REVIEW ARTICLE

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Clinical Reliability of Occlusal Assessment Techniques: From Articulating Paper to Digital Systems

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Abstract

Occlusal assessment is a fundamental component of clinical dentistry, guiding restorative procedures, prosthodontic rehabilitation, and the overall functional evaluation of the masticatory system. Accurate identification of occlusal contacts and force distribution remains challenging due to the limitations of traditional diagnostic approaches. This literature-based review aims to compare the reliability, validity, and clinical usefulness of conventional occlusal assessment techniques with emerging digital systems. Conventional methods, including articulating paper and shimstock foil, remain widely used but are inherently subjective and operator-dependent, with limited ability to quantify occlusal force. In contrast, digital occlusal analysis systems offer improved visualization, reproducibility, and objective data acquisition; however, they still demonstrate limitations in accurately representing true occlusal force magnitude and clinical significance. Overall, current evidence suggests that while digital technologies enhance diagnostic precision, they should be considered adjunctive tools rather than replacements for conventional clinical assessment.

Keywords: Articulating paper, Clinical reliability, Digital occlusion systems, Occlusal analysis, Occlusal force distribution.

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1. Introduction

Occlusal assessment is a critical component of modern dental practice, underpinning diagnosis and treatment planning across restorative dentistry, prosthodontics, and functional analysis of the masticatory system. Accurate identification of occlusal contacts and distribution of occlusal forces is essential for achieving long-term treatment stability, preventing restoration failure, and minimizing functional complications such as occlusal trauma and muscle dysfunction [1]. Despite its clinical importance, occlusal evaluation remains challenging due to the complex and dynamic nature of tooth contacts during functional and parafunctional movements, which cannot always be reliably captured using traditional static recording methods. Evidence has shown that inaccuracies in occlusal assessment may lead to premature contacts being overlooked or overemphasized, potentially influencing clinical decision-making and treatment outcomes [1].

Historically, occlusal analysis has relied on conventional methods such as articulating paper, shimstock foil, and wax registration techniques. While these approaches remain widely used due to their simplicity and low cost, they are inherently subjective and dependent on operator interpretation [2]. Furthermore, they provide limited or no quantitative data on occlusal force magnitude or contact timing. In recent decades, there has been a shift toward digital occlusal analysis systems, which aim to provide more objective and reproducible measurements of occlusal contacts and force distribution. However, despite technological advancements, a universally accepted gold standard for occlusal analysis has not yet been established, and discrepancies remain between conventional and digital findings in clinical settings [2,3]. This review aims to critically evaluate and compare the clinical reliability, validity, and practical usefulness of conventional and digital occlusal assessment techniques. By synthesizing current evidence, this paper seeks to clarify the strengths and limitations of each approach and provide insight into their appropriate application in routine dental practice.

2. Conventional occlusal assessment methods

Conventional occlusal assessment remains the most widely used approach in clinical dentistry due to its simplicity, low cost, and immediate chairside applicability. Despite the emergence of digital technologies, these methods remain the primary reference for evaluating static and dynamic occlusal contacts. However, their diagnostic value is largely dependent on subjective interpretation and operator experience, and multiple studies have highlighted inherent limitations in their ability to accurately represent true occlusal function and force distribution [4].

2.1 Articulating paper

Articulating paper is the most commonly employed tool for occlusal evaluation and functions on the principle of marking contact points between opposing teeth during intercuspation or excursive movements. When interposed between dental arches, pressure generated during biting transfers pigment or ink onto enamel surfaces, producing visible marks that are interpreted as occlusal contacts. Clinicians use these markings to identify high spots, premature contacts, and occlusal interferences [5].

Articulating papers are commercially available in different colours such as red, blue, black, and green. The choice of colour primarily improves visualization under varying clinical conditions rather than influencing diagnostic accuracy. Clinicians often use different colours sequentially to distinguish centric contacts from excursive contacts; for example, blue paper may be used to identify centric occlusion while red paper is used during lateral and protrusive movements. Bicolour articulating papers are also available, allowing simultaneous differentiation of static and dynamic occlusal contacts [5]. The reliability of articulating paper is influenced by multiple material and clinical variables. Paper thickness is a key determinant, with reported ranges varying widely from approximately 8 µm to over 200 µm. Thicker papers tend to produce broader and more numerous marks, potentially exaggerating contact areas, whereas thinner papers provide more precise but sometimes less visible markings. Studies have demonstrated that thinner articulating papers (e.g., 40 µm) may offer improved agreement in detecting contact distribution compared to thicker variants, yet still do not eliminate interpretative variability [6].

Clinical conditions also significantly affect performance. Moisture from saliva can distort marking accuracy, producing false-positive or false-negative contacts. Similarly, variations in applied biting force, patient neuromuscular control, and repeated mandibular positioning during assessment can alter contact patterns between recordings. These factors introduce inconsistency in results even within the same patient session [6]. A major limitation of articulating paper is its inherently subjective interpretation. The clinician must visually assess mark size, intensity, and location without any objective scale linking these parameters to actual occlusal force magnitude. Consequently, markings may be over-interpreted as "high contacts" despite not necessarily representing functionally significant occlusal load [7].

2.2 Shimstock foil

Shimstock foil is an ultra-thin metallic strip used primarily for determining whether a tooth contact is present or absent. Unlike articulating paper, it does not provide visual marking; instead, it relies on tactile feedback, where the clinician assesses whether the foil can be pulled out while the patient maintains occlusion [8]. Its primary advantage lies in its simplicity and high sensitivity for detecting minimal contact. Shimstock is particularly useful for confirming whether a contact exists between opposing teeth and is often considered more reliable than articulating paper for binary contact verification. However, it provides no information regarding contact location, distribution, or intensity [8].

The major limitation of shimstock is its inability to quantify occlusal forces. It cannot differentiate between light and heavy contacts, nor can it map occlusal contact patterns across the dentition. As a result, it serves only as a confirmatory tool rather than a comprehensive diagnostic method.

Additionally, its effectiveness is highly operator-dependent, as variations in pulling force and technique can influence perceived results [9].

2.3 Wax and silicone registration materials

Wax and silicone-based interocclusal registration materials are used to capture static occlusal relationships by recording the spatial relationship between maxillary and mandibular teeth in maximum intercuspation [10]. These materials harden after placement, allowing casts or clinical occlusion to be analyzed outside the oral environment. These records are particularly useful for laboratory procedures, including crown fabrication, prosthetic planning, and mounting of diagnostic casts. Silicone materials, in particular, offer improved dimensional stability compared to wax and provide better resistance to deformation during handling [10].

Polyvinyl siloxane bite registration putty is widely used for recording maxillomandibular relationships because of its excellent dimensional stability, minimal polymerization shrinkage, adequate rigidity, and ease of manipulation [10,11]. It is commonly used during fixed prosthodontic procedures, implant restorations, full-mouth rehabilitation, and digital workflows to accurately transfer the interocclusal relationship to the laboratory or CAD/CAM systems. However, despite its superior dimensional stability compared with wax, bite registration putty records only static occlusion and cannot evaluate occlusal timing, contact sequence, or force distribution [11].

2.4 Clinical limitations of conventional methods

Despite their widespread use, conventional occlusal assessment methods share several fundamental limitations that affect diagnostic reliability. A key limitation is the absence of force quantification. Neither articulating paper nor shimstock provides objective measurement of occlusal load distribution, meaning clinicians must infer force based on mark appearance or tactile resistance [12]. Another significant issue is the occurrence of false-positive and false-negative findings. Broad or dark articulating paper marks may not correspond to clinically significant occlusal contacts, while light contacts may fail to produce visible markings, particularly in the presence of saliva or uneven force application. This can lead to misinterpretation of occlusal interferences and unnecessary adjustment of tooth structure [13]. Operator dependency further reduces reproducibility. Differences in clinician technique, paper selection, patient positioning, and interpretation criteria can result in inconsistent findings across examinations. Even within the same patient, repeated recordings may produce variable results due to neuromuscular adaptation and bite repetition inconsistencies [14]. Collectively, these limitations highlight that conventional occlusal assessment methods are primarily qualitative rather than quantitative. While they remain essential in routine clinical practice, their inherent subjectivity and lack of standardization underscore the need for adjunctive or more objective diagnostic approaches in modern dentistry (Figure 1) [14].

3. Digital occlusal analysis systems

Digital occlusal analysis systems represent a significant advancement in objectively assessing occlusal contacts and force dynamics, addressing many limitations of conventional methods. These technologies aim to provide quantitative, reproducible, and time-sensitive data regarding occlusal interactions, enabling a more precise understanding of functional occlusion in clinical dentistry.

3.1 Sensor-based systems

Sensor-based systems, most notably the T-Scan system, are among the earliest and most widely studied digital occlusal analysis technologies. These systems utilize ultra-thin pressure-sensitive sensors placed between the dental arches to record occlusal contact timing and force distribution during static and dynamic occlusion [15]. The data are then converted into computerized visual maps, allowing clinicians to assess relative force intensity across the dentition and analyze the sequence of occlusal contacts during mandibular closure and excursions [15].

The principal advantage of such systems lies in their ability to provide time-based occlusal analysis, which conventional methods cannot achieve. Studies have shown that sensor-based systems can detect occlusal timing discrepancies and force asymmetries that are not clinically evident using articulating paper alone. However, concerns remain regarding sensor calibration, inter-sensor variability, and the potential alteration of natural bite due to sensor thickness and patient adaptation during testing [15].

3.2 Intraoral scanner-based occlusion mapping

Intraoral scanners have expanded the scope of occlusal evaluation by enabling the digital capture of static intercuspal contacts through three-dimensional surface reconstruction. These systems generate virtual occlusal maps by recording maxillomandibular relationships and superimposing digital impressions to identify areas of contact.

A key advantage of this approach is its seamless integration with CAD/CAM workflows, allowing clinicians to combine occlusal analysis with restorative design, prosthetic fabrication, and virtual articulation. This integration enhances efficiency and reduces laboratory error associated with traditional impression materials. However, intraoral scanner-based occlusion mapping primarily provides static contact information and does not accurately capture occlusal force magnitude or dynamic functional loading patterns, limiting its diagnostic depth in functional occlusion assessment [16].

Despite their advantages, intraoral scanners have several limitations in occlusal assessment. Accurate digital bite registration depends on proper scanning technique, operator experience, and patient cooperation. Errors may occur because of saliva contamination, limited access to posterior regions, patient movement, or incomplete image stitching. Furthermore, current scanners predominantly record static occlusion and cannot accurately reproduce functional mandibular movements or quantify true occlusal force during mastication. Reflective restorative materials and extensive edentulous areas may further reduce scanning accuracy. Consequently, intraoral scans should be interpreted together with clinical examination and other occlusal assessment methods [16].

3.3 Emerging digital platforms

Recent advancements in digital dentistry have introduced emerging platforms that aim to further refine occlusal assessment through enhanced pressure mapping technologies and real-time visualization systems. These platforms combine sensor arrays, cloud-based analytics, and artificial intelligence algorithms to interpret occlusal contact patterns with greater precision and clinical usability [17].

Some systems provide real-time occlusal adjustment feedback during restorative procedures, enabling clinicians to immediately identify and modify high-force contacts. Additionally, pressure mapping technologies attempt to simulate functional loading conditions more accurately than earlier systems. Despite these innovations, standardization remains limited, and clinical validation studies are still evolving, particularly with respect to long-term outcomes and correlation with biological responses of the masticatory system [18].

3.4 Advantages of digital systems

Digital occlusal analysis systems offer several significant advantages over conventional approaches. The most notable benefit is the ability to quantify occlusal force distribution and timing, providing objective data rather than subjective visual interpretation. This allows for more precise identification of occlusal imbalances and functional asymmetries [19].

Another key advantage is high repeatability and data storage capability. Digital records can be archived, compared over time, and used for longitudinal assessment of occlusal changes following restorative or rehabilitative procedures. This enhances diagnostic consistency and supports evidence-based treatment planning. Furthermore, digital systems enable visualization of occlusal dynamics, allowing clinicians to observe contact sequence, force concentration areas, and functional loading patterns in real time. This dynamic representation of occlusion represents a significant improvement over static conventional methods, which cannot capture temporal changes in occlusal function. Collectively, these advantages position digital occlusal analysis as a powerful adjunct in modern dental diagnostics, although its limitations in force calibration accuracy and biological interpretation still necessitate cautious clinical application (Figure 2) [20,21].

4. Evidence on reliability and validity

4.1 Reliability of conventional techniques

Conventional occlusal assessment methods, particularly articulating paper, shimstock foil, and occlusal registration materials, have significant reliability limitations. Clinical studies consistently report high inter-examiner variability, largely due to subjective interpretation of ink markings, differences in applied force, and variability in clinical technique. Even when thinner articulating papers are used, which improve contact delineation, reproducibility remains inconsistent due to patient-dependent and operator-dependent factors such as mandibular positioning, saliva contamination, and repeated biting cycles during recording [22]. Comparative studies have also shown that conventional indicators may record differing numbers and distributions of occlusal contacts depending on material thickness and examiner interpretation, further reducing inter-rater agreement in complex posterior regions. Although articulating paper remains widely used in clinical practice, its reliability is considered moderate at best, with limited reproducibility across repeated assessments and clinicians [23].

4.2. Reliability of digital systems

Digital occlusal analysis systems, particularly sensor-based platforms such as T-Scan, demonstrate improved reproducibility compared to conventional methods. Studies report good inter- and intra-examiner agreement in detecting occlusal contact location and sequencing, with relatively consistent identification of contact timing and distribution patterns across repeated measurements [24].

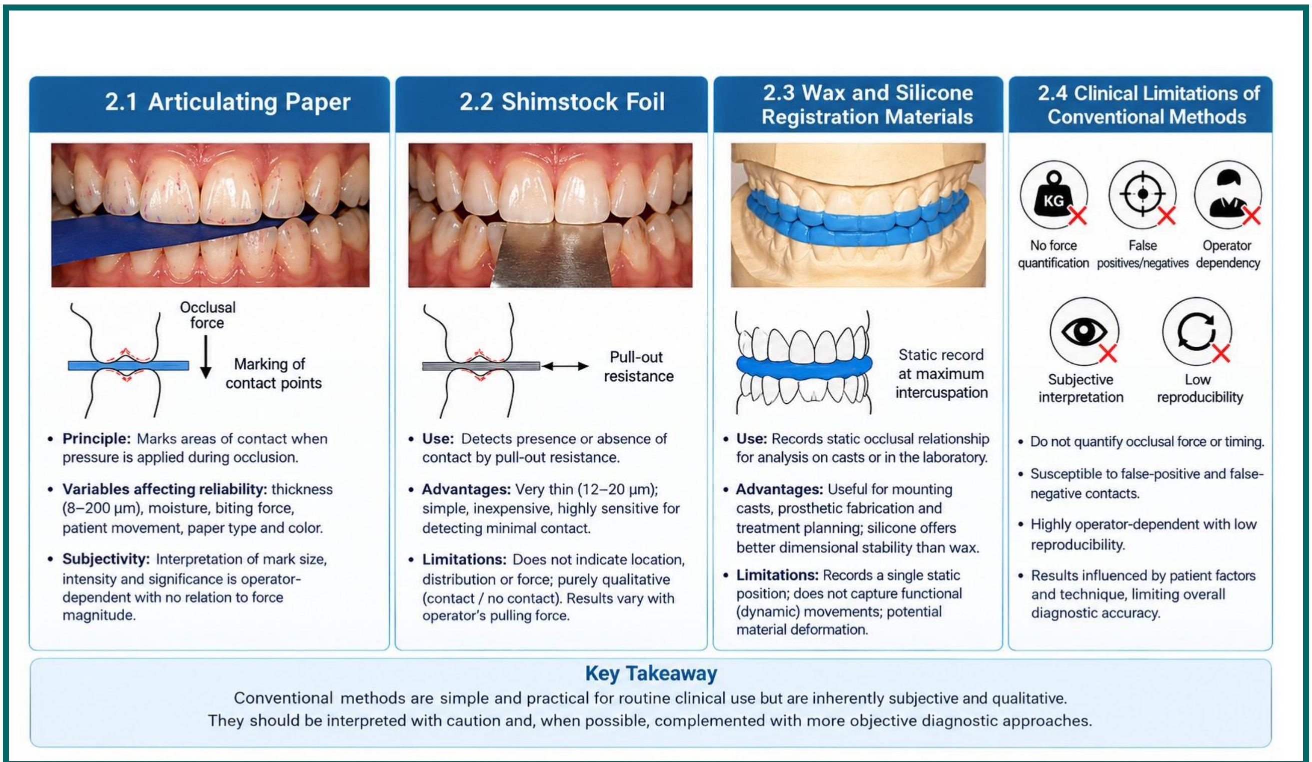

Figure 1. Conventional occlusal assessment methods: principles, application and limitations

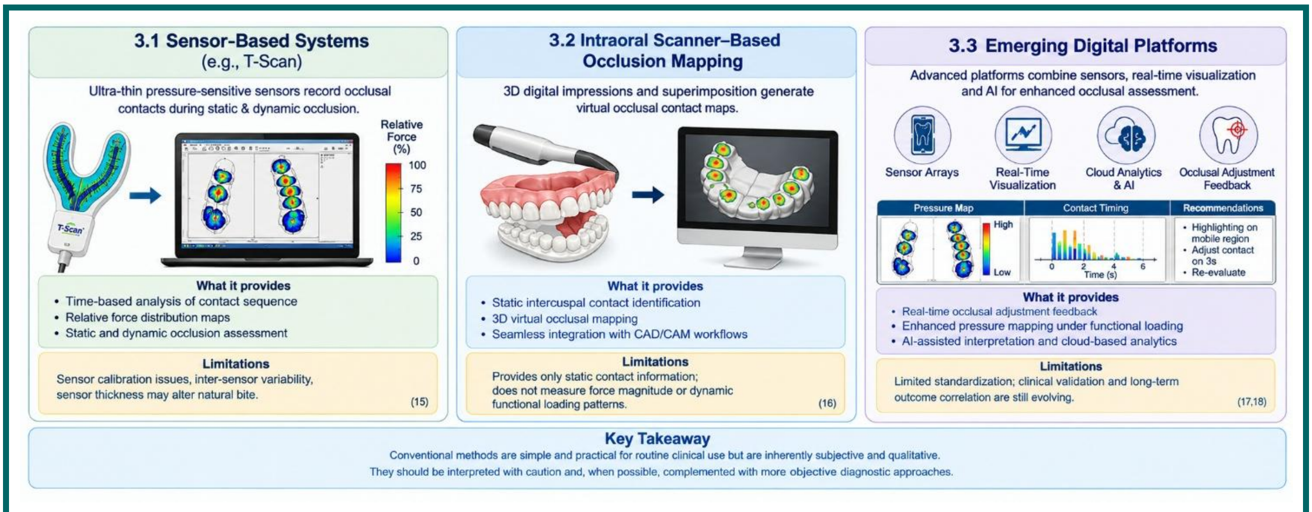

Figure 2. Digital Occlusal Analysis Systems

However, despite this improved consistency, variability still exists depending on calibration, sensor placement, and patient compliance. Intraoral scanner-based systems also show acceptable reproducibility for static occlusal contact mapping, but their performance varies in posterior regions where anatomical complexity reduces scan precision. Importantly, while digital systems are reliable for contact detection and temporal sequencing, they demonstrate limitations in accurately reproducing absolute occlusal force values. This remains a key constraint in translating digital outputs into direct biomechanical interpretations [25].

4.3 Validity concerns

Validity of occlusal assessment refers to how accurately a method reflects true occlusal contact dynamics and force distribution. Evidence indicates that digital systems, including sensor-based devices and intraoral scanning technologies, are valid for identifying the presence and location of occlusal contacts, but are less reliable in quantifying true force magnitude and clinical significance of those contacts. Systematic reviews have demonstrated that both intraoral scanners and sensor-based systems provide relatively accurate representation of contact location; however, their ability to measure contact intensity remains limited, with reduced correlation to actual occlusal loading conditions in vivo. Similarly, force-measuring systems such as T-Scan show reasonable validity for relative force distribution but are less effective in providing absolute force calibration under clinical conditions [26]. These limitations highlight a key conceptual issue: while digital systems improve objectivity, they may not fully capture the biomechanical complexity of functional occlusion, particularly during dynamic mandibular movements.

4.4. Comparative findings

When comparing conventional and digital occlusal assessment methods, a consistent pattern emerges. Conventional techniques remain clinically practical and widely accessible, offering rapid chairside assessment despite their inherent subjectivity and limited reproducibility. Their primary advantage lies in simplicity and immediate clinical applicability, especially in routine restorative adjustments. In contrast, digital systems provide objective, quantifiable, and reproducible data, particularly for occlusal contact timing and distribution. However, their interpretation is often dependent on operator calibration, system settings, and clinical context. Additionally, limitations in force accuracy and cost-effectiveness restrict their universal adoption in everyday practice [27]. Overall, evidence suggests that conventional methods are useful for preliminary assessment, while digital systems enhance diagnostic precision in complex cases. Neither approach is independently sufficient to serve as a complete gold standard, reinforcing the need for an integrated diagnostic strategy combining both conventional and digital modalities [27,28].

5. Clinical applications

5.1. Restorative dentistry

Accurate occlusal assessment plays a pivotal role in restorative dentistry, particularly during the placement and adjustment of direct and indirect restorations such as fillings, crowns, and implant-supported prostheses. Improper occlusal adjustment can result in premature contacts, leading to postoperative sensitivity, restoration fracture, periodontal stress, and even temporomandibular complications. Conventional methods, especially articulating paper, remain the primary tools for chairside occlusal adjustment due to their simplicity and immediate feedback. Clinicians typically rely on the size, intensity, and distribution of markings to guide selective grinding [29]. However, as previously discussed, these markings do not reliably correlate with actual occlusal force magnitude, which may lead to over-adjustment or under-adjustment of restorations.

Digital occlusal analysis systems have introduced a more refined approach to restorative occlusion. Sensor-based technologies allow clinicians to visualize the sequence and timing of occlusal contacts during closure, enabling identification of premature contacts that occur milliseconds before full intercuspation. This is particularly relevant in high-precision restorations such as implant crowns, where lack of periodontal ligament proprioception reduces the patient's ability to detect occlusal discrepancies. Clinical studies indicate that digital systems can assist in achieving more balanced occlusion by identifying force asymmetries and guiding selective adjustments more conservatively. Additionally, integration with CAD/CAM workflows allows occlusal refinement during the design phase, reducing chairside adjustment time. Nevertheless, due to limitations in absolute force calibration, digital findings must still be interpreted alongside clinical judgment and conventional indicators [30].

5.2. Full mouth rehabilitation

Full mouth rehabilitation represents one of the most complex clinical scenarios in dentistry, requiring comprehensive control of occlusal relationships, vertical dimension, and functional harmony [31]. In such cases, occlusal analysis is essential not only for diagnosis but also for treatment planning and post-treatment verification. Conventional methods are often used during provisionalization and final adjustment phases; however, their limitations become more pronounced in full-arch cases where multiple simultaneous contacts must be balanced. The inability to quantify force distribution makes it difficult to ensure even load sharing across restorations, increasing the risk of biomechanical complications [31,32].

Digital occlusal analysis systems provide significant advantages in this context. They enable clinicians to evaluate bilateral force distribution, detect occlusal imbalances, and monitor changes over time following rehabilitation. Importantly, these systems can quantify right-left force symmetry and identify overload on specific segments, which is critical in preventing restoration failure and maintaining long-term stability [33]. Furthermore, digital workflows incorporating intraoral scanning and virtual articulation allow simulation of occlusal relationships before definitive treatment. This facilitates more predictable outcomes, particularly in cases involving altered vertical dimension or extensive prosthetic reconstruction. However, despite these benefits, occlusal schemes in full mouth rehabilitation still rely heavily on clinical principles and practitioner experience, as digital systems cannot fully replicate the biological adaptability of the stomatognathic system [33,34].

5.3. Diagnosis of occlusal interferences

The identification of occlusal interferences, contacts that disrupt harmonious mandibular movement, is a critical diagnostic objective in both restorative and functional dentistry. These interferences may contribute to occlusal trauma, muscle hyperactivity, and temporomandibular disorders [35]. Conventional methods primarily assess occlusion in a static manner, identifying contacts in maximum intercuspation and during guided excursive movements. While articulating paper can indicate the presence and approximate location of contacts, it lacks the ability to determine the temporal sequence of contact formation. As a result, early or deflective contacts, often the most clinically significant, may be overlooked [35,36]. Digital occlusal analysis systems address this limitation by providing dynamic, time-resolved data. These systems record occlusal contact events as a sequence, allowing clinicians to distinguish between initial contact points and subsequent contacts during closure [37]. This capability is particularly important in detecting premature contacts that cause mandibular deflection or prolonged disclusion time.

Clinical evidence suggests that prolonged disclusion time and uneven force distribution are associated with increased muscular activity and symptoms related to temporomandibular disorders [37,38]. Digital systems enable quantification of these parameters, offering a more objective basis for diagnosing functional occlusal disturbances. However, despite their advantages, digital systems should not be used in isolation. Clinical examination, patient symptoms, and functional analysis remain essential components of diagnosis, as occlusal interferences must be interpreted within the broader context of neuromuscular adaptation and patient-specific tolerance [37,38].

5.4. Decision-making in clinical practice

The integration of conventional and digital occlusal assessment methods is essential for informed clinical decision-making. Each approach offers distinct advantages and limitations, and their appropriate use depends on the clinical scenario. Conventional methods remain indispensable for routine procedures due to their accessibility, low cost, and ease of use [39]. They are particularly suitable for quick chairside assessments, minor restorative adjustments, and situations where qualitative evaluation is sufficient. In contrast, digital systems are most valuable in complex cases requiring detailed analysis, such as full mouth rehabilitation, implant-supported restorations, and patients with suspected functional disorders. Their ability to provide objective, reproducible, and time-based data enhances diagnostic precision and supports evidence-based treatment planning [39]. Current evidence emphasizes that digital occlusal analysis should be considered an adjunct rather than a replacement for conventional techniques. While digital tools improve objectivity and reproducibility, their limitations in accurately representing absolute occlusal force and biological response restrict their standalone clinical applicability [40].

6. Future perspectives

6.1 Artificial intelligence in occlusal mapping

The integration of artificial intelligence into occlusal analysis represents one of the most significant future directions in digital dentistry. Modern machine learning algorithms are increasingly being developed to interpret complex occlusal datasets generated from sensor-based and imaging systems [41]. These technologies have the potential to automatically identify occlusal contact patterns by recognizing spatial and temporal relationships within large datasets that would otherwise require manual interpretation. In addition, AI-driven systems may be capable of predicting high-risk occlusal interferences by analyzing subtle variations in force distribution and contact timing that are not easily detectable through conventional clinical observation [41,42].

Convolutional Neural Networks (CNNs), a class of deep learning algorithms widely used in image analysis, have recently been explored for automated occlusal assessment. CNNs can analyse digital intraoral scans, occlusal photographs, and three-dimensional dental models to identify occlusal contact points, classify occlusal relationships, and detect premature contacts with minimal operator intervention [41,42]. By learning complex spatial features from large image datasets, CNN-based systems may improve diagnostic consistency, reduce observer variability, and facilitate automated treatment planning in prosthodontics and orthodontics. Nevertheless, their clinical application remains dependent on the availability of large, high-quality annotated datasets and requires further validation before routine clinical implementation [43].

Beyond pattern recognition, artificial intelligence can process complex force distribution data obtained from sensor-based occlusal systems, transforming raw numerical outputs into clinically meaningful interpretations. This capability may allow for a more precise understanding of functional occlusion and its biomechanical implications. Importantly, AI also holds the potential to improve interpretation consistency between clinicians by reducing subjective variability in occlusal analysis. By standardizing diagnostic interpretation, these systems may enhance reproducibility and reduce inter-operator differences that are commonly observed in both conventional and digital occlusal assessment methods [42].

6.2. Integration of digital occlusion with 3D facial analysis

Another important advancement in occlusal diagnostics is the integration of digital occlusal data with three-dimensional facial and craniofacial analysis. This approach involves the combination of intraoral scanning, facial scanning, and radiographic imaging to create a comprehensive digital representation of the patient. Within this integrated framework, occlusal relationships can be analyzed not only in isolation but also in relation to skeletal morphology and facial symmetry [43].

Such integration allows clinicians to evaluate occlusion within a broader functional and aesthetic context. For example, occlusal discrepancies can be correlated with mandibular positioning, facial midline deviations, and asymmetries in facial soft tissues. This comprehensive approach is particularly valuable in complex restorative and orthodontic cases where functional occlusion must be balanced with aesthetic and skeletal considerations. As digital workflows continue to evolve, the convergence of occlusal and facial data is expected to play an increasingly important role in personalized treatment planning and precision dentistry [44].

6.3. Development of standardized calibration protocols

A major limitation currently restricting the full clinical adoption of digital occlusal systems is the lack of standardized calibration protocols. Different systems utilize varying sensor technologies, force thresholds, and software algorithms, resulting in inconsistencies in data interpretation across platforms. Without standardized calibration, it becomes difficult to compare results between devices or establish universal clinical guidelines for occlusal force interpretation.

Future research must therefore focus on developing universally accepted calibration standards that can be applied across different digital occlusal systems. Such protocols would ideally define clinically relevant force thresholds, ensure consistent sensor sensitivity, and establish validated reference conditions for occlusal measurements [45]. In addition, standardized interpretation criteria would significantly enhance the reproducibility of digital occlusal data and improve its clinical applicability. The establishment of such frameworks would represent a critical step toward the formal integration of digital occlusal analysis into evidence-based dental practice [45].

6.4. Hybrid approaches in occlusal analysis

The future of occlusal diagnostics is likely to be defined by hybrid approaches that combine conventional and digital methodologies rather than relying exclusively on either system. Conventional techniques continue to provide essential qualitative information regarding occlusal contacts and remain valuable for rapid chairside assessment. At the same time, digital systems offer quantitative and time-resolved data that enhance the precision of occlusal evaluation.

In a hybrid model, conventional methods are used as an initial screening tool to identify obvious occlusal discrepancies, while digital systems are employed to refine and validate these findings through objective analysis of force distribution and contact timing. This complementary approach allows clinicians to integrate tactile, visual, and digital information into a unified diagnostic framework. As a result, hybrid occlusal assessment strategies are expected to provide the highest level of diagnostic reliability, particularly in complex restorative and rehabilitative cases where precision is critical [46].

7. Clinical recommendations

Based on current evidence, the following clinical recommendations can be made regarding the use of occlusal assessment methods:

7.1 Use articulating paper as a primary screening tool

Articulating paper remains the most practical and widely applicable method for initial occlusal assessment. It is recommended as a first-line tool for identifying gross occlusal contacts, premature contacts, and general distribution patterns during routine restorative procedures [47].

7.2. Use digital systems for complex or high-precision cases

Digital occlusal analysis systems should be primarily reserved for clinical situations in which a higher level of diagnostic precision is required beyond the capabilities of conventional methods. These include full mouth rehabilitation cases, implant-supported prostheses, patients presenting with suspected temporomandibular disorders, and complex prosthodontic reconstructions involving extensive occlusal reorganization [48].

In such scenarios, the ability of digital systems to provide detailed information regarding occlusal contact timing, force distribution, and the sequential pattern of occlusal contacts offers considerable clinical value. Unlike conventional methods, which primarily provide static and qualitative information, digital technologies allow clinicians to evaluate dynamic occlusal function in a more objective and reproducible manner. This enhanced diagnostic capability is particularly important in cases where even minor occlusal discrepancies may have significant functional or biomechanical consequences [48].

7.3. Combine both methods for best clinical reliability

The highest level of diagnostic reliability is achieved when conventional and digital methods are used together. Conventional tools provide immediate tactile and visual feedback, while digital systems offer objective validation and deeper functional analysis. This combined approach reduces diagnostic error, improves treatment predictability, and enhances long-term clinical outcomes [49].

8. Conclusion

Occlusal assessment remains a complex and evolving area of clinical dentistry, characterized by ongoing technological advancement and persistent methodological limitations. Conventional methods, such as articulating paper and shimstock foil, remain essential due to their simplicity, accessibility, and immediate clinical utility. However, they are fundamentally subjective and lack quantitative force analysis. Digital occlusal systems represent a significant advancement by introducing objective, reproducible, and time-sensitive data. Despite this, they are still limited in their ability to accurately represent absolute occlusal force and biological response within the masticatory system. Currently, no single method can be considered a definitive gold standard for occlusal analysis. The most reliable clinical approach is a combined diagnostic strategy, integrating both conventional and digital techniques to achieve optimal accuracy and clinical decision-making. Future advancements in artificial intelligence, standardized calibration, and multimodal digital integration are expected to further enhance the precision and clinical relevance of occlusal assessment in dentistry.

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References

1. Wong King C, Chuy V, Laran A, d'Incau E, Naveau A. In vitro comparison of digital occlusal analyzers and articulating paper in static and dynamic occlusion. J Dent. 2026;164:106215. https://doi.org/10.1016/j.jdent.2025.106215.
2. Reich KM, Tatzber V, Skolka A, Piehslinger E, Lettner S, Kundi M, et al. A comparative study of digital and conventional

occlusal indicators: accuracy and reliability of the T-Scan Novus, wax occlusogram, and articulating silk in clinical application. J Dent. 2025;156:105695. https://doi.org/10.1016/j.jdent.2025.105695.
3. Velásquez B, Rodríguez M, Mosquera V, Álvarez E, Chauca L, Mena A. Occlusal analysis in natural dentition: systematic review. Eur J Dent. 2023;17(3):615-622. https://doi.org/10.1055/s-0042-1755626.
4. Qadeer S, Kerstein R, Kim RJ, Huh JB, Shin SW. Relationship between articulation paper mark size and percentage of force measured with computerized occlusal analysis. J Adv Prosthodont. 2012;4(1):7-12. https://doi.org/10.4047/jap.2012.4.1.7.
5. Manziuc MM, Savu MM, Almăşan O, Leucuţa DC, Tăut M, Ifrim C, et al. Insights into occlusal analysis: articulating paper versus digital devices. J Clin Med. 2024;13(15):4506. https://doi.org/10.3390/jcm13154506.
6. Lei Q, Lin D, Liu Y, Lin K, Huang W, Wu D. Neuromuscular and occlusion analysis to evaluate the efficacy of three splints on patients with bruxism. BMC Oral Health. 2023;23(1):325. https://doi.org/10.1186/s12903-023-03044-5.
7. Bozhkova T, Musurlieva N, Slavchev D. Comparative study qualitative and quantitative techniques in the study of occlusion. Biomed Res Int. 2021;2021:1163874. https://doi.org/10.1155/2021/1163874.
8. Majithia IP, Arora V, Anil Kumar S, Saxena V, Mittal M. Comparison of articulating paper markings and T-Scan III recordings to evaluate occlusal force in normal and rehabilitated maxillofacial trauma patients. Med J Armed Forces India. 2015;71(Suppl 2): S382-S388. https://doi.org/10.1016/j.mjafi.2014.09.014.
9. Sutter BA. A digital poll of dentists testing the accuracy of paper mark subjective interpretation. Cranio. 2018;36(6):396-403. https://doi.org/10.1080/08869634.2017.1362786.
10. Cowan C. Occlusal records in the production of mounted study casts for tooth wear planning and management. Br Dent J. 2023;234(6):385-392. https://doi.org/10.1038/s41415-023-5674-3.
11. Sharma A, Rahul GR, Poduval ST, Shetty K, Gupta B, Rajora V. History of materials used for recording static and dynamic occlusal contact marks: a literature review. J Clin Exp Dent. 2013;5(1):e48-e53. https://doi.org/10.4317/jced.50680.
12. Zhao Z, Wang Q, Li J, Zhou M, Tang K, Chen J, et al. Construction of a novel digital method for quantitative analysis of occlusal contact and force. BMC Oral Health. 2023;23(1):190. https://doi.org/10.1186/s12903-023-02899-y.
13. Wang Q, Zhao Z, Zhou M, Zheng X, An N, Niu L, et al. In vivo evaluation of the reliability and validity of three digital occlusion analysis methods. J Dent. 2022;127:104355. https://doi.org/10.1016/j.jdent.2022.104355.
14. Rovira-Lastra B, Khoury-Ribas L, Flores-Orozco EI, Ayuso-Montero R, Chaurasia A, Martinez-Gomis J. Accuracy of digital and conventional systems in locating occlusal contacts: a clinical study. J Prosthet Dent. 2024;132(1):115-122. https://doi.org/10.1016/j.prosdent.2023.06.036.
15. Wang Q, Zhao Z, Li J, Zhao R, Zhou M, Tang K, et al. In vivo evaluation of T-Scan in quantifying occlusal contact. J Oral Rehabil. 2024;51(9):1675-1683. https://doi.org/10.1111/joor.13732.
16. Revilla-León M, Kois DE, Zeitler JM, Att W, Kois JC. An overview of the digital occlusion technologies: intraoral scanners, jaw tracking systems, and computerized occlusal analysis devices. J Esthet Restor Dent. 2023;35(5):735-744. https://doi.org/10.1111/jerd.13044.
17. Du X, Sun W, Yao C, Gao Y, Hu J, Song K. AI-driven automation of occlusal surface design in digital prosthodontics: a clinically validated workflow. BMC Oral Health. 2026;26(1):513. https://doi.org/10.1186/s12903-026-07874-x.
18. Levrini L, Deppieri A, Ugas A, Zecca PA, Bocchieri S, Saran S, et al. Comparison of digital and traditional methods for occlusal contact assessment: an experimental cross-sectional study. Appl Sci. 2026;16:132. https://doi.org/10.3390/app16010132.
19. Anandapandian PA, Raza FB, Ar PK, Krishnamoorthy S, Ashok V, Anand Kumar V, et al. Digital occlusal analysis of the impact of natural dentition and different types of rehabilitation on the occlusal force variations: systematic review and meta-analysis. J Oral Biol Craniofac Res. 2025;15(3):534-540. https://doi.org/10.1016/j.jobcr.2025.03.006.
20. Gözen M, Güntekin N. Comparison of occlusal force distribution and digital occlusal analysis methods of single posterior implant restorations: an in vivo study. BMC Oral Health. 2025;25(1):795. https://doi.org/10.1186/s12903-025-06205-w.
21. Sarhan MM, Rady NAE, Khamis MM. Evaluation of interproximal and occlusal contacts of single posterior implant-supported restorations fabricated using different CAD software programs: a clinical study. J Prosthet Dent. 2025;134(6):2246-2255. https://doi.org/10.1016/j.prosdent.2024.11.009.
22. Parker MW. The significance of occlusion in restorative dentistry. Dent Clin North Am. 1993;37(3):341-351.
23. Bozhkova TP. Comparative study of occlusal contact marking indicators. Folia Med (Plovdiv). 2020;62(1):180-184. https://doi.org/10.3897/folmed.62.e48018.
24. Qadeer S, Türp JC. Number of occlusal contacts during maximum intercuspation in dentate adults: a systematised review. J Oral Rehabil. 2023;50(7):617-626. https://doi.org/10.1111/joor.13451.
25. Esposito R, Masedu F, Cicciù M, Tepedino M, Denaro M, Ciavarella D. Reliability of recording occlusal contacts by using intraoral scanner and articulating paper: a prospective study. J Dent. 2024;142:104872. https://doi.org/10.1016/j.jdent.2024.104872.
26. Cerna M, Ferreira R, Zaror C, Navarro P, Sandoval P. Validity and reliability of the T-Scan III for measuring force under laboratory conditions. J Oral Rehabil. 2015;42(7):544-551. https://doi.org/10.1111/joor.12284.
27. McDevitt WE, Warreth AA. Occlusal contacts in maximum intercuspation in normal dentitions. J Oral Rehabil. 1997;24(10):725-734. https://doi.org/:10.1046/j.1365-2842.1997.00596.x.
28. Afrashtehfar KI, Qadeer S. Computerized occlusal analysis as an alternative occlusal indicator. Cranio. 2016;34(1):52-57. https://doi.org/10.1179/2151090314Y.0000000024.
29. Wu X, Jin Y, Xiao R, Liao P, Wang Y. Characteristics of occlusal force and contact in 20 individual normal occlusion children with mixed dentition. Beijing Da Xue Xue Bao Yi Xue Ban. 2025;57(1):154-160. https://doi.org/10.19723/j.issn.1671-167X.2025.01.023.
30. Seth-Johansen C, Gotfredsen K. Validity and reliability of digital occlusal analyzing methods in dentistry: a systematic review. J Dent. 2025;163:106124. https://doi.org/10.1016/j.jdent.2025.106124.
31. Maga W, Cieślik W, Schönborn M, Pihut M. The clinical value of digital occlusal analysis in the treatment of patients with temporomandibular disorders: a review of the literature. Folia Med Cracov. 2024;64(3):103-110. https://doi.org/10.24425/fmc.2024.152170.
32. Tiwari B, Ladha K, Lalit A, Dwarakananda Naik B. Occlusal concepts in full mouth rehabilitation: an overview. J Indian Prosthodont Soc. 2014;14(4):344-351. https://doi.org/10.1007/s13191-014-0374-y.
33. Millstein P, Maya A. An evaluation of occlusal contact marking indicators: a descriptive quantitative method. J Am Dent Assoc. 2001;132(9):1280-1286. https://doi.org/10.14219/jada.archive.2001.0373.
34. Cao H, Lopez D, Lee JD, Lee SJ. Quantitative analysis of occlusion in posterior single-implant supported restorations: a clinical study. J Dent. 2026;164:106233. https://doi.org/10.1016/j.jdent.2025.106233.
35. Čimić S, Žaja M, Kraljević S, Šimunković M, Kopić A, Ćatić. Influence of occlusal interference on the mandibular

condylar position. Acta Stomatol Croat. 2016;50(2):116-121. https://doi.org/10.1564/asc50/2/3.
36. Wang R, Xu X. Effect of 2 methods of occlusion adjustment on occlusal balance and muscles of mastication in patient with implant restoration. Shanghai Kou Qiang Yi Xue. 2015;24(6):748-752.
37. Wang M, Liu L, Ma X, Jin X, Zhang Z, Jia X, et al. Computerized dynamic occlusal analysis and its correlation with static characters in post-orthodontic patients using the T-Scan system and the ABO objective grading system. BMC Oral Health. 2023;23(1):312. https://doi.org/10.1186/s12903-023-02868-5.
38. Dinçer G, Nogueira Chamma-Wedemann C, Reis INRD, da Silva EVF, Çakmak G, Yılmaz B, et al. Comparison of digital technologies for occlusal analysis in dentate arches: a systematic review. J Dent. 2025;163:106114. https://doi.org/10.1016/j.jdent.2025.106114.
39. Nagri D, Jain N, Dhawan P. Comparative assessment of the accuracy of digital versus conventional interocclusal records in dentulous patients: a systematic review. Cureus. 2024;16(10):e72002. https://doi.org/10.7759/cureus.72002.
40. Zupancic Cepic L, Gruber R, Eder J, Vaskovich T, Schmid-Schwap M, Kundi M. Digital versus conventional dentures: a prospective, randomized cross-over study on clinical efficiency and patient satisfaction. J Clin Med. 2023;12(2):434. https://doi.org/10.3390/jcm12020434.
41. Albuhayri FS, Albshaier SJ, Dashti AI, Alrajhi JF, Alhamidy FK, Busuhail MA, et al. The expanding role of artificial intelligence in dentistry: a cross-specialty chairside perspective. Cureus. 2025;17(12):e98449. https://doi.org/10.7759/cureus.98449.
42. Elbanna L, Karne S, Lopez DZ, Mansoor M, Daniel AO, Movva SR, Singh S. The digital transformation of dentistry: AI-driven innovations and clinical challenges. Am J Med Sci Med. 2026;14(1):7-12. https://doi.org/10.12691/ajmsm-14-1-2.
43. Al-Ani Z, Yar R. Evolution of dental occlusion: integrating digital innovations. Prim Dent J. 2025;14(1):53-65. https://doi.org/10.1177/20501684251320452.
44. Xiao Z, Liu Z, Gu Y. Integration of digital maxillary dental casts with 3D facial images in orthodontic patients. Angle Orthod. 2020;90(3):397-404. https://doi.org/10.2319/071619-473.1.
45. Mitchem JA, Katona TR, Moser EAS. Does the presence of an occlusal indicator product affect the contact forces between full dentitions? J Oral Rehabil. 2017;44(10):791-799. https://doi.org/10.1111/joor.12543.
46. Garrido García VC, García Cartagena A, González Sequeros O. Evaluation of occlusal contacts in maximum intercuspation using the T-Scan system. J Oral Rehabil. 1997;24(12):899-903. https://doi.org/10.1046/j.1365-2842.1997.00586.x.
47. Revilla-León M, Ntovas P, Barmak AB, Fernández-Estevan L, Agustín-Panadero R, Kois JC. Discrepancies of centric occlusion located by using a conventional method and four intraoral scanners combined with a computer-aided design program: a pilot investigation. J Prosthet Dent. 2025;134(5):1944-1954. https://doi.org/10.1016/j.prosdent.2024.06.023.
48. Ünal HÖ, İnci MA, Dedeoğlu MT, Akgül Ü. Digital occlusal force analysis in anterior crossbite. Sci Rep. 2025;15(1):30290. https://doi.org/10.1038/s41598-025-16194-z.
49. Solaberrieta E, Otegi JR, Goicoechea N, Brizuela A, Pradies G. Comparison of a conventional and virtual occlusal record. J Prosthet Dent. 2015;114(1):92-97. https://doi.org/10.1016/j.prosdent.2015.01.009.