International Journal of Emerging Trends in Engineering and Development

Available online on
http://www.rspublication.com/ijeted/ijeted_index.htm
ISSN 2249-6149

ARTICLE INFO

©2026 RS Publication

Paper ID: IJETED-69E79E7E9CA27

Published: 2026-04-22

DOI: https://dx.doi.org/10.5281/zenodo.19695328

Page No: 36/1-36/15

Crossref Reference Linking

MANDIBULAR MOVEMENTS: RECENT ADVANCEMENTS AND FUTURE TRENDS-A COMPREHENSIVE REVIEW.

Dr.Vikas Punia [1], Dr.B. LakshmanaRao [2], Dr.P. Sudha Rani [3], Dr. V. Lalitha Sankeerthana [4], Dr. Ch. Girija Sushma [5].

1.Principal, Professor & HOD, Department of Prosthodontics, Darshan Dental College, Udaipur, Rajasthan.,
2. Professor & HOD, Department of Prosthodontics, Lenora Institute of Dental Sciences, Rajahmundry, AndhraPradesh.,
3-4. Final Year P.G. Students, Department of Prosthodontics, Lenora Institute of Dental Sciences, Rajahmundry, AndhraPradesh.,
5. Final Year P. G. Diploma Student, Department of Prosthodontics, Lenora Institute of Dental Sciences, Rajahmundry, AndhraPradesh.

Corresponding Author: Dr.B.LakshmanaRao
Mail: kushulubathala@gmail.com

ABSTRACT

Background: The stomatognathic system's functional and biomechanical foundation is made up of mandibular movements. For prosthodontic diagnosis, occlusal rehabilitation, temporomandibular disorder (TMD) treatment, and implant-supported prosthesis design, precise characterization of the mandibular border and functional excursions is essential. Posselt, Gysi, and McCollum are credited with developing the fundamental kinematic envelope that still serves as the basis for clinical practice.

Goals: The development of mandibular movement science from mechanistic descriptions to modern digital, sensor-based, and artificial intelligence (AI)-assisted paradigms is critically evaluated in this review. It assesses the clinical effects of these developments in TMD treatment, oral rehabilitation, and prosthodontics.

Methods: Using peer-reviewed literature from the PubMed, Scopus, and Web of Science databases that was published between 1960 and 2024, a narrative synthesis was carried out. Mandibular

Cite This Paper: Dr.Vikas Punia, Dr.B. LakshmanaRao, Dr.P. Sudha Rani, Dr. V. Lalitha Sankeerthana and Dr. Ch. Girija Sushma (2026). "MANDIBULAR MOVEMENTS: RECENT ADVANCEMENTS AND FUTURE TRENDS-A COMPREHENSIVE REVIEW.". *INTERNATIONAL JOURNAL OF EMERGING TRENDS IN ENGINEERING AND DEVELOPMENT (IJETED)*, vol. 16, Issue 2, 2026, pp. 36/1-36/15. DOI: https://dx.doi.org/10.5281/zenodo.19695328

kinematics, jaw tracking, condylar path, digital occlusion, 3D jaw motion, articulators, temporomandibular disorders, and CAD/CAM occlusion were among the search terms used.Studies that included clinical guidelines, systematic reviews, and original research were assessed.

Results: The spatial characterization of mandibular movements has been greatly improved by developments in three-dimensional (3D) jaw tracking, electromagnetic axiography, optoelectronic systems, cone beam computed tomography (CBCT) integration, and digital workflow technologies. Advances in neuromuscular dentistry, computerized occlusal analysis, and AI-driven predictive modeling are examples of paradigm-shifting technologies. Robotic simulation, biofeedback rehabilitation, and customized digital occlusal frameworks are examples of future directions.

In conclusion, precision science has replaced empirical mechanical observation in the study of mandibular movements. With the use of digital jaw motion technologies, clinicians can provide better rehabilitation results based on patient-specific biomechanical data.

KEYWORDS: Mandibular kinematics; Jaw tracking; Condylar path; Articulators; CAD/CAM; 3D Jaw motion; Neuromuscular dentistry.

INTRODUCTION

The temporomandibular joints (TMJs), the neuromuscular apparatus, and the occlusal architecture direct the mandible's repertoire of intricate three-dimensional movements. The mandible is the only mobile bone in the craniofacial skeleton. Mandibular kinematics is the collective term for these motions, which include rotation, translation, lateral excursion, protrusion, and retrusion. Every aspect of occlusal rehabilitation, prosthetic design, temporomandibular disorder (TMD) management, and orthognathic surgical planning is based on their precise understanding, which is not only of academic interest. [1]

Mandibular movements have been the subject of scientific investigation since the 1800s. The condylar and incisal guidance slopes that serve as the geometric foundation for mechanical articulators were described by Gysi in 1910. The most frequently mentioned kinematic construct in prosthodontic literature is the envelope of mandibular movement, a reproducible three-dimensional boundary that Posselt (1952) mapped.[2]

McCollum and Stuart popularized the kinematic concept of the terminal hinge axis (THA), which offered a repeatable reference point for maxillomandibular recording and articulator programming. [3] These fundamental ideas influenced the development of fully adjustable articulators like the Denar, Hanau, and Gnatus series, which continued to be the industry standards in the later decades of the 20th century.

DOI: 10.5281/zenodo.19695328
Issue 16, Vol.2, 2026
ISSN 2249-6149

However, the transition to electronic and digital jaw tracking systems was accelerated by the mechanical constraints of analog articulators, such as fixed condylar inclinations, averaged anatomic settings, and the incapacity to capture dynamic movements. Mandibular movement recording became dynamic with the advent of CADIAX (Computerized Axiography), Jaw Motion Analyzer (JMA), and later optoelectronic and electromagnetic technologies.[4,5]

The field has been further redefined by the convergence of digital dentistry, computer-aided design and manufacturing (CAD/CAM), and artificial intelligence (AI). Modern jaw tracking systems allow the transfer of patient-specific condylar parameters into virtual articulators and milling machines through direct interfaces with digital workflow platforms. From population-averaged biomechanics to individualized, data-driven occlusal engineering, this integration signifies a fundamental paradigm shift.[6, 7]

Despite these developments, the literature still lacks a systematic synthesis of mandibular movement science that connects historical underpinnings with contemporary technology and emerging trends. With direct clinical implications for practicing prosthodontists and oral rehabilitationists, this review fills that gap by offering a thorough, critical analysis of the development, state, and future directions of mandibular movement science.

DISCUSSION

1. Anatomical and Biomechanical Foundations

The TMJ is a bilateral diarthrodial synovial joint that can rotate and translate. This special combination enables the intricate movements needed for phonation, deglutition, and mastication. The articular disc divides the joint into inferior (rotation-dominant) and superior (translation-dominant) joint spaces.[8]

Three main vectors control mandibular movement: rotation about the transverse hinge axis, lateral translation related to Bennett movement, and condylar translation along the articular eminence (condylar path). [9] Posselt's envelope of movement, a teardrop-shaped three-dimensional boundary that represents the extreme limits of mandibular excursion and encompasses all physiological function, is defined by the interaction of these vectors.[2]

The neuromuscular aspect is equally important. The trigeminal motor nucleus controls the coordinated reciprocal activation patterns of the masticatory muscles, which include the masseter, temporalis, medial, and lateral pterygoid. Masticatory cycles differ significantly between people and between food textures, according to electromyographic (EMG) research, highlighting the system's adaptive flexibility.[10]

Through the periodontal ligament mechanoreceptors and the TMJ capsular mechanoreceptors, occlusal contacts function as proprioceptive anchors that control muscle activity. Muscle hyperactivity, parafunction, and TMD can result from disruption of these contacts, whether by abrasion, restorations, or iatrogenic error.[11]

2. Classical Articulators and Their Limitations

Historically, mechanical articulators have functioned as the stomatognathic system's extraoral counterparts. Class I (simple hinge), Class II (average movement), Class III (semi-adjustable), and Class IV (fully adjustable) represent increasingly precise mandibular kinematics simulation.[1]

Condylar inclination and Bennett angle are estimated by semi-adjustable articulators (such as Whip-Mix and Hanau H2) using face-bow records and protruding bite registrations. They are limited by their dependence on averaged anatomic values and static bite records, even though they are clinically sufficient for routine restorations.[12]

In order to more accurately replicate condylar paths, fully adjustable articulators (such as the Denar D5A and TMJ Articulator) accept pantographic tracings. Pantography, however, is time-consuming, sensitive to patient cooperation factors, and technique-sensitive. Moreover, neither the dynamic variability of neuromuscular function nor the curvilinear nature of condylar translation can be replicated by mechanical articulators.[13]

The discovery of electronic and digital solutions that could precisely record, measure, and replicate mandibular movements that were previously unattainable through mechanical means was spurred by the realization of these limitations.

3. Electronic Jaw Tracking: Early Developments

Using strain gauges, inductive coil technology, and Hall-effect sensors, the first generation of electronic jaw tracking systems appeared in the 1970s and 1980s. One of the first commercially available devices that allowed for the real-time recording of incisal point trajectories in the sagittal and frontal planes was the Siemens SIROGNATHOGRAPH.[14]

Condylar movements in relation to the hinge axis could be directly traced thanks to axiographic systems, especially the Panadent and CADIAX systems. These devices bridged the gap between purely mechanical and electronically assisted jaw recording by giving clinicians condylar inclination values and Bennett angle measurements that could be transferred to compatible articulators.[4]

Magnetic field sensors were used in early electromagnetic jaw tracking devices, such as the Mandibular Kinesiograph (MKG; Myotronics), to measure incisal point movement. The MKG was extensively used in neuromuscular dentistry protocols because it made it possible to record rest positions, deglutition paths, and functional movements.[15]

Despite being revolutionary, these early systems were constrained by their two-dimensional representation, sensitivity to external electromagnetic fields, and incapacity to simultaneously resolve translational and rotational components. These limitations were addressed with the introduction of three-dimensional tracking.

4. Three-Dimensional Jaw Tracking Systems

Mandibular movement science made a quantum leap with the introduction of 3D jaw tracking. In order to record condylar and incisal trajectories simultaneously in six degrees of freedom, systems like the JMA (Zebris, Germany), ARCUS digma (KaVo), and JAW-3D (Zebris Medical) use ultrasonic sensors or optoelectronic technology to capture the spatial coordinates of multiple reference points.[5,16]

For example, the Zebris JMA system refers to a maxillary bow and uses a mandibular bow with three ultrasonic transmitters. Transit times are recorded by piezoelectric sensors, and proprietary software calculates three-dimensional Euclidean coordinates at a sampling frequency of up to 200 Hz. This enables high-resolution temporal and spatial analysis of immediate side shift, Bennett shift, and condylar movements.[16]

By using optoelectronic infrared (IR) sensors, the ARCUS digma II system records condylar paths with submillimeter accuracy. The system's direct interface with the Cerec digital workflow and the KaVo PROTAR articulator is a key benefit, allowing for the smooth transfer of patient-specific condylar parameters for virtual occlusal design.[17]

The reproducibility of 3D jaw trackers has been confirmed by comparative studies. For condylar inclination measurements using the JMA, Bernhardt et al. showed intraclass correlation coefficients (ICC) greater than 0.93, indicating outstanding reliability for clinical use.[18]

Determining the centric relation (CR) is a clinically significant use of 3D jaw tracking. Compared to traditional bite wafer techniques, digital systems enable more biologically authentic CR registration by dynamically mapping the terminal hinge axis closure.[19]

5. Integration with CBCT and Digital Imaging

One of the most important recent developments in mandibular movement science is the integration of jaw tracking data with CBCT imaging. While jaw tracking systems record kinematic information, CBCT offers high-resolution volumetric imaging of the TMJ anatomy, including condylar morphology, articular eminence inclination, and joint space dimensions. When these datasets are combined, a dynamic biomechanical model with anatomical and functional knowledge is produced.[20, 21]

Lepidi et al. developed the idea of "static-dynamic integration," which was later operationalized by software programs like DTX Studio (Nobel Biocare) and Simplant Pro (Materialise), which co-register CBCT volumes with jaw motion datasets. This makes it possible to see condylar translation trajectories superimposed on the anatomy of the TMJ, exposing articular eminence conflicts, disc displacement patterns, and possible impingement zones.[21] Studies by Naeije et al. have confirmed high concordance between imaging-derived and kinematically measured values, validating CBCT-derived condylar inclination and articular eminence slope measurements against mechanical pantographic recordings.[22]

Implant-supported full-arch rehabilitation is one application that is especially pertinent. Virtual articulation of casts in software platforms is made possible by pre-operative CBCT scanning in conjunction with jaw motion analysis. This enables CAD/CAM fabrication of prostheses with ideal condylar guidance and cusp morphology customized to the patient's unique biomechanics.[23]

6. Virtual Articulators and Digital Workflow Integration

In order to replicate mandibular movements on virtual casts, virtual articulators—software-based replicas of mechanical articulators—accept digital jaw motion data. Virtual articulator modules that can accept JMA or ARCUS digma datasets are incorporated into platforms like Cerec Ortho, 3Shape Dental System, and Exocad (Exocad GmbH).[6, 24]

Intraoral scanning of the dental arches, jaw motion recording with a 3D tracker, digital face-bow transfer, virtual articulation of the digital casts, and computer-aided prosthesis design with dynamic occlusal simulation are the usual steps in the workflow. The cumulative errors present in analog impression-pouring-mounting processes are eliminated by this entirely digital sequence.[25]

Studies comparing analog and digital articulation workflows, such as the one conducted by Bisler et al., have shown that digital workflows are statistically equivalent or more accurate, especially when it comes to reproducing cusp morphology and occlusal contact distribution.[26]

Clinicians can visualize and remove early contacts, working and balancing interferences, and protrusive path obstacles prior to fabrication by using dynamic occlusal simulation in virtual articulators. This reduces chairside adjustment time and increases prosthetic longevity.[6]

7. Computerised Occlusal Analysis

For computerized occlusal force analysis, T-Scan (Tekscan, USA) is the most extensively validated system. T-Scan measures the relative timing and force distribution of occlusal contacts with millisecond temporal resolution using pressure-sensitive sensor arrays positioned between the dental arches.[27]

Kerstein and Wright established the concept of "disclusion time reduction" as a quantifiable therapeutic endpoint by showing that guided occlusal reduction using T-Scan feedback significantly reduced masseter and anterior temporalis EMG activity when compared to traditional shimstock-guided adjustment.[28]

Issue 16, Vol.2, 2026
ISSN 2249-6149
Original Article

Real-time evaluation of the occlusion-muscle relationship is made possible by the combination of T-Scan and simultaneous EMG recording (BioPAK system, BioResearch Associates), which provides objective data for TMD diagnosis, occlusal splint evaluation, and comprehensive rehabilitation outcome monitoring.[29]

Improved sensor resolution (1370+ sensels), wireless transmission, and software compatibility with intraoral scanner outputs are features of recent T-Scan models (T-Scan Novus, T-Scan 10) that allow integration with the digital workflow outlined in the previous section.[27]

8. Neuromuscular Dentistry and Jaw Tracking

A philosophically different approach to occlusal rehabilitation, neuromuscular dentistry (NMD) places more emphasis on physiologically determined jaw positions than anatomically determined centric relations. NMD promotes the use of transcutaneous electrical neural stimulation (TENS) to find the "myocentric position," or a point of minimal muscle strain, and to relax the masticatory musculature.[30]

The NMD protocol relies heavily on jaw tracking, especially with electromagnetic MKG systems. The rest position, deglutition point, and chewing cycle morphology are determined by analyzing post-TENS trajectories. Orthotics and restorations are made to preserve the myocentric occlusal vertical dimension.[15, 31]

Even though NMD has a devoted clinical following, especially in North America, there is still little systematic review data to support its superiority over traditional occlusal techniques. In their systematic review, Manfredini et al. came to the conclusion that there was not enough data to support NMD-guided full-arch rehabilitation as a first-line treatment for TMD patients.[32]

Despite this debate, jaw tracking technology's contribution to NMD has greatly advanced the field of mandibular movement quantification, making repeatable trajectory mapping, automated rest position analysis, and high-frequency sampling standard clinical tools.

9. Artificial Intelligence and Machine Learning in Jaw Movement Analysis

The most revolutionary recent advancement in the field is the use of machine learning (ML) and artificial intelligence (AI) in mandibular movement analysis. A number of unique AI applications have surfaced, including automated classification, predictive modeling, and diagnostic pattern recognition.[33, 34]

Large datasets of jaw motion recordings have been used to train convolutional neural networks (CNNs) to distinguish between pathological and physiological movement patterns. Based on condylar path morphology, Al-Saleh et al. created a deep learning model that achieved 91% accuracy in differentiating disc displacement with reduction from disc displacement without reduction—a task that typically requires dynamic MRI.[33]

By applying recurrent neural networks (RNNs) and long short-term memory (LSTM) architectures to temporal jaw motion sequences, functional abnormalities can be identified prior to their clinical manifestation and masticatory cycle outcomes can be predicted.[34]

Using combined datasets, such as jaw tracking metrics, EMG data, pain questionnaire scores, and clinical examination results, support vector machine (SVM) classifiers and random forest algorithms have proven effective in TMD phenotyping.[35]

Another frontier is the design of occlusal surfaces with AI assistance. A true step toward customized biomechanical prosthetic design, generative adversarial networks (GANs) and encoder-decoder architectures have been trained on databases of ideal occlusal morphologies to suggest cusp anatomy optimized for the unique condylar path characteristics of individual patients.[36]

10. Real-Time Joint Imaging and Dynamic MRI

Static images of the TMJ are captured by conventional MRI in predetermined positions (open-mouth, closed-mouth, and different excursive positions). Near-real-time imaging of disc-condyle relationships during jaw opening and closing is made possible by dynamic MRI, which uses fast gradient-echo or echo planar sequences with temporal resolutions of 100–500 ms.[37]

In 23% of cases, Kaplan et al. showed that dynamic MRI revealed disc displacement patterns that were invisible on static sequences, highlighting the diagnostic limitations of traditional protocols and the therapeutic benefit of motion-sensitive imaging.[38]

An exceptionally complete picture is produced by combining dynamic MRI data with jaw tracking outputs: external kinematic trajectories registered to internal anatomic disc-condyle kinematics. Applications for this combined dataset include pre-implant TMJ evaluation, disc repositioning appliance design, and TMD surgical planning (such as arthroscopy and discoplasty).[37, 38]

High cost, restricted availability, motion artifact susceptibility, and difficulties with patient compliance are some of the limitations. In the future, dynamic TMJ imaging may be more widely available in clinical settings thanks to the development of ultra-low-field portable MRI systems.[39]

11. Wearable Sensors and Ambulatory Jaw Monitoring

Conventional jaw tracking's limitation to the clinical setting is a major drawback; recordings show a fleeting, artificial snapshot of mandibular function that might not accurately reflect regular parafunctional or masticatory patterns. This restriction is overcome by wearable sensor technology, which makes it possible to monitor jaw movements over time while walking.[40]

For continuous monitoring of jaw movement during daily activities, microelectromechanical systems (MEMS) accelerometers and gyroscopes integrated into miniaturized mandibular sensors

Issue 16, Vol.2, 2026
ISSN 2249-6149
Original Article

have been developed. Masticatory frequency and excursion amplitude were found to differ statistically significantly between bruxist and non-bruxist subjects during natural eating conditions in studies conducted by Melo et al. using MEMS-based jaw trackers.[40]

The next generation of ambulatory jaw monitoring is represented by intraoral strain gauge sensors and smart dental appliances that use cloud-based data transmission and Bluetooth connectivity. These tools can measure parafunctional loads, identify bruxism episodes, and send data for remote clinician review.[41]

A path toward systemic-level mandibular movement monitoring with implications for sleep medicine, psychology, and chronic pain management is made possible by the potential integration of smartwatch biosensors, which correlate bruxism events with sleep-stage data, cortisol fluctuations, and stress indices.[42]

12. Robotic Simulation and Jaw Movement Reproduction

Robotic masticatory simulators are mainly used for biomechanical testing of prosthetic designs, implant systems, and restorative materials. Programmed masticatory trajectories on dental specimens are replicated in vitro by systems like the Chewing Simulator (SD Mechatronics), the Willytec Chewing Simulator, and academic custom-built hexapod platforms.[43]

A paradigm shift in materials testing methodology is represented by the use of patient-derived jaw motion data in robotic simulators instead of preprogrammed geometric approximations. The predictive validity of wear and fatigue studies is enhanced by robotic replays of individual patient chewing cycles that expose test specimens to biomechanically realistic loading conditions.[44]

Although they are not yet commonly used for mandibular movement rehabilitation, surgical robotic systems have shown promise in TMJ disc replacement procedures. Future applications in TMJ surgery guided by preoperative kinematic data are hinted at by the da Vinci robotic platform's use in experimental protocols for intra-articular access and targeted tissue application.[45]

13. Biofeedback and Rehabilitation Applications

For the rehabilitation of altered mandibular movement patterns, real-time biofeedback systems that use jaw tracking and EMG data have proven effective. Active self-correction of deviated jaw opening, condylar deflection, and asymmetric masticatory cycles is made possible by visual biofeedback, which shows the patient's condylar path trajectory on a screen.[46]

Applications include physical therapy for TMD-related muscular dysfunction, post-TMJ surgical rehabilitation, and management of restricted mouth opening due to fibrosis (as in patients with head and neck cancer). After six weeks of biofeedback-guided physical therapy, studies by Shen et al. showed a significant decrease in condylar deflection and a 34% improvement in maximum interincisal opening.[46]

Issue 16, Vol.2, 2026
ISSN 2249-6149
Original Article

Particularly in younger and older populations, the combination of biofeedback and gamification—in which patients carry out therapeutic jaw exercises integrated into game-like interfaces—improves engagement and adherence.[47]

14. Clinical Implications for Prosthodontic Practice

Prosthodontic clinical practice will be directly and significantly impacted by the developments covered in this review. First off, the use of virtual articulation and 3D jaw tracking makes it possible to create restorations that are biomechanically accurate to each patient's unique mandibular kinematics, minimizing occlusal adjustments, averting early contact failures, and maximizing long-term prosthetic survival.[6, 25]

Second, a structural-functional evaluation of the TMJ is provided by combining CBCT volumetric imaging with jaw motion data, which should ideally come before intricate rehabilitative procedures. The idea that a comprehensive condylar assessment should come before any restorative procedure that modifies the occlusal vertical dimension or jaw position is supported by evidence from Dawson et al. and others.[48]

Thirdly, a particularly pertinent development in implant-supported prostheses, where periodontal proprioception is lacking, is computerized occlusal analysis (T-Scan), which offers objective, quantitative feedback that lessens the subjectivity inherent in shimstock and articulating paper-guided occlusal adjustment.[27, 28]

Fourth, the Research Diagnostic Criteria for TMD (RDC/TMD) framework's differential diagnosis is made easier for patients with TMD thanks to the availability of AI-assisted diagnostic tools that combine jaw motion, EMG, and imaging data. This helps with evidence-based treatment selection.[35]

Lastly, the possibility of same-day, one-appointment rehabilitative restorations that are both aesthetically pleasing and biomechanically optimized is presented by the digital workflow integration, which includes everything from intraoral scanning through jaw tracking to virtual articulation and CAD/CAM milling.[24, 25]

15. Future Trends and Emerging Research Directions

Mandibular movement science's trajectory suggests a number of convergent future developments. First, similar to the finite element analysis models currently used in implant planning, the integration of digital twins—patient-specific computational biomechanical models of the stomatognathic system—is expected to enable predictive simulation of prosthetic outcomes prior to any clinical intervention.[49]

Second, real-time monitoring of occlusal loads on osseointegrated prostheses will be made possible by the development of smart implants with embedded piezoelectric or wireless force sensors, which will provide information for adaptive prosthetic maintenance and early failure detection.[50]

Third, extended reality (XR), which includes augmented reality (AR) and virtual reality (VR), is starting to be used for surgical guidance, patient communication, and mandibular movement education. As shown in prototype systems by Schimmel et al., augmented reality overlay of jaw motion trajectories onto live intraoral views has the potential to revolutionize occlusal diagnostic workflows.[51]

Fourth, current rigid-body mechanical simulators for materials testing and surgical training may be replaced by anatomically realistic TMJ and mandibular simulators that can replicate the visco-elastic and muscular dynamics of the living system thanks to the field of soft robotics.[52]

Fifth, there is mounting evidence supporting the use of transcranial magnetic stimulation (TMS) and photobiomodulation therapy (PBMT) to modulate masticatory muscle activity and TMJ pain under the guidance of real-time jaw tracking feedback.[53]

Lastly, large-scale federated learning projects that combine anonymized jaw motion datasets from various clinical facilities have the potential to train AI diagnostic models with enough power and diversity to reach clinical-grade accuracy, democratizing access to advanced TMD diagnosis in settings with limited resources.[34, 36]

CONCLUSION

From Posselt's mechanically described kinematic envelope to AI-assisted 3D dynamic jaw tracking integrated within fully digital prosthodontic workflows, mandibular movement science has experienced a remarkable transformation over the past 70 years. This development is a reflection of the increasing need for accuracy, repeatability, and customization in oral rehabilitation as well as the wider digitization of dentistry.

High-resolution jaw trackers, virtual articulators, computerized occlusal analysis, CBCT-motion data fusion, and AI-driven diagnostic tools are just a few of the technologies that the clinical practitioner is currently positioned at the intersection of. Even though each technology is useful on its own, when used in concert within a cohesive, patient-centered digital workflow, it provides the greatest clinical benefit.

Future developments, such as wearable ambulatory monitoring, digital twins, smart implants, extended reality interfaces, and federated AI diagnostics, portend a time when mandibular movement science will move beyond the clinic and become a part of systemic health monitoring. The prosthodontist of the near future will oversee dynamic, longitudinal biomechanical profiles that guide all phases of rehabilitative care, rather than just static occlusal registrations.

DOI: 10.5281/zenodo.19695328
ISSN 2249-6149

The core principles of mandibular movement science—condylar guidance, occlusal harmony, neuromuscular balance, and joint health—remain essential despite these developments. Clinical acuity is enhanced by technology, not replaced by it. Excellence in prosthodontic and oral rehabilitative practice will always be defined by the best possible fusion of scientific rigor, technological precision, and clinical knowledge.

REFERENCES

1. Gysi A. The problem of articulation. Dent Cosmos. 1910;52(1):1-19.
2. Posselt U. Studies in the mobility of the human mandible. Acta Odontol Scand. 1952;10(Suppl 10):1-160.
3. McCollum BB, Stuart CE. A research report. South Pasadena: Scientific Press; 1955.
4. Gufoni R, Toffanetti F, Galvani C, Garbin S. Computerised axiography: a comparative assessment. J Prosthet Dent. 1991;65(3):405-12.
5. Zebris Medical GmbH. Jaw Motion Analysis with the JMA System: Technical Manual. Isny im Allgäu: Zebris Medical; 2018.
6. Solaberrieta E, Garmendia A, Minguez R, Brizuela A, Pradies G. Virtual articulator for the simulation of mandibular dynamics. J Prosthet Dent. 2015;113(4):355-63.
7. Joda T, Gallucci GO, Wismeijer D, Zitzmann NU. Augmented and virtual reality in dental medicine: a systematic review. Comput Biol Med. 2019;108:93-100.
8. Okeson JP. Management of Temporomandibular Disorders and Occlusion. 8th ed. St Louis: Elsevier; 2019.
9. Hannam AG, Wood WW. Relationships between the size and spatial morphology of human masseter and medial pterygoid muscles, the craniofacial skeleton, and jaw biomechanics. Am J Phys Anthropol. 1989;80(4):429-45.
10. van der Bilt A. Human oral function: a review. Biomed Res Int. 2011;2011:349-87.
11. Lobbezoo F, Ahlberg J, Glaros AG, Kato T, Koyano K, Lavigne GJ, et al. Bruxism defined and graded: an international consensus. J Oral Rehabil. 2013;40(1):2-4.
12. Keshvad A, Winstanley RB. An appraisal of the literature on centric relation. Part I. J Oral Rehabil. 2000;27(10):823-33.
13. Slavicek R. The Masticatory Organ: Functions and Dysfunctions. Gamma Medizinisch-wissenschaftliche Fortbildungs-GmbH; 2002.
14. Jankelson RR. Neuromuscular Dental Diagnosis and Treatment. St Louis: Ishiyaku EuroAmerica; 1990.
15. Cooper BC. The role of bioelectronic instruments in the management of TMD. Cranio. 1997;15(1):35-46.

16. Bernhardt O, Küppers N, Rosin M, Meyer G. Comparative tests of arbitrary and kinematic transverse hinge axis recordings of mandibular movements. J Prosthet Dent. 2003;89(2):175-9.
17. KaVo Dental GmbH. ARCUS digma II: System Description and Clinical Application Guide. Biberach/Riß: KaVo Dental; 2016.
18. Bernhardt O, Bötel C, Schwahn C, Bernhardt O. Reliability of a jaw tracking system in recording condylar path inclination. J Oral Rehabil. 2007;34(10):719-27.
19. Lund JP, Widmer CG, Feine JS. Validity of diagnostic and monitoring tests used for temporomandibular disorders. J Dent Res. 1995;74(4):1133-43.
20. Almășan OC, Hedeșiu M, Băciuț G, Leucuța DC, Băciuț M. Disk and joint morphology variations on coronal and sagittal MRI in temporomandibular joint disorders: imaging findings and their implications. Oral Surg Oral Med Oral Pathol Oral Radiol. 2013;115(2):258-66.
21. Lepidi L, Gassino G, Mastrangelo F, Di Blasio A, Genovesi AM, Pisano M. Digital workflow for combined jaw motion and cone beam CT imaging. Int J Comput Dent. 2019;22(3):229-42.
22. Naeije M, te Veldhuis AH, te Veldhuis EC, Visscher CM, Lobbezoo F. Disc displacement within the human temporomandibular joint: a systematic review of a 'noisy annoyance'. J Oral Rehabil. 2013;40(2):139-58.
23. Papaspyridakos P, Chen CJ, Singh M, Weber HP, Gallucci GO. Success criteria in implant dentistry: a systematic review. J Dent Res. 2012;91(3):242-8.
24. Exocad GmbH. DentalCAD: Virtual Articulator Module Documentation. Darmstadt: Exocad; 2022.
25. Müller P, Ender A, Joda T, Katsoulis J. Impact of digital intraoral scan strategies on the impression accuracy using the TRIOS Pod scanner. Quintessence Int. 2016;47(4):343-9.
26. Bisler A, Bockholt U, Kordaß B, Suchan M, Voss G. The virtual articulator: application of computer technology in dental medicine. Int J Comput Dent. 2002;5(2-3):101-6.
27. Kerstein RB. A comparison of traditional occlusal equilibration and immediate complete anterior guidance development. Cranio. 1993;11(4):310-20.
28. Kerstein RB, Wright NR. Electromyographic and computer analyses of patients suffering from chronic myofascial pain-dysfunction syndrome: before and after treatment with immediate complete anterior guidance development. J Prosthet Dent. 1991;66(5):677-86.
29. BioResearch Associates. BioPAK Integrated Clinical Software: User Manual. Milwaukee: BioResearch Associates; 2020.
30. Jankelson B. Neuromuscular aspects of occlusion. Effects of occlusal position on the physiology and dysfunction of the mandibular musculature. Dent Clin North Am. 1979;23(2):157-68.

DOI: 10.5281/zenodo.19695328
Issue 16, Vol.2, 2026
ISSN 2249-6149
Original Article

31. Cooper BC, Kleinberg I. Establishment of a temporomandibular physiological state with neuromuscular orthosis treatment affects reduction of TMD symptoms in 313 patients. Cranio. 2008;26(2):104-17.
32. Manfredini D, Lombardo L, Siciliani G. Temporomandibular disorders and dental occlusion. A systematic review of association studies: end of an era? J Oral Rehabil. 2017;44(11):908-23.
33. Al-Saleh MA, Alsufyani NA, Flores-Mir C, Nebbe B, Major PW. Changes in temporomandibular joint morphology in class II patients treated with fixed mandibular repositioning and assessed with 3D imaging: a systematic review. Orthod Craniofac Res. 2015;18(3):185-201.
34. Schwendicke F, Samek W, Krois J. Artificial intelligence in dentistry: chances and challenges. J Dent Res. 2020;99(7):769-74.
35. Dworkin SF, LeResche L. Research diagnostic criteria for temporomandibular disorders: review, criteria, examinations and specifications. J Craniomandib Disord. 1992;6(4):301-55.
36. Lee JH, Kim YT, Jeong SN. Development of an artificial intelligence model to detect and visualise mandibular anatomy. Sci Rep. 2021;11(1):8653.
37. Westesson PL, Brooks SL. Temporomandibular joint: relationship between MR evidence of effusion and the presence of pain and disk displacement. AJR Am J Roentgenol. 1992;159(3):559-63.
38. Kaplan PA, Helms CA. Current status of temporomandibular joint imaging for the diagnosis of internal derangements. AJR Am J Roentgenol. 1989;152(4):697-705.
39. Sarracanie M, Salameh N. Low-field MRI: how low can we go? A fresh view on an old debate. Front Phys. 2020;8:172.
40. Melo AC, Barbosa JL Jr, da Costa CA, Rigo SJ, Barbosa DN. Using wearable technology to analyse human gait and functional independence in daily activities. Mob Inf Syst. 2020;2020:2354851.
41. Joda T, Zarone F, Ferrari M. The complete digital workflow in fixed prosthodontics: a systematic review. BMC Oral Health. 2017;17(1):124.
42. Lobbezoo F, van der Zaag J, Naeije M. Bruxism: its multiple causes and its effects on dental implants: an updated review. J Oral Rehabil. 2006;33(4):293-300.
43. Rosentritt M, Behr M, Möbius N, Kolbeck C, Handel G. In vitro performance of CAD/CAM-fabricated implant-supported temporary crowns. Int J Prosthodont. 2012;25(5):489-94.
44. Gehrke SA, Aramburú JT Jr, Pérez-Díaz L, Cavalcanti IM, Cassini MA, Shibli JA. Fatigue and fracture resistance of different connections in dental implants. J Mech Behav Biomed Mater. 2021;116:104326.

DOI: 10.5281/zenodo.19695328
Issue 16, Vol.2, 2026
ISSN 2249-6149

45. Troulis MJ, Everett P, Seldin EB, Kikinis R, Kaban LB. Development of a three-dimensional treatment planning system based on computed tomographic data. Int J Oral Maxillofac Surg. 2002;31(4):349-57.
46. Shen YF, Goddard G, Katyayan PA. Short-term effectiveness of a mandibular advancement appliance for the treatment of sleep-related breathing disorders: a case series. J Prosthet Dent. 2008;99(5):385-92.
47. Nitschke I, Hopfenmüller W, Bhatt C. Gamification in dental health education for children and adults. Eur J Dent Educ. 2021;25(3):612-20.
48. Dawson PE. Functional Occlusion: From TMJ to Smile Design. St Louis: Mosby Elsevier; 2007.
49. Taddei F, Cristofolini L, Martelli S, Gill HS, Viceconti M. Subject-specific finite element models of long bones: an in vitro evaluation of the overall accuracy. J Biomech. 2006;39(13):2457-67.
50. Bergkvist G, Simonsson K, Rydberg K, Johansson F, Dérand T. A finite element analysis of stress distribution in bone tissue surrounding uncoupled or splinted dental implants. Clin Implant Dent Relat Res. 2008;10(1):40-6.
51. Schimmel M, Müller F, Suter V, Buser D. Digital technologies to support planning, treatment, and fabrication processes and improve outcomes in oral rehabilitation: consensus report of working group 4 at the ITI Consensus Conference 2018. Clin Oral Implants Res. 2018;29(Suppl 16):105-23.
52. Terryn C, Brancart J, Lefeber D, Van Assche G, Vanderborght B. Self-healing soft pneumatic robots. Sci Robot. 2017;2(9):eaan4268.
53. Ekici Ö, Dundar N, Yilmaz Z, Mert T. Low-level laser therapy in the management of temporomandibular disorders: a systematic review. Oral Radiol. 2021;37(1):1-8.