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Development of a Device to Study Fatigue Life of Fixed Partial Dentures

S.C. Gutierrez(1), M.D. Meseguer(1), R. Estal(2), F. Folguera(3), V. Vidal(3)

(1) Departamento de Ingeniería Mecánica y Materiales. Universitat Politècnica de València. Camino de Vera s/n 46022 Valencia (Spain)
(2) Escuela Técnica Superior de Ingenieros Industriales. Universitat Politècnica de València
(3) Escuela dental Folguera Vicent S.L. Avda. Divino Maestro nº 14, bajo 46120 Alboraya

Abstract. Fixed partial dentures can be fabricated by means of different materials and with different manufacturing processes. In order to establish possible differences among them, their behaviour, as fatigue life or cement shear bond strength, have to be evaluated. This article presents a modular, economic and robust device to evaluate fixed partial dentures and dental crowns. A base to support the fixed partial dentures and a device to simulate masticatory loads have been developed. The device has got a simple design. It is based on a pneumatic piston, with a pressure regulator to control masticatory loads. On a first stage, only vertical forces have been taking into account. However, the device will allow simulating tangential masticatory loads on the other axis, studying the behaviour of the fixed partial dentures submerged in a solution similar to saliva, changing masticatory load application, etc. with little modifications.

Keywords: Fixed partial dentures, masticatory force simulation device, testing device, validation, laboratory equipment.
PACS: 06.60 Mr

INTRODUCTION

Fixed partial dentures (FPDs) can be manufactured by means of different materials and different techniques to improve their properties, reduce costs and decrease its manufacturing time [1]. Studies analyzing the behaviour of the FPD can be carried out in two ways:
- "In vivo": the behaviour of the FPD is observed in the patient. Its main drawback is the duration of the study and the discomfort suffered by the patient.
- "In vitro": the behaviour of the FPD is studied with devices that simulate mastication and the working environment of the FPD.

In vivo studies are more difficult to perform. The dentist monitors the patient in order to detect premature wear of the FPD, fracture of enamel, loss of cement retention, etc. These situations often depend on the patient, mainly of the configuration of his dental arch and masticatory habits.

This variability makes necessary to test the FPD before being placed in the patient with "in vitro" devices. Commercial devices are expensive and do not let possible extensions because they are often restricted equipment [2]. Therefore, a device that simulates mastication can be useful in the following cases:

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1.- To study the fatigue behaviour of the FPDs, not only depending on the type of material used, but the manufacturing process used. The fatigue behaviour of materials used in the manufacturing of FPDs should be established, especially with the incorporation of new materials and the variability of percentages in the alloy of the existing ones. Moreover, new manufacturing techniques are used, which could affect the structure of the material. For example, traditionally the chromium-cobalt (Cr-Co) FPDs were produced by lost wax casting. Nowadays, the use of CAD/CAM technologies by the prosthetic technician is more relevant. These technologies let better control in the adjustment (or fit) of the resulting geometries and economic viability using processing techniques such as high speed machining and laser sintering [3]. New processing techniques in the dental field and the introduction of new materials and alloys make necessary to study and test FPD to ensure their behaviour and a long life [4].

2.- To check the initial marginal fit in the FPDs and after testing their fatigue behaviour. FPDs are fixed with cement to the abutments, and masticatory efforts can move or cause deformation in it varying the fit and causing the retention and filtration of food to a not desired area.

3.- To check cement life. The joint between the FPD and the abutments is made through cement bonding. The cement used must support efforts and do not degrade in a long time, with saliva or any other external agent. There are many types of cements used in dentistry, being interesting, to test their behaviour in different materials, different material surface finishes and different geometric configurations (tooth sizes, available separations, necessary guidelines for the adjustment with the antagonistic, etc.).

4.- To test the FPDs connectors. FPDs have connectors to support pontic parts. Connectors are the weakest part of the structure. It is possible to test the behaviour of the connectors on the FPD due to variations of the patient's mouth (taking into account the occlusion). It is necessary to check the connector’s life when varying its section, length and position within the FPD. The parameters that affect the connector (section, length, position) can be determined by previous studies by finite elements [5]. However, it is necessary to prove that the theoretical predictions are according to real results.

5.- To check the FPD deflection that takes place along the time. Depending on the geometric configuration of the FPD and the mastication forces, there is another phenomenon to take into account: the deflection of the prostheses, that is always present. If the connectors are correctly sized the FPD will not break during its life, but the deflection at various points of the prostheses can cause local deformations, ceramic cracks, etc.

For all these reasons, this paper presents the development of a robust and economic device to perform tests on dental prostheses. In a first step, a simple and modular equipment has been developed, which can be easily expanded in the future by taking advantage of the existing resources (software applications and laboratory equipment).

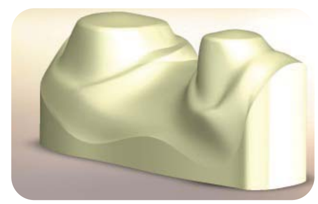
MATERIALS AND METHODS

A support for the FPDs and a device that simulate the loads produced by mastication have been designed.

Development Of The Support

A "base support" prototype for holding a three-unit FPD, one premolar and two molars, has been developed. The dentist took an impression of a patient and made a plaster model (Figure 1(A)).

(A)



(B)

FIGURE 1. (A) Plaster model. (B) Solid model.

The plaster model was scanned with a laser scanner (Roland Picza LPX-60), similar to the used by the dentist to prepare the prostheses, FPDs, etc. The result is a file that contains a cloud of points that reproduce the model.

In the next step, reverse engineering module of a CAD/CAM software has been used (Catia v.5). 3D surface that best fits to the points cloud obtained has been built, after filtering and closing hollow points. Although the plaster used is specially designed for use in optical scanners, reflections and inherent discretization errors of the scanning process introduce defects that must be corrected.

From the 3D surface, a solid was constructed using SolidWorks (Figure 1 (B)). In this solid the tops of the supports and the finishing line have been changed for an easy manufacture, facilitating the coupling of the FPDs and the study of marginal fit as well [6].

Once available the 3D solid model in a CAD/CAM software, raw material, operations, tools and cutting conditions have been defined. CNC program for the high-speed machining with Siemens control has been generated. Figure 2 (A) shows the mechanized support, and Figure 2 (B) a line extension of the marginal fit.

Although initially the testing machine has been particularized to a three-piece FPD, space for major prostheses (including full dental arch) has been taken into account. All the steps followed, setting scanning parameters (X, Y, Z cadence, angle of incidence of the beam, etc.), operations used in surface and solid reconstruction (cutting, smoothing, adjustment, incorporating closures, etc.), machining operations carried out with the tools and cutting conditions employed and finishing parameters used (tool path, cutting constant chip section to achieve finish surface and minimize tool wear, etc.) have been stored for being used in the manufacturing of another supports.

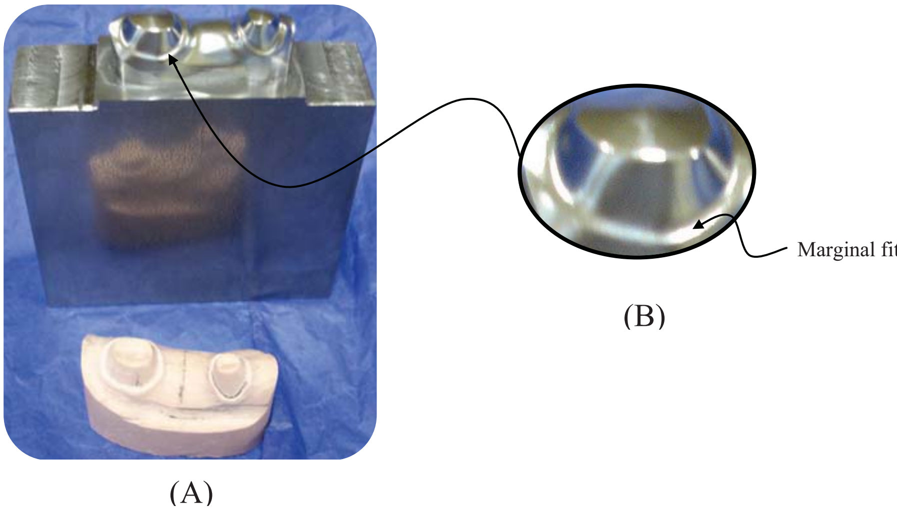


FIGURE 2. (A) Support base. (B) Marginal fit.

Development Of The Testing Device

The basic equipment for FPD testing consists of a strong structure, to support the pneumatic cylinder that applies stress on the FPD to be tested (Figure 3). It is taking into account the search for a low cost device and the possibility of its future extensions. Robustness requirement is essential, because fatigue tests on FPDs need a large number of cycles, depending on its material and geometry. Another important aspect is the ease and quick reconfiguration of its components, including the machined support for the FPD.

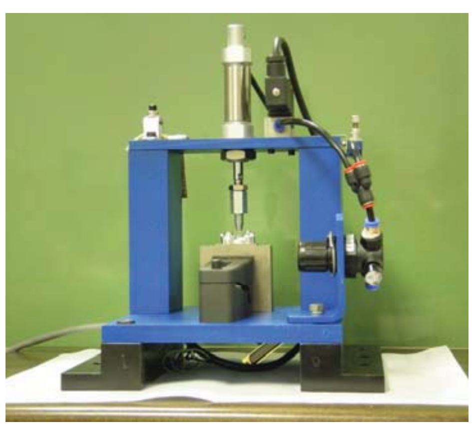


FIGURE 3. Testing device.

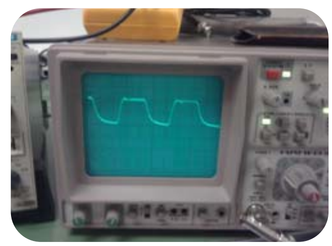
Two options were considered to build the main body of the test device. The first option was to build the device with aluminium profiles, apparently cheaper and faster, but it was dismissed because of the need of using large profiles to minimize the deflections in the structural elements. Besides, the quantity of iron fittings increases the cost considerably.

The chosen option was to use construction steel. The raw material is very cheap, but it needs machining, increasing the cost. Differences between both options were minimal but benefit to use steel is its greater weight, which gives better stability and rigidity to the structure.

Mastication forces are simulated with a pneumatic cylinder, which has in the end of its rod tip a hardened steel ball of 3.5 mm in diameter [7]. This ball presses the FPD, which has been previously cemented to the support base. The cylinder is arranged at 90 degrees with respect to the FPD. The inclination between the ball and the FPD can be adjusted by wedges. Thus there are not limitations on the angular range and the gaps in the cylinder holder are avoided.

The masticatory load is set with a manometer and it depends on the cylinder section. A load cell, a signal amplifier and a digital multimeter are used to verify the force applied (Figure 4 (A)).





(A) (B) (C)

FIGURE 4. (A) Load cell and signal amplifier. (B) PLC. (C) Oscilloscope.

Signal generation and pulse counting are important parts of the device. A PLC has been used for their implementation. This PLC is not exclusive for the machine and it is possible to use any automata with inputs/outputs available (Figure 4 (B)). In the proposed device, an Omron PLC is in charge of activating/deactivating the cylinder through a pneumatic electrovalve, pulse counting and reporting stop or error signals.

Due to the limited operation frequency of the electrovalve, the device has been programmed to press the FPD twice per second (which is similar to human mastication frequency). Furthermore, it has been necessary to adjust the timing of the "on" and "off" signal that reaches the electrovalve to distend the device. Elastic recovery of the FPD is used to return the cylinder to its initial position. Thus, the steel ball does not impact on the FPD, only presses and relaxes it.

The use of a PLC, rather than an electronic counter and an RC circuit with variable resistance, let an adjustment in the frequency of the signal at the level of tenths of second and allow to reprogram the device. Therefore, test parameters can be changed easily.

To avoid the initial shock is an important aspect because a fatigue test is desired, not an impact test. The oscilloscope screen (Figure 4 (C)), shows the behaviour of the system during the pressure cycles. The system relaxes and the cylinder goes to its original position when the electrical signal from the load cell is shown at 0 volts, and no load is being applied. The required load is been applied when the signal is shown at a particular voltage (a function of the applied load). The small peak observed at the beginning of the "on" signal on the oscilloscope, which corresponds to the initial "impact", is almost completely negligible.

Regarding the attachment of the support base on which the FPD is cemented, it was decided to use a small jaw. As large tangential forces do not intervene, many fixtures are adequate.

RESULTS AND DISCUSSION

Various FPDs of Cr-Co with different geometries, connectors and manufacturing processes have been tested with the proposed device. These FDP have been simulated by finite elements to estimate loads, durations and critical points in the design of the FPD, serving as a starting point to conduct the tests. Figure 5 shows a screen capture to evaluate the stress in the connectors in one of the FPD tested.

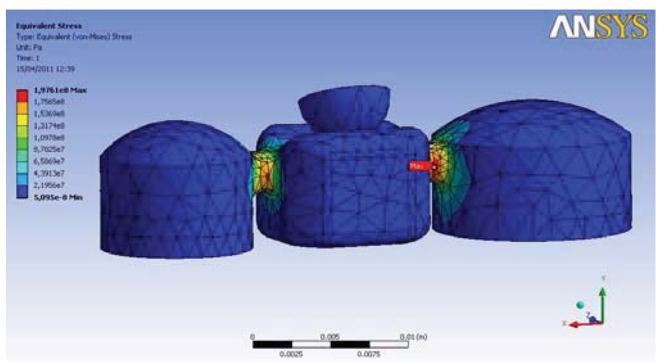


FIGURE 5. Finite element analysis of a FPD

The device control is very important, because as test results are obtained, the system can be modified (e.g. adjusting times and cycles in the program, modifying the pneumatic circuit, etc.). Later on, it would be possible to check and validate or reject the initial assumptions.

Tests allow to check and to compare the performance of different FPDs and are being used to adjust and improve the device. Below, some improvements in progress in the device are presented:

- Most devices that simulate masticatory forces do not include tangential movements that occur during mastication [8]. For their inclusion in the proposed scheme, the FPD support base must be supported on a mobile platform that will be powered by a second cylinder. Eccentricity can be varied in the holding of the platform to vary motion effect. The tangential movement is a small magnitude, but must be considered during the application of the load. Synchronization between both movements can be done via the PLC. During tangential movements the master cylinder can be damaged. To avoid it, a mechanical joint between the piston rod and the steel ball nose can be used, e.g. an Uni-Lat ®.

- To verify the cement bonding, it is useful to know the number of cycles applied before it loose its retentive. The cements used by dentists can be divided into conductive and nonconductive ones. For nonconductive cements, a simple circuit has been developed: it connects a 0.1 mm copper wire to the FPD section at various points to identify where and when the lack of cement bonding is produced (Figure 6).

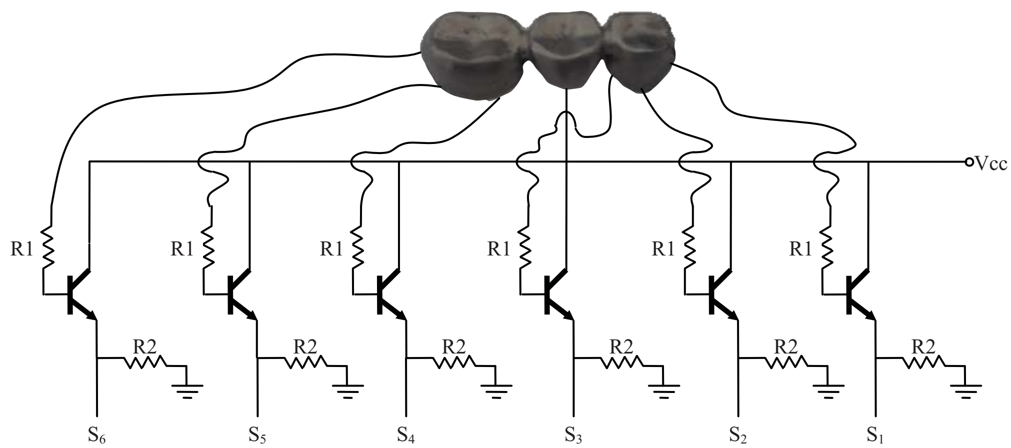


FIGURE 6. Cement loosing detection.

To test the FPD in a real environment, it should be immersed in a solution with a pH and density comparable to foods and liquids that can be swallowed, including human saliva. In this way, the behaviour of ceramics and cement subjected to efforts in a particular solution can be tested.

- To check the deflections, the device can be extended with a pneumatic commuter and a set of manometers (2 or 3), adjusted to a specific load. Thus, it is possible to check deflection in a fatigue test, without removing the support base and the FPD.

- Another proposed extension for the device is to add another pneumatic cylinder to distribute and modify the applied loads on the FPD. Space is limited due to the dimensions of the FPD and the full dental arch. Therefore, the maximum number of cylinders to use is three, misaligned. There is also a proposal to make multiple steel balls holders, where each element can be adjusted in height independently.

Working with generic software applications for scanning, modelling and fabrication, allow to test and to make adjustments that are not achievable with commercial applications and specific equipment developed within the sector. Especially since these applications use copyright data formats.

CONCLUSIONS

The main purpose of this communication was to obtain a low cost test device with easy maintenance and control, covering the needs identified in the dental field. The device works with standard tests, although it is also possible to test a patient-specific situation at a low cost.

The developed device is completely configurable, allowing to extend benefits and modify/change any parameter that is used in the PLC control program. There is an important difference with commercial equipment, in which the extensions are fixed by the manufacturer and in no way gives access to source code, which only supports the changes in the parameters through its interface. The device is a laboratory equipment, therefore it is essential to customize any test depending on the sensors available, the settings in the control signal, embedded devices in the machine, the type and number of variables, the software applications available to process the model input and output data, etc.

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