

Review article

Virtual Articulators: A Digital Excellence in Prosthetic and Restorative Dentistry

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ARTICLE INFO



Keywords:

Virtual articulators, CAD/CAM, Virtual reality, Mechanical articulator

ABSTRACT

virtual technologies in dentistry provide better education and training by simulating complex contexts and enhancing procedures that are traditionally limited, such as work with mechanical articulator. The virtual articulator is intended to use as a tool for the analysis of the complex static and dynamic occlusal relations. The main goal of the virtual articulator is to improve the design of dental prosthesis, adding kinematic analysis to the design process. This paper reviews the need of virtual articulator, its advantages in the field of prosthetic and restorative dentistry.

Introduction

In the field of prosthetic and restorative dentistry, the virtual dental articulators incorporate virtual reality applications to the world of clinical dental practice for the analysis of complex static and dynamic occlusal relations¹. The virtual reality lets you to navigate and view a world of three dimensions in real time, with six degrees of freedom. Virtual reality is a clone of physical reality creating a virtual environment to replace the real world. The equipment's and technologies by which we can interact reality are known as virtual reality equipment's and virtual reality technologies. Virtual articulator chief application is in the simulation of the mechanical articulator. The virtual articulator requires digital 3D representation of the jaws and patient specific data on jaw movements and provides a dynamic visualisation of the occlusal contacts.²

Currently, the mechanical articulator is used for the functional simulation of the effects of dysmorphology and dysocclusion. However, this mechanical device is

very different from the real life biological setting and has many drawbacks. In effect, the movements reproduced by the mechanical articulator follow the margins of the structures that conform the mechanical joint, which remain invariable over time, and which cannot simulate masticatory movements that are dependent upon the muscle patterns and resilience of the soft tissues and joint disc. Tooth mobility cannot be simulated by plaster model and thus are unable to reproduce the real life dynamic conditions of occlusion^{3, 4}. There are also other problems derived from the procedures and materials used for assembling the models in the articulator: precision in orienting the model, expansion and contraction of the plaster, deformation of the bite-recording material, the stability of the articulator, etc⁴. Because of these basic problems, the reproduction of dynamic, excursive contacts seems to lower the reliability.

The virtual articulator offers the possibility of significantly reducing the limitations of mechanical articulators⁵. This tool incorporates virtual reality

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applications to the world of dental practice with the purpose of replacing mechanical articulators and thereby avoiding the errors and limitations of the latter. Combined with CAD/CAM technology, this tool offers great potential in planning dental implants, since it affords greater precision and a lesser duration of treatment. The virtual articulator can be defined as a software tool for improved clinical outcome based on virtual reality technology. There are two types of virtual articulators namely-completely adjustable and mathematically simulated.^{4, 7}

Completely adjustable articulator:

- It records / reproduces exact movement paths of the mandible using an electronic jaw registration system called jaw motion analyser.
- The digitised arches then moves along these movement paths that can be viewed in the computer screen consisting of three main windows showing the same movement of the arches from different planes
- The software calculates and visualises both static and kinematic occlusal collisions and is used in designing and correction of occlusal surfaces in computer aided designing systems Eg:Kordass and Gartner Virtual articulators.

The software of the DentCAM virtual articulator developed at the university of Griefswald consists of three main windows and a slice window, which show the same movement of teeth from different aspects:

Rendering window: shows both jaws during dynamic occlusion and can visualise unusual views throughout dynamic patterns of occlusion i.e. the view from the occlusal cusps while watching the antagonistic teeth coming close the intercuspitation position during chewing movements.

Occlusal window: shows the static and dynamic occlusal contacts sliding over the surfaces of the upper and lower jaw as a function of time.

Smaller window: the movements of the temporomandibular joint are represented in a sagittal and transversal view which allows the analysis and diagnosis of interdependencies between tooth contacts and movements of the temporomandibular joint.

Slice window: shows any frontal slice throughout the dental arch .The tool helps to analyse the degree of intercuspitation and the height and functional angles of the cusps. With this window, the analysis of guidance and balancing becomes easy.

Mathematically simulated virtual articulator.⁸

- It records /reproduces movements of the articulator based on mathematical simulation of articulator movements.
- A fully adjustable 3D virtual articulator is capable of reproducing all articulator movements
- These virtual articulators allow for additional settings such as curved Bennett movement or other movements for adjustment in real settings.
- The main disadvantage is that it behaves as an average value articulator and it is not possible to obtain individualised movement paths of each patient.

Eg:Statros 200,Szentpetrey's Virtual articulators

Development and Designing of the virtual articulator

The designing of virtual articulator is achieved by means of CAD systems and reverse engineering tools. The development is made at the product design laboratory in the faculty of engineering of Bibao (The university of the Basque Country) in collaboration with the department of the Martinluther University as follows:

- Different mechanical articulators are selected first to be modelled through CAD systems.

- The design process will then be carried out using measuring tools and reverse engineering tools that are available at the product design laboratory. The tools used are Handyscan Revscan 3D scanner and its software. Reverse engineering and computer aided inspection software .

- After the virtual articulator is constructed, all the measurements are verified and checked

- If any problem exists, that needs to be rectified and redesigned accordingly.⁷

PROGRAMMING AND FUNCTIONING OF VIRTUAL ARTICULATOR

The programming and adjustment methods of the virtual articulator were described by Kordass and Gärtner in 1999. First a digital image is obtained of the surfaces of each tooth, of the global dental arches, and of the bite registries. To this effect a three-dimensional laser scanner is used, such as for example the Laser Scan 3D (Willytec, Munich, Germany). This scanner projects a vertical laser beam onto the surface of the object. A digital camera equipped with a charge coupled device (CCD) registers the beam reflected from the object and transmits the digital signals to an electronic processing system. The processed image data are stored as digital matrix brightness values, ready for use by the scanner software and for on-screen visualization and computer-ized manipulation ⁹. In this phase, the real geometry of the mouth and its relation location are reconstructed in a CAD system using face bow¹⁰.

Selection of the articulator

The selected articulator ¹¹, and even more importantly, the skill and care, with which it is used, have a direct effect/impact on the success of fixed or removable restorations. Since the intercuspation position is static, the articulator will need to act only as

a rigid hinge, which is little more than a handle for the model. The mandible, however, does not act as a simple hinge. Rather than this, it is capable of rotating around axes in three planes. The occlusal morphology of any restoration for the mouth must accommodate the free passage of the antagonist teeth without interfering with the movement of the mandible. Because of their potential to produce pathologies, occlusal interferences must not be incorporated into restorations placed by the dentist. One way of preventing this problem is the use of fully adjustable articulators which simulate mandibular movements with a high degree of precision. Treatments using these articulators are time consuming and demand a great skill from both dentist and technician. As a result, the cost of such treatments does not make it feasible for minor routine treatment plans.

Virtual articulator design process

Once the articulators are selected, their structures and shapes are analyzed in order to clarify how to use the Reverse Engineering and measuring tools. The general structure, this is, upper and lower bodies, is similar in both articulators, but the TMJ-s, which are the most important part of the articulators, present a great variety of configurations.

Hanau H2

The Hanau H2 has been modelled using ATOS I 3D scanner , in order to have the drafts located on the correct position in space. To get the sections of the scanned point cloud, the Rapidform XOR software has been used. The whole articulator has been constructed combining both measured and scanned parts. Once the Virtual Articulator is constructed, all the measures are verified. The final step deals with locating the models on the articulator. For this purpose, the relative position of the upper model is scanned using the face

bow. Afterwards, the location in the virtual articulator is direct, and the location of the lower model is made using an electronic bite in Centric Relation. Then, the virtual articulator is ready to apply the kinematic simulation using the CATIA CAD system 12.

Stratos 200

The Ivoclar Stratos 200 has been modelled using a SolidEdge CAD system. Some parts were modelled directly after measuring the mechanical dental articulator. However, the Handyscan 3D scanner has been used, due to its mobility, and almost all the articulator has been scanned. Using Geomagic point cloud edition software, the useful data has been taken from the millions of points that had been scanned. Finally, as it has been done with Hanau H2, the models have been located in the correct position, ready to apply the kinematic analysis.

Functioning of the Virtual Articulator

After the articulator is modelled, the simulation is run and any possible interference on the designed prosthesis are checked out and if they are present corrected accordingly.

The basic system of the virtual articulator generates an animation of the movements of the mandible based on the input data, and calculates the points of occlusion, which in turn are shown on-screen by means of some type of code.

Ideally, the virtual articulator is equipped with a device for registering the specific mandibular movements of a given patient (such as the Jaw Motion Analyser system), and can integrate the movements recorded in the animation. This system is based on measuring the velocity of ultrasonic impulses emitted from three transmitters attached to the lower sensor. Four receivers are attached to a face bow opposite them. This positioning enables the detection of all

rotative and translative components in all degrees of freedom. A special digitizing sensor is used to determine the reference plane, which is composed of the hinge axis infraorbital plane and special points of interest (eg, on the occlusal surface).

There are also other systems for the detection of mandibular movements based on other technologies, such as optoelectronic devices that use CCD cameras to register the emissions of light-emitting diodes (LEDs) positioned over the head of the patient and generate an image from these signals¹³.

If JMA tool is not available for registering the mandibular movements, specific movements must be defined by means of parameters, in a way similar to the practice used with mechanical articulators. Some parameters of interest in these cases would be the following: protrusion (radius of the condylar guide, maximum distance of condylar protrusion), retrusion (radius of the condylar guide, maximum distance of retrusion), laterotrusion (maximum protrusion, Bennett angle, radius of the right and left condylar guide, right and left horizontal condylar slope, phase angle, lateral displacement), and aperture / closure slope (maximum angle of aperture). After defining the movement parameters, collision detection is required in order to identify the movement restrictions. In these cases, it may be of interest to leave a distance corresponding to the thickness of the occlusion paper used in the mechanical articulators, for calculating the points of occlusion on the basis of this distance.

As an example, the software of the Dent-CAM® virtual articulator (Comp. KaVo, DLeutkirch) uses three main windows that show the same movement pattern, distinguishing a series of aspects:

a) Interpretation window: this shows both maxilla in dynamic occlusion and allows us to obtain unusual

points of view, e.g., observation from an occlusal surface of closing of the opposing tooth during mastication.

b) Occlusion window: this shows the points of contact that appear on the occlusal surfaces of the upper and lower teeth as a function of time.

c) Section window: this offers different frontal sections along the dental arch. This tool can be used to analyze the degree of intercuspitation, as well as the height and functional angles of the cuspids.

The latest software versions incorporate an orthodontic module allowing the creation of a virtual setup. The program has also been equipped with the representation of the condylar trajectories in the sagittal and horizontal planes. This tool allows us to observe the inter-relationship between the incisal guide and the condylar guide, and the effects of joint mobility upon occlusion¹¹.

One of the most recent new developments in the virtual articulators is the 3D virtual articulation system (Zebris company, D-Isny). This system requires the following:

- a) An input unit in the form of a 3D scanner
- b) The software for prosthesis modeling and collision detection, based on a virtual articulator
- c) The output module (a rapid prototyping system).

With this system, and in addition to mandibular movement, we can analyze masticatory movement – including force at the points of contact and the frequency of contacts in relation to time¹⁴.

Validation: The results of validation were recently presented^{15,16}. Comparing the model situation of a mechanical articulator (KaVo, Leutkirch, Germany) to the virtual articulator module, DentCAM showed approximately the same number of dynamic contacts in lateral movements to the left and right in eight cases

(mechanical articulator: 90, virtual articulator: 92). The results demonstrate the correspondence under standardized conditions in relation to the detected number of contacts in both situations¹⁷. To examine reliability, three operators measured the mandibular movements two times in eight persons. After data implementation, data matching, and programming of the VR articulator, good correspondence was demonstrated in visualizing the number and position of dynamic contacts¹⁶. In this same line, Pröschel et al.¹⁸ carried out a study of 57 asymptomatic patients in order to determine the occlusal errors appearing in the mechanical articulators. To this effect comparisons were made with the virtual articulator, yielding an error in the second molar of 200 µm in 16% of the patients and of 300 µm in 6% of the subjects – this implying a low risk of error, though the acceptable limits in clinical practice could be exceeded. Likewise, other studies have compared the maximum number of contacts between the conventional method and the virtual articulator – the occlusal contacts calculated from the virtual models being shown to precisely reproduce the contacts obtained with the mechanical articulator^{19,20}.

Recent developments in the virtual articulators²¹

The development of 3D virtual articulator system requires three main unit devices namely:

- An input device in form of a 3D scanner
- 3D virtual articulator software for prosthesis modelling with collision detection
- An output device in the form of rapid prototyping system with stereoscopic inkjet technology

The advantage with this 3D virtual articulator system is that in addition to analysis of mandibular movements, even masticatory movements can be

analysed including force at the points of contact and the frequency of contacts in relation to time

Advantages of virtual articulator

- Provides best quality of communication between dentist and dental technician
- Analyses both static and dynamic occlusions
- Designing of occlusal surface in CAD CAM systems
- Analyses gnathic and joint conditions
- Offers a detailed 3 d visualisation of region of interest
- Possible to modify or introduce new setting according to the patient and helpful for patients education

Limitations of the virtual articulator

Cost effective as it requires the digital scanners, digital sensors, software's and different types of virtual articulator models mimicking the mechanical ones according to the patient need

Knowledge about the CAD/CAM technology, mechanical articulators, designing and modelling of virtual articulators etc. and technical skills regarding the interpretation of data recorded scanners, sensors, minor adjustments, incorporating motion parameters etc.

Future Modules of Virtual Articulator1

1)Fixed crown and bridge work with CAD/CAM:The virtual models of the casts that are digitally mounted in virtual articulator are used for diagnosis and treatment planning of prosthetic restorations from single to multiple crowns to bridges including complex cases like full mouth rehabilitation achieved by CAD/CAM systems .The virtual articulator combined with CAD/CAM technology offers great potential in treatment planning with dental implants since it

affords greater precision and shorten the duration of implant treatment.

2) For the detection of tooth wear and bruxism: A module that semi automatically analyses the teeth for signs of wear or bruxism is available. The algorithm searches for wear facets and separates them from the surrounding surface using special segmentation algorithms.

3)For orthodontic virtual set up:The latest version of Dent CAM software, a special orthodontic CAD module was added to simulate the therapeutic result by repositioning single teeth and reforming the dental arch (virtual set up).

Haptic based first touch enabled virtual articulator:Sensible dental technologies has developed the newest version of its Intellifit TE (Touch enabled) digital restoration system that offers dental labs even more choice ,performance and flexibility in digitally designing and fabricating a wide range of dental restorations. The system's support for both fixed and removable restorations including full ceramic monolithic crowns, bridges and prepared veneers, produced faster and with heightened precision though its unique touch enabled technology ,allows dental labs of all sizes to gain a competitive advantage.

Intellifit's unique 3D virtual touch interface and integrated touch enabled articulator allow lab technicians to actually feel how the teeth including the new restoration they are producing will fit together in the patient's mouth. Articulators are essential to testing the occlusion of almost every type of dental restoration and lab technicians have long used them, as well as their sense of touch, to assess whether a restoration will allow the patient to function with the correct amount of contact and excursive movements.Intellifit's virtual articulator mimics the

feel and function of a physical articulator, yet allows dynamic settings to meet patient specifications and freedom of movement in three dimensions. Touch enabled, virtual articulator allows technicians to test occlusion of restoration before it is produced and enabling them to actually feel the fit.²²

Conclusion

The virtual reality technology has opened door for dental professionals towards successful diagnosis and treatment planning with virtual articulator in day to day clinical practice. The virtual articulator is a precise software tool dealing with the functional aspects of occlusion along with CAD/CAM systems substituting mechanical articulators and thus avoiding their errors.

Conflict of interest: Nothing to declare

Acknowledgements: None

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