DOI: 10.7860/JCDR/2014/8929.4648

Review Article

Dentistry Section

The Role of Virtual Articulator in Prosthetic and Restorative Dentistry

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ABSTRACT

Virtual reality is a computer based technology linked with the future of dentistry and dental practice. The virtual articulator is one such application in prosthetic and restorative dentistry based on virtual reality that will significantly reduce the limitations of the mechanical articulator, and by simulation of real patient data, allow analyses with regard to static and dynamic occlusion as well as to jaw relation. It is the purpose of this article to present the concepts and strategies for a future replacement of the mechanical articulator by a virtual one. Also, a brief note on virtual reality haptic system has been highlighted along with newly developed touch enabled virtual articulator.

Keywords: CAD/CAM, Mechanical articulator, Touch enabled virtual articulator, Virtual articulator, Virtual reality, Virtual reality haptic system,

INTRODUCTION

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". The virtual reality lets you to navigate and view a world of three dimensions in real time, with six degrees of freedom. In essence, virtual reality is a clone of physical reality creating a virtual environment to replace the real world environment. The equipments and technologies by which we can interact in a virtual reality are known as virtual reality equipments and virtual reality technologies [1].

In the field of prosthetic and restorative dentistry, the virtual dental articulator incorporates virtual reality applications to the world of clinical dental practice for the analysis of complex static and dynamic occlusal relations. Its chief application is in the simulation of the mechanical articulator. The virtual articulator requires digital 3D representations of the jaws and patient specific data on jaw movements. It then simulates jaw movements and provides a dynamic visualization of the occlusal contacts. If no patient specific data are available, then the modus operandi of the mechanical articulator can be simulated [2].

The Virtual articulator can be defined as a software tool for improved clinical outcome based on virtual reality technology [2-4].There are two types of virtual articulators namely -Completely adjustable and Mathematically simulated [5,6].

Completely Adjustable Virtual Articulator [5,6]:

- It records /reproduces exact movement paths of the mandible using an electronic jaw registration system called Jaw motion analyser (JMA).
- The digitised dental 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 (CAD) 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 to the intercuspidation position during chewing movements.
- **Occlusion 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. This tool helps to analyse the degree of intercuspidation and the height and functional angles of the cusps. With this window, the analysis of guidance and balancing becomes easy [6].

The recent 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 software tool allows us to observe the inter relationship between the incisal guide and the condylar guide, and the effects of joint mobility upon occlusion [7].

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 ideal 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: Stratos 200, Szentpetery's virtual articulators.

Development and Designing of Virtual Articulator

The designing of dental virtual articulator is achieved by means of CAD systems and reverse engineering tools. The development is made 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 prosthetic of the Martin-Luther University of Halle as follows:

- Different mechanical articulators are selected first to be modeled through CAD systems (Solid Edge and CATIA).
- The design process will then 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 verified and checked.
- If any problem exists, that need to be rectified and redesigned accordingly [5] [Table/Fig-1].

Selection of the Articulator

If the relationship of antagonist teeth at the patient of maxillary intercuspation is the only concern of the dentist then selection of the articulator will be greatly simplified. In this scenario, the articulator capable of simple hinge movement will be sufficient for the designing of the prosthesis.

If the mandible 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 mandible. So, selection of the suitable articulator is an important step in the designing of virtual articulator by this approach. Finally, the selected articulator should have a direct impact on the success of fixed and removable prosthetic restorations [5,9].

Programming the Virtual Articulator

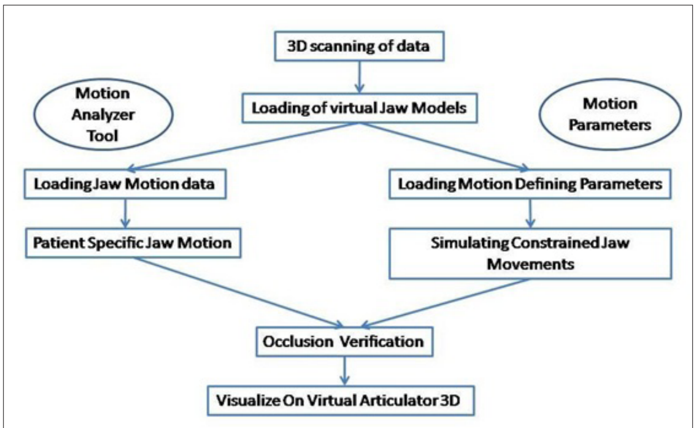
The programming and adjustment methods of virtual articulator were described by Kordass and Gartner in 1999. The input data entry is done as follows [Table/Fig-2]:

a) Scanning/digitising – of a tooth or tooth surface or restoration or complete denture models or centric relation, 3D Laser scanner (Willytec, Munich, Germany) is used. 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 visualisation and computerised manipulation [7].

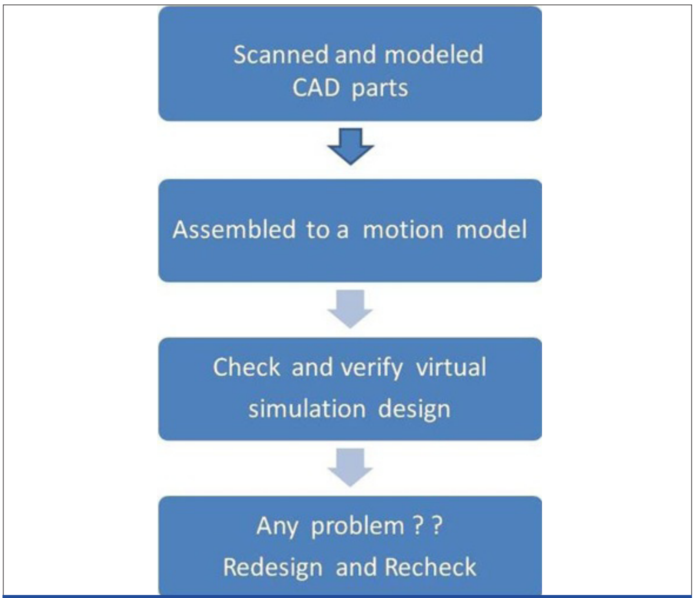
b) The scanning can be done in 2 ways:

- Direct digitising - done directly from the patient's mouth using an intra oral scanner.
- Indirect digitising - done outside on the patient's master cast obtained after making final impression.

c) Patient Specific Motion Data of Temporo mandibular joints (TMJ) –



[Table/Fig-1]: Virtual articulator designing method



[Table/Fig-2]: Virtual articulator functioning method

i) The Jaw motion analyser (JMA) tool (Comp Zebris, Isny, Germany) has reference points fixed on the patient mandible.

- This system is based on measuring the velocity of ultrasonic impulses emitted from three transmitters attached to the lower sensor bound to labial surface of mandible and four receivers attached to a face bow opposite to them for detecting all rotative and translative components in all degrees of freedom.
- A special digitising sensor is used to determine the reference plane, composed of the hinge axis- infra orbital plane and special points of interest (eg: on the occlusal surface).
- An ultra sound is then used to measure the position of these points in space describing physiological masticatory motion of the patient.
- Thus simulating the patient specific movement patterns with the attached scanned/digitised virtual models constructed in the virtual articulator.
- The relative position of the upper or maxillary virtual model in reverse position is digitised using face bow and located directly in the virtual articulator.
- The lower or mandibular virtual model is then located in centric relation with the upper virtual model using an electronic bite.
- Finally, visualise the occlusion 3D in all planes on the computer screen.
- The virtual articulator system is now ready to be applied for kinematic simulation analysis.

ii) If the jaw motion analyser tool is not available, different jaw motions can be defined via parameters as used with the mechanical articulators (Protar 7, KaVo).

- The following movement parameters selected are: 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, shift angle, immediate side shift), and opening/ closing movement (maximum opening angle).
- After defining the motion parameters, collision detection is triggered to recognise the motion constraints, which results in the upper and lower jaws gliding on each other.
- For collision detection, a ray based algorithm is used that is executed in a preprocessing step.

- For occlusion detection, a distance corresponding to the thickness of the occlusion paper used in the mechanical articulator is chosen, for calculating the occlusion points according to this defined distance [6,10,11].
- Other systems for the detection of mandibular movements available newly are based on other 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. Fang and Kuo, presented a new model using this system for assessing mandibular dynamics. They designed customised device for each patient, fixed in the same position in both the plaster models and in the oral cavity. After scanning of models, the patients performed mandibular movements (aperture/closure, protrusion/retrusion, and lateral excursions) for 20min. The data recorded were later processed by mathematical models to reconstruct customised dynamics for each patient for visualization and computer based analysis [11,12].

Recent Developments in the Virtual Articulator

The development of 3D virtual articulator system (Zebris Company, D-Isny) requires three main unit devices namely:

- An input device in form of a 3D scanner.
- A 3D virtual articulator software for prosthesis modeling 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 [13].

DISCUSSION

According to Glossary of Prosthodontic Terms 8Ed, an 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" [14].

With the use of semi adjustable mechanical articulators, one cannot reproduce mandibular movements with associated time frames. These dilemmas can be resolved by replacing the mechanical articulator by its digital replication like virtual articulator [5].

Virtual articulator can signify and quantify the effects of resilience of the soft tissue on the time dependent basis during muscular movements of chewing or eating. That is why it can exemplify the real time dynamics of the occlusion [2]. Other significant advantages of using virtual articulators over mechanical ones are the reduction in inaccuracies while making interocclusal registration with materials prone to deformation (eg: Bite registration wax) and accurate repositioning of the master cast into bite impression without leaving any space.

The most accurate occlusal surface reproduction can be achieved either by using fully adjustable articulator that simulates mandibular movements with high degree of precision or by using virtual articulators with CAD/CAM systems [15], But the dynamic reproduction of excursive movements recorded appears to be unreliable according to study reported by Tamaki et al., where the mechanical articulator reproduces 82% protrusive and 90% laterotrusive contacts in which correctly located are 66% protrusive and 81% laterotrusive contacts respectively even showing that the mechanical articulator also creates new contacts [16].

In Prosthetic and Restorative dentistry, the virtual articulator improves the designing of dental prosthesis by adding kinematic analysis to the design process achieved by CAD systems and Reverse Engineering tools. It provides a wide changeability or flexibility in order to adjust the patient settings. In some mechanical articulators, some settings are not possible to adjust, but virtually this hindrance can be easily overcome. Thus making virtually produced prostheses even more accurate than that from mechanical articulators. The virtual models of 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 [15].

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].

The virtual articulator has been compared with the mechanical articulator in orthognathic surgery, to establish ideal maxillary position and for preparing surgical splints and concluding that the virtual method is more precise than the conventional approach [17].Thus the virtual articulator can precisely reproduce conventional planning and help even inexperienced surgeons to obtain good results [18].

Functioning of Virtual Articulator

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 the computer screen by means of some type of code [13].

Advantages of Virtual Articulator

- Provides best quality of communication between the dentist and dental technician
- Simulating real patient specific data
- Analyses both static and dynamic occlusions
- Analyses ganathic and joint conditions
- Acts as a 3D navigator

Limitations of 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 modeling of virtual articulators etc and technical skills regarding the interpretation of data recorded from scanners, sensors, minor adjustments, incorporating motion parameters etc.

Virtual Reality Haptic System

Haptics are also known as virtual reality systems. The word haptics is derived from Greek word 'haptein', meaning "contact or to touch". Haptics refers to sensing and manipulating through touch, enabling the user to touch and feel virtual reality or an existing distant object indirectly. This sensation can now be added to the current computer models which have sight and sound only. It also provides forced feed back to those who interact with virtual or remote environments, so that a bi-directional flow of information is created. There are special devices like joysticks, data gloves, etc through which operators can receive feedback from computer applications in the form of sensations which are felt in any part of the body. The Haptic technology along with visual display can be used to train people for tasks which require hand-eye coordination such as a dental surgeon makes an incision, drilling into a carious lesion, etc. [19].

Applications of Virtual Reality Haptic System in Prosthetic and Restorative Dentistry

3D haptic technology of virtual reality has introduced dental simulators that provide an efficient means to quickly teach preclinical dental students about dental procedures, while increasing their hand-skills considerably. Repetitive procedures such as proper hand and instrument usage and placement are primary targets which have to be learned on dental simulators [20]. Two kinds of dental simulators are currently available: manikin-based simulators that provide a physical model of the patient's head and mouth, on which certain dental procedures can be performed by using real dental instruments eg: DentSim™, which is developed by [DenX Ltd], Image Guided Implantology (IGI) which is also developed by DenX, Ltd and haptics based simulators that employ a PHANToM™ haptic device [SensAble Technologies, Inc] and virtual models of a human tooth or mouth as a platform for facilitating dental practices e.g.: Virtual Reality Dental Training System (VRDTS) [Novint Technologies], Iowa Dental Surgical Simulator (IDSS) [21]. Instead of using real dental instruments, the trainee holds the haptic device stylus to manipulate a set of virtual instruments that are shown on a monitor screen. The tactile feedback reproduces clinical sensations in the hand of the operator who is using dental instruments [19].

VirDenT is a dental medicine e-learning system with a haptic interface that allows students in dental schools to practice tooth preparations in Fixed Prosthetics in a virtual environment. The advantages of VirDentT system over earlier systems used in prosthetic and restorative dentistry such as DentSim, Virtual Reality Dental Training System (VRDTS), Iowa Dental Surgical Simulator, HapTEL system etc are that VirDentT system does not require simulation, plastic models, dental parts, turbines, dental drills and more, so costs are much reduced [22].

Haptic Based First Touch Enabled Virtual Articulator

SensAble 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 prepped veneers, produced faster and with heightened precision though its unique touch-enabled technology, allows dental labs of all sizes to gain a competitive advantage [23].

Also, 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.

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.

Haptic based virtual reality system's touch enabled virtual articulators allow lab technicians to actually feel how the teeth, including the new restorations produced will fit together in the patient's mouth. The future is not far enough where routine conventional methods used in dentistry will be transformed totally into a virtual reality dental world.

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FINANCIAL OR OTHER COMPETING INTERESTS: None.

Date of Submission: Feb 17, 2014
Date of Peer Review: Mar 13, 2014
Date of Acceptance: Jun 10, 2014
Date of Publishing: Jul 20, 2014