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Review Article

From static to dynamic prosthodontics: digital recording of mandibular function for personalized prosthetic rehabilitation

Rohit Raghavan, Shajahan P. A., Shaman Shalu S. B.*

Department of Prosthodontics, Royal Dental College, Palakkad, Kerala, India

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***Correspondence:**
Dr. Shaman Shalu S. B.,
E-mail: shamanshalu65@gmail.com

ABSTRACT

Conventional prosthodontic diagnosis and treatment planning rely extensively on static records such as diagnostic casts, maxillomandibular relationship records, facebow transfers, interocclusal records, and mechanical articulators. Although these methods remain clinically valuable, they provide only a limited representation of the continuously changing relationship between the maxilla, mandible, temporomandibular joints, dentition, and neuromuscular system. Advances in digital dentistry have enabled the acquisition of three-dimensional anatomical information together with patient-specific mandibular movement. Intraoral scanning, facial scanning, cone-beam computed tomography, digital maxillomandibular registration, optical jaw tracking, computerized occlusal analysis, and virtual articulation can now be combined to develop increasingly comprehensive digital representations of the prosthodontic patient. Incorporating movement into a three-dimensional virtual patient introduces a fourth dimension-time-and provides an opportunity to evaluate prosthetic designs under dynamic rather than purely static conditions. This transition may be particularly relevant to complete dentures, implant-supported prostheses, and extensive restorative rehabilitation. However, differences among acquisition systems, registration errors, limited standardization, equipment costs, and insufficient long-term clinical evidence currently restrict widespread implementation. This narrative review discusses the evolution from static to dynamic prosthodontic records, contemporary technologies for recording mandibular function, their integration with virtual articulation, and their potential contribution to personalized prosthetic rehabilitation. Emerging concepts including four-dimensional virtual patients, artificial intelligence-assisted movement analysis, and functional digital twins are also considered.

Keywords: Digital prosthodontics, Mandibular movement, Jaw tracking, Virtual articulator, Dynamic virtual patient, Personalized prosthodontics

INTRODUCTION

Prosthodontic rehabilitation has traditionally depended on the accurate reproduction of oral structures and maxillomandibular relationships. Conventional impressions, diagnostic casts, occlusion rims, jaw-relation records, facebow transfers, and articulators provide representations of the patient's anatomy and selected mandibular positions. These records remain fundamental to diagnosis, treatment planning, tooth arrangement, occlusal adjustment, and fabrication of definitive prostheses.

However, most conventional prosthodontic records are essentially static. A cast represents anatomy at a particular point in time, while an interocclusal record captures a specific maxillomandibular position. A facebow transfers the spatial position of the maxillary arch to an articulator, which subsequently reproduces selected mandibular movements according to its mechanical design and programmed parameters. The biological mandible, in contrast, continuously changes its relationship with the maxilla during opening, closing, protrusion, lateral excursion, speech, swallowing, and mastication.

Digital prosthodontics initially addressed this limitation by converting conventional anatomical information into three-dimensional digital records. Intraoral scanners produce digital representations of dental surfaces, facial scanners capture extraoral morphology, and cone-beam computed tomography (CBCT) provides three-dimensional information regarding dental and craniofacial structures. These datasets can be integrated within the virtual articulators and computer-aided design environments.[1]

The next stage of this development is the incorporation of function. Jaw-tracking systems can record mandibular trajectories, while computerized occlusal analysis can provide information about the sequence and relative distribution of occlusal contacts. When these functional datasets are combined with intraoral scans, facial scans, CBCT and maxillomandibular records, the resulting model extends beyond a static digital patient.

The concept of a four-dimensional virtual patient has emerged from this integration. Zambrana et al described a workflow in which computed tomography data were combined with intraoral surface scans and video-based mandibular movement tracking to incorporate mandibular kinematics into a static virtual patient.[2] Subsequently, Lepidi et al described a more comprehensive 4D workflow integrating intraoral scanning, CBCT, extraoral scanning, digital facebow information, virtual articulation and jaw-tracking data.[3]

The significance of this transition is not simply that digital technology can reproduce mandibular movement. It creates the possibility of incorporating individual functional behavior into prosthetic design**.**

The progression can therefore be conceptualized as: Static record → three-dimensional virtual patient → dynamic virtual patient → functional digital twin.

This narrative review discusses the transition from static to dynamic prosthodontics, evaluates current methods of recording mandibular function, examines their integration with virtual articulation and considers their potential role in personalized prosthetic rehabilitation.

EVOLUTION FROM STATIC TO DYNAMIC PROSTHODONTIC RECORDS

Conventional static records

Conventional prosthodontics uses a combination of anatomical and functional records to reproduce the patient's occlusion. Impressions reproduce oral surfaces, casts reproduce morphology, and jaw-relation records establish the spatial relationship between the arches. Facebows provide a craniofacial reference for mounting the maxillary cast, while articulators simulate selected mandibular movements.

These methods have several established advantages, including accessibility, familiarity, and extensive clinical experience. Their limitation is that functional information is generally obtained at selected positions rather than continuously recorded throughout movement.

Two patients may therefore demonstrate similar maximum intercuspation while exhibiting different mandibular trajectories, condylar pathways or occlusal contact sequences.

The increasing use of digital technologies has created the possibility of preserving this individual functional information as part of the patient's digital record.

Three-dimensional digital patients

A digital patient may incorporate intraoral scans, facial scans, CBCT, photographs and maxillomandibular records. Virtual articulation allows digital casts to be positioned and evaluated within a computer-generated environment. Virtual articulators have been investigated for both static and dynamic occlusal analysis and may provide efficient visualization of dental relationships.[1]

However, a conventional virtual patient remains predominantly static. It describes where structures are, rather than how they move**.**

This distinction provides the conceptual basis for dynamic prosthodontics.

Mandibular movement as the fourth dimension

The mandible performs combined rotational and translational movements through the temporomandibular joints. Border movements such as protrusion, retrusion, lateral excursions and opening provide reproducible trajectories, while functional movements such as mastication involve more complex and variable patterns.

A three-dimensional digital model can reproduce the spatial relationship between anatomical structures but cannot, by itself, describe their movement through time.

When temporal information is added, the model becomes four-dimensional.

Zambrana et al demonstrated that mandibular kinematics could be incorporated into a virtual patient by merging CBCT data, intraoral scans and target-tracking video of mandibular movement.[2] The workflow was designed as a relatively cost-effective approach using open-source software, with patient-specific movement parameters capable of being exported for individualization of virtual or conventional articulators.

Lepidi et al subsequently described a 4D virtual-patient workflow in which intraoral scanning, CBCT, extraoral scanning, digital facebow information and jaw tracking were superimposed to introduce space-time information into the virtual patient.[3]

Thus, the fourth dimension does not merely provide another visual display. It allows the prosthodontist to examine the relationship between anatomy and movement.

DIGITAL TECHNOLOGIES FOR RECORDING MANDIBULAR FUNCTION

Jaw-tracking systems

Jaw-tracking systems are central to the development of dynamic prosthodontics. They record the relative movement between the maxilla and mandible and generate digital representations of mandibular trajectories.

Available systems use different technologies, including optical, electromagnetic and ultrasonic approaches. The principles differ, but the objective is to obtain reproducible information about mandibular movement that can subsequently be integrated with digital anatomical records.

Optical systems commonly use cameras to detect reference markers attached to the maxillary and mandibular components. The relative movement between these reference frames can then be reconstructed computationally.

A technique described by Revilla-León et al. demonstrated digital recording of maximum intercuspation, centric occlusion and mandibular movement using an optical jaw-tracking system. The movement information was subsequently incorporated into the three-dimensional virtual patient.[4]

This represents an important change from conventional records because the clinician is no longer restricted to recording the endpoint of movement.

Accuracy of jaw tracking

The usefulness of a jaw-tracking system depends on the accuracy and repeatability of its measurements. Grande et al. evaluated a novel optical jaw-tracking system in healthy participants performing protrusive and lateral mandibular movements. The authors identified measurable variations in repeated recordings and emphasized the importance of assessing repeatability when movement data are intended for functional digital modeling.[5]

Different tracking technologies may also produce different measurements. Gu et al compared an ultrasonic jaw-tracking system with a conventional electronic tracking system and found comparable measurements for several parameters, although differences were observed in Bennett-angle measurements. The ultrasonic system was also rated more favorably for comfort and ease of the use.[6]

These findings illustrate an important principle: digital movement data should not automatically be assumed to be interchangeable between systems.

The choice of tracking technology, calibration, reference frame, marker stability, patient cooperation and software processing can influence the resulting digital movement record.

A 2026 systematic review of jaw-motion tracking systems identified 20 studies and reported promising accuracy and clinical utility, particularly for optical systems, but also highlighted methodological heterogeneity, small samples and a lack of long-term evaluation.[7]

Therefore, jaw tracking currently represents a promising technology rather than a universally standardized clinical procedure.

Digital maxillomandibular relationship

The maxillomandibular relationship is fundamental to prosthodontic treatment. In edentulous patients, establishing this relationship is particularly challenging because natural tooth contacts are absent.

Li et al investigated a direct digital method for determining and recording the maxillomandibular relationship in edentulous patients using a custom jaw-movement tracking system. The investigators analyzed habitual opening and closing trajectories and used the repeatable characteristics of these trajectories to establish a digital relationship. Although the technique demonstrated feasibility, the authors concluded that its accuracy required further improvement.[8]

This approach is conceptually different from simply replacing a conventional jaw-relation record with a digital one. It attempts to use the patient's movement pattern itself as a source of information.

This could be particularly relevant to complete denture prosthodontics, where the final prosthesis must function without natural tooth guidance.

However, movement data should be interpreted within the clinical context. Mandibular trajectories can be influenced by neuromuscular control, patient cooperation, pain, fatigue and the recording protocol. Consequently, dynamic records should complement rather than replace conventional clinical assessment.

Virtual articulation

Virtual articulators represent the digital extension of conventional articulators. Their capabilities range from simple digital mounting to simulation of individualized mandibular movements.

A comprehensive review by Doshi et al described the development and applications of virtual articulators and emphasized their potential for analyzing static and dynamic occlusal interactions.[9] Lepidi et al similarly reviewed virtual mounting procedures and highlighted differences in data-acquisition methods, reference systems and digital workflows.[1]

The distinction between digital and personalized articulation is important. A virtual articulator programmed using average values remains based on generalized assumptions. In contrast, a virtual articulator incorporating recorded mandibular movement can potentially reproduce an individual's functional pathway.

A recent systematic review directly comparing static and dynamic virtual articulation with conventional articulators found that virtual articulation demonstrated accuracy comparable to conventional articulation for static occlusion. However, evidence for dynamic occlusal simulation was less conclusive, and further refinement was considered necessary.[10]

Therefore, the current evidence supports virtual articulation as a promising tool, but does not justify assuming that dynamic virtual articulation is already clinically superior to conventional articulation.

Computerized occlusal analysis

Jaw tracking describes how the mandible moves, whereas computerized occlusal analysis provides information about how and when occlusal contacts occur.

Conventional articulating paper remains widely used, but it primarily provides a visual indication of contact locations. Computerized systems such as T-Scan provide time-dependent information and relative force distribution.

A systematic review by Chowdhary and Sonnahalli evaluated the clinical applications of T-Scan and reported evidence supporting its ability to measure relative occlusal contact forces and the temporal sequence of contacts across several dental disciplines.[11]

In implant prosthodontics, Aradya et al reviewed studies involving T-Scan assessment of implant-supported prostheses. Their review included 17 studies involving 359 patients and 1,126 implants and concluded that T-Scan could provide useful information regarding occlusal force, contact timing and localization.[12]

The distinction among these approaches is clinically useful: articulating paper primarily indicates where contacts occur; computerized occlusal analysis adds information about when contacts occur and their relative distribution; and jaw tracking records how the mandible moves during the process. Integrating these datasets could therefore provide a more comprehensive representation of dynamic occlusion than any individual technology.

Articulating paper where contacts occur. Computerized occlusal analysis when contacts occur and their relative distribution; and jaw tracking: how the mandible moves during the process.

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The dynamic virtual patient

The dynamic virtual patient is the central concept of contemporary functional digital prosthodontics.

A conventional virtual patient may incorporate intraoral scans, facial scans, CBCT data, digital photographs and maxillomandibular records. A dynamic virtual patient extends this representation by adding mandibular trajectories, temporal movement information, functional occlusal pathways and, where available, computerized occlusal data.

The workflow described by Revilla-León et al demonstrated integration of digital maxillomandibular relationships and mandibular motion using optical jaw tracking.[4] Zambrana et al demonstrated the integration of mandibular kinematics with CBCT and intraoral surface data.[2] Lepidi et al subsequently demonstrated a broader 4D virtual-patient workflow incorporating multiple digital datasets and jaw tracking.[3]

This changes the fundamental question from where the patient's mandible is to how that mandible moves within the prosthetic environment. That distinction provides the foundation for personalized dynamic prosthodontics.

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CLINICAL APPLICATIONS

Complete denture prosthodontics

Complete denture treatment may benefit particularly from individualized functional information. In an edentulous patient, the absence of periodontal receptors and natural occlusal contacts changes the neuromuscular environment in which the prosthesis functions.

Digital workflows have increasingly incorporated mandibular movement into complete denture fabrication. Wang et al described a fully digital technique for replicating treatment dentures in which the treatment denture was digitally duplicated, jaw relations were transferred to a virtual articulator, and mandibular motion tracks were used for dynamic occlusal adjustment.[13]

A more recent 2026 technique integrated facial scanning and dynamic mandibular tracking into CAD/CAM complete denture fabrication. In this workflow, jaw tracking recorded intercuspal position and mandibular excursions, while the recorded functional envelope was used to guide occlusal morphology. Facial scanning provided additional information for esthetic orientation.[14]

This is an important development because it combines two traditionally separate aspects of denture fabrication: facial information for esthetics and mandibular movement for function.

The potential workflow can therefore be described as a sequence in which facial and intraoral scans, the maxillomandibular relationship and mandibular tracking are integrated to define a virtual functional envelope that can guide individualized tooth arrangement and dynamic occlusal adjustment.

Although promising, the current evidence largely consists of technical and clinical workflow reports. Whether these methods consistently reduce adjustment appointments or improve long-term patient outcomes remains to be established.

Implant prosthodontics

Dynamic digital records may also have applications in implant-supported rehabilitation. Because osseointegrated implants do not possess a periodontal ligament, implant-supported prostheses function under a different biomechanical and sensory environment from natural teeth.

Computerized occlusal analysis can be used to evaluate contact timing and relative force distribution.[12] Jaw tracking can add information about the mandibular pathway during excursions.

A potential digital implant workflow can integrate CBCT-based implant planning, intraoral scanning, facial reference data, jaw tracking, virtual articulation, dynamic occlusal assessment and CAD/CAM prosthetic design.

Such integration may be particularly useful in extensive implant rehabilitation where multiple restorations must function within the patient's individual movement pattern.

However, current evidence does not establish that dynamic digital recording improves implant survival or prosthesis longevity. The principal current value is the additional diagnostic and planning information it can provide.

Full-mouth rehabilitation

Full-mouth rehabilitation requires coordinated management of vertical dimension, occlusal plane, anterior guidance, posterior morphology and mandibular movement.

Jaw tracking has been incorporated into digital workflows for extensive restorative treatment. Park et al reported a full-mouth rehabilitation case involving severe tooth wear and posterior tooth loss in which a digital workflow incorporating jaw-motion tracking was used to assist restorative planning.[15] Another case report described full-mouth rehabilitation using jaw-motion tracking and a double-scan technique in a patient with temporomandibular joint osteoarthrosis.[16]

These reports demonstrate technical feasibility, but case reports cannot establish comparative clinical superiority.

The potential advantage is that proposed restorative morphology can be assessed against the patient's recorded mandibular pathway before definitive fabrication. This may be particularly useful when extensive changes to anterior guidance or posterior occlusion are planned.

Personalized prosthetic rehabilitation

Personalization is not new to prosthodontics. Conventional clinical practice already incorporates individualization through facebow transfer, customized jaw relations, articulator programming, tooth arrangement and clinical adjustment.

Digital technology potentially increases the amount of individual information that can be captured, stored and incorporated into treatment.

A dynamic digital patient may contain individual anatomical information, an individualized maxillomandibular relationship, patient-specific mandibular movement and individual occlusal behavior. Together, these datasets can contribute to individualized prosthetic planning.

This distinction is important because a digitally fabricated prosthesis is not necessarily a personalized prosthesis. A standardized design can be digitally manufactured with very high precision.

True personalization occurs when the patient's own anatomical and functional information influences the prosthetic design.

The concept is particularly relevant to contemporary digital complete denture workflows, in which facial scanning, digital jaw relations and dynamic mandibular tracking can be combined to guide both esthetic and functional decisions.[14]

ADVANTAGES OF DYNAMIC DIGITAL PROSTHODONTICS

Patient-specific functional information

Jaw tracking provides movement information derived from the individual patient rather than relying entirely on average articulator settings. Dynamic digital models can improve visualization of mandibular trajectories and occlusal interactions within a three-dimensional environment, while stored functional records can potentially be reused when a prosthesis requires modification or replacement. A shared digital model may also facilitate communication among prosthodontists, dental technicians and other members of a multidisciplinary treatment team. In addition, a proposed prosthesis can potentially be evaluated against recorded movement before definitive manufacturing, although whether this consistently reduces clinical adjustment remains insufficiently established. Longitudinal storage of functional records may eventually permit comparison of mandibular movement and occlusal behavior during repeated prosthetic rehabilitation.

LIMITATIONS AND CHALLENGES

Measurement accuracy

The accuracy of dynamic digital prosthodontics depends on every stage of data acquisition and processing. Errors may arise from scanning, tracking, calibration, marker movement, software processing and registration.

Grande et al. demonstrated that repeated recordings using a novel optical system were subject to measurable variation, emphasizing the importance of repeatability.[5] Gu et al similarly showed that different tracking systems may produce differences in specific movement parameters.[6]

Registration errors

The dynamic virtual patient may require integration of several independent datasets. CBCT, intraoral scans, facial scans and movement coordinates must be aligned within a common reference system.

A small registration error can therefore affect the apparent relationship between the digital anatomy and recorded movement.

Soft-tissue deformation

The facial and intraoral soft tissues are dynamic structures. Facial expression, lip movement, tongue movement, muscle activity and mandibular position can change their morphology.

A static scan therefore captures only one state of a continuously changing biological system.

Cost and accessibility

Advanced jaw tracking, facial scanning, CBCT, CAD software and computerized occlusal analysis require equipment and trained personnel. This may limit their use in smaller clinical practices and laboratories.

Lower-cost optical approaches may eventually improve accessibility, but they require adequate validation before routine clinical adoption.

Learning curve

Dynamic digital prosthodontics requires knowledge of both conventional prosthodontics and digital data management. Clinicians must understand scanning, coordinate systems, registration, file formats and the limitations of individual technologies.

Limited clinical evidence

The most important limitation remains the gap between technical feasibility and clinical outcome evidence.

The 2026 systematic review of jaw-tracking systems identified promising applications but also noted small study populations, methodological inconsistencies and insufficient long-term evaluation.[7] Similarly, the 2026 systematic review of virtual articulation found that dynamic occlusal simulation remains less established than static simulation.[10]

Consequently, more sophisticated technology should not automatically be equated with better prosthodontic outcomes.

FROM MORE DATA TO BETTER DECISIONS

A major challenge for dynamic prosthodontics is determining whether additional information actually improves treatment.

A jaw-tracking system can generate large quantities of movement data. However, the clinical importance of each parameter may not be clear.

The objective should therefore not be to collect the maximum amount of data but to identify which functional measurements have meaningful consequences for prosthetic design.

For example, if a recorded mandibular trajectory does not alter tooth arrangement, occlusal morphology or treatment planning, its clinical value may be limited.

Future research should therefore move beyond questions of technical accuracy and investigate whether dynamic data influence measurable patient outcomes.

FUTURE PERSPECTIVES

Artificial intelligence-assisted movement analysis

The growing availability of digital mandibular movement datasets creates opportunities for artificial intelligence and machine learning.

Potential applications include automated identification of mandibular movement patterns, classification of functional trajectories, detection of potential occlusal interference and assistance in virtual articulator programming.

AI could eventually compare a patient's movement with large databases and identify patterns associated with particular prosthodontic conditions.

However, AI-generated recommendations should initially be considered decision-support tools. Algorithms trained on limited populations may not perform equally well across different ages, skeletal relationships, dentitions and prosthetic conditions.

Functional digital twins

The logical extension of the dynamic virtual patient is the functional digital twin.

A functional digital twin would potentially contain not only the patient's morphology but also: mandibular movement; occlusal behavior; facial morphology; implant positions; prosthetic designs; treatment history; longitudinal functional records.

Such a system could allow previous prostheses and their associated functional data to be retained.

When a prosthesis requires replacement, the clinician could compare the previous design with current anatomy and movement rather than beginning the digital workflow again from the beginning.

At present, this remains a conceptual future direction rather than a routine clinical technology.

Beyond mandibular movement

The ultimate development of dynamic prosthodontics may involve the integration of several forms of functional information.

A future multimodal system could potentially combine: mandibular movement + occlusal force + facial movement + muscle activity + speech + mastication + temporomandibular joint motion.

Such a system would move digital prosthodontics from anatomical reproduction toward functional simulation.

The purpose would not be to create an unnecessarily complex digital model, but to identify clinically relevant relationships between function and prosthetic design.

RESEARCH PRIORITIES

Several research priorities should be addressed before dynamic digital prosthodontics becomes routine.

First, standardized protocols for mandibular movement acquisition are needed. Different systems use different sensors, reference frames, sampling characteristics and software environments.

Second, clinically meaningful accuracy thresholds should be established. A statistically measurable difference is not necessarily clinically important.

Third, repeatability should be evaluated across multiple sessions and operators.

Fourth, clinical studies should compare dynamic digital workflows with conventional workflows using patient-centered outcomes rather than technical accuracy alone.

Relevant outcomes should include: number of post-insertion adjustments; treatment time; laboratory time; patient comfort; patient satisfaction; masticatory performance; prosthetic complications; maintenance requirements; prosthesis longevity and cost-effectiveness.

Finally, research should identify which patients benefit most from dynamic recording. Not every prosthodontic treatment requires same degree of functional digitization.

PROPOSED DYNAMIC PROSTHODONTIC WORKFLOW

Based on current technological developments, conceptual dynamic workflow can be organized into five stages.

A conceptual dynamic prosthodontic workflow begins with morphological acquisition using intraoral scanning, facial scanning and CBCT, followed by spatial registration using a digital facebow, maxillomandibular relationship and virtual articulation. Functional acquisition can then incorporate jaw tracking, mandibular excursions and computerized occlusal analysis. These datasets can be combined during dynamic simulation with the proposed prosthetic design, after which CAD/CAM fabrication, clinical verification and functional adjustment complete the rehabilitation process. This should be considered a conceptual framework rather than a mandatory clinical protocol; the appropriate combination of technologies depends on the clinical indication, patient characteristics, available equipment and operator expertise.

CONCLUSION

Prosthodontics has traditionally relied on static representations of anatomy and selected mandibular positions. Digital technologies initially reproduced these records in three dimensions, but advances in jaw tracking, computerized occlusal analysis, virtual articulation and multimodal data integration have created the possibility of incorporating mandibular function into the digital patient.

The transition from a static three-dimensional virtual patient to a dynamic four-dimensional patient represents an important conceptual development. Contemporary workflows have demonstrated that CBCT, intraoral scans, facial records, maxillomandibular relationships and mandibular movement can be integrated within a common digital environment.

Dynamic recording may have particular relevance to complete dentures, implant-supported prostheses and extensive restorative rehabilitation, where individualized mandibular movement and occlusal behavior may influence prosthetic design. However, current evidence does not establish that dynamic digital workflows consistently produce superior clinical outcomes compared with well-executed conventional methods.

The future of digital prosthodontics should therefore not be defined simply by replacing mechanical articulators with virtual ones or conventional records with digital records. Its greater potential lies in integrating individual functional information into prosthetic decision-making.

The eventual development of functional digital twins could allow prostheses to be designed according not only to the patient's anatomy but also to the way that individual patient moves and functions.

The fundamental transition can therefore be summarized as: Static record → three-dimensional digital patient → dynamic virtual patient → functional digital twin.

This progression represents a shift from reproducing anatomy toward understanding function and, ultimately, toward a more individualized model of prosthetic rehabilitation.

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