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Development of a Chewing Simulator for Testing Dental Materials: A Pilot Study

Hazem Abouelleil[1*], Christophe Jeannin[1,2], Amadou Sadat[1] and Brigitte Grosgogeat[1,2]

[1]Laboratory of Multimaterials and Interfaces, UMR CNRS 5615, Lyon1 University, Villeurbanne, France.
[2]UFR Odontology, Lyon1 University, Dental Consultation Service and Treatment, Hospices Civils de Lyon, Lyon, France.

Authors' contributions

This work was carried out in collaboration between all authors. Authors CJ, HA and AS designed the device, wrote the protocol, and wrote the first draft of the manuscript and managed literature searches. Authors HA and BG managed the analyses of the study and literature searches. All authors read and approved the final manuscript.

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ABSTRACT

This paper presents the primary results of 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 Open Meca® 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

**Corresponding author: E-mail: hazem.abouelleil-sayed@univ-lyon1.fr;*

chemical). It is the first stage of work which will be validated a posteriori. 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.

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].

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

Multiple reviews discussed the 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 study is to present a prototype which may be able 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 (Fig. 1).

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®, Fig. 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 Rapid form (Rapid Form; 2004) and Catia (Catia, VR18) software.

Open Meca software (Open Meca, 2007) was used to reproduce extreme mandibular movements. The software allows us to produce a three-dimensional mechanical linkage (Fig. 3). Three programmable electric motors with brushless technology were used (Fig. 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.

In order to simulate the teeth, existing database can be used to reproduce different teeth (canine, incisive, premolar and molar) which then can be inserted into corresponding holes on the dental arch in order to be involved in the masticatory process. Natural 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.

2.2 Construction and Working Principle

The teeth are placed in corresponding holes in a dental arch form, whether natural or artificial teeth issued from anatomical database, 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. Periodontal ligament simulation could be easily acquired through the use of the rubber sockets as those present in the Zurich wear simulator [15].

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 dynamic occlusion pattern selected is balanced occlusion to maintain force equilibrium over all the regions during chewing simulation. The design allows for a water tight environment, needed for the fluid injection device integrated in the mastication bench; 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 and+70ºC; low-pressure sprays of these solutions injected on the teeth with the possibility of making very fast changes of temperature (Fig. 5). The passage of liquids is controlled by electronic solenoids, and a water pump. The exact temperature and pH of the injected solutions will be monitored by special sensors present inside the cavity of the chewing bench.

2.3 Configuration Settings

2.3.1 Loading force and direction

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

According to the trajectory and motors used, the velocity of each cycle descent speed would be 33 mm/s at 1.1 Hz as calculated [15], and the time to simulate 20,000 cycles correspond to one month of clinical service [24].

2.3.2 Parameters of the chewing bench

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

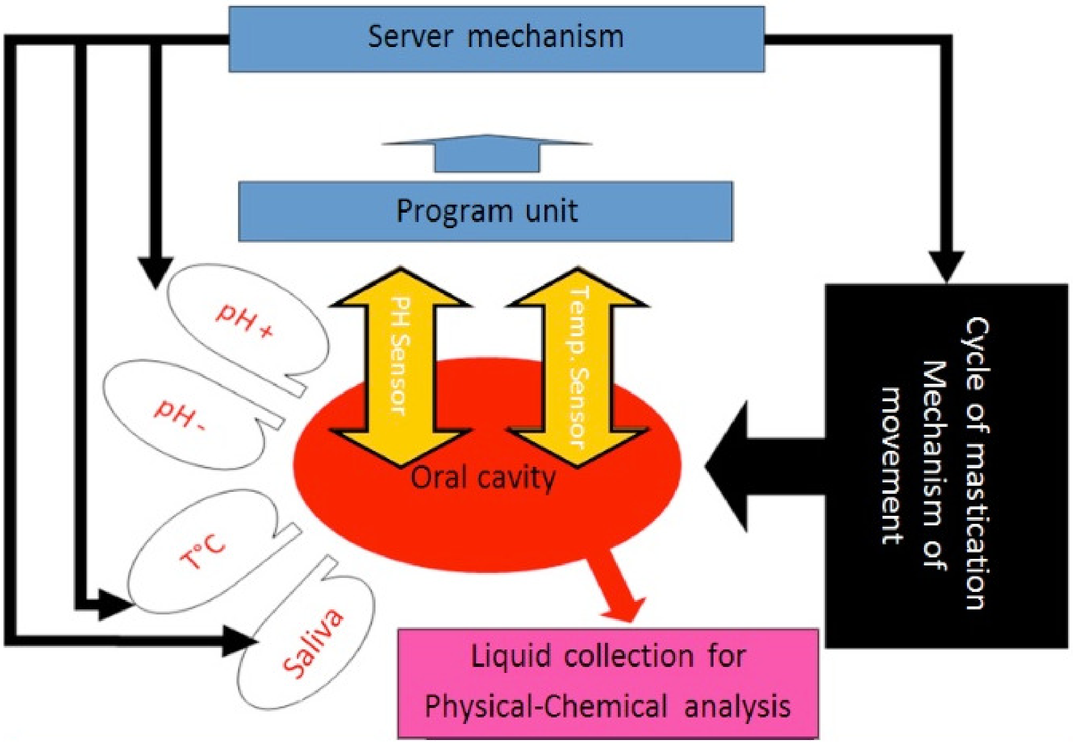

Fig. 1. Chewing bench principle

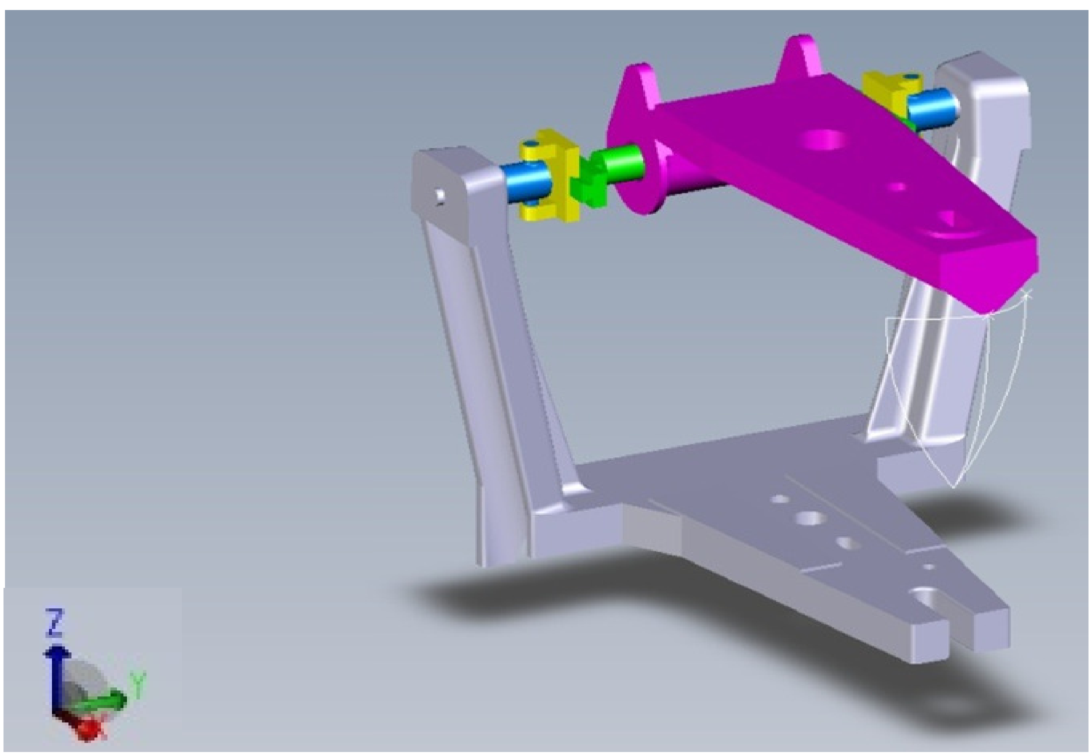

Fig. 2. Dental articulator (Fag Quickmaster®)

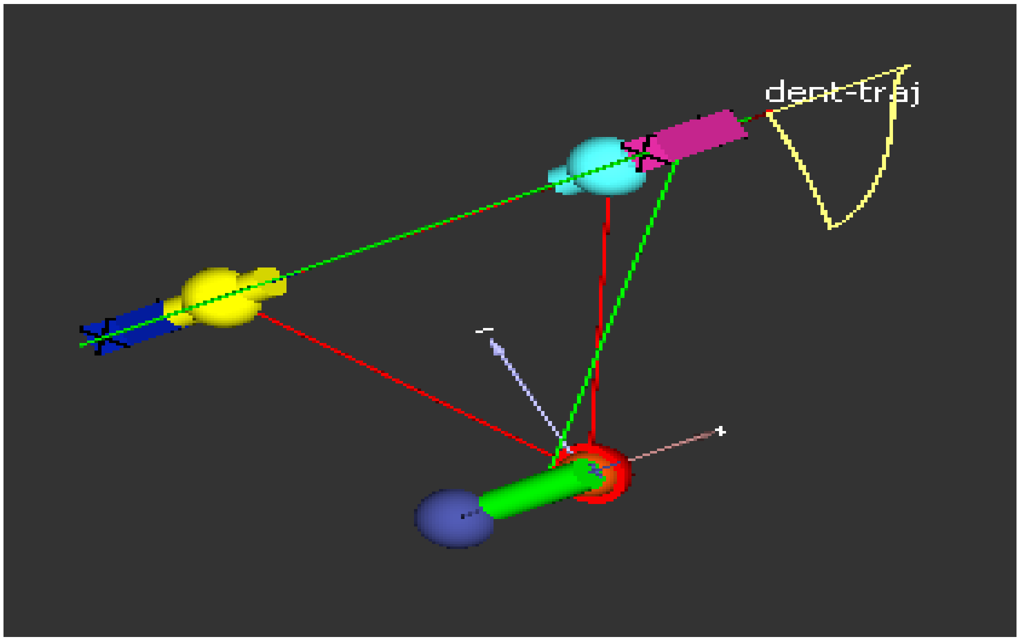

Fig. 3. Modeling mandible movement with open meca to simulate the movement trajectory in the X, Y and Z axes

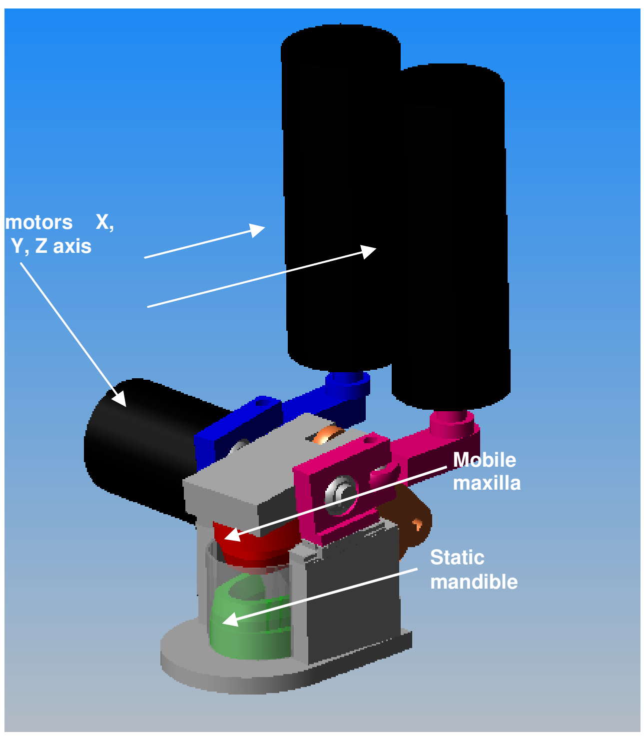

Fig. 4. Simulation of the oral cavity with the chewing bench and motors

Table 1. Parameters of chewing bench

Parameters	Values
Oral cavity volume of	25cm3
Maximal forces	500N
Trajectory	Mastication cycle
Solution	Normalized artificial saliva
Temperature of solutions	Between -5℃ + 70℃
Ph of solutions	Between 2-9
Maximal number of cycles	5000

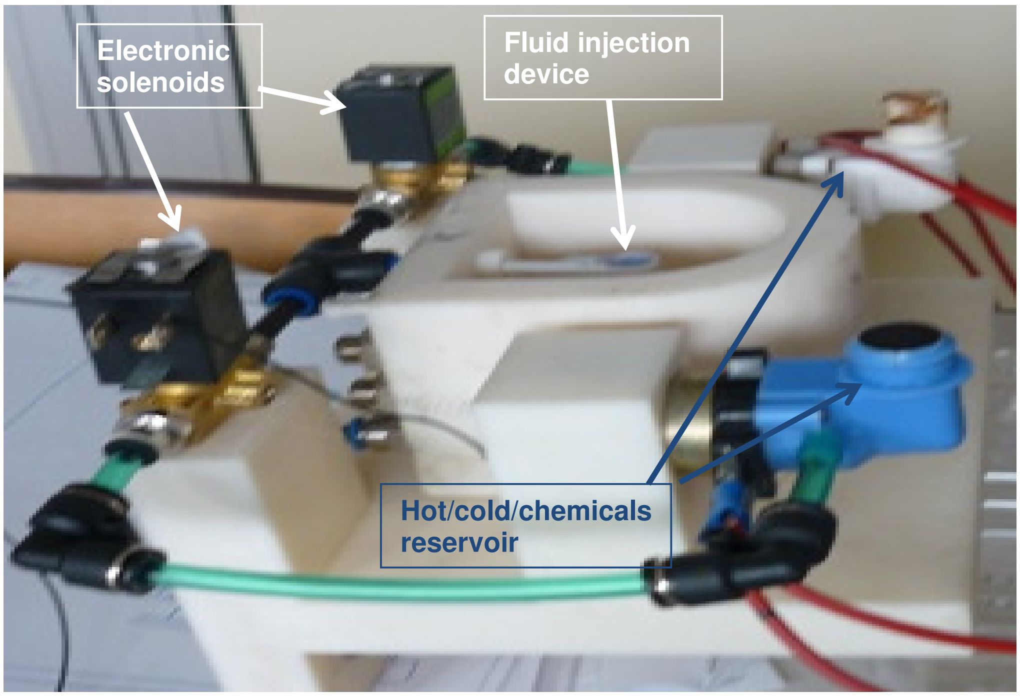

Fig. 5. Thermo-chemical device using pumps for spraying

The material chosen for the chewing bench was PolyetheretherKetone (PEEK), the properties of which are shown in Table 2; this material allows working with solutions with a pH ranging from 2 to 9. It corresponds to the pH range present in human food. In addition, this material stands temperatures in ranges between -5℃ and +70℃, 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.

Silicone rubber has been tested successfully; its texture is as close to food a possible, so it can be used for food simulating [13,25]. Different slurries with different compositions and foodstuffs could be used interchangeably with silicone, to test the different textures and consistencies of food material; these will mimic the action of different foods (thermal and chemical parameters) on dental restorative materials while using artificial saliva.

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

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

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 artificial oral environment for 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 at 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 in our opinion significantly change the overall results obtained.

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

4. CONCLUSION

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.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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