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A VIRTUAL DENTAL PROSTHESES DESIGN METHOD USING A VIRTUAL ARTICULATOR

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1. Introduction

This project arises out of the need to design a Dental Virtual Articulator in order to simulate and analyse mandibular movements of the human jaw. This can be achieved by means of CAD systems and Reverse Engineering tools.
This development has been made at the Product Design Laboratory (PDL, www.ehu.es/PDL), in the Faculty of Engineering of Bilbao, University of the Basque Country. This Laboratory has focused its investigation 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 neighbouring companies.
The PDL is developing the design of this virtual articulator in collaboration with the Department of Prosthetic of the Martin-Luther University of Halle. In addition, the Dentistry Department at our university - The University of the Basque Country- has supported this project with some useful advice.
To begin with, different articulators were selected to be modelled through different CAD systems (SolidEdge and CATIA). The design process was carried out using the measuring tools and Reverse Engineering tools available at the PDL. These tools are: the Handyscan EXAscan 3D scanner and its software (VXscan), the Reverse Engineering and Computer-Aided Inspection Software (Geomagic Studio and Qualify), the Rapidform XOR, as well as the ATOS I rev.2 GOM 3D scanner.
After a thorough analysis of the results obtained with different articulators in different systems, the Panadent PSH articulator and the ATOS I scanner were selected, together with the Rapidform and Solidedge software.
In this process, the articulator is first digitized. Then, the next stage consists in obtaining the upper and lower dentures digitally. Apart from this, it is necessary to register the relative location of the occlusal surface referred to the intercondilar axis. This is achieved by means of the face bow. Afterwards, the design of the dental prosthesis is carried out using the CAD system and finally, mandibular movements are simulated. The ultimate aim of this process is to optimize the design of the dental prosthesis whilst avoiding collisions during the excursive movements.

2. Approximation

The main tool used in this project is the dental articulator presented in this chapter, together with the complementary registration systems.

2.1 Dental mechanic articulators

Figure 1. Dental physical articulators

Physical dental articulators (Figure 1) are tools that simulate the movements of the human lower jaw and the TemporoMandibular Joints (TMJ-s). They have been used for more than 100 years for different purposes in dentistry [Hoffmann, 1976] (Figure 2). Since they simulate specific patients for dental technicians in their laboratory work, they have become indispensable instruments for dentists in their diagnostic activity. Physical dental articulators enable technicians to carry out a study of the occlusal relations between dental arches and to detect harmful occlusal interferences on models 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 the dental laboratory 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.

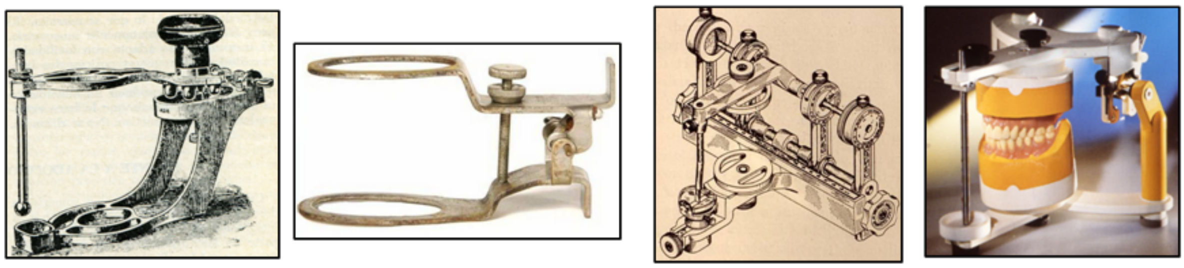

Figure 2. Articulators of Luce, Kerr, Hanau-Kineskope and Stratos-200

Over the last 120 years, hundreds of different articulators have been constructed [Mitchell 1940-I] [Mitchell 1940-II]. Throughout these years, there has been no remarkable 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, etc.
In order to reproduce the individual parameters of each patient, the articulator must be adjustable. The setting data are measured on the patient and, using the face bow, the relative location of the occlusal plane is transferred from the patient onto the physical dental articulator.
Due to its three-dimension condilar trajectory, the Panadent PSH semiadjustable articulator has been chosen for this project [Hobo, 1997], [Lee, 1969].

2.2 Registering systems

To simulate the specific movements of each patient, the articulator must be adjusted with the specific setting obtained from each patient. Different registration systems are used for this purpose.

2.2.1 Face bow

To ensure that the movements in an articulator are as similar as possible to those of the human masticatory system, models have to be mounted onto the articulator with the help of a so called face bow. This ensures a relationship between the plaster models and the joints of the articulator similar to the relationship between the jaws of the patient and his/her TMJ-s (Figure 3). Then, with the help of a silicone bite, the upper and lower models have to be oriented with respect to each other with a high degree of precision in the so-called intercuspidal position.

2.2.2 Interocclusal registrations

These bites or interocclusal registrations 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, and the standard registrations are: centric relation, maximum intercuspidation, protrusion and the two lateral registrations.

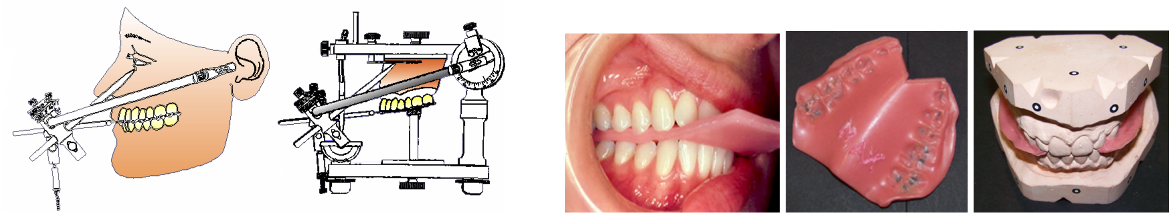

Figure 3. Face bow and interocclusal registrations

3. State of the art

3.1 Design processes

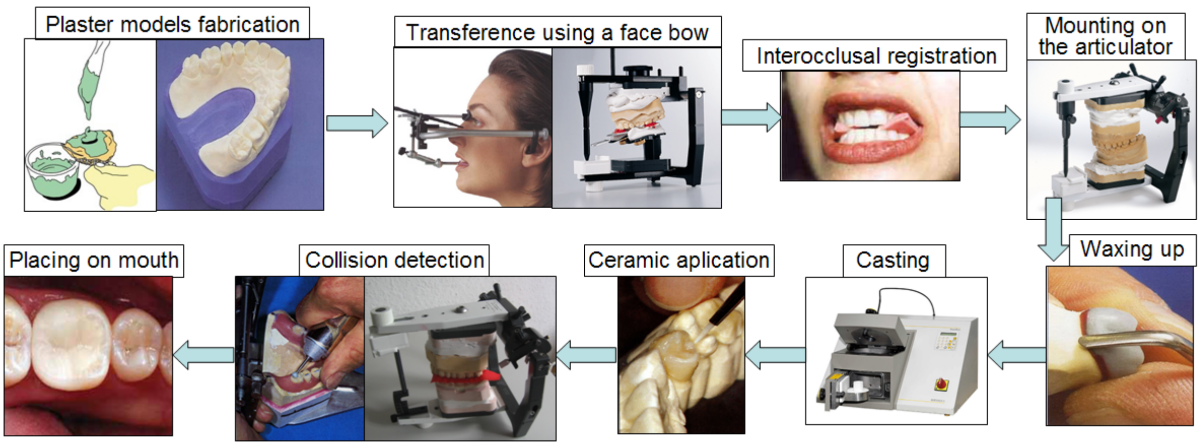

Figure 4. Conventional design process

Over the last few years, the design process of dental prostheses has changed and technicians can now design a complex prosthesis virtually without having a large experience.

In order to contextualize, the coexisting design processes will be briefly presented. The first one (Figure 4) 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-up technique (drop by drop) [Sharry, 1977]. 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 to check out for possible interferences. If found, they are removed. Once the final design is generated, a thermal treatment is carried out on the ceramic part, which is finally located in the mouth.

Nowadays, the most advanced dental laboratories work with CAD/CAM systems and follow the process described in Figure 5. This change has involved some significant improvements in terms of time, data registration, material resistance, parameters control, etc. Besides this, CAD/CAM systems are using new materials such as zirconium oxide, calcinable polymers, feldespathic ceramics, etc., being this aspect one of the differential factors among CAD/CAM systems. 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 theses systems could generate pathology due to the existence of occlusal interferences during the movements.

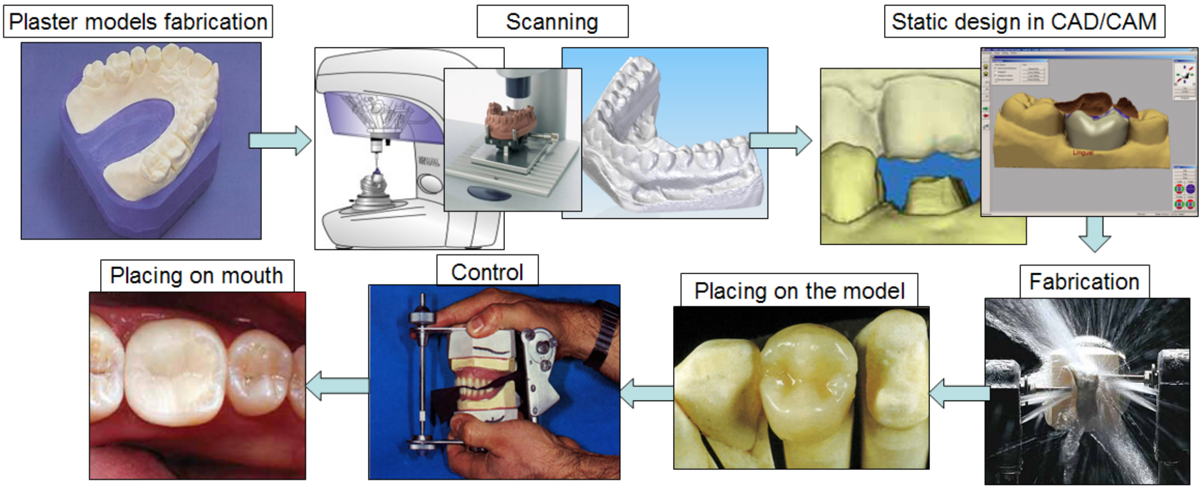

Figure 5. CAD/CAM design process

Therefore, in virtual design processes [Colombo, 2008] (Figure 6) physical articulators are not necessary. All the steps are carried out aided by computer till the prosthesis is located in the mouth.

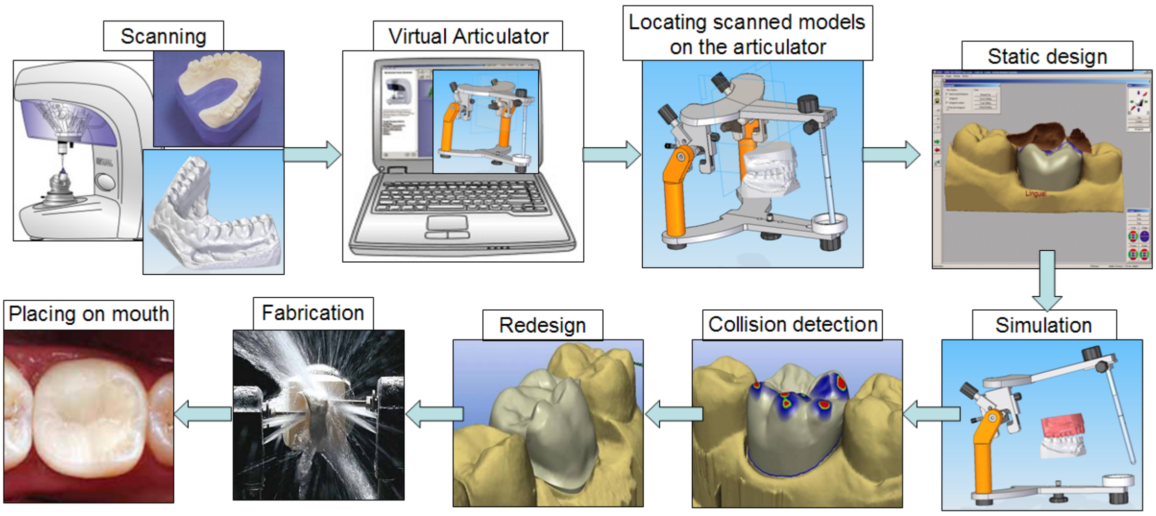

Figure 6. Virtual design process

3.2 Virtual Articulator

Over the recent years, two virtual articulators have been developed by Kordass and Szentpétery, who were the first developers of such software. By using these articulators it is possible to:

- simulate human mandibular movements
- move digitized occlusal surfaces against each other according to these movements
- correct digitized occlusal surfaces to enable smooth and collision-free movements

The virtual articulator developed by Kordass and Gaertner [Kordass, 2002] [Gaertner, 2003] 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 and move digitized dental arches along these movement paths on the computer (Figure 8). This software is able to calculate and visualize static and kinematic occlusal collisions. However, it must be pointed out that the electronic jaw recording system required by this virtual articulator is very sophisticated and expensive.

The virtual articulator developed by Szentpétery, from the Martin-Luther University of Halle [Szentpétery, 1997], [Szentpétery, 1998], [Padros, 2006] 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 (Figure 7). In addition, mathematical simulation contributes to offer some possibilities not offered by some physical dental articulators, such as the curved Bennet movement or different movements in identical settings. This makes it more versatile than a physical dental articulator. The graphic interface is currently being improved.

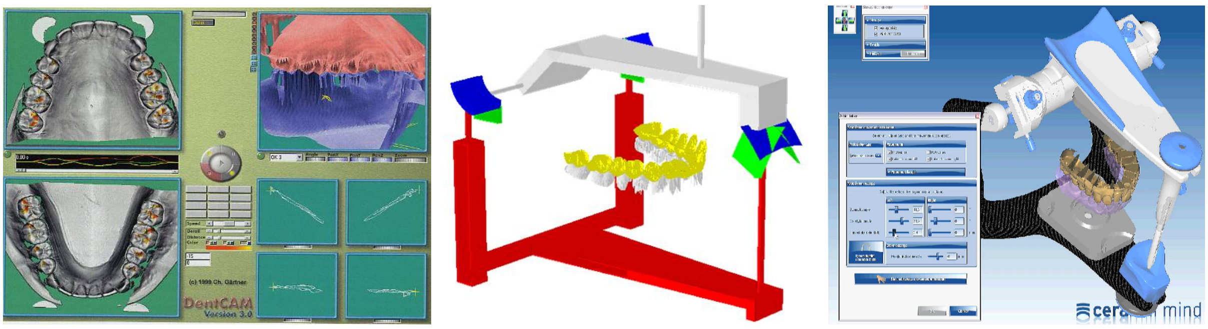

Figure 7. Kordass', Szentpétery's and Amman Girbach´s virtual articulators

Besides this, a new virtual articulator was presented by Amman Girbach at the IDS´09 (International Dental Show 2009, Cologne, Germany), integrated in the so-called Ceramill Map 300 CAD/CAM system. This virtual articulator allows for the simulation of protrusive and lateral movements, whilst collisions are visualized in real time. The main disadvantage of this articulator is that the models have to be mounted with gypsum in the physical articulator to scan them in this position, and this step requires time.

4. Design of the virtual articulator

4.1 Introduction

As it has been explained, the first purpose is to build up a virtual articulator. Firstly, different types of articulators were selected (Figure 8), and several tries were carried out using different scanning systems, Reverse Engineering software and different CAD systems. Once the results and difficulties were analysed, the Panadent PSH and the ATOS I scanner were selected, together with the Reverse Engineering software Rapidform and Solidedge as CAD systems.

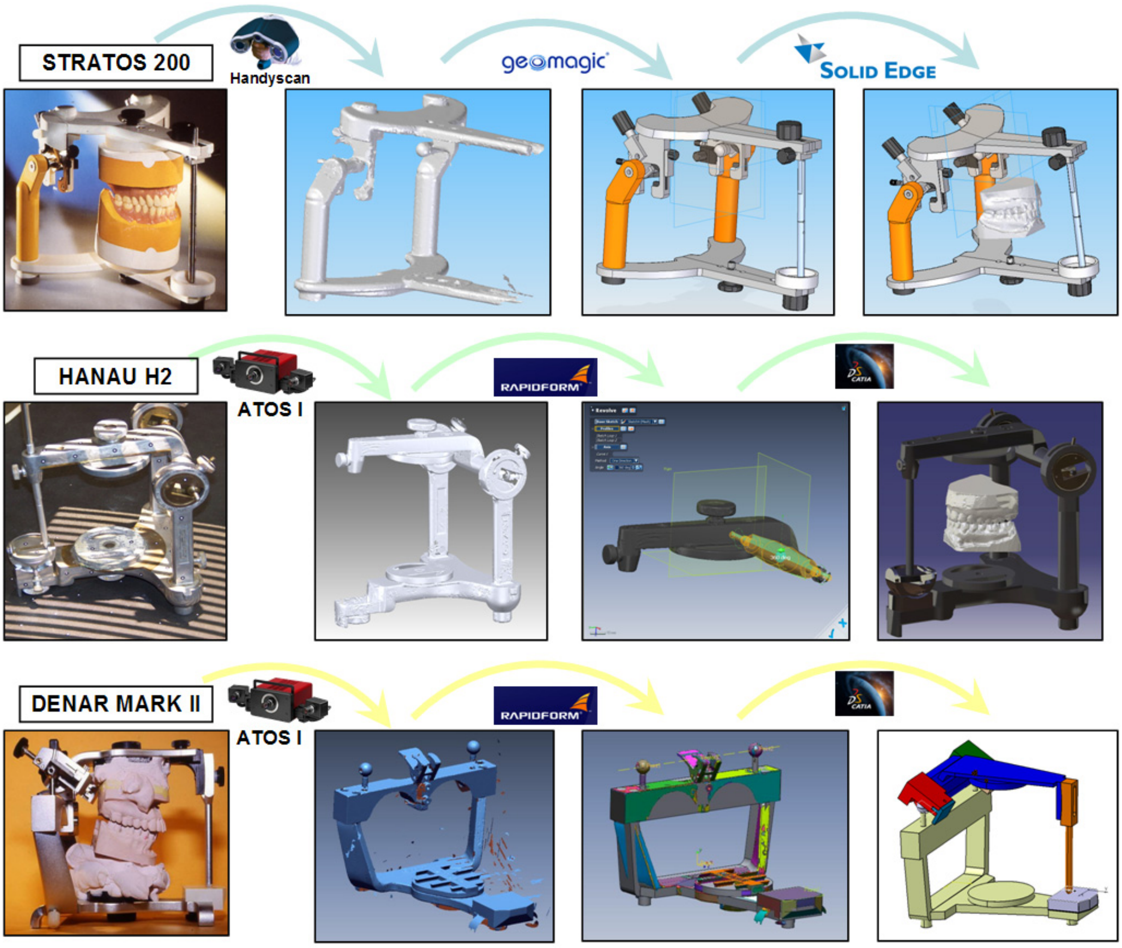

Figure 8. Modelling processes of different articulators

4.2 Process

The following lines present in detail the modelling of the Panadent PSH (Figure 9):

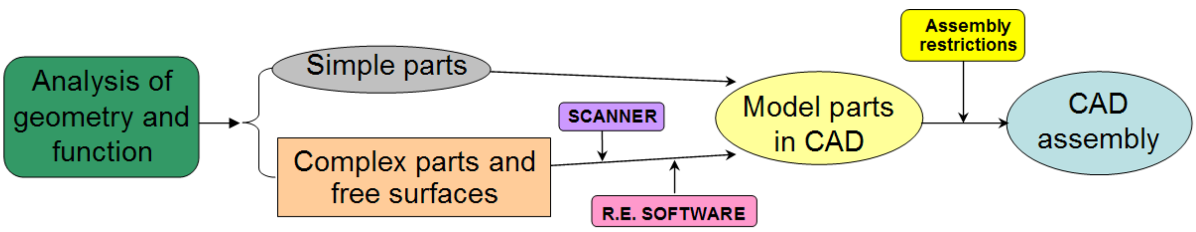

Figure 9. Modelling flow chart and assembly of the articulator

First of all, the primitive geometries are identified as cylinders, spheres or prismatic bodies. These bodies are measured and modelled directly on the CAD system. Apart from this, the function of all parts is analysed to simplify the virtual assembly. For example, pressure threads are substituted by a restriction on the virtual environment. Parallel, when complex bodies and free form surfaces are identified, a 3D scanning is carried out, thus obtaining the point of clouds. Reverse Engineering software allows for the edition of clouds in order to obtain the necessary information for the subsequent modelling on the CAD system. The parts of the articulator are then generated and assembled in the CAD system (Figure 10).

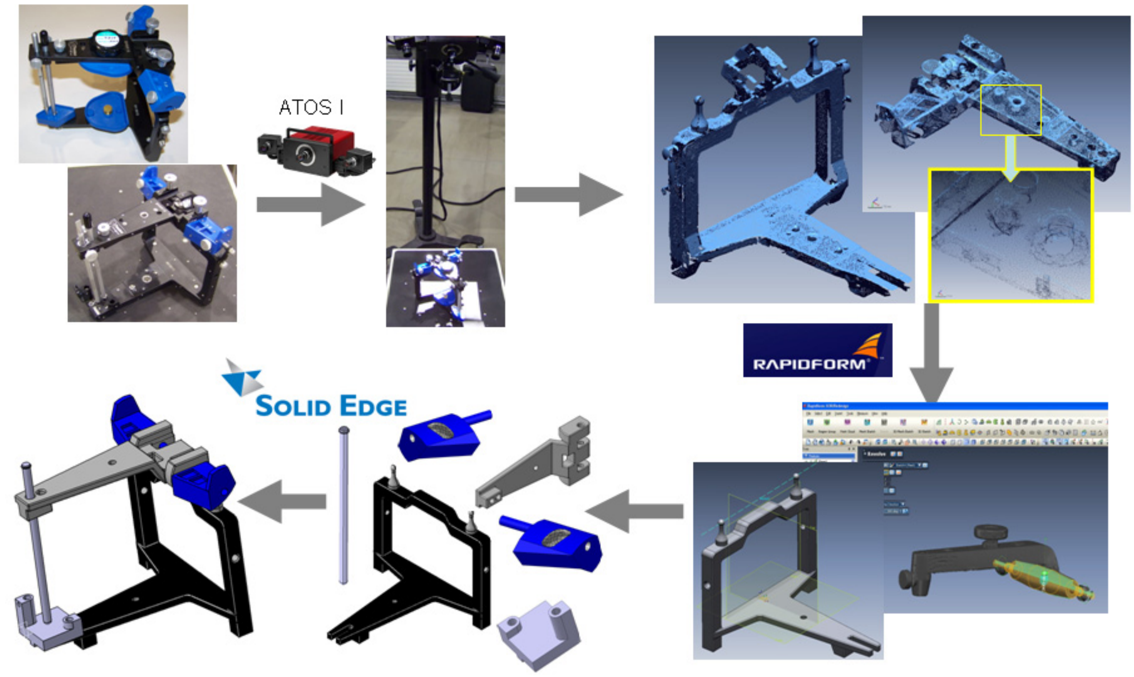

Figure 10. Modelling process of Panadent PSH articulator

On this articulator, it is possible to adjust the condilar inclination and condilar fossa parameter (Figure 11).

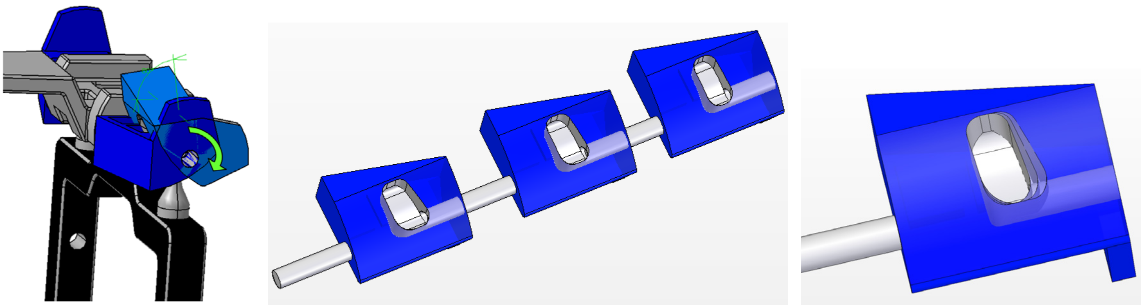

Figure 11. Adjustment of condilar inclination

5. Real case in virtual environment

Once the virtual articulator is generated, the procedure to follow is similar to the manual one. First, models are scanned. Then, a physical face bow is used to locate the occlusal plane. The location is taken from the patient (Figure 12), and the reference points of the transferring table and the upper model are scanned. This scanning allows technicians to locate the upper model on the articulator.

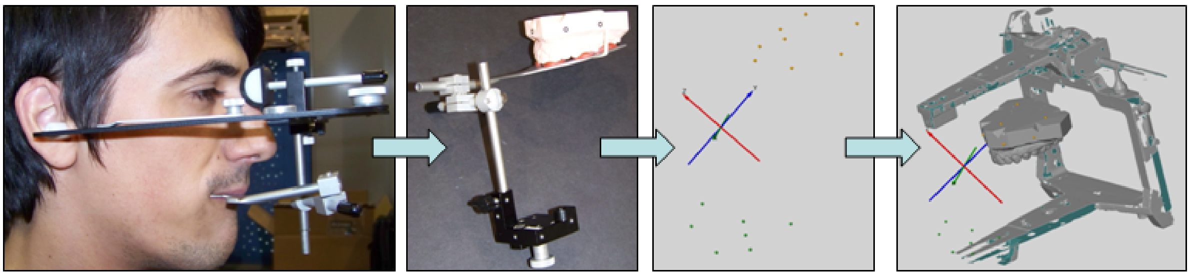

Figure 12. Virtual location of upper model

To locate the lower model with respect to the already located upper model (Figure 13), the bite of maximum intercuspidation is scanned. This file is then exported to the RE software and there, the reference elements are generated in order to locate the models in the CAD system.

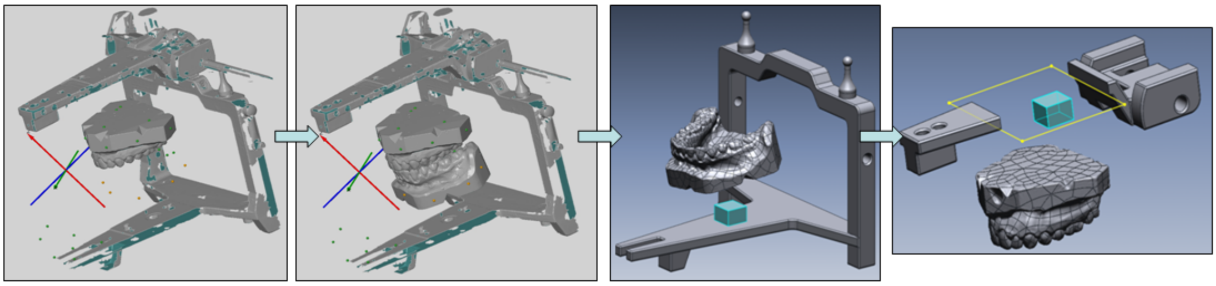

Figure 13. Virtual location of lower model and generation of reference elements

These reference elements play the role of the plaster. The models are easily positioned on the CAD system.
Afterwards, the paremetres of the articulator are adjusted with the help of the lateral and protrusive bites. This involves generating reference elements in new positions. Afterwards, they are imported to CAD and the necessary adjustments are determined. For example, on figure 14, the condilar inclination is adjusted. Once the condilar inclination and fossa dimensions are determined, the articulator is individualized to apply the movements.

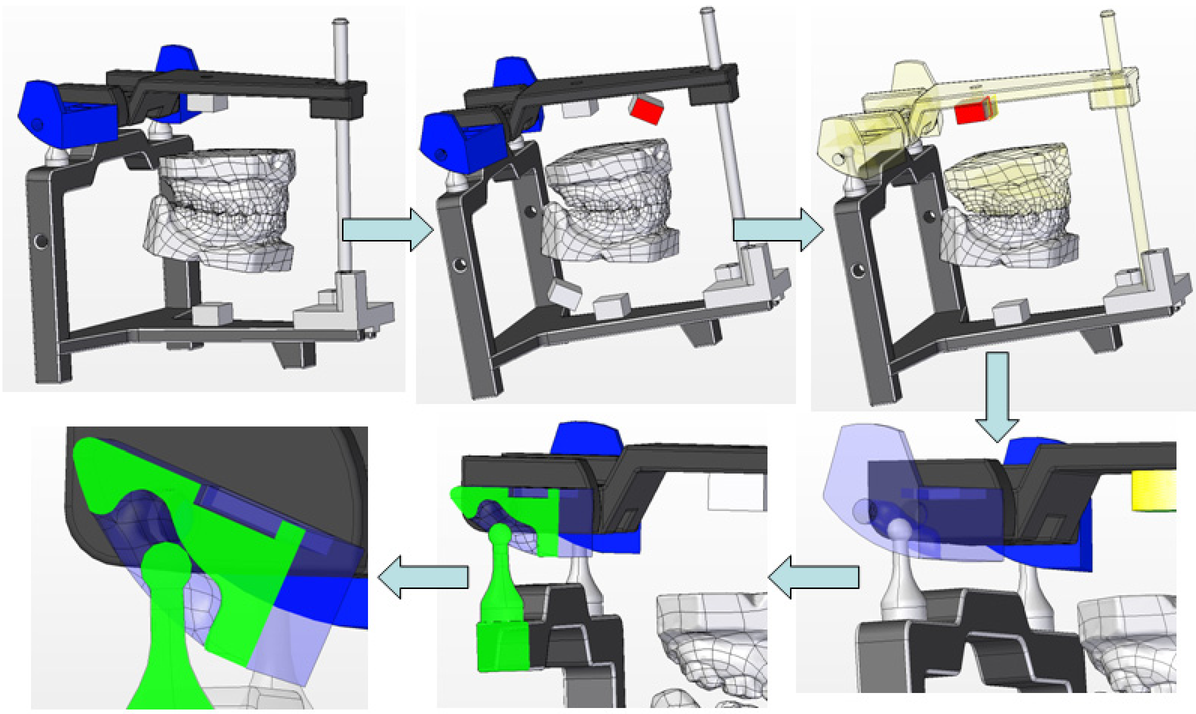

Figure 14. Location of upper part in protrusive position and adjustment of condilar inclination

Then, the prosthesis is designed statically, same as with any commercial CAD/CAM, by fitting it with the antagonist. The movements are simulated and collissions are removed, thus obtaining the final and functional design (Figure 15).

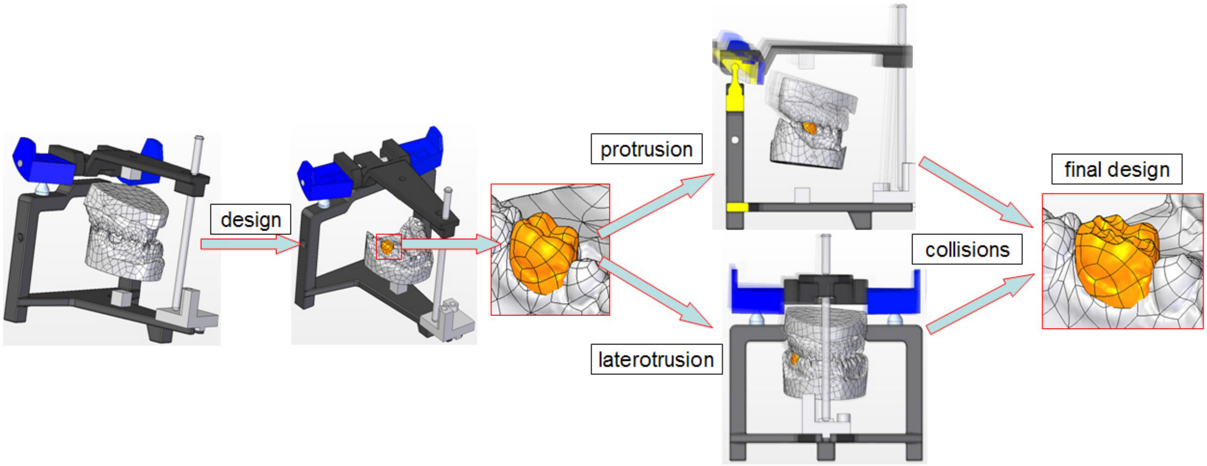

Figure 15. Cinematic design process of the prostheses

6. Results

The main result of this project is the construction of the virtual articulator and its validation. For this design process, physical articulators are not necessary, whilst for the other existing virtual articulators, unless a complex registration system is used, physical articulators are still necessary. This fact reduces the required time and increases the automatisation of the process.

Another result is the parametrisation of the condilar fossa. This involves a greater control of the condilar trajectory. Using the parametrization is posible to introduce new parameters (Figure 16). This is certainly not possible on physical articulators.

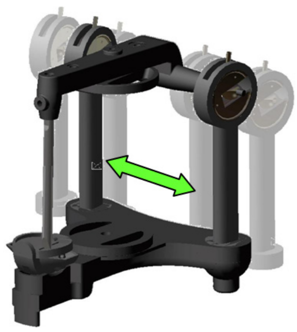

Figure 16. Introduction of a new parameter (intercondilar distance)

Apart from this, the virtual environment allows technicians to calculate this easily, without having to use analog selectors (which are necessary in the conventional process to calculate the lateral displacement and select the condilar fossa). The lateral bite is introduced and the lateral displacement is visualized on the screen, thus obtaining the necessary information to choose the fossa.

To conclude, one more point to take into account is that, with the available systems, only static collisions can be calculated whilst kinematic collisions have to be calculated by sweeping. Once kinematic collisions are removed, the movement is free from non-desirable collisions.

7. Conclusions and future work

This project arises from the implementation of CAD systems and Reverse Engineering systems in the construction of a dental virtual articulator. Following the proposed system, it has been proved that is possible to produce a dental prosthesis digitally. The commercialized CAD/CAM system does not take into account the kinematics, while existing virtual articulators require a complex registering system or several manual steps to mount on the physical articulator. This process reduces manual steps whilst computer aided design is increased.

Another certainly important conclusion is that when the collisioned part is removed, the result is valid. However, these interferences should be integrated on the redesign process while the geometry is being improved. With this aim, collisions should be visualize and according to them, an optimum geometry should be generated in real time.
Finally, when the most important articulators are digitalized, the accuracy of their generated paths will be analyzed. Apart from this, a further step will involve the performance of the whole virtual process based on the intraoral scanner and virtual face bow.

References

Colombo, G., Filippi, S., Rizzi, C., Rotini, F., 2008, "A Computer Assisted Methodology to Improve Prosthesis Development Process", CIRP Design Conference, 2008, Design Synthesis, Twente, Netherlands Canada.

Gaertner, C., Kordass, B., "The Virtual Articulator: Development and Evaluation", Int Jour Computerized Dent, 2003, 6, 11-23

Hobo, S., Herbert, T., Whitsett, D., "Articulator Selection for Restorative Dentistry", Journal Prosthetics Dentistry, 1976.

Hoffmann-Axthelm, W., "History of Dentistry", Quintessence Publishing Co., 1976

Kordass, B., "The virtual articulator-concept and development", Dent Clin N Am, 2002, 493-506

Lee, R., "Jaw movements engraved in solid plastic for articulator controls. Part I. Recording apparatus." Journal of Prosthetic Dentistry, 1969

Mitchell, D.L., Wilkie N.D., "Articulators through the years. Part I. Up to 1940", J Prosthet Dent, 1978, 39: 330-8.

Mitchell, D.L., Wilkie N.D., "Articulators through the years. Part II. From 1940", J Prosthet Dent, 1978, 39: 330-8.

Padrós, E., "Bases diagnósticas, terapéuticas y posturales del funcionalismo craneofacial. " Tomo II. Ed.Ripano, 894-901, 2006

Sharry JJ, ed. "Prostodoncia dental completa", Toray, Barcelona, 1977

Szentpétery, A., "3D Mathematic movement simulation of articulators and its application by the development of a software articulator", Martin-Luther University of Halle, 1999

Szentpétery, A., "Computer Aided Dynamic Correction of Digitized Occlusal Surfaces", J Gnatho,; 16: 53-60, 1997

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