foreign object contact), chemical (body fluids and dietary products) and thermal challenges. These challenges lead to ageing, wear and failure due to fatigue. Wear factors are classified in various ways (Mair, 1992) and the dental

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nomenclature, e.g., erosion and attrition, is sometimes different from that used in other fields of science like for example in geophysics. Tooth wear is generally regarded as the result of an interaction of several fundamental processes. In the behavior of intra-oral structures fatigue plays an important role. Fatigue wear occurs as a result of the formation and propagation of subsurface micro cracks when two surfaces move under dynamic load. A recent overview on the performance of dental composites stresses the importance of a resistance to fatigue for these materials (Ferracane, 2013). Composites that were subjected to dynamic mechanical loading prior to fracture testing demonstrated a reduction 45 to 62% of the static loading values (Lohbauer et al., 2006). Simulated oral aging is also considered to be essential in evaluating long-term adhesive bonding to dentin (Skovron et al., 2010). Subjecting materials to a regime of fatigue / aging is considered to make a test more predictive for their clinical behavior.

In 2006 a special issue of Dental Materials focusing on wear in all its facets was published. Lambrechts and colleagues discussed available wear testing devices and distinguished tooth brushing machines and two- and three-body wear machines (Lambrechts et al., 2006a, 2006b). According to the authors, the ideal wear machine perfectly mimicking the oral environment does not exist. Each of the machines has advantages and disadvantages, and limitations. Heintze compared in vitro and in vivo wear data and concluded that a strong correlation is impossible to obtain due to differences in patient-related factors (Heintze, 2006). The current available wear and fatigue machines make use of complex technology, are expensive and require special technical skills to let these devices perform well. Also, they often concentrate on a single type of challenge. This article describes a new in vitro fatigue and/or wear (aging) simulator that allows separate or simultaneous mechanical and chemical loading experiments, requires little technical support, is inexpensive and can be used to load a high number of specimens of natural teeth or restorative materials per experiment.

2. Material and methods

2.1. Design

The Rub&Roll consists of a container in which a cylinder is placed that is driven by a stirring motor (Fig. 1). In the cylinder up to at least 16 specimens can be mounted. Between the cylinder and the inner wall of the container there is a space of 14 mm in which one or more rod(s) are placed (Fig. 2). The rod is a RVS core in a PVC hose and is held between the inside of the container and the cylinder. When the stirring motor (cylinder) starts rotating, the rod rotates in an opposite direction to the rotation of the stirring motor, rolling over the specimens mounted in the cylinder. When the rod contacts the specimen a force is applied. Using shims, the top surface of the specimen can be positioned to protrude a predetermined distance from the surface of the cylinder. In that way forces up to 75 N can be generated on the specimen. The stirring motor can be set at different speeds to simulate the speed of mastication. In the container different kinds of liquids and abrasive slurries can be applied during the testing procedure, allowing a controlled mechanical and chemical loading.

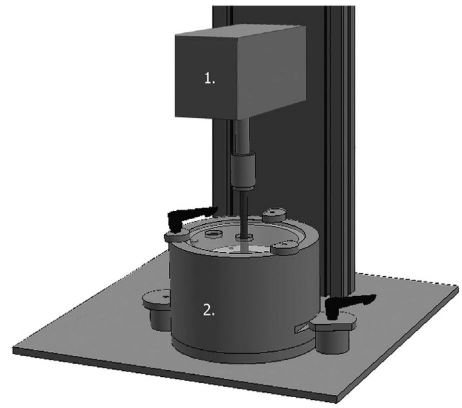

Fig. 1 – Schematic presentation of the Rub&Roll and its main components: 1) stirring motor, 2) container. The cylinder is attached to the stirring motor and placed in the container.

2.2. Construction and working principle

The cylinder is attached to the stirring motor and fits with the aid of a locator pin exactly in the center of the container. When the cylinder starts moving clockwise it activates the rod that will move counter clockwise. As a consequence the rod will pass a different distance along the edge of the container than the cylinder (Fig. 2). By using the measurements of cylinder, container and rod, respectively, several parameters can be calculated, such as rod displacement (Table 1).

In a single rotation the rod moves 44 mm along the container, the angular rotation 0.56 rad. The displacement at the cylinder side can be determined by multiplying the cylinder radius by the angular rotation: 36.2 mm. The total displacement of the cylinder required to produce one rotation of the rod is 36.2+44=80.2 mm. This means that the rod will rotate around the cylinder 408 / 80.2=5.1 times (Fig. 3).

From this measure we can calculate the "delay" of the rod compared to the cylinder: $408/(5.09 \times 44)=1.8$. The rod will return to the start position after 1.8 rotations of the cylinder having turned 5.1 times around its own axis.

A maximum of 16 samples can currently be mounted simultaneously in the cylinder. All types of sample can be mounted, such as embedded flat enamel or dentin, or natural shaped complete molars or teeth with or without root. Also samples made of dental restorative materials can be tested. Samples are embedded in PMMA (Autoplast, Candulor, Wangen, Swiss) to fit in the sample spaces with their top flush with the cylinder surface. By using a shim, the sample can be made to protrude at a fixed height from the cylinder. The shim can be made from rubber to mimic resilience of the periodontal membrane movement and efficiently reduces the effect of contact force variation (Rues et al., 2011).

2.3. Configurable settings

2.3.1. Rod

For the rod a standardized shape and size (diameter of 14 mm and a length of 85 mm) should be used. In order to ensure that the rod can rotate around the cylinder a flexible PVC coating is necessary. For simulation of the human mastication, according to Dejak et al. (2003) who did finite elements