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Original Research Article

Development of a chewing bench for testing dental materials: first stage

ABSTRACT

This paper presents the primary results in the development of a chewing bench prototype. The final aim of the device is to reproduce the human oral cavity environment in order to predict ageing of dental materials, it automatically imitates chewing cycles and reproduces the physical and chemical changes observed during meals. A dental articulator used for prosthodontics was chosen as an ideal structure for simulating human mandible kinematics; it has the advantage of being water tight compared to a hexapod device. Using OpenMeca® software and three motors the extreme movements of the mandible were replicated. Four thermally controlled tubs were used to mimic physical and chemical changes observed during meal. The chewing bench provides a valuable tool for the evaluation of dental materials; its relevance is based on the simultaneous presence of all parameters that affect dental materials during function (mechanical, thermal and chemical). It is the first stage of work which will be validated a posteriori.

Keywords: mastication, dental simulator, modeling, mandible movements

1. INTRODUCTION

The past decade has witnessed rapid advancement in various fields of dental materials, in particular restorative ones. This advancement has led to the emergence of new products on the market and improvement in existing products [1].

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Despite this, there is often a gap between in vitro performance of dental materials and clinical observations. This gap is related to the oral cavity environment; which accelerates the ageing of dental materials [2, 3, 4, 5].

Generally, failures in dentistry have multifactor origins, and wear and ageing of dental materials inside the oral cavity are related to different phenomena that vary among individuals and even in time for a given individual, these include; chewing forces, mandibular movements and physical and chemical changes during meals [2, 4, 6, 7, 8, 9, 10, 11] .

Recent research about the failure of dental materials sets more focus on enzymatic activity and slow degradation, and while secondary caries and fracture are considered the main causes for limiting the longevity of restorations, wear remains to be a significant mode of failure [12]. On the other hand, the ability to reproduce the complex oral environment even to a limited extent, continue to provide valuable information, about different materials ability to maintain their properties during function. Unfortunately other methods; whether animal studies or clinical testing, that could provide such information before hand, are expensive, time consuming and complicated. Furthermore, human mastication can't be reproduced by other species, since teeth shapes, mandibular kinematics and type of food are different among species [1, 13] .

In recent years, several wear simulators have tried to reproduce the oral environment for testing dental materials as closely as possible to in vivo conditions [11]. Starting with early trials as that of DeLong and Douglas [14] that reproduced human chewing cycles with two servo-hydraulic actuators, [1, 13, 15], and up to recent simulators based on hexapod design; and equipped with six degrees of freedom, and that could faithfully reproduce mandibular kinematics and simulate all chewing movements after programming. [1, 16].

One of the main drawbacks of such devices is that they allow for single parameter investigations [4], typically chewing forces; while other parameters are not considered despite their potential role in material aging [4, 6]. Newer devices claim to enable chemical, thermal and mechanical testing at the same time; the most recent is the "Rub&Roll" device by Ruben et al.,

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while for the present time; none of these devices include all parameters in a systematic manner [17, 18].

Multiple reviews discussed results obtained by different simulators available; they also provided a critic for the information obtained with such devices; in an in depth study of the various wear methods used, Heintze et al. found little correlation with clinical results, when comparing a large number of composite resin materials, yet he still concluded that these methods are important for categorizing various types of material used, mostly for new materials that are introduced in the market [19] .

In light of the above observations, a simulator is being developed (referred to as a Chewing Bench) that allows for the evaluation of dental material. This device will be capable of simulating the oral cavity and most of its parameters (mechanical, chemical and thermal), predict ageing of dental restorative materials and to imitate human chewing cycles and to make the materials undergo physical and chemical changes observed during meals, as well as clinical or pathological conditions.

The aim of this work is to reproduce the oral environment and all parameters (trajectory, chewing force, chemical or thermal changes during meals) that contribute to wear in order to predict the ageing of dental materials. (Figure 1)

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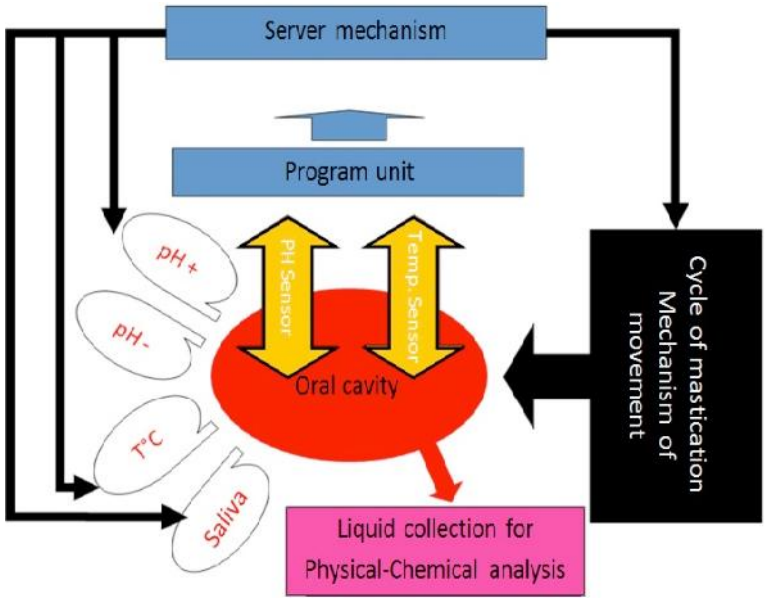

Figure 1: chewing bench principle

2. MATERIALS AND METHODS

2.1 Design

The chewing bench consists of an artificial jaw with three degrees of freedom during the chewing cycle, based on the semi-adaptable dental articulator (Fag, Quickmaster®, Figure 2) designed for realizing dental prosthodontics. It produces movements which are reversed compared to humans because its maxilla is movable and its mandible is still [20]. The scanning of the dental articulator (Fag) movement was performed using Romer jib SIGMA 2022 equipped with a Laser G-SCAN camera. This method allowed observing the triangulation deformations made by the articulator. Point clouds were obtained which were processed using Rapidform (RapidForm; 2004) and Catia (Catia, VR18) software.

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OpenMeca software (OpenMeca, 2007) was used to reproduce extreme mandibular movements. The software allows us to produce a three-dimensional mechanical linkage (Figure 3). Three programmable electric motors with brushless technology were used (Figure 4); two of the motors move from side to side and the third motor rotates, imitating the mandibular translation and rotation movements that begin in the temporomandibular joint.

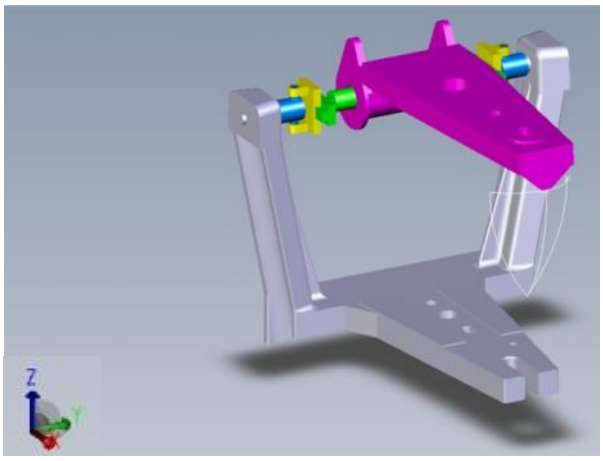
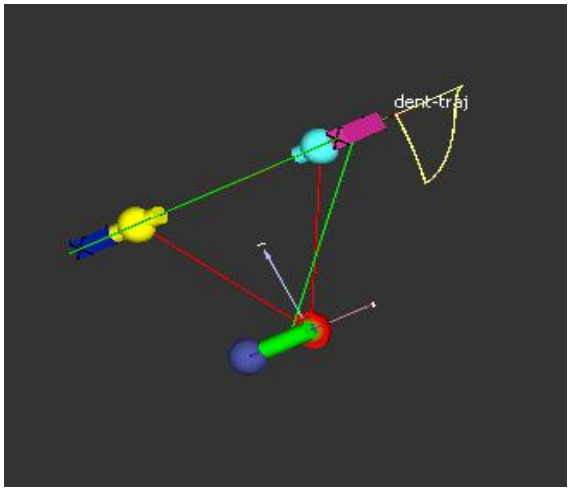


Figure 2: Dental articulator (Fag Quickmaster®)

In order to simulate the teeth, existing database can be used. Different teeth reproduced (canine, incisive, premolar and molar) can be inserted into corresponding holes on the dental arch in order to be involved in the masticatory process. The natural sample teeth can replace any tooth so reproduced. This method allows testing several teeth at the same time, comparing different restoration materials simultaneously, and changing the antagonist material used.



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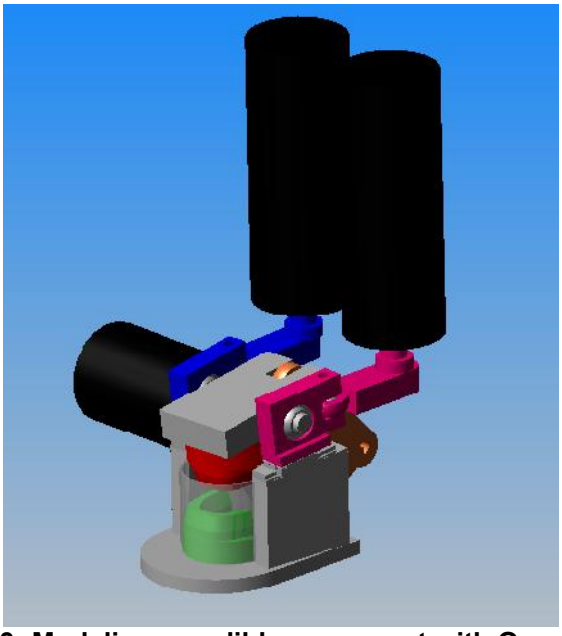

Figure 3: Modeling mandible movement with OpenMeca

Figure 4: Simulation of the oral cavity with the chewing bench and motors

2.2. Construction and working principle

The teeth are placed in corresponding holes in a dental arch form, whether natural or artificial teeth according to the test performed. The number of samples corresponds to the number of teeth in the arch; that is 14 for each of the two arches. Materials to be tested will be inserted into the cavities prepared in the teeth, in case of restorative materials, or shaped into teeth form in case of ceramics. The antagonist arch can be changed according to need whether with natural teeth or ceramic material. The design allows for a water tight environment, needed for the fluid injection device integrated in the device; responsible for varying the medium's pH and temperature.

A thermo-chemical device was developed especially for the chewing bench. Four tubs containing artificial saliva and different solutions with varying pH values and at different temperatures ranging between -5 - 70°C; low-pressure sprays of these solutions injected on the

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147 teeth with the possibility of making very fast changes of temperature (figure 5). The passage of
148 liquids is controlled by electronic solenoids, and a water pump. The exact temperature and pH of
149 the injected solutions will be monitored by special sensors present inside the cavity of the chewing
150 bench.

151 2.3. Configuration settings

152 2.3.1. Loading force and direction

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154 The three motors allow reaching a maximum force of approximately 500N which
155 corresponds to a majority of individuals for a full arch (as compared to a maximum of 700N) [21,
156 22, 23], and is greater than current in vitro tests which only reach a force of 150N [13].

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160 **Figure 5: thermo-chemical device using pumps for spraying**
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2.3.2. Parameters of the chewing bench

Other parameters and specifications of the chewing bench are shown in Table 1

Parameters	Values
Oral cavity Volume of	25cm3
Maximal forces	500N
Trajectory	Mastication cycle
Solution	Artificial saliva normalised
Temperature of solutions	Between -5°C - 70°C
Ph of solutions	Between 2-9
Maximal number of cycles	5000

Table 1: Parameters of chewing bench

The material chosen for the chewing bench was PolyetheretherKetone (PEEK); this material allows working with solutions with a pH ranging from 2 to 9. It corresponds perfectly to the chemicals in human food. In addition, this material stands temperatures in ranges between -5°C and +70°C, needed to produce thermal shocks of large amplitude to simulate the hottest as well as the coldest foods. The disadvantage is that PEEK is very rigid; cheeks made of silicone will be used for their flexibility, in order to easily reproduce the mastication trajectory.

Parameters	Value
Young (MPa)	3,7-4
Hardness	M99
Poisson	0,4
Friction	0,18
Density ($g.cm_{-3}$)	1,26-1,32
Spécific heat	1340
Acid strength	Good
Base strength	Good

Table 2 Properties of Polyetheretherketone (PEEK) (Polyetheretherketone, www. goodfellow)

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Silicone rubber has been tested successfully; its texture is as close to food a possible, so it can be used for food simulating [13, 24]. These devices will mimic the action of different foods (thermal and chemical parameters) on dental restorative materials while using artificial saliva.

3. DISCUSSION

Mastication is an essential function in human development. It is complex and involves several parameters (chewing forces, temperature, pH, and saliva). The device presented in this paper is capable of reproducing an oral environment and testing dental materials in conditions which are very close to in vivo conditions.

The dynamic fatigue and aging have been recognized to limit the longevity of restorative and prosthetic dental materials, and while wear is an important factor involved in the process, other factors seem to play an important role as well, especially on the tooth material interface [5] . The presented device not only tries to mimic the complex mandibular movement, to simulate mechanical wear and fatigue, but also integrates thermal and chemical effects, in systematic and programmable manner.

The proposed chewing bench has three degrees of freedom, it cannot thus accurately reproduce the complete kinematics of the human mandible [22] compared to the hexapod design [1, 16]. This limitation is related to the semi-adaptable dental articulator (Fag) chosen as a starting model; however, this choice should not significantly change the overall results, since their relevance is based on the simultaneous presence of other parameters (thermal and chemical) in the oral environment.

Further development of the chewing bench includes the ability to collect and analyze the eluted material after the chewing cycle. Whether during the chewing cycle, or after the passage of a number of cycles, using different testing solutions, the funnel shaped base of the bench will help collect it using a pump, while a special computer program and a charley robot can assign the collected solution corresponding to specific time of dispersion, thus allowing the examination of the

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instant effect of different solution used at different scale of time, different methods can then be used to analyze the collected solution.

Having concluded the first stage, worked out the requirement and accepted the technical solutions, manufacturing settings and working tests of the chewing bench can now begin. Additionally, comparison of data from the chewing bench and those observed clinically may be necessary in order to validate the protocol.

Testing dental materials is very important and the identification of released products and their quantification in order to measure their toxicity is a vital human health issue. Therefore, this chewing bench would hopefully reduce the gap between in vitro performance and in vivo observation and serve as a benchmark for existing materials and as a device for testing new ones.

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