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From Simulation to Reality: Understanding Virtual Articulators: A Narrative Review

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ABSTRACT: The virtual articulator (VA) is quickly becoming an essential tool in modern dentistry, offering a digital method for analyzing how the jaw and teeth interact. With the growing influence of augmented reality (AR) and virtual reality (VR) in dental care and education, it's increasingly important for dental professionals to stay up to date with these advancements, even though the pace of change can be fast. Digital tools have lots of potential in dentistry, and virtual articulators are a prime example. Virtual Articulator allows dentists to simulate jaw movements in a highly detailed way, providing valuable insight into how teeth come together in both static and dynamic scenarios. This not only improves the accuracy of diagnosis and treatment planning but also enhances communication with patients by visually demonstrating their unique dental needs. In combination with other software, Virtual Articulator enhances treatment planning and patient education, leading to quicker and more precise diagnosis. This article reviews the mechanism, types, necessity and purpose of Virtual Articulator and problems in using Virtual Articulator.

Key words: Augmented reality, Virtual reality, Virtual articulators, Occlusal analysis.

I. INTRODUCTION:

A virtual articulator is an advanced digital tool designed to simulate the movement of the jaw, enabling dentists to analyze and evaluate occlusion (the contact between teeth) in a highly accurate and efficient manner. Traditionally, occlusion and articulation have been carried out manually using a mechanical articulator, which replicates jaw movements based on physical models and patient records. However, the virtual articulator offers a significant leap forward by integrating digital technologies such as 3D imaging, CAD/CAM systems, and virtual reality. Applications of virtual articulators span across various fields of dentistry, including prosthodontics, orthodontics, and restorative dentistry[1]. In prosthodontics, they are used to design precise dentures, crowns and bridges by replicating natural jaw movements. Orthodontists benefit from the virtual articulator's ability to visualize and adjust bite alignment, improving the design of braces and retainers. In restorative dentistry, it aids in crafting well-fitting restorations that seamlessly integrate with the patient's bite, ensuring longevity and comfort. Compared to manual articulators, the virtual version simplifies the complex time-consuming process of recording jaw movements and analyzing tooth interactions[2]. Manual articulators rely on physical impressions and bite registrations, which can be prone to inaccuracies due to material deformation and human error. Virtual articulators, on the other hand, use digital data, providing real-time, dynamic simulations of how teeth interact during various jaw movements. This eliminates the need for plaster models and repetitive adjustments, significantly reducing chairside time. The difference between manual and virtual articulators is not just in the technology used, but also in the precision and efficiency they offer[3]. Virtual articulators can store, adjust, and visualize data with far greater accuracy, leading to better treatment outcomes. Their implications in dental care are to provide more precise diagnoses, quicker treatment planning, improved patient educationand ultimately more comfortable and durable restorations.Virtual articulator uses a software tool that utilizes virtual reality technology to enhance clinical outcomes[4].

Mechanism of Virtual Articulators:

Virtual articulator is like a digital assistant for dentists, making it easier to study and plan treatments that involve how upper and lower teeth come together (occlusion) and how jaw moves. The processes involved are:

1. Data Collection :

First, dentist gets a 3D scan of the teeth and jaw. By using an intraoral scanner, the dentist can scan the entire maxillary and mandibular arches and also upon scanning dental impressions or plaster models using model scanner. The movement of the jaw was analyzed usingJaw Motion Analyzer (JMA) which captures the dynamic elements of occlusion and masticatory functions[5]. Ultrasonic Sensors are strategically placed on the patient’s jaw and a headbow is used

to capture movement in multiple dimensions. The system tracks rotative and translational jaw components (e.g., lateral, protrusive, and retrusive movements)[4].

2. Building a 3D Model:

The scanned data of the jaw is then transferred into special softwares like VXscan, DentalCAD, DentCAM, through STL or XML files. Then the software creates a digital 3D model of the teeth and jaws. Nextusing the information from the jaw movement tracker, the virtual articulator starts simulating the real-life jaw motions, whether it is opening, closing, or moving from side to side[5].

3. Simulating the Movements:

The Motion Analyzer Tool recreates how the teeth meet and move against each other as the patient chew or speak[2]. Using the softwares like VXscan, DentalCAD, DentCAM, dentists can adjust settings like bite pressure during occlusion to identify areas where excessive or uneven pressure occursand ensure proper occlusion without any unwanted interference and angular movement for simulating realistic and individual jaw movements which define the path and range of motion for the jaw such as Bennett angle (the angle formed between the sagittal plane and the average path of advancing condyle viewed in the horizontal plane which is approximately 8 degrees), FMA angle (angle formed by the Frankfort horizontal plane and mandibular plane which is approximately 25 degrees), Horizontal Condylar Inclination (the angle between steep slope of articulator surface of temporal bone and horizontal plane), thus creating an accurate digital copy to ensure that the teeth occludes correctly and do not interfere with each other which is important for proper function and comfort[3].

4. Checking and Adjusting:

The software highlights areas where the teeth may not meet evenly, allowing the dentist to visually identify any discrepancies in alignment[4]. Adjustments are made by virtually modifying the bite, tooth angulation, or positions in the software. This helps to fine-tune the occlusion (bite relationship) before any physical work is done, ensuring a more favorable outcome. The best part is they can make adjustments right thereall in the digital model and avoiding the hassle of dealing with physical impressions[6].

5. Treatment Planning:

Based on the data gathered from this digital process, the dentist can precisely plan treatments like crowns, bridges, or braces, ensuring they are adapted to fit the natural function of the teeth to maintain the occlusion (horizontal, vertical and centric occlusion). This level of customization helps improve the fit and effectiveness of the dental work, minimizing the need for adjustments and enhancing overall treatment outcomes[2].

6.Data Exportation for CAD/CAM Fabrication

CAD Integration: After occlusal refinements, the final model is exported in compatible formats (e.g., STL, XML) for integration into CAD/CAM systems, where restorations are fabricated based on the individualized occlusal plan established by the virtual articulator[5].

Types of Virtual Articulators:

There are two types of virtual articulators:

COMPLETELY ADJUSTABLE VIRTUAL ARTICULATOR:

The exact movement pattern of the mandible is recorded using an electronic jaw registration system called Jaw Motion Analyzer. This system is composed of several key parts, including a main unit, a lower jaw sensor, a head bow, a bite fork, and a sensor pen. The system operates with both a transmitter and receiver thatonce positioned correctly, capture jaw movements precisely. The head bow contains eight ultrasonic transmitters that send continuous pulses to measure distances using the triangulation method (technique used to determine the position of an object by measuring the angles from two or more known points), enabling the device to pinpoint the exact position of the patient's mandible[6]. The setup process begins with installation of softwares like VXscan, DentalCAD, DentCAM and device connection to a computer[7]. The dentist then attaches the bite fork to the patient's mandible, places the head bow on the patient's head, and positions the face support on the nose. Using the sensor pen, the dentist marks the patient's temporomandibular joint (TMJ) and infraorbital notch according to the manufacturer's instructions. The mandibular sensor is then connected to the bite fork, allowing the device to track jaw movements, which highlight patterns like retrusion, protrusion, and lateral movements. These movements are recorded as data points that can be programmed into a fully adjustable articulator, such as the KaVo Protarevo 7, SAM 2, Artex CR, or Stratos 300. Additionally, certain jaw movements

can be exported to CAD systems via XML files, allowing the dentist to view and analyze these motions from different perspectives on three computer screens[8].
The software includes three primary screens, each providing a different view of the jaw's motion to enhance analysis:

1. Rendering Screen: This view allows for detailed analysis of premature contacts and occlusal collisions during mandibular movements in a 3D (perspective) view. For instance, the surfaces of the teeth and their interactions can be closely examined during chewing[9].
2. Occlusion Screen: It displays both static contacts (when teeth are at rest and come together) and dynamic contacts (when teeth slide or grind across each other during chewing or talking) between teeth which are shown in detail, giving insight into how the upper and lower teeth interact over time in the occlusal view. This screen captures the changing nature of occlusal contacts, helping to analyze and refine bite function[10].
3. Section Screen: Here, various frontal views along the dental arch are displayed. It provides detailed information on the alignment and interaction between maxillary and mandibular teeth, including tooth shape, cusp height, and intercuspidation levels, making it easy to assess occlusal guidance[9].

MATHEMATICALLY-SIMULATED VIRTUAL ARTICULATOR:

Virtual articulators use mathematical simulations to accurately mimic the movements of traditional mechanical articulators, which are tools used by dentists to study jaw motions. They rely on complex algorithms, allowing dentists to create fully adjustable three-dimensional models of how the jaw moves[11]. One of the great features of these virtual systems is that they can be customized, such as by simulating **curved Bennett movement,** a specific type of jaw motion. This flexibility makes virtual articulators much more adaptable than many mechanical options, providing dentists with better tools for analyzing and planning treatments[12]. However, there is a significant drawback where virtual articulators often do not provide individualized movement paths for each patient. This means that while they can effectively simulate average jaw movements but they might not accurately capture the specific bite and jaw dynamics that vary from person to person. As a result, they tend to function as average articulators, which can limit their precision when it comes to reflecting the unique characteristics of a patient's jaw movements[7]. Examples of these virtual articulators include the **Stratos 200** and **Szentpetery's virtual articulators**. They mark an important advancement in how dentists examine and plan treatments related to bite relationships, but they also highlight the need for individualized patient information to achieve the best results in dental care[13].

Necessity of Virtual Articulators:

The virtual articulator marks a groundbreaking leap in dental practice, seamlessly integrating virtual reality technology to replace traditional mechanical articulators. Its innovation lies in offering a comprehensive analysis of both static and dynamic occlusion, inter-maxillary relationships, and joint conditions[8]. By dynamically visualizing the mandible and maxilla in three dimensions (3D)allowing selective sectioning for detailed examinationsuch as of the temporomandibular jointit overcomes the limitations of mechanical counterparts. Ferrin LM, et al. in his study in 2012, found that when paired with CAD/CAM technology, virtual articulators revolutionize dental implant planning by providing greater precision and reducing treatment times. Besides implants, these tools are used in prosthodontics to create perfectly fitted occlusal restorations[10]. Additionally, they are invaluable for educating students about dental articulation, jaw movements, and their effects on occlusal surfaces. Its role in enhancing dentist-technician communication further elevates its significance in modern dentistry[12].

Purpose of Virtual Articulators:

The purpose of virtual articulators is to enhance precision in dental procedures by using advanced digital technology to simulate how the patient's jaws and teeth move.

1. Accurate Bite Analysis:

Accurate bite analysis in virtual articulators refers to the detailed and precise evaluation of how the patient's upper and lower teeth come in contact when the mouth is closed which is known as occlusion. Virtual articulators give dentists a detailed, 3D view of how a patient's teeth fit together. This helps them spot issues like misalignment or bite problems early on, ensuring the problem is diagnosed before it becomes more serious. With this level of precisioneven minute issues that might be missed with traditional methods can be detected[14].

2. Better Treatment Planning:

Virtual articulators serve as a highly accurate guide when designing dental restorations, such as crowns, bridges, and implants. By analyzing the patient's natural bite and jaw movements, dentists can tailor these devices to fit perfectly, minimizing the need for multiple adjustments after the restoration is made. This ensures a more comfortable and functional fit from the start[13].

3. Improving Results:

One of the key benefits of virtual articulators is their ability to simulate jaw movements in real time. This allows dentists to foresee potential issues, like improper bite or interference between teeth, before starting treatment. Being able to make adjustments based on these simulations leads to more effective treatments and better long-term outcomes for the patient[15].

4. Saves Time:

Traditional methods of diagnosing bite problems and planning treatments often involve taking physical molds and making repeated adjustments. Virtual articulators streamline this process by providing instant, accurate data. This reduces the time needed for diagnosis and treatment planning, and cuts down on follow-up visits for corrections or refinements[14].

5. Clearer Communication:

Virtual articulators are advanced digital tools that generate precise 3D models of a patient's bite, allowing the dentist to assess and analyze dental and occlusal problems like cavities, cracks, misalignment, overbite or crossbite with greater accuracy. These visual representations help dentists effectively communicate the nature of the problem and treatment options, offering a clear understanding for patients and improving the overall treatment planning process as the dental technicians can better understand how to fabricate restorations that will fit perfectly[13].

Problems in Using Virtual Articulators:

1. Cost-effectiveness is a concern due to the expenses associated with digital scanners, sensors, software, and custom virtual articulator models designed for individual patient needs[16].
2. Requires advanced knowledge in CAD/CAM technology, mechanical articulators, and the development and design of virtual articulators.
3. Requires technical skill in analyzing data from scanners and sensors, making precise adjustments, and effectively incorporating motion parameters[17].
4. The casts still need to be mounted on a physical articulator using gypsum and a physical facebow. After that, they must be scanned while in this mounted position.
5. While virtual articulators offer high precision, they rely on the accuracy of the input data. Inaccurate scanning, improper patient movements during data collection, or issues with the facebow alignment can lead to errors in the digital model[15].

II. DISCUSSION:

In prosthodontics, an articulator is a mechanical tool designed to replicate the movements of the temporomandibular joints and jaws. It allows for attaching maxillary and mandibular casts to simulate various jaw movements. Kordass B et al. during his study in 2008 detected various inaccuracy in the replication of mandibular movements with specific time frames. This limitation has spurred the adoption of digital replicas like virtual articulators, which offer solutions to these challenges[18]. Virtual articulators excel at accurately measuring the impact of soft tissue flexibility during chewing or eating, offering real-time insights into occlusion dynamics. They offer notable advantages over traditional mechanical articulators, such as reducing errors associated with material deformation in interocclusal registrations (like bite registration wax) and ensuring exact placement of the master cast in bite impressions without gaps. To achieve the most accurate reproduction of occlusal surfaces, fully adjustable articulators that precisely simulate mandibular movements, or virtual articulators combined with CAD/CAM systems, can be employed[10]. Goldstein G in his study in 2023 suggested that using a virtual articulator involves a detailed setup process. It requires high-tech scanning tools to capture precise data from the patient's teeth, jaw movements, and facial structure. This process can take a bit of time and demands a good level of technical skill to ensure accuracy[5].

However, it has been explained by Tamaki et al. in 1997 in his study which suggests that dynamic reproduction of excursive movements recorded by mechanical articulators may be unreliable. They found mechanical articulators reproduced 82% of protrusive and 90% of laterotrusive contacts with correct locations at 66% and 81%, respectively, often resulting in new contacts being created. This study revealed that when excursive tooth contacts were simulated using a mechanical articulator, the resulting

representation was an approximation of the actual dynamic occlusal relationships which was limited to mechanical articulators. This suggests that articulators, though effective, might benefit from advanced technologies to enhance their accuracy and clinical relevance[19]. The integration of virtual articulators enhances the design of dental prostheses by incorporating kinematic analysis through CAD systems and Reverse Engineering tools. This technology provides extensive adjustability to tailor settings according to individual patient needs, surpassing the limitations of mechanical articulators[20]. Virtual articulators allow for precise adjustment during the design process, resulting in prostheses that are often more accurate than those produced by traditional mechanical methods. Digital model of casts, mounted in virtual articulators, serve crucial roles in diagnosing and planning treatments for various prosthetic restorationsfrom single crowns to complex bridges and full mouth rehabilitationsfacilitated by CAD/CAM systems. Integrating virtual articulation with CAD/CAM technology greatly improves dental implant planning. This combination allows for more accurate implant placement and shortens the overall treatment time, leading to better results for patients undergoing implant procedures[21]. However, in his study in 2013, Iwaki et al. pointed out that despite the digitization of the process, the physical casts still need to be mounted using a facebow. This step limits some of the benefits of an entirely virtual workflow, as it keeps part of the process manual[22].

III. SUMMARY:

Recent literature has highlighted the key steps for creating and transferring virtual models into virtual articulators (VAs), underlining their importance in modern dentistry. While clinical reports on prosthetic applications using VAs are still limited, ongoing studies show promising results for integrating virtual assembly procedures. The technology allows precise simulation of occlusal conditions aiding in accurate diagnosis and treatment planning. With a range of compatible software and devices available VAs offer a valuable tool for replicating complex occlusal relationships, surpassing traditional mechanical articulators in precision.Virtual articulators enhance treatment outcomes, especially in complex cases like full-mouth reconstructions and implant-supported prosthetics. This review emphasizes VAs' evolving role in digital dentistry offering streamlined procedures, reduced errors, and improved occlusal analysis. Byincorporating patient-specific data and enabling fully digital workflows, VAs optimize clinical decision-making and improve patient outcomes marking a shift towards more efficient and precise dental care.

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