VIRTUAL ARTICULATORS: A PROMISING TECHNOLOGY OF THE FUTURE

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Abstract
Use of computer technology is strongly linked to the future of dentistry. Virtual reality technologies have a major impact on development, research and industrial production. Virtual reality can be experienced visually in 3-dimension of width, height and depth as it is the simulation of real and imagined environment. It also provides an experience with sound, motion, tactile effects and other forms of feedback. In dentistry, the introduction of kinematic analysis in virtual design processes was achieved by the use of computer aided design (CAD) systems and Reverse engineering tools. Development of a virtual articulator simulant to mechanical articulator is one of the recent innovations in virtual field. Dentistry has become easier, accurate and time saving after the advent of digitalization. This article reviews about virtual articulators including their need, designing of the articulator, types and programming of virtual articulators, advantages, usage and limitations, and shortly about haptic based touch enabled virtual articulator.

**Key words:** Virtual articulator, dental occlusion, dental articulator, virtual reality.

**Introduction**

The mechanical articulator (MA) has been used in different fields of dentistry, such as Orthodontics, Prosthodontics, and Orthognathics for long as an essential tool in laboratory procedures so as to aid in both diagnosis and treatment planning.\(^1\) “Articulator is defined as a mechanical instrument that represents the temporomandibular joints and jaws, to which maxillary and mandibular casts may be attached to simulate some or all mandibular movements.”\(^2\) The articulator is also changing from a mechanical device to its digital alternative; the virtual articulator (VA) with the advancements in technology.\(^3\) A VA involves software tools as it is a virtual instrument. It reproduces the relationship between the upper and lower jaw in a virtual environment.\(^4\) In the initial period of 2000s, clinicians use to verify the feasibility of digitally designing prostheses with a VA. Since then, some articles related to this topic have been reported.\(^3-5\) The exhaustive analysis of static and dynamic occlusion was done by the virtual articulator. This tool replaces mechanical articulators by introducing virtual reality applications to the world of dental practice. Various limitations in design of mechanical articulators were overcome by innovative research and development. Limitations such as:
Mechanical articulators cannot simulate the following:

- When plaster casts are used mobility of the teeth is not simulated
- During loading conditions the distortion and deformation of the mandible occurs (In maximal opening position the mandible bends to the inner side, which creates problems while impressions making of teeth during wide opening)
- The movement patterns complexity because the mechanical articulator follow the movements along the border structures of the mechanical joint, and it never represent the effects of resilience of the soft tissue or the time-dependent, muscle-guided movement pattern of chewing.

Many other problems related to the technical procedure and dental materials decreases the accuracy of reproduction which includes:

- Registration material gets deformed (eg, wax, it is susceptible to heat)
- The cast repositioning without leaving any space into the bite impressions
- The articulator stability itself
- The proper orientation of the cast
- The use of expanded and rigid plaster material

Because of all these problems, the reliability is lowered while the reproduction of dynamic, excursive contacts.\(^{3,6-10}\) It also creates new contacts. VA helps to solve these problems. The VA tools enables three-dimensional navigation through the occlusion based on every point of view while the mandible moves along predefined pathways (as the mechanical articulator would do) or reproduce movement patterns of mastication that never can be simulated in mechanical systems. Possibilities in manipulation procedures are opened by digitizing the tooth surfaces so as to improve the occlusion. Computer aided design/computer aided manufacturing (CAD/CAM) techniques or tools could be linked for a virtual set-up of the teeth. Moreimportantly, it would affect the quality of the communication between dental practice and laboratory, helping to produce the best-fitted occlusal restorations possible. The VA will be affordable and economical in private practice, with costs perhaps depending on demands for use. This articles reviews about the present ideas on need of virtual articulators, development, designing and programming of
virtual articulators, advantages and limitations of virtual articulators, and a briefly about haptic based touch enabled virtual articulator.

**Need for virtual articulator**

As the mechanical articulator follow border structure of mechanical joint and it cannot represent the time-dependent muscle guided movement pattern of chewing or the effects of resilience of the soft tissue. It also cannot represent the real dynamic condition of the occlusion in mouth. The mechanical articulator which is currently used in the fabrication of fixed dental prosthesis has numerous limitations. Because of those problems, the reliability is lowered while the reproduction of dynamic, excursive contacts. Replacement of the mechanical articulator with the virtual articulator will solve this problems. The main goal of virtual articulator is to add kinematic analysis to the design process and improve the design of dental prosthesis.

**Development and designing of virtual articulator**

The development occurred at the product design laboratory (PDL) in the faculty of Engineering of Bilbao (The University of the Basque Country) in collaboration with the department of Prosthetics of the Martin-Luther University of Halle as follows. The designing of dental virtual articulator is done by computer aided design (CAD) systems and reverse engineering tools. First to get modeled through CAD systems (Solid Edge and CATIA) different mechanical articulators are selected. Then the design process will be carried out using measuring tools and reverse engineering tools that are available at the PDL. The tools used are: Handyscan, REVscan, 3D scanner and its software (VXscan), Reverse engineering and computer-aided inspection software (Geomagic Studio and Qualify), Rapidform XOR, ATOS I rev.2 GOM 3D scanner. After the virtual articulator is constructed, all the measurements are checked and verified. If any problem exists, it needs to be redesigned and rectified accordingly.

**There are two types of virtual articulators**

1. Mathematically simulated articulators
2. Completely adjustable articulators

**Mathematically simulated articulators**
It was first designed by Szentpetery, depends on a mathematical simulation of articulator movements (Szentpétery, 1997). Dentist can reproduce the movement of a mechanical articulator by this device and makes it a fully adjustable 3D virtual articulator (Luthra et al., 2015). Additionally, mechanical dental articulator does not supply measures such as Bennett angle, condyle angle, and movements of retrusion, laterotrusion or protrusion in the setting that are obtained in mathematical simulation. Because of these measures, the VA innately simulates the movement of the mandible, just like mechanical dental articulator would do (Mitchell and Wilkie, 1978; Solaberrieta et al., 2009). Mathematically simulated articulator becomes more versatile than a mechanical dental articulator by these properties. As the mathematical approach is used so average value are taken like that of mechanical articulator. Consequently, for each patient the individual movements cannot be tracked easily. Examples of mathematically similar articulators include the Stratos 200 (IvoclarVivadent; Amherst, NY) and Szentpetery’s virtual articulators (Gugwad et al., 2011; Koralakunte and Aljanakh, 2014; Bhayana et al., 2015).

Completely adjustable articulators

Gaertner and Kordass first designed this articulator. By using an electronic jaw registration system called the ‘Jaw Motion Analyser’ (JMA), it can record and reproduce the precise movements of the lower jaw. This system components are basic unit, lower jaw sensor, head bow, bite fork and sensor pen (Gärtner and Kordass, 2003). With the help of the sensor, its components transmitter and receiver are mounted in the correct position. To determine the location of the patient’s mandible, head bow has eight ultrasonic microphones transmitters that make pulse continuously and it calculates the pulse via the triangulation method between the transmitter and receiver microphone (Koralakunte and Aljanakh, 2014).

The working procedure is explained as follows:

1) Firstly, the software should be installed and the device should be connected to the computer.
2) Then the clinician should attach the bite fork to the mandible followed by placing the head bow device on the patient’s head and the face supporter on the patient’s nose.
3) Then according to manufacturer’s instructions patient’s TMJ and infraorbital notch should be pointed by a sensor pen.
4) Finally, the mandible sensor should be connected to the bite fork.
5) Then the device will track the movement of the mandible identifying issues such as retransmission, protrusion and laterotrusion.
6) These movements will then be converted to numbers that can be used to program a fully adjustable articulator, such as KaVoProtarevo 7 (KaVo Dental GmbH), SAM 2 (SAM Prazisionstechnik GmbH), Artex CR (AmannGirrbach AG) or Stratos 300 (IvoclarVivadent; Amherst, NY).14

**Programming the virtual articulator**

Kordass and Gartner (1999) described the programming and adjustment methods of virtual articulator. The data entry for input is done as follows:

a) Scanning/Digitizing: Scanning of a tooth surface or tooth or restoration or complete denture models or centric relation can be done. A vertical laser beam will be projected onto the surface of the object by the scanner and the beam reflected from the object will be registered by the digital camera equipped with a charge coupled device (CCD) and the digital signals will be transmitted to an electronic processing system. The image data will then be processed and stored as digital matrix brightness values. Then it is ready for use by the scanner software and for on screen visualisation and computerised manipulation. The scanning can be done in 2 ways:

1) Direct digitizing – It is done using an intra oral scanner directly from the patient’s mouth.
2) Indirect digitizing – It is done using the laboratory scanner outside the patient’s mouth on master cast, obtained from final impression.

b) Patient Specific Motion Data of Temporomandibular joint

i) Using Jaw motion analyser (JMA) tool (Comp Zebris, Isny, Germany):

It has reference points that are fixed on the patient mandible. To measure the position of these points in space an ultra sound is used describing physiological masticatory motion of the patient. Thus, mimic the patient specific movement patterns. Then face bowis used to digitized, the relative position of the upper or maxillary virtual model in reverse position and located directly in the virtual articulator. An electronic bite is then used to locate the lower or mandibular virtual...
model in centric relation with the upper virtual model. Finally, on the computer screen the occlusion can be visualized in 3D in all planes. Now the virtual articulator system is ready to be applied for kinematic simulation analysis.

ii) Different jaw motions can be achieved via parameters such as protrusion (radius of the condylar guide, maximum distance of condylar protrusion), retraction (radius of the condylar guide, maximum distance of retraction), laterotrusion (maximum protrusion, Bennett angle, radius of the right and left condylar guide, right and left horizontal condylar slope, shift angle, immediate side shift), and opening/closing movement (maximum opening angle) as used with the mechanical articulators, if the jaw motion analyser tool is not available. After achieving the motion parameters, collision detection is activated to recognize the motion constraints, which results in the upper and lower jaws gliding on each other. A ray based algorithm is used for collision detection that is executed in a preprocessing step. For calculating the occlusion points according to this defined distance, a distance corresponding to the thickness of the occlusion paper used in the mechanical articulator is chosen, for occlusion detection. For the detection of mandibular movement other systems available newly are based on technologies such as optoelectronic devices that use CCD cameras to register the emissions of light emitting diodes (LED’s) positioned over the head of the patient and generate an image from these signals.³

**Advantages of virtual articulator:**

- Supply best communication quality between the dentist, dental technician and patient.
- Help in analysis of both static and dynamic occlusions.
- Help in designing of occlusal surface with CAD CAM system.
- Gnathic and joint conditions can be analyzed.
- Provides a detailed three dimension visualization of region of interest and Problems occurred by manufacturing get eliminated.
- Procedures is simplified for the dentist and technician
- Very time-efficient
- Very helpful for patient’s education.
- New setting can be introduced or modification of previous can be done according to the patient.
Limitations of virtual articulator:

- High cost as it demands the use of supplemental technology such as the digital scanners, digital sensors, software’s, and different types of virtual articulator models mimicking the mechanical ones according to the patient need.
- Knowledge related to CAD/CAM technology, modeling and designing of virtual articulators, mechanical articulators, and technical skills regarding the interpretation of data recorded scanners, sensors, minor adjustments, incorporating motion parameters etc should be known to operator.  

Haptic based first touch enabled virtual articulator:

Newest version of Intellifit™ TE (TouchEnabled) Digital Restoration System has been developed by the Sensable Dental Technologies that offers dental labs even more choice, performance and flexibility in digitally designing and fabricating a wide range of dental restorations. This system supports both fixed and removable restorations including full ceramic monolithic crowns, bridges and prepped veneers. It produce faster and with heightened precision through its unique touch enabled technology. It allows dental labs of all sizes to gain a competitive advantage.

Conclusion

The Virtual articulators offer various advantages over mechanical articulator. They can design prosthesis kinematically. They are proficient of:

1. Mimicking human mandibular movements
2. According to these movements they can move digitalized occlusal surfaces against each other
3. They enable smooth and collision-free movements by eliminating the occlusal interferences.

The acquired knowledge of the specific domain directly supports each activity used in designing process of the Virtual Articulators by integrating all the necessary tools and performs a
collaborative-based approach. Thus, the concept of Virtual Articulator will replace the mechanical tools by revolutionizing the conventional ways in dentistry.

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