NOVEL METHODOLOGY TO TRANSFER DIGITIZED CASTS ONTO A VIRTUAL DENTAL ARTICULATOR

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ABSTRACT: This paper introduces a research project aiming at building a digital facebow with which maxillary casts (upper models or arcades) can be located on a virtual dental articulator. Its main goal is to improve the design process of dental prostheses by adding this virtual step to the already available methodology. The main practical implication of this digital facebow is the improvement on dental CAD/CAM system by transferring the position of the maxillary cast directly from the patient without having to use a physical facebow and a physical articulator. Thanks to this new method, dental prostheses can be produced following a complete chain of digital workflow.

Keywords: Virtual dental articulator, Dental prostheses design, Digital facebow, Dental CAD/CAM, Virtual design.

1. INTRODUCTION

This project arises out of the need to build a digital facebow in order to locate the digitized maxillary cast (upper model or arcade) of patients on a dental virtual articulator. This can be achieved by means of reverse engineering tools.

This development has been made at the Product Design Laboratory (PDL, http://www.ehu.es/PDL), in the Faculty of Engineering of Bilbao (The University of the Basque Country UPV/EHU). This Laboratory has focused its investigation efforts on reverse engineering and rapid prototyping knowledge areas and is currently looking for new fields of application for these new design methods in an effort to promote technological transference with a series of neighbouring companies.

The PDL got engaged in the development of this methodology in collaboration with the Department of Prosthetics of the Martin-Luther University of Halle. In addition, the Dentistry Department at our university (The University of the Basque Country UPV/EHU), has supported this project with some useful advice.

2. APPROXIMATION

The main tool used in this project is the hereby presented facebow [1], together with the complementary dental physical articulator.

2.1 Dental physical articulators

Dental physical articulators (Fig. 1) are tools that simulate the movements of the human lower jaw and those of the Temporo-Mandibular Joints (TMJ-s). They have been used for more than 100 years for different purposes in dentistry [2]. They simulate specific patients for dentists and dental technicians in their laboratory work, and they have become indispensable instruments for these professionals in their diagnostic and therapeutic activity. Physical dental articulators enable the dentist or technician to carry out a study of the occlusal relations between dental arches and to detect harmful occlusal interferences on casts before more sophisticated occlusal equilibration procedures are performed on the patient. This equilibration of partial and full dentures is also carried out in dental articulators. Together with the wax-up technique, articulators enable technicians to construct fixed or removable prostheses in dental laboratories according to the particularities of the different movements of each patient. Nowadays, this procedure is considered standard, so current efficient dentistry necessarily involves the use of physical dental articulators.

Over the last 120 years, hundreds of different articulators have been constructed [3,4]. Throughout these years, there has been considerable development in articulators. Today's articulators are handy, functional and more precise in both construction and operation. Many differences can be pointed out among them: adjustment, cost, Arcon and Non-Arcon, versatility, type of facebow, etc.

In order to reproduce the individual parameters of each patient, the articulator must be adjustable. Once the setting data are measured on the patient, using the facebow, the relative location of the occlusal plane is transferred from the patient onto the physical dental articulator.

2.2 Facebow

To ensure that the movements in an articulator are as similar as possible to those of the human masticatory system, casts have to be mounted onto the articulator with the help of a so-called facebow. This ensures a relationship between the maxillary plaster cast and the joints of the articulator similar to the relationship between the upper arcade of the patient and his/her TMJ-s (Fig. 1).

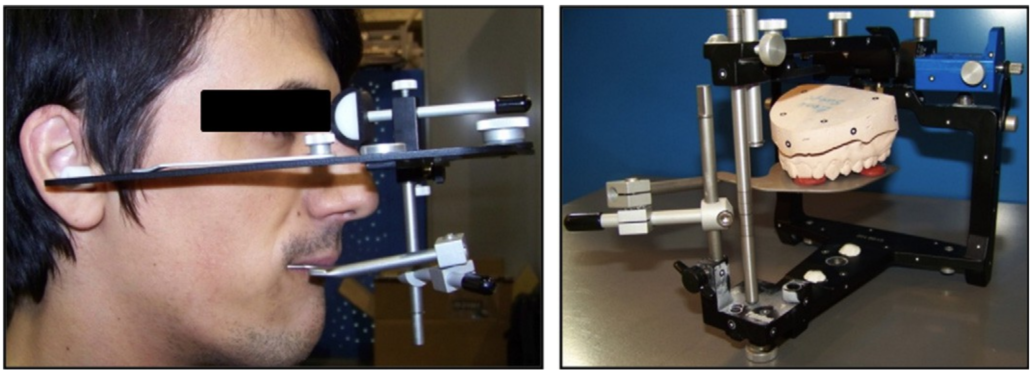

Fig. 1. Mounting the maxillary cast onto a dental physical articulator.

2.3 Interocclusal registrations

Once the maxillary cast is located, with the help of a silicone bite registration in centric occlusion, the maxillary and mandibular casts have to be located with respect to each other with a high degree of precision. In the majority of common articulators, eccentric bites or interocclusal registrations (protrusive, left and right laterotrusive) are used to adjust the settings. Each registration corresponds to a positional relation between the upper and the lower parts of the mandible. The eccentric bites or interocclusal registrations (protrusive, left and right laterotrusive) are used in the majority of common articulators to adjust the settings. Each registration is just the positional relation between the upper and the lower parts of the mandible.

3. STATE OF THE ART

3.1 Design process

In order to contextualize, the currently coexisting design processes will be briefly presented. The first one is the most widely used design process and is still in use in the majority of dental laboratories. The structure of the prosthesis is generated using the wax-modelling technique and later on casting in metal. Then, the ceramic is added, generating the occlusal surface, which should fit with the antagonist. Apart from this, the excursive movements (lateral and protrusive) are applied on the physical articulator to detect possible collisions. If any collision is found, it is removed. Once the final design is generated, a thermal treatment is carried out on the ceramic part before it is finally located in the mouth.

Nowadays, the most advanced dental laboratories work with CAD/CAM systems and follow the process described below (Fig. 2). This change has involved some significant improvements in terms of time, data registration, material resistance, parameters control, etc. Besides this, another factor that differentiates CAD/CAM systems is that they are introducing new materials such as zirconium oxide, calcinable polymers, and feldespathic ceramics. The future of prostheses design will undoubtedly be based on these systems.

On the other hand, these systems present some deficiencies. The most remarkable one is that they do not take into account the kinematics of the mandible. In other words, the prostheses designed using these systems could generate some problems due to the existence of occlusal interferences during the movements.

Although CAD/CAM systems represent a considerable improvement on the design process of dental crowns and bridges, the design process proposed in this article is far more promising (Fig. 3). This virtual process consists in a series of digital steps, for which physical articulators and facebows are not necessary. This requires the use of a virtual articulator (available in some CAD/CAM systems) and a digital facebow, which is the main goal of this paper.

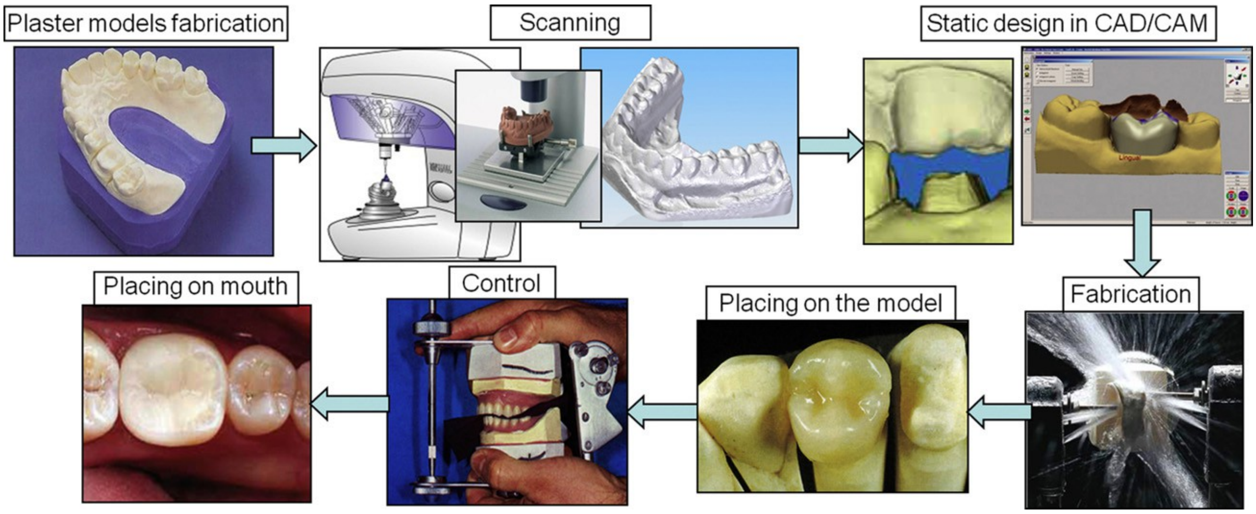

Fig. 2. CAD/CAM design process.

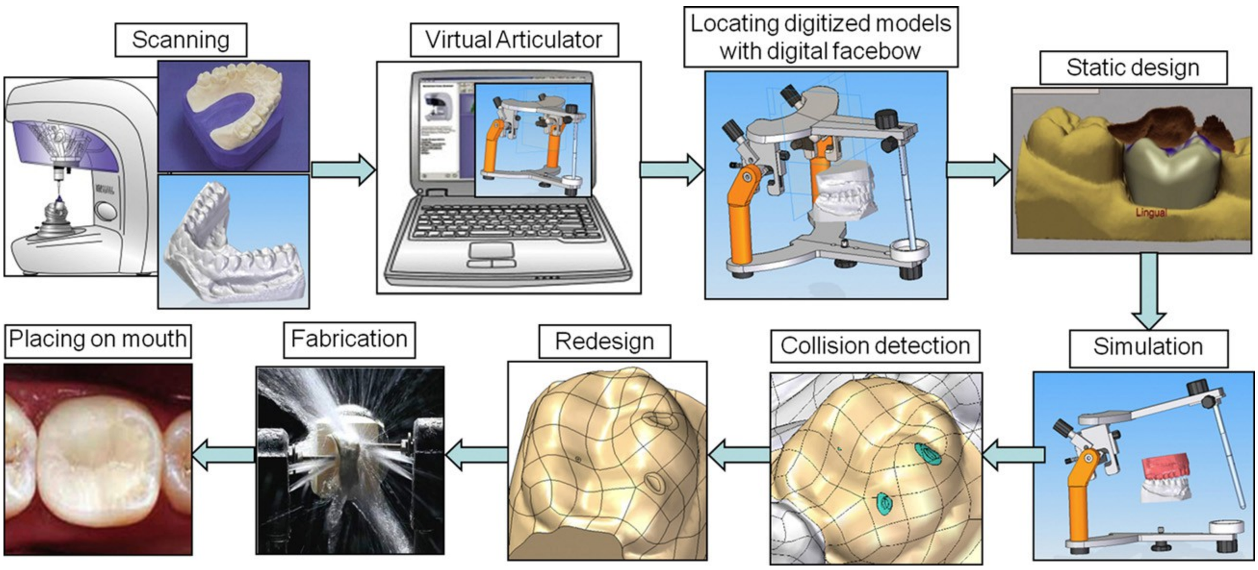

Fig. 3. Virtual design process.

3.2 Virtual articulator

The use of these articulators allows dental technicians to simulate human mandibular movements and correct all possible digitized occlusal surfaces in order to achieve smooth and collision-free movements. The first developers of this software have come up with two different virtual articulators.

The virtual articulator developed by Szentpétery, from the Martin-Luther University of Halle [5,6] (Fig. 4A) is based on a mathematical simulation of the movements that take place in an articulator. It is a fully adjustable three-dimensional virtual dental articulator, capable of reproducing the movements of an articulator. In addition, mathematical simulation contributes to offer some possibilities that are not offered by some physical dental articulators, such as the curved Bennet movement and the possibility of working with different movements in identical settings. This makes it more versatile than a physical dental articulator. Its graphic interface is currently undergoing some improvements. A great advantage of this virtual articulator is that it can work with registered movements, but if the user does not have such a sophisticated system, they are not absolutely necessary.

The virtual articulator developed by Kordass and Gaertner [7,8] from the Greifswald University in Germany, was designed to record the exact movement paths of the mandible with an electronic jaw movement registration system called Jaw Motion Analyser (Zebris®) and to move digitized dental arches along these movement paths on the computer (Fig. 4B). With this software, static and kinematic occlusal collisions can be calculated and visualized. However, a clear drawback of the electronic jaw recording system required by this virtual articulator is that it is very sophisticated and expensive.

Besides these articulators, several state-of-the-art virtual articulators were presented at the IDS'11 (International Dental Show 2011, Cologne, Germany). The Exocad® and the 3Shape® were the source-code developers, and several leading brands count on their own version of virtual articulator, such as the Amman Girbach® [9] (Fig. 4C). The main disadvantage of these virtual articulators is that the casts have to be mounted with gypsum onto the physical articulator by means of a physical facebow and then, they must be scanned in this position. Apart from a physical articulator, this is a tedious step that requires a long time.

Fig. 4. Virtual articulators. (A) Szentpétery; (B) Kordass; (C) Amman Girbach®

4. DIGITAL FACEBOW CONSTRUCTION

With the aim of dealing with this drawback, this paper proposes a new methodology. And in order to develop this methodology, it has been necessary to design a series of physical tools that will be described below.

Some pieces have been built to locate a point in the space. The following set (Fig. 5) is made up of a fixed part or base, a flexible part and a pointer. By using reference points located on the fixed part and on the pointer, it is possible to obtain the location of the required points.

The fixed part is used as a common reference element in the location of any point. This piece allows the dental technician to lead the six scanned points to the same coordinate system, which is fixed to the patient's head.

The pointer has two different parts: the base and tip. The tip consists of a cylinder and a conic angle, the apex of which determines the required extent. The base is composed of parallelepipeds, the faces of which are positioned reference points. In each scan, it is necessary to take at least four reference points between the fixed part and the base of the pointer. Having located the points on both sides of the head, it is not possible to record these points in a single shot; this accounts for the need to use a pointer.

These two elements, the fixed part and the pointer, have been modelled in SolidEdge ST2™ and have been manufactured in the rapid prototyping machine Dimension Elite®.

Once these tools have been built, the second step consists in having the pointer and the fixed part thoroughly scanned. Then, by using reference points or stickers, it will be possible to associate different scans.

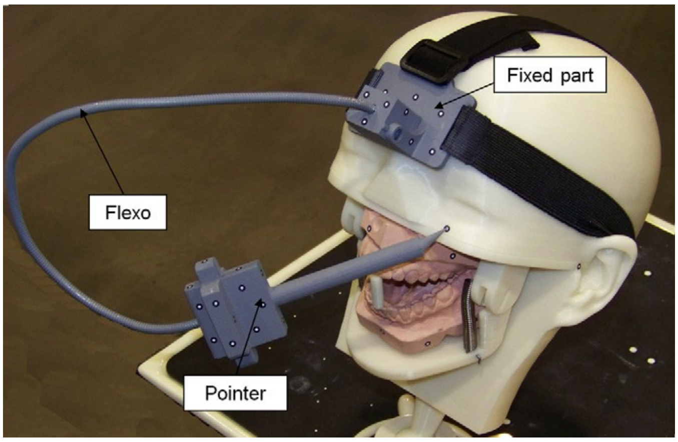

Fig. 5. Set mounted on the patient.

5. METHODOLOGY

5.1 Introduction

First, the location of the maxillary cast will be described following the conventional design process and then, the same location will be described following this proposed virtual methodology.

In the conventional technology a facebow is placed on the patient, and then, anthropometric measurements are recorded. The bottom of the facebow is extracted and it is placed on the incisal table. Then, the maxillary cast is placed on the bite (prints are left) on the facebow. The upper part of the articulator is rotated until the incisal pin (which is 0 position) contacts the transfer table. Finally, the maxillary cast is plastered onto the upper part of the articulator (Fig. 6).

In the proposed methodology, the following paragraphs explain the steps required to locate the maxillary digitized cast on the virtual articulator (Fig. 7).

Firstly, three points are located and scanned as reference points on the patient. The first two points represent the ends of the imaginary rotational axis of the mandible over the two temporomandibular joints and the third one corresponds to the infraorbital point just below the left eye. These three points represent the coordinate system of the head of the patient, which must be brought to coincidence with the coordinate system of the virtual articulator. Secondly, with the help of articulating foil, three other points are marked on the cusps of the protruding upper teeth, thus generating the occlusal plane. The pointer is placed on those points and the scanner registers the positions of the base and the fixed parts. Matching all the fixed parts, the six points are on the same cranial coordinate system. In this way, the horizontal plane and the occlusal plane are generated. Then, the occlusal plane points are located on the maxillary cast and transferred onto the cranial coordinate system. The maxillary digitized cast is now on this coordinate system and since both coordinate systems coincide, the maxillary digitized cast can then be located on the virtual articulator.

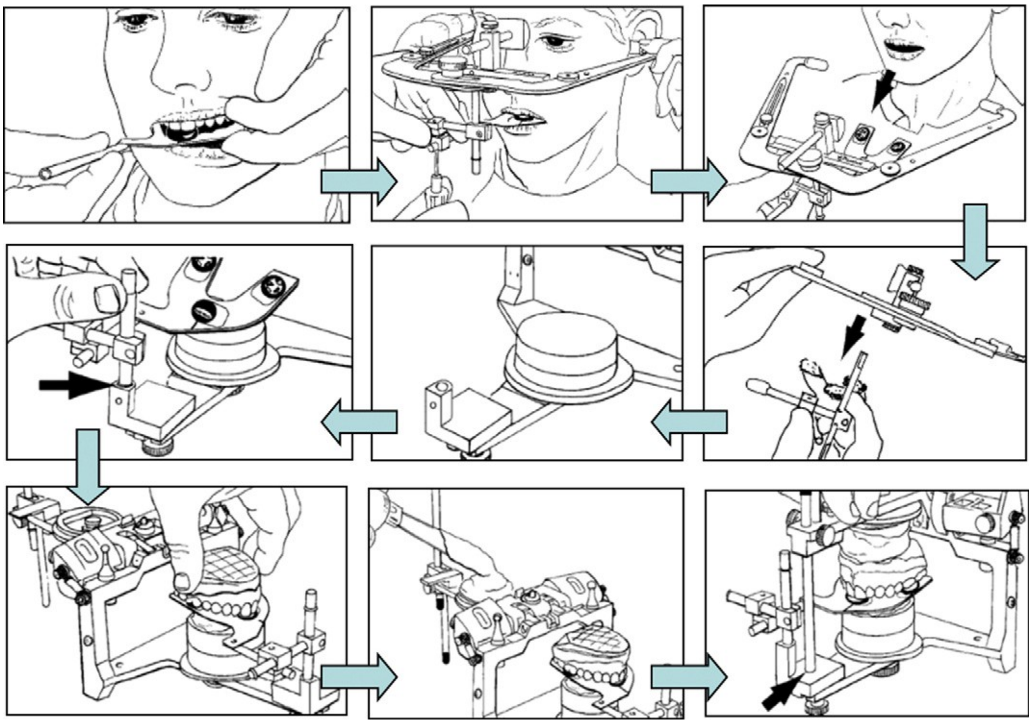

Fig. 6. Transfer of the location of the occlusal surface from patient to articulator.

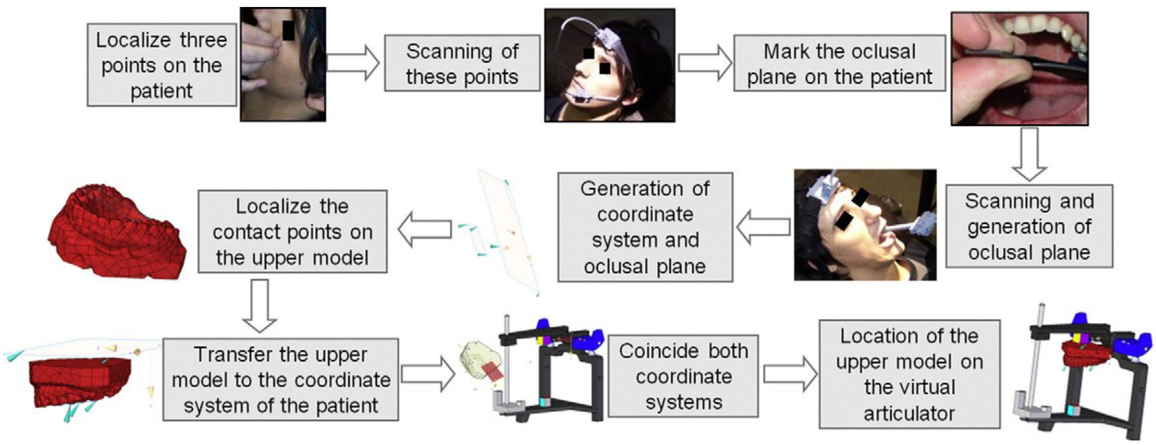

Fig. 7. Steps of the proposed methodology.

5.2 Experiment: comparison of conventional and virtual processes

In the conventional process, a physical facebow is used to locate the occlusal plane and the maxillary cast on a physical articulator. In order to compare both methods, the reference points of the transferring table and the maxillary cast are scanned (Fig. 8). This scanning allows the dental technician to locate the maxillary cast on the virtual articulator in a conventional way.

This file is then exported to the RE software and there, the reference elements are generated in order to locate the casts in the CAD system. These reference elements play the role of the plaster. The casts are easily positioned on the CAD system.

In the virtual method, three reference points are scanned with the help of the pointer and they are located in the space, forming the horizontal plane of the patient. In order to locate the occlusal plane, three more points are marked on the maxillary arch, using articulating foil (Fig. 9).

Making all reference points of the fixed part from different scanning's coincide, different locations of the pointers are located on the same cranial coordinate system. The ideal pointer, previously modelled in the CAD system, is loaded in Rapidform®, and with each set of three points the horizontal and the occlusal planes are generated (Fig. 10).

Then the three contact points of the maxillary cast, are located by moving the arch until it contacts a plane. The maxillary cast is added to the assembly of the six points and the three occlusal points are matched, thus obtaining the maxillary cast on the cranial coordinate system. Finally, the maxillary cast is located on the virtual articulator (Fig. 11).

In both experiments, the resulting location of the intercondylar axis is approximate. In traditional methods, the arbitrary facebow is not accurate at locating the axis [9,10], and in virtual methods, the locations of condylar points are not very exact either. Therefore, it is not possible to compare both locations. The result of the experiment is a 2.21 mm deviation (applying symmetry) in condylar points and a 1.88 mm infra-orbital deviation (Fig. 12).

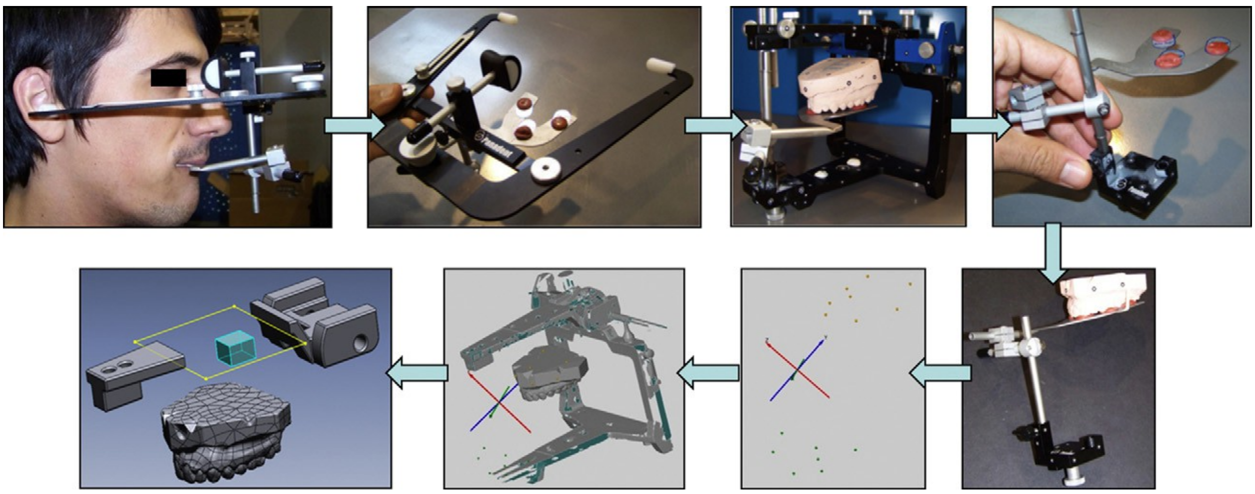

Fig. 8. Location of the maxillary cast conventionally and scanning for locating in a virtual articulator.

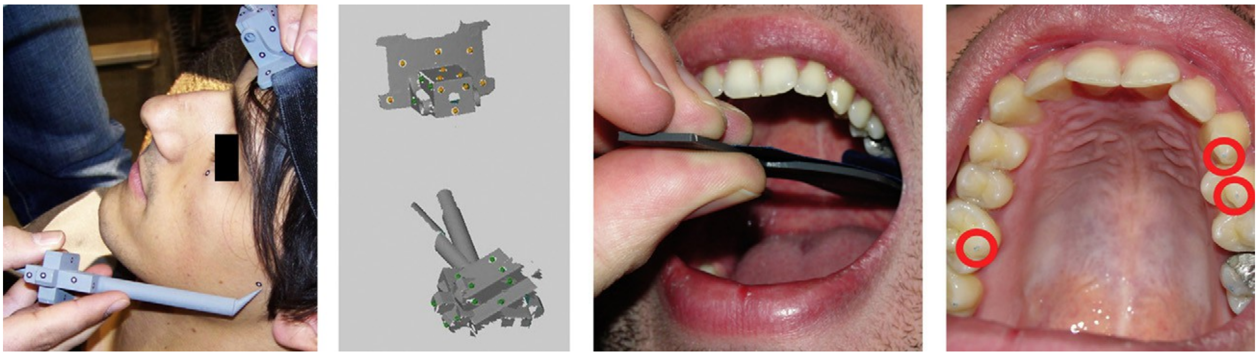

Fig. 9. Scanning the first point and marking the occlusal plane with articulating foil.

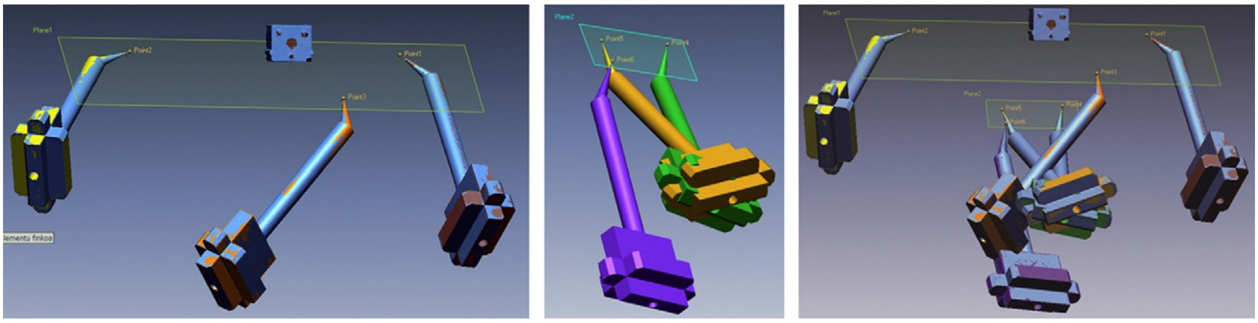

Fig. 10. Horizontal and occlusal plane generation in Rapidform®.

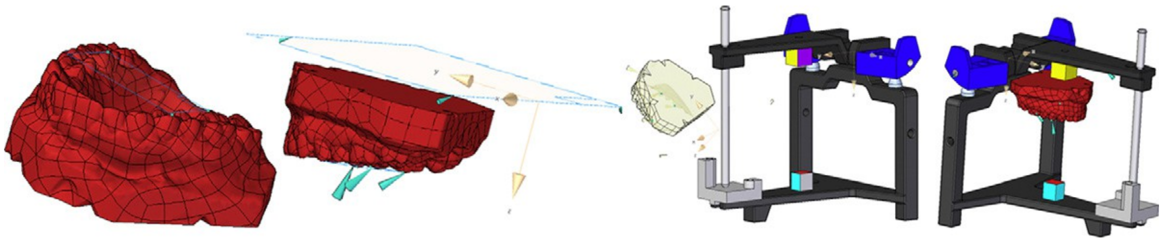

Fig. 11. Maxillary cast on the cranial coordinate system and transferring to the virtual articulator.

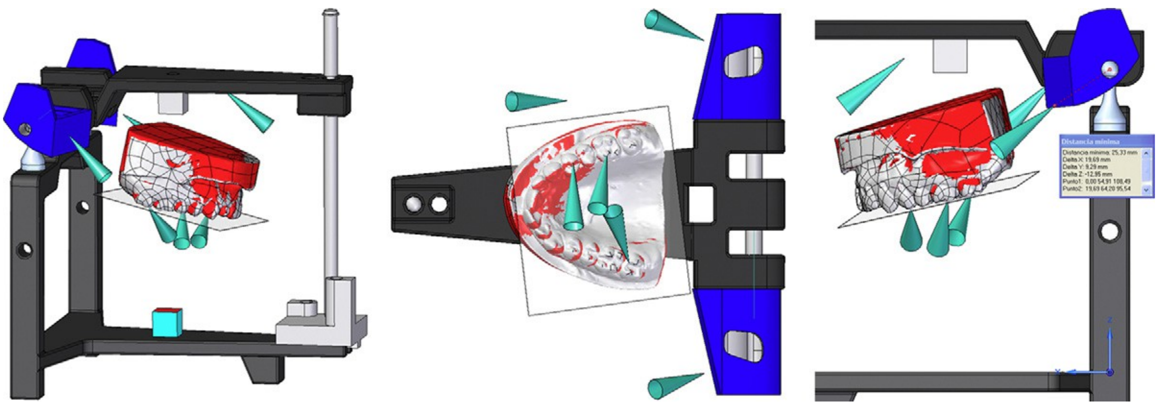

Fig. 12. Comparison of virtual and conventional methods.

6. CONCLUSION AND FUTURE WORKS

The main result of this project is the construction of a digital facebow and its validation. Whilst for the existing virtual articulators physical articulators and facebows are still necessary, this new design process requires none of them. This achievement reduces the time necessary to obtain the prostheses and increases the automation of the process.

Apart from this, the geometry of the digitized dental arcades is filed in digital format. If the patient needs any further restoration in the future, the dentist will be able to resort to the digital database. The location of both digitized arcades on the virtual articulator, as well as the parameters of the virtual articulator, can also be filed, and this involves avoiding many registration steps in a future restoration.

Finally, note that working in a virtual environment offers the possibility to calculate the volumetric interference between teeth, which is obviously not possible in the physical articulator. This facilitates the elimination of interferences. In the traditional method, when interferences are detected, the only possible solution is to mark them with articulating foil, whereas virtual articulators show these interferences in three dimensions (in volume) (Fig. 13).

Concerning future works, a new alternative to this digital facebow is being developed to reduce the resulting deviation. Also, a new cinematic digital facebow, with a more accurately determined axis is currently being developed.

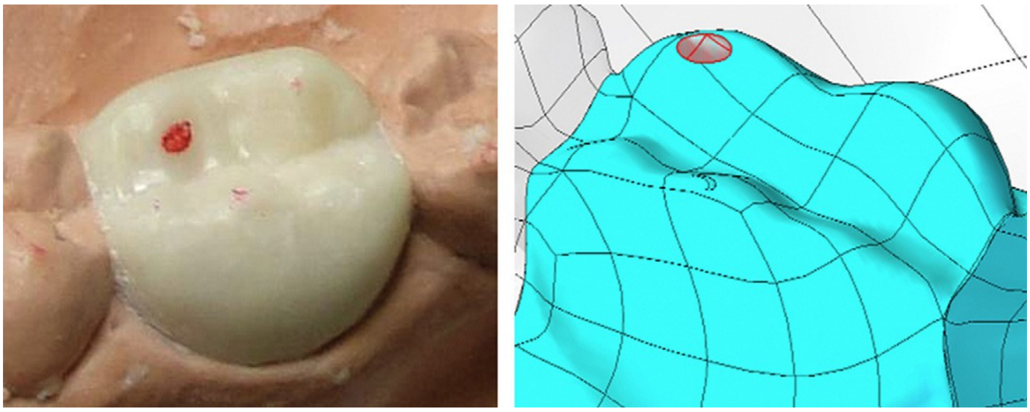

Fig. 13. Comparison of the interference obtained in conventional and virtual procedures.

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