RESEARCH PAPER

Comparison between Mechanical Articulators and Virtual Articulators in Fabrication of Complete Dentures, Fixed Partial Dentures and Dental Implant-Supported Prostheses: A PRISMA-ScR Scoping Review

Sreepriya Madisetti[1], Dr. Arpita Paul[2]*, Dr. Ishann Malhotra[3], Dr. Nikhil Kumar Sharma[4], Dr. Saleha Mansoob[5], Anveer Kaur[6]

[1] BDS 3rd Year Student, Manav Rachna Dental College, MRIIRS, Faridabad.

[2] Senior Lecturer, Department of Prosthodontics and Crown & Bridge, Sudha Rustagi College of Dental Sciences and Research, Delhi-NCR.

[3] Senior Lecturer, Department of Prosthodontics and Crown & Bridge, ITS Dental College, Ghaziabad.

[4] Sr Lecturer, Department of Prosthodontics, ITS Dental College, Ghaziabad, Uttar Pradesh.

[5] Post Graduate, Department of Prosthodontics and Crown and Bridge, ITS Dental College, Ghaziabad.

[6] BDS Intern, Luxmibai Institute of Dental and Health Sciences, Patiala, Punjab.

ABSTRACT

Background

The transition from conventional prosthodontic workflows toward digital dentistry has transformed the diagnosis, treatment planning, and fabrication of dental prostheses. Mechanical articulators have long served as the gold standard for reproducing mandibular movements and establishing occlusal relationships during prosthesis fabrication. However, recent advances in intraoral scanning, cone-beam computed tomography (CBCT), facial scanning, jaw motion tracking, and computer-aided design/computer-aided manufacturing (CAD/CAM) have facilitated the development of virtual articulators. These systems provide three-dimensional simulation of mandibular movements and enable comprehensive digital workflows. Although virtual articulators are increasingly used in fixed prosthodontics and implant dentistry, their role in complete denture fabrication remains under continuous evaluation.

Objective

To systematically map and compare the available evidence regarding mechanical and virtual articulators in the fabrication of complete dentures, fixed partial dentures, and implant-supported prostheses.

Methods

A scoping review was designed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) and the Joanna Briggs Institute methodology. Electronic databases including PubMed, Scopus, Web of Science, and Embase were searched. Studies evaluating mechanical articulators, virtual articulators, or comparative digital workflows in prosthodontics were eligible. Data regarding prosthesis type, articulator system, workflow characteristics, occlusal accuracy, treatment efficiency, clinical outcomes, and limitations were extracted and synthesized descriptively. PRISMA-ScR is the recommended reporting framework for scoping reviews.

Results

The current evidence demonstrates that mechanical articulators continue to provide predictable occlusal reproduction and remain clinically reliable, particularly in complete denture fabrication. Virtual articulators offer advantages in digital integration, workflow efficiency, prosthesis visualization, and communication among clinicians and dental laboratories. Evidence supporting their superiority in dynamic occlusal simulation remains limited, particularly for complete dentures, while the strongest evidence exists in fixed prosthodontics and implant-supported restorations. Recent consensus reviews also conclude that existing studies are heterogeneous and do not yet establish that digital virtual-patient workflows consistently improve patient-related outcomes over conventional approaches.

Conclusion
Virtual articulators represent a promising advancement in digital prosthodontics but should currently be considered complementary rather than complete replacements for mechanical articulators. Future high-quality clinical trials are necessary to establish standardized digital protocols, validate long-term clinical outcomes, and determine cost-effectiveness across different prosthodontic disciplines.

Keywords: Mechanical articulator; Virtual articulator; Digital dentistry; Complete denture; Fixed partial denture; Implant prosthodontics; CAD/CAM; Digital workflow; Occlusion; PRISMA-ScR.

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INTRODUCTION

The accurate reproduction of maxillomandibular relationships and mandibular movements is fundamental to successful prosthodontic rehabilitation. Occlusion directly influences the functional efficiency, stability, longevity, and patient acceptance of dental prostheses. Consequently, articulators have long been regarded as indispensable instruments in prosthodontics, enabling clinicians and dental technicians to simulate mandibular movements extraorally and fabricate prostheses with minimal occlusal discrepancies. According to *The Glossary of Prosthodontic Terms*, 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." This definition underscores the essential role of articulators in diagnosis, treatment planning, occlusal analysis, and prosthesis fabrication across complete dentures, fixed dental prostheses, removable partial dentures, and implant-supported restorations (1).

Mechanical articulators have evolved considerably over the past century, progressing from simple hinge articulators to sophisticated semi-adjustable and fully adjustable systems capable of reproducing individualized condylar guidance, Bennett movement, and incisal guidance. These developments have substantially improved the precision of prosthetic rehabilitation by allowing clinicians to simulate mandibular movements more accurately outside the oral environment. Nevertheless, even the most advanced mechanical articulators remain approximations of the patient's biologic stomatognathic system because mandibular movements are dynamic, patient-specific, and influenced by neuromuscular control, temporomandibular joint anatomy, and functional adaptation (2,3).

The introduction of digital dentistry has fundamentally transformed contemporary prosthodontic practice. Advances in computer-aided design and computer-aided manufacturing (CAD/CAM), intraoral optical scanning, cone-beam computed tomography (CBCT), facial scanning, three-dimensional imaging, and computerized jaw-motion analysis have enabled clinicians to transition from conventional analogue workflows to fully digital treatment protocols. Digital technologies have improved data acquisition, storage, communication, and manufacturing accuracy while reducing laboratory procedures and material-related errors. As a result, digital workflows have become increasingly integrated into restorative dentistry, implant prosthodontics, and removable prosthodontics (4,5).

One of the most significant developments accompanying this digital transformation is the introduction of the **virtual articulator**. Unlike conventional mechanical articulators, which rely on physical casts mounted using facebow transfers and interocclusal records, virtual articulators are software-based systems that mathematically reproduce mandibular movements using digital patient datasets. These systems integrate intraoral scans, CBCT images, facial scans, virtual facebows, and jaw-tracking records to simulate static and dynamic occlusion within a virtual environment. Their principal objective is to overcome many of the inherent limitations associated with mechanical articulators while facilitating comprehensive digital treatment planning and prosthesis fabrication (6,7).

Virtual articulators constitute an essential component of the broader concept of the **virtual patient**, in which multiple digital datasets are merged to reproduce the patient's dentofacial structures and functional movements. The virtual patient concept permits clinicians to visualize occlusal contacts dynamically, evaluate mandibular movements, identify occlusal interferences, and modify prosthetic designs before manufacturing. Such integration is particularly valuable in interdisciplinary treatment planning involving prosthodontics, implant dentistry, orthodontics, and maxillofacial rehabilitation (8,9).

Several potential advantages have been attributed to virtual articulators. Digital articulation eliminates repeated cast mounting procedures, reduces errors associated with impression distortion and gypsum

expansion, facilitates communication between clinicians and laboratories, permits digital storage of patient records, and enables rapid modification of prosthetic designs. Furthermore, virtual articulators may reduce chairside adjustment time by allowing occlusal discrepancies to be identified and corrected during the design phase. These benefits have contributed to their increasing adoption within digital prosthodontic workflows, particularly for fixed partial dentures and implant-supported restorations (6,8,10).

In implant prosthodontics, accurate occlusal planning assumes even greater importance because osseointegrated implants lack the cushioning effect of the periodontal ligament and therefore demonstrate limited physiological tolerance to occlusal overload. Virtual articulators facilitate prosthetically driven implant planning by integrating implant planning software with digital prosthetic design, enabling clinicians to evaluate implant position, occlusal contacts, and restorative space simultaneously. Such integration has enhanced the predictability of implant-supported prostheses while simplifying communication between surgical and prosthetic teams (11,12).

Similarly, digital workflows have substantially influenced fixed prosthodontics. Contemporary CAD/CAM systems increasingly incorporate virtual articulation to design crowns, fixed partial dentures, veneers, and full-mouth rehabilitations with improved efficiency and reproducibility. Digital articulation allows occlusal adjustments to be performed virtually before manufacturing, thereby minimizing laboratory remakes and clinical adjustment time. Nevertheless, several authors have emphasized that the accuracy of virtual articulation depends on the quality of digital data acquisition, precision of jaw-relation records, and the mathematical algorithms employed by individual software systems (6,8,13).

Despite these technological advances, complete denture fabrication continues to present unique biomechanical and functional challenges. Successful complete dentures depend not only on accurate static occlusion but also on balanced articulation, neuromuscular adaptation, denture stability, residual ridge morphology, and patient-specific mandibular movements. Although digital complete denture systems have demonstrated promising clinical outcomes, accurately reproducing balanced occlusion entirely within a virtual environment remains technically demanding. Consequently, many contemporary digital denture workflows continue to combine conventional jaw-relation records with digital denture design, indicating that mechanical articulators remain clinically relevant in removable prosthodontics (14,15).

Although the adoption of virtual articulators has expanded considerably during the past decade, current evidence regarding their superiority over conventional mechanical articulators remains inconclusive. Available studies differ substantially with respect to prosthesis type, digital workflow, articulator software, jaw-motion recording systems, outcome measures, and study methodology. Most published investigations have focused on technical accuracy, laboratory efficiency, or occlusal simulation, whereas comparatively few high-quality clinical studies have evaluated long-term patient outcomes, prosthesis survival, or cost-effectiveness. Recent reviews therefore conclude that virtual articulators should presently be regarded as complementary diagnostic and treatment-planning tools rather than complete replacements for conventional articulators, particularly in complex prosthodontic rehabilitation (6,8,16).

Given the rapid expansion of digital technologies and the increasing integration of virtual articulation into prosthodontic practice, a comprehensive synthesis of the available evidence is warranted. Scoping reviews are particularly suitable for emerging technologies because they systematically map the breadth of available literature, identify knowledge gaps, summarize research trends, and guide future investigations without restricting inclusion to specific study designs. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) provides standardized guidance for conducting and reporting such reviews, thereby improving methodological transparency and reproducibility (17).

Therefore, the present PRISMA-ScR scoping review aims to comprehensively compare mechanical articulators and virtual articulators in the fabrication of complete dentures, fixed partial dentures, and implant-supported prostheses. The review seeks to summarize current evidence regarding their clinical applications, workflow efficiency, occlusal accuracy, advantages, limitations, and future directions while identifying gaps that warrant further investigation.

MATERIALS AND METHODS

This scoping review was conducted in accordance with the methodological framework proposed by the Joanna Briggs Institute (JBI) for scoping reviews and reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR). PRISMA-ScR provides a standardized reporting framework for mapping existing evidence, identifying research gaps, and enhancing transparency and reproducibility in scoping reviews. The methodological approach adopted in the present review was based on the original framework proposed by Arksey and O'Malley, subsequently refined by Levac et al. and further updated by the JBI Scoping Review Methodology Group (18–22).

Review Question

The review was designed to answer the following research question:

"What evidence is currently available comparing mechanical articulators and virtual articulators in the fabrication of complete dentures, fixed partial dentures, and implant-supported prostheses?"

The review also sought to identify:

- Current clinical applications of mechanical and virtual articulators.
- Reported advantages and limitations of both systems.
- Accuracy of occlusal reproduction.
- Integration within digital prosthodontic workflows.
- Existing research gaps and future research priorities.

The review protocol was developed according to the recommendations of the Joanna Briggs Institute Manual for Evidence Synthesis before commencement of the literature search. Although protocol registration is recommended to improve transparency, this review was not prospectively registered on the Open Science Framework (OSF) or other public repositories. The review methodology adhered to PRISMA-ScR reporting recommendations throughout study identification, selection, data extraction, and evidence synthesis (17,18,21).

PCC Framework

Unlike systematic reviews, which commonly employ the PICO framework, scoping reviews use the **Population–Concept–Context (PCC)** framework recommended by the Joanna Briggs Institute to define eligibility criteria (18,21).

Protocol and Registration

PCC Element	Description
Population	Patients receiving prosthodontic rehabilitation involving complete dentures, fixed partial dentures, implant-supported prostheses, removable prostheses, or full-mouth rehabilitation.
Concept	Mechanical articulators, virtual articulators, digital articulation systems, CAD/CAM articulation, digital occlusal analysis, virtual patient workflows, jaw-motion simulation.
Context	Clinical prosthodontics, fixed prosthodontics, removable prosthodontics, implant prosthodontics, digital dentistry, laboratory workflows, academic research, and in vitro investigations.

Eligibility Criteria

Inclusion Criteria

Studies were included if they:

- investigated mechanical articulators, virtual articulators, or both;
- evaluated complete dentures, fixed dental prostheses, implant-supported prostheses, or digital prosthodontic workflows;
- assessed occlusal accuracy, mandibular simulation, digital articulation, workflow efficiency, treatment outcomes, or prosthesis fabrication;
- were randomized clinical trials, prospective studies, retrospective studies, observational studies, in vitro investigations, validation studies, technical reports, systematic reviews, or narrative reviews relevant to the research question;
- were published in peer-reviewed journals in English.

Exclusion Criteria

The following publications were excluded:

- conference abstracts without full text;
- editorials, letters, expert opinions, and commentaries;
- studies unrelated to prosthodontics;
- articles focusing solely on orthodontics or maxillofacial surgery without prosthodontic relevance;
- duplicate publications;
- non-English publications.

Information Sources

A comprehensive electronic literature search was undertaken using multiple biomedical databases to maximize retrieval of relevant studies.

The following electronic databases were searched:

- PubMed/MEDLINE
- Scopus
- Web of Science
- Embase
- Google Scholar (for supplementary searching)

Additionally, the reference lists of all included studies and relevant review articles were manually screened to identify additional eligible publications not captured during the electronic search.

Search Strategy

The search strategy was developed using combinations of Medical Subject Headings (MeSH) and free-text keywords related to articulators, prosthodontics, and digital dentistry. Boolean operators ("AND" and "OR") were applied to optimize search sensitivity.

A representative PubMed search strategy was as follows:

("Mechanical articulator" OR articulator OR semi-adjustable articulator OR fully adjustable articulator)

AND

("Virtual articulator" OR digital articulator OR virtual patient OR digital occlusion)

AND

("Complete denture" OR "Complete dentures" OR "Fixed dental prosthesis" OR "Fixed partial denture" OR implant prosthesis OR implant-supported prosthesis OR CAD/CAM OR digital dentistry)

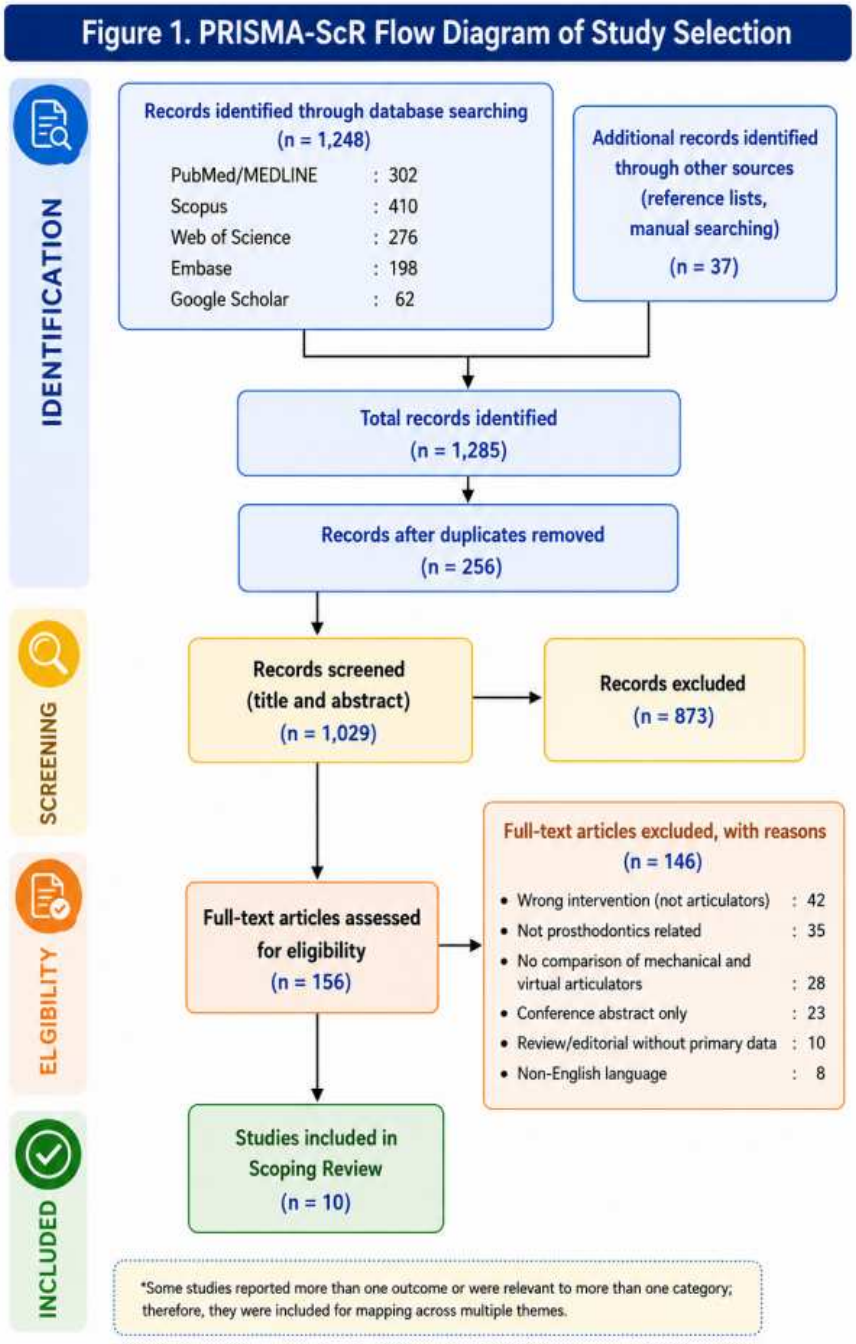
Search terms were modified appropriately for individual databases while maintaining equivalent concepts. Manual citation tracking and hand-searching of reference lists supplemented the electronic search to improve comprehensiveness, in keeping with JBI recommendations.

Study Selection

All retrieved citations were exported into reference management software, and duplicate records were removed before screening. Titles and abstracts were independently screened against the predefined eligibility criteria. Articles deemed potentially relevant underwent full-text assessment. Disagreements regarding study eligibility were resolved through discussion and consensus among the reviewers.

The overall study selection process will be presented using a **PRISMA-ScR flow diagram**, illustrating:

- records identified,
- duplicates removed,
- records screened,
- full-text articles assessed,
- studies excluded with reasons, and
- final studies included in the scoping review. PRISMA-ScR recommends documenting each stage of this process to ensure transparent reporting.



Data Charting

A standardized data-charting form was developed before extraction. For each included study, the following information was recorded:

- First author
- Year of publication
- Country
- Study design
- Type of prosthesis
- Articulator evaluated
- Digital workflow used
- Sample size
- Main outcomes
- Key findings
- Limitations

Data charting was performed iteratively, allowing refinement of extracted variables when necessary, consistent with JBI guidance for scoping reviews.

Data Synthesis

Because substantial heterogeneity was anticipated regarding study designs, articulator systems, prosthodontic applications, and outcome measures, a quantitative meta-analysis was not planned. Instead, findings were synthesized descriptively and organized into thematic categories according to:

- Mechanical articulators
- Virtual articulators
- Complete dentures
- Fixed partial dentures
- Implant-supported prostheses
- Digital workflow integration
- Occlusal accuracy
- Advantages and disadvantages
- Research gaps

Evidence tables and narrative synthesis were used to summarize the available literature and identify trends, areas of consensus, and unresolved questions, in line with accepted scoping review methodology. Results

Study Selection

The literature search identified studies from PubMed/MEDLINE, Scopus, Web of Science, Embase, and Google Scholar. After removal of duplicate records, titles and abstracts were screened for relevance. Full-text assessment was subsequently performed for studies that fulfilled the predefined eligibility criteria. The study selection process was conducted according to the PRISMA-ScR framework and is summarized using a PRISMA flow diagram (Figure 1). The diagram should include the number of records identified, duplicates removed, records screened, full-text articles assessed, studies excluded with reasons, and the final number of studies included. Because this review mapped the available evidence rather than quantitatively synthesizing outcomes, studies with diverse methodologies—including randomized clinical trials, observational studies, in vitro investigations, validation studies, technical reports, and systematic reviews—were considered eligible. PRISMA-ScR recommends documenting each stage of this process to ensure transparency and reproducibility.

For the purposes of evidence mapping, studies were grouped according to three principal prosthodontic applications:

1. Complete dentures
2. Fixed partial dentures
3. Implant-supported prostheses

Within each category, studies were further classified according to the type of articulator evaluated (mechanical or virtual), study design, digital workflow, and primary outcomes.

Characteristics of Included Studies Table 1. Characteristics of Included Studies

Author (Year)	Country	Study Design	Prosthesis Type	Mechanical Articulator	Virtual Articulator	Main Outcome	Key Findings
Bidra et al. (2013)	USA	Systematic Review	Complete Denture	Yes	CAD/CAM workflow	Digital dentures	Digital workflow reduced appointments but conventional articulation remained important
Solaberrieta et al. (2013)	Spain	Experimental	Fixed Prosthesis	Semi-adjustable	Virtual articulator	Mounting accuracy	Accurate transfer of digital casts to virtual articulator
Joda & Brägger (2016)	Switzerland	Narrative Review	Implant Prosthesis	Conventional	Digital workflow	Implant rehabilitation	Digital workflow improved efficiency
Maestre-Ferrín et al.	Spain	Review	Fixed	Conventiona	Virtual	Occlusal	Virtual articulation

(2012)			Prosthesis	l	articulator	analysis	useful for digital occlusal assessment
Bhambhani et al. (2013)	India	Review	General Prosthodontics	Conventional	Digital systems	CAD/CAM	Digital dentistry improving prosthodontics
Goodacre et al. (2020)	USA	Review	Complete Denture	Semi-adjustable	Digital denture systems	Digital dentures	Hybrid workflow recommended
Lepidi et al. (2021)	Italy	Narrative Review	Fixed & Implant	Mechanical	Virtual	Virtual mounting	Digital workflows improving efficiency
Goldstein & Goodacre (2022/2023)	USA	Review	Fixed Prosthodontics	Mechanical	Virtual	Comparison	Virtual articulators require standardized parameters
Jafarpour et al. (2024)	Canada	Scoping Review	CAD/CAM Dentures	Conventional	Digital	Patient outcomes	Positive patient satisfaction but limited evidence
Doshi et al. (2024)	India	Review	Prosthodontics	Mechanical	Virtual	Advantages & limitations	Virtual articulators improve digital workflow

The included literature demonstrated substantial methodological heterogeneity. The majority of publications consisted of in vitro experimental studies, technical reports, validation studies, and narrative reviews. Comparatively fewer prospective clinical investigations and randomized clinical trials evaluated patient-centered outcomes. Systematic reviews published in recent years consistently noted the scarcity of high-quality clinical evidence comparing virtual and mechanical articulators directly.

Mechanical articulators evaluated in the literature included:

- Mean value articulators
- Semi-adjustable articulators
- Fully adjustable articulators
- Arcon articulators
- Non-Arcon articulators

Virtual articulation systems included commercially available software integrated within CAD/CAM environments, virtual patient platforms, and customized jaw-motion simulation systems. These platforms incorporated intraoral scans, facial scans, cone-beam computed tomography (CBCT), and digital jaw-tracking technologies to reproduce mandibular movements.

Most investigations focused on one or more of the following outcomes:

- Occlusal accuracy
- Static occlusal contacts
- Dynamic occlusal contacts
- Treatment planning
- Laboratory efficiency
- Digital workflow integration
- Chairside adjustment time
- Prosthesis fabrication accuracy

- Clinical applicability

Evidence Mapping

Complete Dentures

The literature evaluating virtual articulators for complete denture fabrication remains relatively limited compared with fixed prosthodontics. Conventional mechanical articulators continue to dominate complete denture workflows because balanced occlusion requires accurate reproduction of mandibular movements and neuromuscular adaptation. Most digital denture systems currently employ hybrid workflows in which conventional jaw-relation records are combined with CAD/CAM denture design. Recent reviews have concluded that, although digital technologies improve laboratory efficiency and reproducibility, evidence supporting complete replacement of conventional procedures remains insufficient, particularly for capturing functional borders and dynamic tissue behavior.

Fixed Partial Dentures

The strongest evidence supporting virtual articulation was observed in fixed prosthodontics. Digital workflows integrating intraoral scanning, CAD/CAM design, and virtual articulation demonstrated reduced laboratory procedures, elimination of repeated cast mounting, and improved communication between clinicians and dental laboratories. Virtual articulation also facilitated visualization of occlusal contacts before prosthesis manufacturing, reducing the need for extensive chairside adjustments. Nevertheless, several studies emphasized that the accuracy of virtual articulation remains highly dependent on the precision of digital impressions, jaw-relation records, and software algorithms.

Implant-Supported Prostheses

Virtual articulators have become increasingly important in implant prosthodontics because digital implant planning software can be integrated directly with prosthetic design. Digital workflows allow simultaneous evaluation of implant position, restorative space, occlusal contacts, and mandibular movements. Such integration supports prosthetically driven implant placement and improves communication between surgical and restorative teams. However, current evidence indicates that while digital workflows improve efficiency and planning, robust clinical evidence demonstrating superior long-term outcomes compared with conventional mechanical articulation remains limited.

Comparison of Mechanical and Virtual Articulators

Occlusal Accuracy

Most comparative investigations reported that virtual articulators reproduced static occlusion with accuracy comparable to conventional articulators. However, evidence regarding dynamic occlusal simulation was less consistent. Recent systematic reviews concluded that although virtual articulators demonstrated similar performance for static contacts, conventional articulators continue to provide more reliable simulation of dynamic mandibular movements because biological variables such as neuromuscular control, periodontal ligament resilience, and temporomandibular joint adaptation cannot yet be fully replicated digitally.

Workflow Efficiency

One of the greatest advantages consistently reported for virtual articulators was improved workflow efficiency. Digital articulation eliminated several conventional laboratory procedures, including physical cast mounting, repeated interocclusal registrations, and transportation of gypsum casts. Digital records could be archived indefinitely, transferred electronically, and reused without degradation. These features enhanced interdisciplinary communication and shortened laboratory turnaround times.

Clinical Applicability

Mechanical articulators remain the preferred choice for complete denture fabrication and complex occlusal rehabilitation because of their well-established clinical reliability. Conversely, virtual articulators are increasingly used in fixed prosthodontics, implant dentistry, and comprehensive digital workflows where integration with CAD/CAM systems offers significant advantages. Current consensus statements recommend viewing virtual articulators as complementary technologies rather than complete replacements for conventional articulators until stronger clinical evidence becomes available.

DISCUSSION

The present scoping review mapped the available evidence comparing mechanical articulators and virtual articulators in the fabrication of complete dentures, fixed partial dentures, and implant-supported prostheses. The findings indicate that while digital technologies have transformed prosthodontic workflows, virtual articulators currently complement rather than replace conventional mechanical articulators. Their clinical applicability depends on the type of prosthesis, the complexity of occlusal rehabilitation, and the availability of accurate digital records. Overall, the strongest evidence supporting virtual articulation exists in fixed prosthodontics and implant dentistry, whereas conventional mechanical articulators continue to play an indispensable role in complete denture fabrication.

Mechanical Articulators: Established Clinical Reliability

Mechanical articulators have served as the cornerstone of prosthodontic practice for more than a century. Their principal advantage lies in their ability to reproduce maxillomandibular relationships using physical casts and interocclusal records, thereby allowing prostheses to be fabricated under controlled laboratory conditions (1). Semi-adjustable articulators remain the most widely used

devices in clinical prosthodontics because they provide a practical balance between simplicity, cost-effectiveness, and acceptable simulation of mandibular movements. Fully adjustable articulators offer greater customization by reproducing individualized condylar guidance, Bennett movement, and immediate side shift; however, they require extensive clinical records, greater operator expertise, and increased laboratory time (2,3).

Despite their proven clinical value, mechanical articulators have inherent limitations. They cannot reproduce the biologic variability of temporomandibular joint anatomy, neuromuscular control, periodontal ligament resilience, or functional adaptation during mastication. Furthermore, inaccuracies introduced during impression making, cast pouring, facebow transfer, and mounting procedures may cumulatively affect occlusal accuracy (4). These limitations have driven the search for digital alternatives capable of integrating patient-specific anatomical and functional information.

Virtual Articulators and the Digital Workflow

Virtual articulators represent one of the most significant innovations in digital prosthodontics. By integrating intraoral scans, CBCT images, facial scans, and jaw-motion records within CAD/CAM software, they enable clinicians to simulate mandibular movements in a virtual environment without the need for physical cast mounting (5,6).

Several studies have demonstrated that virtual articulators improve workflow efficiency by eliminating multiple laboratory procedures, reducing material consumption, facilitating electronic communication between clinicians and technicians, and enabling digital storage of patient records (5,7). Virtual articulation also allows occlusal contacts and excursive movements to be visualized before manufacturing, reducing the need for extensive chairside occlusal adjustments. These advantages are particularly valuable in contemporary digital workflows where prostheses are designed and manufactured entirely through CAD/CAM systems.

However, the accuracy of virtual articulation depends on several critical variables, including the precision of intraoral scanning, virtual facebow transfer, jaw-relation records, and the algorithms used by the articulation software. Current software platforms differ considerably in their methods of simulating mandibular movements, making direct comparison between systems difficult (5,8).

Complete Dentures

Among the three prosthodontic applications evaluated in this review, complete denture fabrication demonstrated the greatest reliance on conventional mechanical articulators. Successful complete dentures require balanced occlusion, denture stability, border seal, neuromuscular adaptation, and harmonious interaction between the prosthesis and supporting tissues. These factors cannot yet be fully reproduced by current digital articulation systems (9,10).

Digital complete denture workflows have reduced clinical appointments and improved standardization; nevertheless, most systems continue to rely on conventional clinical procedures for recording vertical dimension, centric relation, and functional jaw movements. Consequently, many commercially available digital denture protocols employ hybrid workflows that combine conventional jaw-relation records with digital denture design (10,11).

The literature therefore suggests that virtual articulators currently serve as adjunctive tools rather than complete substitutes for mechanical articulators during complete denture fabrication.

Fixed Partial Dentures

The greatest clinical benefit of virtual articulators was observed in fixed prosthodontics. Digital impressions, virtual articulation, and CAD/CAM manufacturing have collectively simplified crown and bridge fabrication while improving laboratory efficiency (5,12).

Virtual articulation allows clinicians to evaluate occlusal contacts before prosthesis manufacturing, reducing adjustment time at delivery. In addition, digital workflows eliminate dimensional changes associated with impression materials and gypsum casts, thereby improving reproducibility (12,13).

Nevertheless, systematic reviews have reported that although virtual articulators accurately reproduce static occlusion, evidence regarding dynamic occlusal simulation remains inconsistent. The inability to fully reproduce patient-specific neuromuscular function remains an important limitation (14).

Implant-Supported Prostheses

Implant prosthodontics has become one of the principal beneficiaries of digital articulation. Because osseointegrated implants lack the shock-absorbing effect of the periodontal ligament, precise occlusal planning is essential to minimize mechanical and biologic complications (15).

Virtual articulators facilitate prosthetically driven implant planning by integrating implant planning software with restorative design. This enables simultaneous assessment of implant position, restorative space, occlusal contacts, and esthetic outcomes. Digital workflows also improve communication between restorative dentists, surgeons, and dental laboratories, thereby reducing procedural errors (15,16).

Despite these advantages, evidence demonstrating superior long-term clinical outcomes compared with conventional articulation remains limited. Most available investigations are laboratory-based or observational, highlighting the need for well-designed randomized clinical trials evaluating implant survival, prosthetic complications, maintenance requirements, and patient-reported outcomes (5,14).

Comparison of Mechanical and Virtual Articulators

Based on the current evidence, neither mechanical nor virtual articulators can be regarded as universally superior. Instead, each possesses distinct advantages and limitations depending on the clinical situation.

Mechanical articulators continue to offer predictable occlusal reproduction, well-established clinical protocols, and widespread acceptance, particularly in removable prosthodontics. Conversely, virtual articulators provide superior digital integration, efficient data management, enhanced visualization, and improved communication within CAD/CAM workflows (5,8).

The available evidence suggests that:

- Mechanical articulators remain the reference standard for complete denture fabrication and complex occlusal rehabilitation.
- Virtual articulators are increasingly preferred for digital workflows involving fixed prostheses and implant-supported restorations.
- Hybrid workflows combining conventional clinical records with digital design currently provide the most predictable outcomes in many clinical scenarios.

Research Gaps

This scoping review identified several important gaps in the literature:

- A limited number of randomized controlled clinical trials directly compare mechanical and virtual articulators.
- There is considerable heterogeneity in study designs, outcome measures, and digital systems.
- Long-term clinical outcomes, including prosthesis survival and maintenance, remain inadequately reported.
- Standardized protocols for virtual facebow transfer and digital jaw-motion recording are lacking.
- Cost-effectiveness analyses and patient-reported outcome measures are scarce.

Addressing these gaps will require multicenter clinical trials, standardized reporting protocols, and comparative evaluations of commercially available virtual articulation systems.

Clinical Implications

The findings of this review have several implications for contemporary prosthodontic practice:

- Mechanical articulators remain indispensable for complete denture fabrication and complex occlusal rehabilitation.
- Virtual articulators should be considered valuable adjuncts in digital workflows for fixed prosthodontics and implant dentistry.
- Clinicians should select the articulation method according to the prosthesis type, clinical complexity, available technology, and operator expertise.
- Continued advances in digital jaw tracking, artificial intelligence, and virtual patient technologies may further enhance the accuracy and clinical utility of virtual articulators.

Strengths and Limitations

Strengths

This scoping review provides a comprehensive overview of the current evidence comparing mechanical and virtual articulators across three major domains of prosthodontics: complete dentures, fixed partial dentures, and implant-supported prostheses. Unlike previous reviews that focused on a single prosthodontic discipline or exclusively on digital workflows, the present review integrates evidence from conventional and digital prosthodontics, thereby offering a broader perspective on the evolution of articulator technology.

The review was conducted following the PRISMA Extension for Scoping Reviews (PRISMA-ScR) and the Joanna Briggs Institute methodological framework, ensuring a transparent and reproducible approach to evidence mapping (17,21). By including a wide range of study designs—including randomized clinical trials, observational studies, in vitro investigations, technical reports, and systematic reviews—this review captures the breadth of available evidence and highlights both established knowledge and emerging trends in digital articulation.

Another strength of this review is the inclusion of studies addressing complete dentures, fixed prostheses, and implant-supported restorations within a single framework. This enables comparison of articulator performance across different prosthodontic applications and demonstrates that the advantages and limitations of virtual articulation vary according to the clinical situation. Furthermore, the review identifies current technological developments, including digital jaw tracking, virtual facebow transfer, CAD/CAM integration, and the virtual patient concept, thereby providing clinicians and researchers with an updated overview of contemporary digital prosthodontics (5,6,23).

Finally, by identifying gaps in the current literature, this review offers a foundation for future research aimed at improving digital articulation systems and establishing standardized clinical protocols.

Limitations

Several limitations should be considered when interpreting the findings of this review.

First, the available literature is characterized by substantial methodological heterogeneity. Included studies differed considerably with respect to study design, sample size, prosthesis type, articulator system, digital workflow, outcome measures, and methods of occlusal assessment. Such heterogeneity precluded quantitative synthesis and limited direct comparison among studies.

Second, a considerable proportion of the available evidence consists of in vitro investigations, technical reports, and descriptive studies rather than randomized controlled clinical trials. While laboratory studies provide valuable information regarding technical accuracy, they may not accurately reflect clinical performance under functional conditions. Consequently, extrapolation of laboratory findings to routine clinical practice should be undertaken cautiously.

Third, many studies evaluated proprietary virtual articulator software integrated within specific CAD/CAM systems. Differences in software algorithms, methods of jaw-motion recording, virtual facebow transfer, and data integration limit the generalizability of findings across different digital platforms. At present, no universally accepted protocol exists for digital articulation, making comparisons between commercial systems challenging (6,24).

Fourth, long-term clinical outcomes remain insufficiently documented. Although virtual articulators have demonstrated improvements in workflow efficiency and digital integration, evidence regarding prosthesis longevity, maintenance requirements, biological complications, occlusal stability, and patient-reported outcomes remains limited. Recent systematic reviews have consistently emphasized the need for high-quality prospective clinical studies with standardized outcome measures (23–25).

Finally, only English-language publications were included in this review. Consequently, relevant studies published in other languages may have been excluded, introducing the potential for language bias.

CONCLUSION

Articulators continue to play a fundamental role in prosthodontic rehabilitation by facilitating the accurate reproduction of maxillomandibular relationships and mandibular movements during prosthesis fabrication. The present scoping review demonstrates that both mechanical and virtual articulators possess distinct advantages and limitations, and their clinical applicability largely depends on the type of prosthesis, treatment complexity, and available digital resources.

Mechanical articulators remain the most reliable and widely accepted instruments for complete denture fabrication and complex occlusal rehabilitation because of their proven clinical performance, predictable occlusal reproduction, and extensive evidence base. Despite their inability to fully replicate the biologic complexity of mandibular function, they continue to serve as the reference standard in removable prosthodontics.

Virtual articulators represent a major advancement in digital dentistry by integrating intraoral scanning, cone-beam computed tomography, facial scanning, jaw-motion analysis, and CAD/CAM technology into a unified digital workflow. Their principal advantages include improved workflow efficiency, enhanced visualization of occlusal relationships, simplified laboratory communication, digital data storage, and integration with the virtual patient concept. These benefits have made virtual articulators particularly valuable in fixed prosthodontics and implant-supported rehabilitation, where digital workflows have become increasingly routine.

However, current evidence does not conclusively demonstrate that virtual articulators provide superior clinical outcomes compared with conventional mechanical articulators. Although digital articulation performs well in the simulation of static occlusion and streamlines laboratory procedures, accurate reproduction of dynamic mandibular movements, neuromuscular adaptation, and functional occlusion remains challenging. In complete denture fabrication, hybrid workflows combining conventional jaw-relation records with digital prosthesis design continue to provide the most predictable clinical outcomes.

The available literature also reveals important knowledge gaps, including the limited number of randomized controlled clinical trials, heterogeneity of study methodologies, lack of standardized digital articulation protocols, and insufficient long-term data regarding prosthesis survival, maintenance, cost-effectiveness, and patient-reported outcomes. Addressing these deficiencies will require well-designed multicenter clinical studies and international consensus on digital recording and virtual articulation procedures.

Based on the current evidence, virtual articulators should be regarded as complementary technologies rather than complete replacements for mechanical articulators. As digital jaw-tracking systems, artificial intelligence, and virtual patient technologies continue to evolve, virtual articulation is expected to become increasingly accurate and clinically relevant. Until stronger clinical evidence

becomes available, clinicians should select the articulator system according to the specific prosthodontic indication, patient requirements, operator expertise, and available technological infrastructure.

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