Review Article

Virtual Articulator – A Review

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Abstract

The mouth comprising the maxilla and two temporomandibular joints (TMJs) are considered the best articulator. Due to various procedures needed to fabricate a prosthesis, a mechanical device simulating two jaws and TMJs are needed for ease of work and comfort of the patient. Such mechanical device is known as "Articulator". Some of these devices cannot simulate masticatory movements, some cannot reproduce dynamic condition of occlusion. To overcome these drawbacks of mechanical articulator, the authors decided to develop virtual articulator (VA) which can reproduce dynamic condition of occlusion. As it is strongly linked to the use of computer technology, it will be the future of dentistry. Hence, the purpose of this study is to investigate whether VA can replace mechanical articulator in future. The data about VA is collected from Google Scholar, Pubmed to know its development, procedural steps to mount casts on VA, and its current status in market. Thus, the concept of VA will change the conventional ways of production and communication in dentistry and will replace the mechanical tools.

Keywords: Virtual articulator, Mechanical articulator, Virtual facebow, Virtual reality technology.

Introduction

The evolution of articulators started from the 18th century. Phillip Pfaff was the first person to design an articulator named the "Plaster Articulator" to preserve the cast in 1756. As more knowledge gained about anatomy, mandibular movement, and mechanical principles, mechanical hinge articulators came into existence. The first mechanical articulator designed by Garriot in 1805, was known as "Garriot Hinge Joint Articulator". The real "Articulator Wars" started in the 20th century between 1907 and 1914 which led to the introduction of Truebyte Tooth System and Gysi's technique that made the articulation of artificial teeth possible for the first time. Transfer of patient information to fully adjustable and semi-adjustable articulator came into existence in 1940. Historically, jaw movements such as hinge movement was easy to reproduce but it was difficult to reproduce Bennett movement in three dimensions, the timing of the Bennett movement, the exact curvature of the condylar path, and intercondylar distance. The problems involved in duplicating these movements were solved by modern instrument design.[1-3]

As the technology develops and future of dentistry is linked strongly to the use of computer technology, dentistry is developing with virtual reality technology. Virtual reality refers to "immersive, interactive, multi-sensory, viewer centered, three dimensional (3D) computer-generated environments and the combination of technologies required to build these environments."[4] The latest breakthrough in the world of articulators based on virtual reality technology is the introduction of the virtual articulators (VAs) in 2002. This system simulates the temporomandibular joint (TMJ) movements in the modeling software by viewing it on the computer screen. The dental technician can take the measurements of articulator, scan it and the data can be transferred to the software database with the help of VA. The dimensions of the articulator can be stored in the software which will be helpful in mounting the models virtually.

Mechanical Articulator Versus Virtual Articulator

Mechanical articulator

A mechanical instrument that represents the TMJs and jaws, to which maxillary and mandibular casts may be attached to simulate some or all mandibular movements.

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Virtual Articulator

"A tool for the analysis of the complex static and dynamic occlusal relations" with a goal of helping clinicians reach beyond the limits of traditional analog techniques involving a mechanical articulator. VAs are also called as "software articulators" as they are not concrete but exist only as a computer program. They consist of virtual condylar and incisal guide planes (Table 1).

Need for Virtual Articulator

Development of VA initiated because of two main reasons:

- Problems with mechanical articulator
- Problems with technical procedure and dental materials.

Problems with Mechanical Articulator

The mechanical articulators cannot simulate:

- The teeth mobility
- The deformation of the mandible during loading conditions
- The complexity of movement patterns
- Cannot simulate the real dynamic conditions of the occlusion in the mouth.

Problems with Technical Procedure and Dental Materials

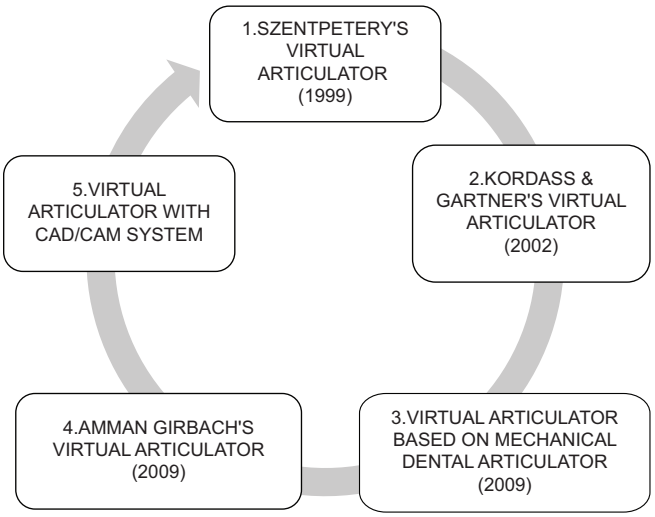
The following problems decrease the accuracy of reproduction:

- The registration material tends to deform (e.g., wax, which is susceptible to heat)
- The stability of the articulator itself
- The correct orientation of the cast
- The application of rigid and expanded plaster material
- Maintainance of mechanical articulator
- They create new contacts also.

These led to the development of VA which help to solve these problems.[5,6]

Development of Virtual Articulator

- VA Software was first described by Szentpetery in late 1990
- The first developed software was Dentcam at the University of Griefswald[6]
- Collision Detection was developed in cooperation with the Fraunhofer Institute for Computer Graphics (IGD, Darmstadt, Germany) and Kettenbach GmbH and Co KG (Eschenburg, Germany)[7-9]
- VA was introduced in 2002 with the work of Bisler *et al*. and his team from the University of Griefswald, Germany.[10]



Virtual Articulator

Bisler *et al*. defined VA as "a tool for the analysis of the complex static and dynamic occlusal relations" with a goal of helping clinicians reach beyond the limits of traditional analog techniques involving a mechanical articulator.[10] VAs are also called as "software articulators" as they are not concrete but exist only as a computer program. Virtual condylar and incisal guide planes are parts of VA (Figure 1).

Types of Virtual Articulator

Various modules for Virtual Articulator

To enhance the properties of VA, various modules are added:

- Computer-aided design (CAD) module - It is useful in improving the functional occlusion by manipulating the occlusal surface
- Orthodontic set-up module - It allows an individual set-up of selected teeth or whole arch. This makes the orthodontic treatment planning interesting because the

Table 1: Mechanical articulator versus virtual articulator

Mechanical articulator	Virtual articulator
Developed in 1805	Developed in 2002
Cannot simulate masticatory movements and resilience of soft tissues and joint disc	Can simulate masticatory movements
Cannot simulate tooth mobility using plaster models	Can simulate tooth mobility digitally
Cannot reproduce Bennet movement	Can reproduce Bennet movement
Cannot reproduce real life dynamic condition of occlusion	Can reproduce static and dynamic conditions of occlusion, intermaxillary relationships and joint conditions

future occlusion can be simulated to a certain degree
- Implant positioning tool - This tool helps in guiding the best implant position by combining image data (radiographs or computed tomography [CT] scans).

Design Process of Virtual Articulator

The design process of VA can be carried out by:

- Selecting mechanical articulator - Hanau H2 articulator, Stratos 200, Denar mark II
- Measuring tools and Reverse Engineering tools - 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 (Figure 2).

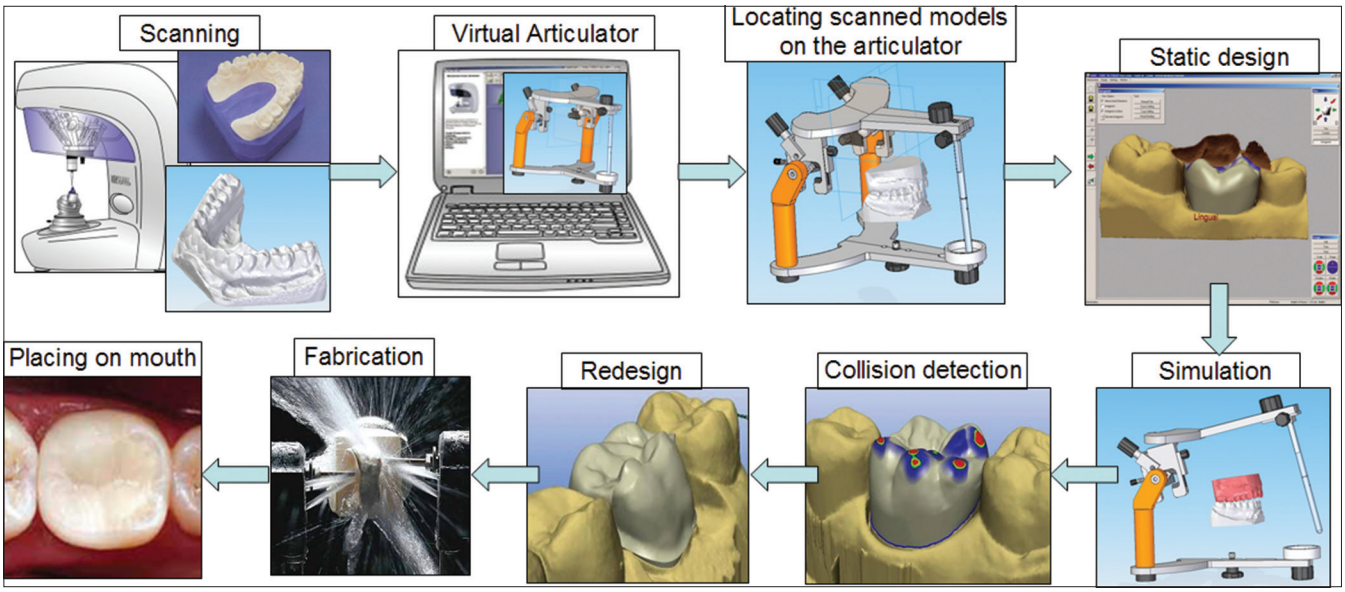


Figure 1: Virtual articulator

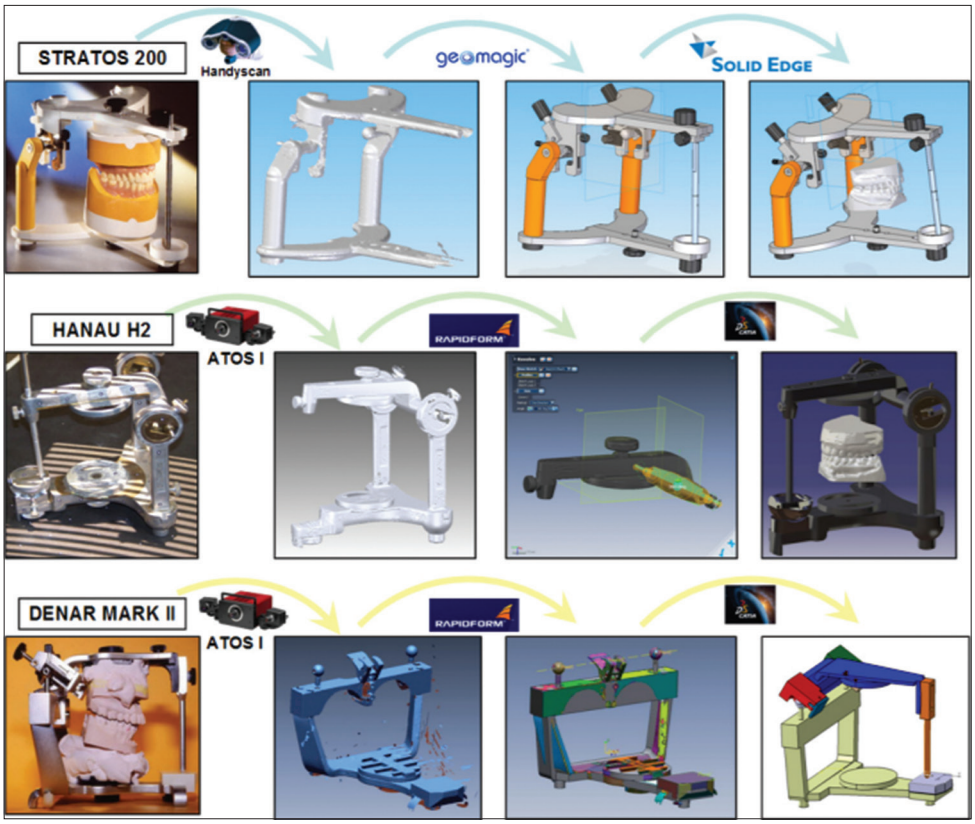


Figure 2: Design process of virtual articulator

The parts of the mechanical articulator are scanned using Handyscan 3D scanner. The useful data of the scanned parts are collected using Geomagic software. Finally, articulator is modeled using SolidEdge CAD system.[11]

Virtual Mounting Procedures

The two essential elements common to all available VAs are data acquisition and transfer of the arches to the virtual environment, and subsequent articulation of virtual models need four steps to be followed:[10]

- Step 1: Accurate impressions of the maxillary arches by digital scanning
- Step 2: Accurate occlusal registration in maximum intercuspation (MIP) and centric relation (CR)
- Step 3: Virtual facebow (VF)
- Step 4: Virtual mounting.

Accurate impressions of maxillary arches by digital scanning

A significant aspect of chairside CAD/computer-aided manufacturing (CAM) is the implementation of intraoral scanning (IOS). IOS impressions omit the need for impression materials, trays, cost pouring, minimize the material wastage and enhance patient comfort. Hence, IOS is preferred.

Acquisition (i.e.) obtaining maxillary arch data can be carried out with the help of IOSs or DLSs. If maxillary arch data is obtained using IOS device, then it is known as direct method. If the maxillary arch data is obtained using DLS device, then it is known as indirect method. Accuracy can be checked by its trueness and precision.[10]

Method of using IOS

- To acquire three-dimensional data, object is irradiated with a laser
- The data is converted into polygon data, which is a set of triangular surfaces
- First, occlusal surface is scanned by placing the scanner 5–6 mm away from the occlusal surface
- Later, buccal and palatal/lingual surfaces are scanned by tilting the scanner to 45 degree
- IOS scanner cannot capture whole arch with a single scan and it needs a multiple scan which are then combined by stitching process
- This stitching process can lead to additional discrepancy. As the length of the arch increases, accuracy decreases.[12,13]

Order of trueness obtained when measuring partially edentulous arches:[12,14]

CS 3600 > TRIOS 3 > Cerem OMNI > True Definition

iTero and TRIOS give similar accuracy and can be used for full arch dental scan.[15]

Accurate occlusal registration in MIP and CR

Method of virtual occlusal record registration

- Maxillary and mandibular casts are fabricated
- Casts are scanned with 8–10 images captured to digitize the entire occlusal surface
- Then, they are mounted in articulator
- Interocclusal record is determined using articulating paper, wax, or shimstock tray
- The occlusal contact is digitized with 3D scanner from buccal side and 3-4 images are captured
- Rapidform 3 (Rapidform; INUS Technology), GOM Inspect, Geomagic studio (Geomagic Desiogn X; 3D Systems) are some software that can be used for this procedure.[16]

VF

VF was discovered for the placement of maxillary cast in cranial coordinate system. If facebow is used in a virtual environment without manual preparation, then it is known as VF. It is used to orient arches with respect to reference plane from patient's head. The types of VF are:

- Average value/arbitrary (based on cutaneous landmarks and planes)
- Kinematics (based on cephalometric landmarks and planes).

Before the use of VF, reference plane has to be assessed. A reference plane is a plane that passes through three points (2 at posterior and 1 at anterior). The two posterior landmarks arbitrarily or anatomically determine the terminal transverse hinge axis. Kinematic facebow identifies the rotational hinge axis by marking the cutaneous landmarks which represent the pinpoint anatomical condylar projections and therefore, it can be more precise. There are different methods for transferring the position of the arch to VA.[10]

Those are based on:

- Cephalometric images[17]
- Scanning the position of marker in six positions with reference to head using 3D optical scanner[18,19]
- A series of photographs converted into 3D face scan[20]
- Digital axiography[21]
- Stereophotogrammetery[22]
- Standardized extraoral photographs[23]
- Cone Bean CT[24-26]

Mounting of cast

Lam, described a protocol for mounting virtual model on VA using natural head position. An iterative algorithm is used to align mounted models in VA in reference to 3D facial photography. It is a user-friendly way to fabricate a VF and allows assembly of the virtual models in a VA using the transverse horizontal plane as a reference. Transferring this method clinically is limited by the need for a calibrated stereophotogrammetry device.[27]

Vas Available in Market

Exocad software

Exocad is a CAD software that allows both completely adjustable and mathematically simulated type of VAs

(Table 2).[9] It is one of the more widely used software tool. It can be used in different articulator brands like:

- Bio-Art A7 Plus articulator
- Bio-Art A7 Plus – Adjustable articulator
- Denar Mark 30, Type A, Type P, Type S articulators.

4D concept

The completely adjustable articulator makes use of a digital facebow to capture the movements to make 3D virtual models. This can be done without the help of third-party software in real time and hence, it is known as 4D concept.[9]

Examples for 4D optical technology used with CAD software currently available on market are:

- MODJAW (Modjaw; Sainte-Helene-du-Lac, France)
- JMAnalyser + (Zebris MedicalGmbH, Isny, Germany).

Exocad and other software systems can also work under 4D optical technology. 4D concept will gain more importance in future clinical aspect and research.

Virtual Articulator with CAD/CAM system

Several companies have customized a VA for their CAD/CAM systems.[28] Examples include:

- Smart Optics
- Zirkonzahn.

Haptic based first touch enabled (TE) Virtual Articulator

SensAble Dental Technologies has developed the new version of its Intellfit TE Digital Restoration System. It allows the lab technician to touch and feel the teeth that has been produced for new restoration to fit in patient's mouth.[4]

PN-300 Virtual Articulator

VA can simulate mandibular movement with the help of the mandibular movement-recording device. These devices are:

- Electromagnetic tracking device
- Electromagnetic articulograph
- Ultrasonic motion capture device
- Zebris jaw motion analyzer
- Imaging methods like CT, MRI.

These devices record mandibular movement by fixing the device to mandible and soft tissue of the head. The instability of the soft tissue will affect the accuracy of mandibular movement recording and interfere with the normal mandibular movement when fixed to the mandible. To solve this problem, Li *et al*. developed a low-cost VA based on computer binocular vision, raster scanning and simulation technology, named, "PN-300 VA". This articulator can record maxillary and mandibular movements in real time and can acquire 3D data of the dentition in the same system at the same time. This articulator shows good accuracy for recording mandibular movement and can be expected to calculate the movement of the condyle.[29]

Discussion

Aragon *et al*.[30] suggested that accuracy and reliability of intraoral scanners showed high accuracy and reliability when compared to conventional impressions. Guth *et al*.[31] said that the type of scanner and software used determined the degree of accuracy.

Edher *et al*.[32] (2018) reported that the occlusal contacts acquired in maximum intercuspal position using IOS were dependent on the area of the arch. Single anterior interocclusal scans showed greater accuracy than single posterior right or left interocclusal scans. Also, suggested that multiple scans are required for full-arch cases, and a quadrant occlusal scan is required for single-unit restoration. A high similarity was found between analog and virtual environments regarding the acquisition of occlusal contacts.

A study by Úry *et al*.[33] in 2019 investigated the accuracy of transferring maxillary data arch in static occlusion from a conventional articulator to VA using an indirect digital method. The acquired occlusal contacts showed similar results for both conventional and VAs.

Solaberrieta et al (2013) found a method to transfer the data directly to VA in vivo without scanning the mounted mechanical articulator**.** Solaberrieta *et al*. (2015) found an indirect method to construct virtual kinematic facebow to determine the intercondylar hinge axis without using a physical axiograph.

Petre *et al*. (2018) reported a novel, user-friendly, quick technique to transfer digitized maxillary casts into a VA module based on standardized 2D facial photographs, IOS, a

Table 2: Completely adjustable articulator versus mathematically simulated articulator

Completely adjustable articulator	Mathematically simulated articulator
• A completely adjustable articulator	• An average value articulator[11]
• Jaw motion analyser is used to record the mandibular movements[11,12]	• Jaw motion analyser is not required to record the mandibular movements
• The morphology of the occlusal plane can be assessed during mandibular movements using completely adjustable articulator to avoid interferances in excursions	• Reproduces the movement of mechanical articulator
• Expensive than mathematically simulated articulator	• The relationship between the arches can be reproduced using mathematically simulated articulator which will be helpful in planning the occlusal morphology of the prosthesis
• E.g. - Kordass and Gartner virtual articulators	• User-friendly and less expensive than completely adjustable articulator
	• E.g. - Szentpetery's virtual articulator

facebow fork, and CAD software (Exocad GmbH, Darmstadt, Germany). Thus, this method is considered an arbitrary VF. Lepidi *et al*. (2019) proposed a digital method to transfer the positions of the maxillary arches and to mount them in a VA. Kim *et al*.[34] (2020) reported a novel method to mount a casts in a MA without facebow transfer. The arches and MA were scanned and the data was combined with CBCT imaging to reproduce the occlusal plane and to help in mounting 3D printed casts on the MA.

Conclusion

The current status of VA assembly procedures in digital dentistry provides encouraging evidence supporting the clinical implementation of fully-digital workflows aimed at assembling VAs to aid in the diagnostic and treatment planning phases of complex cases. Thus, the VA will replace the mechanical articulator by changing the traditional way of fabricating a prosthesis. Although the "Articulator Wars" are still existing in the field of dentistry, such "Articulator Wars" issue will enlighten the future.

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