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Review Article

Virtual Articulators in Prosthodontics: A Narrative Review

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ABSTRACT

The integration of digital technologies into prosthodontics has transformed conventional diagnostic and therapeutic workflows, leading to the development of virtual articulators capable of simulating mandibular movements in a digital environment. Virtual articulators have been proposed as an alternative or adjunct to mechanical articulators by incorporating patient-specific data obtained from digital impressions, jaw tracking systems, and three-dimensional imaging. This narrative review synthesizes evidence from published literature to describe the evolution, concept, classification, working principles, clinical applications, advantages, limitations, and future prospects of virtual articulators in prosthodontics. The available evidence suggests that virtual articulators enhance visualization and precision during prosthesis design; however, heterogeneity among systems and limited long-term clinical validation currently restrict their universal adoption [1–4].

INTRODUCTION

Reproducing mandibular movements and occlusal relationships with precision is fundamental to the success of prosthodontic treatment. Conventional mechanical articulators have historically served this purpose; however, their ability to reproduce patient-specific mandibular dynamics remains limited due to mechanical constraints and reliance on average values [5,6]. The introduction of computer-aided design and computer-aided manufacturing (CAD/CAM) systems has facilitated a paradigm shift toward digital workflows in prosthodontics [7,8]. Within this digital ecosystem, virtual articulators have emerged as tools designed to simulate jaw movements digitally, allowing evaluation of static and dynamic occlusion during prosthesis design [1,3]. This narrative review aims to critically summarize existing literature on virtual articulators and highlight their relevance in contemporary prosthodontic practice.

Evolution of Articulators

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The evolution of articulators reflects continuous efforts to improve the accuracy of mandibular movement simulation. Early hinge articulators permitted only opening and closing movements and were subsequently replaced by mean value articulators incorporating average anatomical parameters [6]. Semi-adjustable articulators introduced adjustable condylar guidance and incisal.

tables, while fully adjustable articulators attempted to replicate individual mandibular movements using pantographic tracings [5,9]. Despite improved accuracy, fully adjustable articulators are technique sensitive, time-consuming, and require extensive clinical and laboratory expertise [9,10]. Advances in digital technology enabled the transition from mechanical to virtual articulators, eliminating physical constraints and permitting repeated simulations without mechanical wear [1,2].

Concept of Virtual Articulators

A virtual articulator is defined as a computer-based simulation system that reproduces mandibular movements and occlusal relationships using digital datasets [1]. Digital dental casts obtained from intraoral or laboratory scanners are articulated virtually using jaw relation records and mandibular movement parameters [11]. Unlike mechanical articulators, virtual articulators allow visualization of occlusal contacts during functional movements such as protrusion and lateral excursions within a CAD environment [3,12]. This digital representation facilitates real-time modification of occlusal surfaces during prosthesis design [4].

Classification of Virtual Articulators

Virtual articulators may be classified based on the complexity of simulation and the type of input data used. Mean value virtual articulators operate using average anatomical parameters similar to mean value mechanical articulators [13]. Fully adjustable virtual articulators incorporate patient-specific mandibular movement data acquired through jaw tracking systems [2,14]. Mathematical model-based virtual articulators rely on algorithms to estimate mandibular dynamics without direct motion capture [15]. Motion capture-based virtual articulators integrate real-time jaw tracking data, enabling dynamic simulation of mandibular movements [14,16].

Working Principles

The functioning of virtual articulators relies on the integration of three primary datasets: digital dental arches, maxillomandibular relationship records, and mandibular movement parameters [3,11]. Digital impressions are obtained using intraoral or laboratory scanners with high accuracy [17,18]. Jaw relation records are transferred digitally, while mandibular movement data may be obtained from axiography, electronic pantography, or optical jaw tracking systems [14,16,19]. These datasets are processed within CAD software to simulate hinge movements, protrusive and lateral excursions, and occlusal contacts, which are visualized using color-coded contact maps [12,20].

Clinical Applications in Prosthodontics

Virtual articulators have been applied across various domains of prosthodontics. In fixed prosthodontics, they aid in designing crowns and fixed dental prostheses with optimized occlusal

morphology [3,21]. In implant prosthodontics, virtual articulators facilitate evaluation of occlusal schemes and load distribution, contributing to improved prosthesis longevity [22,23]. Complete denture fabrication workflows have also incorporated virtual articulators for tooth

arrangement and occlusal analysis [24,25]. Additionally, virtual articulators have been used in full-mouth rehabilitation and occlusal equilibration procedures, reducing chairside adjustments and remakes [26,27].

Table 1. Comparison between Mechanical and Virtual Articulators

Parameter	Mechanical Articulators	Virtual Articulators
Nature	Physical, mechanical device	Software-based digital system
Simulation	Limited by mechanical components	Dynamic and repeatable simulations
Patient specificity	Mostly average values	Patient-specific data integration
Wear and tear	Present	Absent
Integration with CAD/CAM	Not possible	Fully integrated
Storage of records	Physical casts	Digital storage
Cost	Lower initial cost	Higher initial investment

Table 2. Classification of Virtual Articulators

Type	Basis of Simulation	Key Feature
Mean value virtual articulator	Average anatomical values	Simple digital articulation
Fully adjustable virtual articulator	Patient-specific jaw data	High accuracy
Mathematical model-based	Algorithm-based estimation	No motion capture required
Motion capture-based	Jaw tracking systems	Real-time movement simulation

Advantages of Virtual Articulators

Several advantages of virtual articulators have been reported in the literature. These include patient-specific simulation of mandibular movements, integration with digital workflows, enhanced visualization of occlusal contacts, reduced laboratory remakes, and improved.

communication between clinicians and technicians [1,3,4]. Digital storage of patient data allows repeated analysis without loss of accuracy and facilitates long-term documentation [28].

Limitations

Despite their advantages, virtual articulators exhibit certain limitations. High initial costs of hardware and software, dependence on the accuracy of digital records, and a steep learning curve limit widespread adoption [2,29]. Furthermore, variability among different virtual articulator systems complicates standardization and comparison of outcomes [15,30]. The lack of long-term randomized clinical trials evaluating clinical performance remains a significant concern [31].

Comparison with Mechanical Articulators

Mechanical articulators remain widely used due to their affordability, simplicity, and long-standing clinical reliability [5,6]. However, they are constrained by mechanical wear, limited movement simulation, and reliance on preset values [10]. Virtual articulators provide enhanced flexibility, dynamic analysis, and seamless integration with CAD/CAM systems, although current evidence supports their role as complementary rather than replacement tools [3,31].

FUTURE DIRECTIONS

Future developments in virtual articulators are expected to focus on improved jaw tracking accuracy, integration of artificial intelligence, and the creation of comprehensive virtual patient models [16,32]. Standardization of digital protocols and high-quality clinical trials are essential to establish evidence-based guidelines for routine clinical implementation [31,32].

CONCLUSION

Virtual articulators represent a significant advancement in digital prosthodontics, enabling improved simulation of mandibular movements and occlusal relationships. While existing literature supports their potential to enhance precision and efficiency, further long-term clinical studies are required to validate their routine use and determine whether they can fully replace mechanical articulators in clinical practice [1–4,31]

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