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Articulators in prosthodontics: evolution from mechanical to digital systems: a narrative review

Oğuzhan Kaya*, Eyyüp Altıntaş
Department of Prosthodontics, Faculty of Dentistry, Fırat University, Elazığ, Turkiye

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ABSTRACT

Articulators are mechanical or digital devices that simulate mandibular movements and reproduce maxillomandibular relationships in prosthodontic procedures. Throughout prosthodontic history, articulators have evolved from simple hinge devices to fully adjustable mechanical and virtual systems. This narrative review summarizes conventional and digital articulator systems, with emphasis on their clinical indications, limitations, and relevance to contemporary prosthodontic workflows. Mechanical articulators remain useful for diagnostic mounting, treatment planning, and laboratory communication; however, they cannot fully reproduce patient-specific neuromuscular control, tissue resilience, tooth mobility, or dynamic occlusion. Digital facebows, mandibular motion analyzers, computer-aided design/computer-aided manufacturing (CAD/CAM) systems, and virtual articulators may improve data integration and visualization, but their clinical value depends on the quality of input records, software compatibility, cost, and clinician experience. A critical understanding of each system is therefore necessary for selecting an articulator according to treatment complexity, occlusal risk, vertical dimension changes, and the need for individualized mandibular movement simulation.

Keywords: Dental occlusion, mandibular movement, temporomandibular joint, jaw relation record, computer-aided design, computer-aided manufacturing

INTRODUCTION

Articulators are mechanical devices designed to mimic all or part of jaw movements, to which upper and lower models can be attached, and which can represent the jaws and temporomandibular joint (TMJ).[1] They are used for diagnosis, treatment planning, prosthesis fabrication, and laboratory communication. For accurate prosthodontic treatment, the movements and positional relationships of the mandible must be transferred and interpreted as reliably as possible.[2]

Although articulators may reproduce selected anatomical and functional determinants of mandibular movement, they should not be considered exact replicas of the stomatognathic system. Muscles, ligaments, the TMJ, bone, connective tissues, neuromuscular adaptation, tissue resilience, and tooth mobility cannot be fully reproduced in mechanical devices.[3,4] Therefore, the value of an articulator depends not only on its mechanical complexity but also on the accuracy of clinical records and the clinician's ability to interpret its limitations.

Historically, before the first mechanical articulator attributed to Gariot in 1805, plaster occludators were used to preserve horizontal and vertical relationships between casts.[5] Since then, articulators have evolved from simple hinge devices to semi-adjustable, fully adjustable, and virtual systems. The current clinical question is not whether one articulator is universally superior, but which system provides sufficient accuracy and practicality for a specific treatment scenario.

CLINICAL ROLE AND INHERENT LIMITATIONS OF CONVENTIONAL ARTICULATORS

The clinical value of conventional articulators lies in transferring maxillomandibular relationships to a stable laboratory setting, reducing chairside adjustments, and improving communication between the clinician and the dental technician. Nevertheless, their limitations must be interpreted critically. Increasing mechanical complexity does not automatically improve clinical outcome if facebow transfer, interocclusal records, cast mounting, or occlusal analysis are inaccurate.[6-8] These clinical benefits and limitations are summarized in **Table 1**.

ARTICULATOR RECORDS AND CLASSIFICATION

Traditional classifications of articulators are based on the type of mandibular movement reproduced, the records accepted by the device, and the degree of adjustability. Instead of presenting long historical lists of device names, the clinically relevant distinction is whether the articulator can accept facebow transfer, interocclusal records, graphic records, and patient-specific movement information.[9-18] A clinically oriented classification is presented in **Table 2**.

*Corresponding Author: Oğuzhan Kaya, o.kaya@firat.edu.tr

Table 1. Clinical value and limitations of conventional articulators

Clinical aspect	Potential benefit	Main limitation	Clinical implication
Diagnostic mounting	Permits extraoral evaluation of occlusion and jaw relations	Static casts cannot reproduce neuromuscular adaptation or tissue resilience	Useful for planning, but intraoral verification remains necessary
Laboratory procedures	Allows occlusal adjustments and wax-up/restoration design without the patient present	Errors may arise from record deformation, mounting inaccuracies, and articulator instability	Accurate records and careful mounting are as important as articulator type
Mandibular movement simulation	Higher-level articulators can approximate condylar guidance, Bennett movement, and intercondylar distance	Mechanical pathways remain simplified compared with patient-specific functional movement	Semi- or fully adjustable devices are more justified in extensive rehabilitations than in simple single-unit treatments
Clinical efficiency	May reduce chairside occlusal adjustments when the selected system matches the clinical problem	Complex systems require additional time, cost, and operator skill	Selection should balance accuracy, practicality, treatment extent, and clinician experience

Table 2. Clinically oriented classification of conventional articulators

Articulator category	Records commonly required	Strengths	Limitations/appropriate use
Simple hinge articulators	Centric relation or maximum intercuspation record only	Inexpensive, rapid mounting, suitable for limited procedures when eccentric contacts are not being developed	Cannot orient casts to the TMJ or simulate eccentric movements; not appropriate for complex occlusal rehabilitation
Mean-value articulators	Average condylar/incisal settings; usually no individualized dynamic records	More functional than hinge articulators and practical for simple prosthetic procedures	Uses population-based values; limited individualization and limited relevance when anterior guidance is absent or vertical dimension is changed
Semi-adjustable articulators	Facebow transfer and protrusive/lateral interocclusal records	Allows adjustment of condylar inclination, Bennett angle, and selected guidance parameters; useful for routine fixed/removable prosthodontics	Movements are still mechanically simplified; record quality strongly influences accuracy
Fully adjustable articulators	Kinematic facebow, pantographic/graphic records, and interocclusal records	Allows the highest level of individualization among mechanical systems	Technique-sensitive, time-consuming, and rarely necessary for simple cases; best reserved for complex occlusal rehabilitation
Arcon/non-arcon design	Depends on the chosen category and mounting protocol	Arcon design resembles the anatomical relationship of condyle and fossa; non-arcon designs may provide simpler centric locking	Evidence is not uniform regarding clinical superiority; the operator must understand how design affects vertical dimension changes and lateral movement interpretation

TMJ: Temporomandibular joint

ARCON AND NON-ARCON DESIGNS

Arcon and non-arcon articulators differ in the location of the mechanical condylar and fossae elements. In arcon articulators, the mechanical fossae are located on the upper member, approximating the anatomical relationship of the glenoid fossae to the cranium. In non-arcon systems, the arrangement is reversed.[11,18] The literature does not support a simple assumption that one design is always superior; rather, the clinical effect depends on record accuracy, vertical dimension changes, and the intended restorative procedure. Goyal et al.[19] reported different sagittal condylar guidance values between arcon and non-arcon articulators, whereas previous reports have also noted comparable condylar guidance or improved mandibular movement representation with arcon devices.[18-20] The main clinical differences between the two designs are summarized in **Table 3**.

CLINICAL SELECTION OF ARTICULATORS

Articulator selection should be guided by four variables: the patient's occlusal characteristics, the extent of restorative treatment, the limitations of the device, and the clinician's skill.[16,21,22] Simple or mean-value articulators may be acceptable when restoring a single unit or when stable anterior guidance is present. Semi-adjustable articulators are generally more appropriate for routine fixed prosthodontics, balanced complete denture arrangements, and removable partial dentures. Fully adjustable articulators are most justified when extensive fixed prostheses, full-mouth rehabilitation, major occlusal adjustment, or vertical dimension changes are planned. The most sophisticated device may still lead to inaccurate outcomes if clinical records are poor; conversely, a semi-adjustable articulator used by an experienced clinician may outperform a fully adjustable device used without proper records.

FACEBOW RECORDS: EVIDENCE AND CLINICAL INDICATIONS

A facebow records the spatial relationship of the maxillary arch to selected cranial reference points and transfers this relationship to the articulator.[1] Although prosthodontic

Table 3. Comparative clinical interpretation of arcon and non-arcon articulators

Design feature	Arcon articulator	Non-arcon articulator	Clinical interpretation
Anatomic analogy	Condylar elements are on the lower member and fossae on the upper member	Condylar elements are generally on the upper member	Arcon design is more intuitive for demonstrating mandibular movements
Vertical dimension changes	Condylar guidance settings are less affected by opening the articulator	Changes in vertical dimension may require greater caution or readjustment	Arcon systems may be advantageous when vertical dimension is altered
Laboratory handling	Upper and lower members can often be separated easily	More compact assembly and simpler centric locking	Ease of laboratory handling must be balanced against maintenance of centric relation
Evidence-based selection	Some studies report more accurate movement representation	Some reports suggest similar condylar guidance values	Selection should not rely on design alone; records, calibration, and clinician skill are decisive

teaching has traditionally emphasized facebow use, clinical evidence is mixed.[23-25] In extensive fixed restorations, full-mouth rehabilitation, or cases involving alteration of vertical dimension, facebow records may be more defensible because errors in the arc of closure may be clinically relevant.[26,27] For complete dentures and occlusal splints, systematic review evidence has not shown consistent superiority of facebow transfer.[23,28-30] The main facebow-related records and clinical considerations are summarized in **Table 4**.

in a digital environment.[40-42] It should be regarded as an adjunctive diagnostic and planning tool rather than a complete replacement for biological assessment. Virtual articulators may incorporate average-value settings, semi-adjustable mechanical parameters, or patient-specific movement data from jaw tracking systems.[40,43-46] Their clinical utility is greatest when data acquisition and transfer are standardized. The principal data inputs and limitations of virtual approaches are summarized in **Table 5**.

Table 4. Facebow records and evidence-based clinical use

Record/system	Clinical purpose	Advantages	Limitations/evidence considerations
Arbitrary facebow	Transfers the maxillary cast to an articulator using average hinge-axis references	Simple, widely taught, and useful for many semi-adjustable articulator protocols	Skin and external reference points may be unreliable; benefit for complete dentures and splints is not consistently supported
Kinematic facebow	Locates the transverse horizontal hinge axis more precisely	Provides more individualized axis transfer for fully adjustable systems	Time-consuming and technique-sensitive; may be uncomfortable or unstable in edentulous patients
Digital facebow	Aligns facial, intraoral, and/or jaw-motion data in a digital workflow	Improves data storage, transfer, visualization, and clinician-technician communication	Requires scanners, software, calibration, and interoperable data formats
No facebow/simplified mounting	Uses average mounting or simplified jaw relation records	May be practical for simple cases and complete dentures where evidence does not show clear superiority of facebow use	Less suitable when vertical dimension is altered or full-arch fixed prostheses require individualized transfer

PANTOGRAPHIC AND DIGITAL RECORDS

Pantographs graphically record mandibular movement pathways and provide information for articulator adjustment.[31] In contemporary workflows, digital facebows and jaw-motion tracking systems extend this concept by integrating facial scans, intraoral scans, cone-beam computed tomography (CBCT) data, and mandibular movement records.[32-39] Digitalization may reduce physical record storage, improve repeatability, and facilitate communication; however, accuracy is dependent on scanner calibration, registration protocols, software alignment, and operator training.

Digital facebow techniques share a common principle: digital facial data are aligned with intraoral or cast scan data to determine the spatial position of the maxillary arch. Systems and protocols vary, including the use of optical face scanners, jaw tracking devices, intraoral scanners, photogrammetry, and virtual mounting software.[34,37-39] Therefore, current evidence should be interpreted according to the specific hardware/software combination rather than generalized to all digital facebow systems.

VIRTUAL ARTICULATORS AND DIGITAL OCCLUSAL ANALYSIS

A virtual articulator is software that simulates maxillomandibular relationships and mandibular movements

Earlier digital articulator designs and integrated craniofacial movement models also demonstrate the broad range of virtual simulation approaches.[47-53]

Several studies suggest that full-arch digital impressions and virtual interocclusal registration may provide clinically useful data when appropriate software and scanning protocols are used.[54,55] However, virtual contacts should be interpreted cautiously because scanner accuracy, matching algorithms, mandibular recording errors, and data export formats can affect the final occlusal design. The lack of a universal digital format for mandibular movement transfer remains a relevant limitation.[49]

CRITICAL COMPARISON OF CONVENTIONAL AND DIGITAL SYSTEMS

The transition from mechanical to virtual articulators should be understood as an expansion of available clinical tools rather than a linear replacement. Mechanical articulators are accessible, familiar, and adequate for many treatments, whereas virtual systems can improve visualization, dynamic occlusal assessment, and digital design integration. Yet digital systems are not free of error; they shift the source of error from stone casts and mechanical joints to scan accuracy, registration algorithms, software compatibility, and clinician training. In addition, adoption of fully digital workflows can be influenced by the clinician's learning curve.[56] The major comparative advantages and limitations of conventional and digital systems are summarized in **Table 6**.

Table 5. Digital and virtual articulator approaches

Virtual approach/system	Data input	Potential benefit	Main limitation
Mathematically simulated articulator	Average or user-defined condylar and incisal parameters	Easy integration with CAD/CAM design and educational visualization	Relies on average values; cannot fully represent individual mandibular dynamics
Patient-specific virtual articulator	Jaw movement analyzer, pantographic/dynamic records, intraoral scans, and facial/CBCT data when available	Allows static and dynamic occlusal contact analysis during mandibular movement	Requires additional hardware, calibration, and technical expertise
Optical systems such as Modjaw or Freecorder BlueFox	Optical tracking of mandibular movement and digital model integration	Can visualize functional movement and support dynamic occlusal mapping	Cost and interoperability vary across systems
CBCT/4D-integrated systems	Radiographic data combined with facial or mandibular tracking data	May support three-dimensional visualization of craniofacial structures and jaw motion	Radiation exposure, hardware requirements, and clinical indications must be justified

CBCT: Cone-beam computed tomography, CAD/CAM: Computer-aided design/computer-aided manufacturing

Table 6. Critical comparison of conventional and digital articulator systems

System	Main advantages	Main limitations	Most relevant indications
Mechanical articulators	Low to moderate cost, familiar protocols, physical handling of casts, compatibility with many laboratory workflows	Limited simulation of dynamic occlusion, potential mounting and material errors, inability to reproduce tissue resilience and tooth mobility	Diagnostic mounting, routine fixed/removable prosthodontics, complete denture tooth arrangement
Semi-adjustable articulators	Practical balance between individualization and efficiency; accepts facebow and eccentric records	Still mechanically simplified; depends heavily on record accuracy	Routine crown/bridge work, removable prostheses, balanced occlusion arrangements
Fully adjustable mechanical articulators	Highest mechanical individualization and compatibility with pantographic records	Complex, time-consuming, costly, and technique-sensitive	Full-mouth rehabilitation, major vertical dimension alteration, complex occlusal analysis
Virtual articulators	Digital storage, visualization, CAD/CAM integration, potential dynamic occlusal analysis, improved communication	Software/hardware cost, interoperability issues, data-entry requirements, dependence on scanner and motion-recording accuracy	Digital prosthodontics, full-arch digital workflows, complex treatment planning, patient education

CAD/CAM: Computer-aided design/computer-aided manufacturing

CONCLUSION

Articulators remain important instruments in prosthodontics because they allow the clinician and technician to evaluate maxillomandibular relationships outside the oral cavity. However, the clinical value of an articulator is determined by the match between device capability, treatment complexity, record accuracy, and clinician experience. Mechanical systems remain suitable for many conventional procedures, while digital facebows, jaw motion analyzers, and virtual articulators provide additional opportunities for three-dimensional visualization and individualized digital restoration design. Current evidence supports a selective rather than universal approach. Simple or mean-value articulators may be adequate for limited procedures, semi-adjustable devices provide a practical standard for routine prosthodontics, and fully adjustable or virtual systems are most justified in complex rehabilitations, vertical dimension changes, and workflows requiring dynamic occlusal analysis. Future improvements in sensor accuracy, software interoperability, and standardized digital record transfer may further increase the role of virtual articulators in routine prosthodontic practice.

ETHICAL DECLARATIONS

Peer Review Process

This manuscript was subject to external peer review.

Conflict of Interest

The authors declare no conflicts of interest related to this study.

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