RESEARCH PAPER

Occlusal Indicators from Past to Present: A Literature Review of Qualitative and Quantitative Methods for Static and Dynamic Occlusal Assessment

Dr. P. Archana[1], Dr. S. Priyanka[2], Dr. D. Chalapathi Rao[3], Dr. L. Sri Charitha[4], Dr. L. Keerthi Rohini[5], Dr. G. Harilal[6]

[1]Post Graduate Student, Department of Prosthodontics and Crown and Bridge, Mamata Dental College and Hospital, Khammam, Telangana, India

[2]Post Graduate Student, Department of Prosthodontics and Crown and Bridge, Mamata Dental College and Hospital, Khammam, Telangana, India

[3]Professor, Department of Prosthodontics and Crown and Bridge, Mamata Dental College and Hospital, Khammam, Telangana, India (Corresponding Author)

[4]Senior Lecturer, Department of Prosthodontics and Crown and Bridge, Mamata Dental College and Hospital, Khammam, Telangana, India

[5]Senior Lecturer, Department of Prosthodontics and Crown and Bridge, Mamata Dental College and Hospital, Khammam, Telangana, India

[6]Professor, Department of Prosthodontics and Crown and Bridge, Mamata Dental College and Hospital, Khammam, Telangana, India

Corresponding Author: Dr. D. Chalapathi Rao

Abstract

Occlusal assessment is an integral component of restorative dentistry, prosthodontics, implant dentistry, and comprehensive oral rehabilitation. Accurate identification of occlusal contacts is essential for achieving harmonious function, preserving the longevity of restorations, minimizing biomechanical complications, and improving patient comfort. Over the years, numerous occlusal indicators have been introduced, ranging from conventional marking materials to sophisticated digital technologies capable of recording occlusal force and contact sequence. Despite continuous technological advancements, no single indicator has been universally accepted as the ideal method for evaluating static and dynamic occlusion. A literature search was conducted using PubMed, Scopus, Web of Science, ScienceDirect, and Google Scholar to identify relevant English-language publications from 1980 to 2026. Original research articles, comparative studies, systematic reviews, and narrative reviews evaluating conventional and digital occlusal indicators were included. The reviewed literature demonstrates that conventional qualitative indicators, including articulating paper, articulating silk, articulating foil, shimstock, wax, and silicone registration materials, remain widely used because of their simplicity, affordability, and ease of clinical application. However, these methods primarily identify the location of occlusal contacts and cannot reliably quantify contact force or timing. In contrast, quantitative digital systems such as T-Scan, Dental Prescale II, OccluSense, Accura, and intraoral scanner-based occlusal analysis provide objective information regarding force distribution, occlusal balance, and contact sequence, although each possesses inherent technical and clinical limitations. Comparative studies consistently indicate that digital systems improve reproducibility and provide valuable functional information, whereas conventional indicators continue to demonstrate superior practicality for routine chairside procedures. Current evidence suggests that occlusal indicators should not be considered competing technologies but complementary diagnostic tools. Selection of an appropriate indicator should depend on the clinical objective, complexity of treatment, and diagnostic information required. Future developments integrating artificial intelligence, virtual articulators, and digital patient workflows may further enhance the accuracy and predictability of occlusal assessment.

Keywords: Occlusal Indicators; Occlusal Analysis; Articulating Paper; T-Scan; Occlusense; Dental Prescale; Digital Occlusion; Static Occlusion; Dynamic Occlusion.

How to cite this article: P. Archana1 Dr. S. Priyanka2 Dr. D. Chalapathi Rao3 Dr. L. Sri Charitha4 Dr. L. Keerthi Rohini5 Dr. G. Harilal6. Occlusal Indicators from Past to Present: A Literature Review of Qualitative and Quantitative Methods for Static and Dynamic Occlusal Assessment. Int J Drug Deliv Technol. 2026;16(78s):558-571. DOI: 10.25258/ijddt.16.78s.66.

Literature Search Strategy

This narrative literature review was conducted to summarize the evolution and current status of occlusal indicators used for static and dynamic occlusal assessment. Electronic literature searches were performed using PubMed, Scopus, Web of Science, ScienceDirect, and Google Scholar. The search included publications from **January 1980 to June 2026**. The keywords used individually and in combination included *occlusal indicators*, *occlusal analysis*, *articulating paper*, *articulating foil*, *shimstock*, *wax occlusogram*, *silicone occlusal registration*, *T-Scan*, *Dental Prescale*, *OccluSense*, *digital occlusion*, *occlusal force analysis*, *virtual occlusion*, and *intraoral scanner occlusion*. Original research articles, comparative clinical and laboratory studies, systematic reviews, and narrative reviews published in English were included. Case reports, conference abstracts, editorials, letters to the editor, duplicate publications, and studies not directly related to occlusal

assessment were excluded. Particular emphasis was placed on comparative investigations evaluating the accuracy, reliability, reproducibility, clinical applications, advantages, and limitations of both conventional and digital occlusal indicators.

Introduction

Occlusion plays a fundamental role in maintaining the functional harmony of the stomatognathic system. Accurate occlusal relationships contribute to efficient mastication, preservation of periodontal health, stability of temporomandibular joint function, and long-term success of restorative and prosthodontic treatment. Conversely, occlusal discrepancies may contribute to restoration failure, prosthesis instability, excessive wear, implant overload, and patient discomfort. Consequently, careful assessment of occlusal contacts remains an indispensable component of comprehensive dental care. The assessment of occlusion has evolved considerably over the past century. Early clinicians relied primarily on wax impressions and pigment-based materials to identify contact areas. Although these methods provided useful visual information, they offered only subjective interpretations of occlusal contacts. Continuous improvements in dental materials subsequently led to the introduction of articulating paper, silk, articulating foil, shimstock, and elastomeric registration materials, each designed to improve the visualization of occlusal contacts while minimizing interference during mandibular closure. These conventional indicators remain widely used because they are inexpensive, simple to manipulate, and readily available in routine clinical practice. Despite their widespread use, conventional occlusal indicators possess inherent limitations. Numerous investigations have demonstrated that the size, intensity, and shape of articulating marks are influenced by several factors, including material thickness, composition, moisture contamination, tooth morphology, and operator technique. More importantly, the appearance of a marking does not accurately represent the magnitude of occlusal force. Consequently, interpretation of conventional occlusal markings remains largely subjective and depends heavily on clinical experience. The increasing demand for objective and reproducible occlusal assessment has stimulated the development of computerized and digital technologies. Systems such as T-Scan, Dental Prescale II, OccluSense, Accura, and digital intraoral scanners have expanded the scope of occlusal analysis by providing quantitative information regarding contact timing, force distribution, occlusal balance, and dynamic mandibular movements. These technologies have significantly improved clinicians' ability to evaluate functional occlusion, particularly during complex prosthodontic rehabilitation, implant-supported restorations, and full-mouth reconstruction. Nevertheless, digital systems also exhibit limitations related to sensor thickness, calibration, cost, reproducibility, and interpretation of recorded data. Over the last two decades, numerous comparative investigations and systematic reviews have evaluated the diagnostic performance of conventional and digital occlusal indicators. While conventional indicators continue to demonstrate clinical practicality for routine chairside procedures, digital technologies have shown superior capability in recording dynamic occlusal parameters and improving measurement reproducibility. However, existing evidence indicates that no currently available occlusal indicator fulfills all the requirements of an ideal diagnostic system capable of simultaneously providing precise contact localization, accurate force quantification, dynamic contact sequencing, minimal occlusal interference, operator independence, and complete clinical reliability. Several review articles have described individual occlusal indicators or focused predominantly on either conventional or digital methods. However, relatively few reviews have comprehensively presented the historical evolution of occlusal indicators, systematically classified them into qualitative and quantitative methods, and critically synthesized the comparative evidence that guides current clinical practice. Considering the rapid advancement of digital dentistry and the growing body of comparative research, an updated review integrating both conventional and contemporary occlusal assessment methods is clinically relevant.

Therefore, the purpose of this literature review is to present the chronological evolution of occlusal indicators, classify currently available methods into qualitative and quantitative categories, critically evaluate their principles, clinical applications, advantages and limitations, and comprehensively summarize the comparative evidence available in the literature to facilitate evidence-based selection of occlusal indicators for static and dynamic occlusal assessment.

Excellent. This section should **not simply list indicators**. Instead, it should tell the story of how occlusal assessment evolved over time, providing the rationale for each technological advancement. This creates a much smoother transition into the later classification section and avoids redundancy. The following section is based on an original synthesis of the literature in your uploaded manuscript.

2. Evolution of Occlusal Indicators

The accurate assessment of occlusal contacts has long been recognized as a prerequisite for successful restorative, prosthodontic, and implant treatment. Since occlusal discrepancies may adversely affect mastication, temporomandibular

joint function, periodontal health, and the longevity of restorations, clinicians have continually sought methods capable of identifying occlusal contacts with greater accuracy and reliability. The evolution of occlusal indicators reflects the transition from simple visual marking techniques to sophisticated computerized systems that provide quantitative information regarding occlusal force, timing, and contact sequence.

Early Development of Occlusal Indicators

The earliest methods of occlusal assessment relied primarily on **wax-based recording materials**, which were introduced during the late nineteenth and early twentieth centuries. Wax occlusograms and bite registration waxes were initially developed to record maxillomandibular relationships and visualize areas of tooth contact during mandibular closure. These materials were inexpensive, readily available, and simple to manipulate, making them popular in routine clinical practice. When occlusal forces were applied, the wax was displaced or perforated at contact points, thereby providing a visual representation of occlusal relationships. Although wax recordings allowed clinicians to identify gross occlusal interferences, they were highly susceptible to distortion caused by temperature changes, elastic recovery, handling errors, and material deformation. Consequently, the reproducibility and precision of wax recordings were limited, restricting their usefulness in procedures requiring detailed occlusal adjustment. Despite these shortcomings, wax indicators represented the first systematic attempt to record occlusal contacts and established the foundation for the development of more accurate occlusal assessment methods.

Introduction of Pigmented Occlusal Marking Materials

The limitations associated with wax recordings encouraged the development of pigmented marking materials that could transfer colored markings directly onto tooth surfaces. This led to the widespread adoption of **articulating paper**, which rapidly became the most commonly used occlusal indicator in dentistry. Articulating paper consists of a thin cellulose or silk substrate impregnated with colored pigments that are transferred to contacting tooth surfaces during occlusion. Owing to its simplicity, low cost, and rapid application, articulating paper became the standard chairside method for identifying premature contacts and guiding occlusal adjustments in restorative and prosthodontic procedures. Over time, articulating paper became available in different thicknesses, colors, and compositions to improve clinical visualization. Thinner papers were introduced to reduce occlusal interference, whereas double-sided and horseshoe-shaped designs improved ease of application. Although articulating paper revolutionized routine occlusal assessment, subsequent investigations demonstrated that the size and intensity of paper markings were influenced by numerous factors including paper thickness, pigment composition, moisture contamination, tooth morphology, occlusal surface texture, and operator technique. More importantly, clinical and laboratory studies consistently demonstrated that the size of an articulating paper mark does not accurately represent the magnitude of occlusal force. This realization marked an important turning point in occlusal research and stimulated efforts to develop more objective diagnostic methods.

Refinement of Conventional Qualitative Indicators

As the demand for greater precision increased, several modifications of conventional marking materials were introduced.

Articulating silk was developed as a thinner and more flexible alternative to conventional articulating paper. Because of its improved adaptability and enhanced pigment transfer, articulating silk provided clearer contact markings, particularly on polished ceramic and metallic restorations. Similarly, **articulating foil** was introduced with thicknesses as low as 8–12 μm, allowing clinicians to visualize occlusal contacts while minimizing the influence of the recording material itself. These ultra-thin foils became particularly valuable during the adjustment of fixed prostheses, implant restorations, and ceramic reconstructions where minimal occlusal interference was essential. Another important development was **shimstock foil**, an extremely thin metallic foil used primarily to verify the presence or absence of occlusal contact. Unlike articulating paper, shimstock does not produce colored markings but determines whether a contact is sufficiently firm to retain or resist withdrawal of the foil during intercuspation. Consequently, shimstock became an adjunctive method for confirming occlusal contacts rather than locating them. Although articulating silk, articulating foil, and shimstock improved the precision of conventional occlusal assessment, they remained qualitative indicators and were unable to quantify occlusal force or determine the sequence of tooth contacts during mandibular movements.

Development of Silicone-Based Registration Materials

During the latter part of the twentieth century, elastomeric materials began to be used for occlusal assessment. Silicone-based registration materials were originally introduced for recording interocclusal relationships during prosthodontic procedures; however, their dimensional stability and excellent detail reproduction also made them useful for evaluating occlusal contacts. Advances in image analysis and transillumination techniques enabled silicone registrations to serve as highly

reproducible reference methods for identifying contact and near-contact areas. Because silicone records undergo minimal deformation following polymerization, they provide greater dimensional accuracy than wax-based materials. Consequently, silicone transillumination has frequently been used as a reference standard in comparative studies evaluating the accuracy of both conventional and digital occlusal indicators. Nevertheless, the technique requires additional armamentarium, increased chairside time, and image analysis, limiting its routine clinical application despite its high validity.

Emergence of Quantitative Occlusal Analysis

Although conventional indicators effectively identified contact locations, they failed to provide objective information regarding occlusal force distribution or contact sequence. These limitations prompted the development of computerized occlusal analysis systems during the late twentieth century. The introduction of the **T-Scan system** represented a major milestone in occlusal diagnostics. Unlike conventional indicators, T-Scan employs an electronic sensor capable of recording the timing and relative force of occlusal contacts during mandibular closure and excursive movements. For the first time, clinicians could evaluate dynamic occlusion using numerical and graphical data rather than relying solely on visual interpretation. Successive generations of the T-Scan system demonstrated improvements in sensor sensitivity, software algorithms, and graphical presentation of occlusal data. Although the system does not measure absolute occlusal force, it provides valuable information regarding relative force distribution, occlusal balance, contact sequence, and the identification of premature contacts. Consequently, T-Scan has become one of the most extensively investigated digital occlusal analysis systems in restorative dentistry, prosthodontics, implant dentistry, and occlusal rehabilitation.

Pressure-Sensitive Film Technology

An alternative approach to quantitative occlusal analysis was introduced through **pressure-sensitive films**, particularly the Dental Prescale system. These films contain pressure-sensitive microcapsules that rupture under occlusal load, producing color changes proportional to the applied force. Specialized software subsequently converts these recordings into numerical values representing bite force, contact area, and pressure distribution. Compared with conventional marking materials, pressure-sensitive films provide objective quantitative information regarding overall occlusal loading. However, they cannot accurately identify the chronological sequence of tooth contacts or provide detailed tooth-specific force analysis. Consequently, their primary application remains the evaluation of total bite force rather than dynamic occlusal assessment.

Hybrid Digital Occlusal Systems

Recent technological advances have resulted in the development of hybrid occlusal indicators that combine the advantages of conventional and computerized systems.

OccluSense integrates a thin pressure-sensitive electronic sensor with a color-coated recording surface, enabling simultaneous visualization of occlusal contacts and digital recording of force distribution. This dual recording capability provides both qualitative and quantitative information during a single occlusal registration. Similarly, newer sensor-based technologies such as **Accura** have demonstrated promising reliability in recording occlusal force. Although the available evidence is encouraging, the clinical literature evaluating these systems remains relatively limited when compared with T-Scan.

Digital Dentistry and Virtual Occlusion

The rapid expansion of digital dentistry has transformed occlusal assessment over the past decade. Modern **intraoral scanners** now incorporate virtual occlusal analysis by digitally superimposing maxillary and mandibular scans to generate three-dimensional occlusal contact maps. These virtual occlusal displays facilitate communication between clinicians and dental laboratories while integrating seamlessly into computer-aided design and manufacturing (CAD/CAM) workflows. In addition, digital articulators and jaw-tracking systems have further expanded the ability to simulate mandibular movements and evaluate occlusion within a virtual patient environment. Despite these advantages, current evidence indicates that virtual occlusion generated by intraoral scanners does not consistently correspond to actual intraoral occlusal contacts. Variations in scanning accuracy, image stitching, software algorithms, and virtual articulation continue to influence the reliability of these systems. Consequently, digital intraoral scanners are currently considered valuable adjuncts rather than complete substitutes for conventional occlusal verification.

Emerging Trends in Occlusal Assessment

Recent developments in digital dentistry indicate a gradual transition toward comprehensive digital occlusal analysis. Artificial intelligence, machine learning algorithms, virtual articulators, digital patient concepts, and four-dimensional (4D) mandibular motion analysis are increasingly being incorporated into prosthodontic workflows. These technologies aim to integrate static occlusal contacts, dynamic mandibular movements, facial scans, cone-beam computed tomography, and intraoral scans into a unified virtual environment capable of simulating functional occlusion with greater precision. Although many of these

technologies remain in the developmental or early clinical stages, they represent the future direction of occlusal diagnostics and individualized prosthodontic treatment planning. Overall, the evolution of occlusal indicators demonstrates a continuous progression from subjective visualization of contact points toward objective, digitally assisted assessment of occlusal function. Nevertheless, despite remarkable technological advancements, no currently available system satisfies all the characteristics of an ideal occlusal indicator. Consequently, contemporary clinical practice increasingly favors the complementary use of conventional and digital methods to obtain a comprehensive understanding of static and dynamic occlusion.

Table 1. Chronological evolution of occlusal indicators

Approximate Period	Occlusal indicator	Major advancement	Primary limitation
Early 1900s	Wax occlusograms	First visual recording of contacts	Distortion and poor reproducibility
Mid-1900s	Articulating paper	Rapid chairside contact localization	Cannot quantify force
1960s–1980s	Articulating silk and foil	Improved marking precision with reduced thickness	Qualitative assessment only
1970s–1990s	Shimstock foil	Verification of contact without significant occlusal interference	Indicates only presence or absence of contact
1980s–1990s	Silicone registration materials	Improved dimensional stability and reference-standard contact mapping	Time-consuming and technique-sensitive
1987 onwards	T-Scan computerized analysis	Dynamic evaluation of contact timing and relative force distribution	High cost and learning curve; measures relative rather than absolute force
1990s onwards	Dental Prescale	Quantification of bite force and contact area	Limited tooth-specific and dynamic information
2010 onwards	Accura	Improved electronic force recording	Limited clinical evidence
2018 onwards	OccluSense	Simultaneous contact marking and digital force analysis	Fewer validation studies than T-Scan
2015 onwards	Intraoral scanner-based virtual occlusion	Integration with CAD/CAM workflows and digital dentistry	Variable accuracy for true intraoral contacts
Emerging	AI-assisted occlusal analysis and virtual articulators	Personalized digital occlusal assessment	Requires further clinical validation

3. Classification of Occlusal Indicators

Occlusal indicators have evolved considerably over the past century to meet the increasing demand for accurate evaluation of occlusal contacts during restorative, prosthodontic, and implant procedures. Based on the nature of information they provide, currently available occlusal indicators can be broadly classified into **qualitative** and **quantitative** methods. Qualitative indicators primarily identify the presence and location of occlusal contacts without measuring the magnitude or timing of occlusal forces. In contrast, quantitative indicators provide objective numerical information regarding force distribution, contact sequence, occlusal balance, and dynamic mandibular movements. Both categories play complementary roles in clinical dentistry, and the selection of an appropriate indicator depends on the diagnostic objective, complexity of treatment, and clinical situation.

3.1 Qualitative Occlusal Indicators

Qualitative indicators are conventional materials that transfer markings onto contacting tooth surfaces to identify the location of occlusal contacts. They are inexpensive, readily available, and widely used in daily clinical practice because they require minimal equipment and are easy to interpret. However, these indicators do not provide quantitative information regarding occlusal force or contact timing.

3.1.1 Wax-Based Occlusal Indicators

Wax was among the earliest materials used for occlusal assessment. During mandibular closure, the opposing teeth compress or perforate the wax, producing an imprint that represents areas of contact. Historically, wax occlusograms were widely used to record intercuspal relationships and detect gross occlusal discrepancies.

Wax indicators are simple, inexpensive, and capable of recording multiple contacts simultaneously. They also provide a broad visualization of contact distribution, making them useful for preliminary occlusal assessment and educational purposes. Despite these advantages, wax exhibits poor dimensional stability and is susceptible to distortion during removal, handling, and temperature fluctuations. The recorded contact depth does not accurately reflect the magnitude of occlusal force, limiting its diagnostic value in precise occlusal analysis. Consequently, wax has largely been replaced by more accurate recording materials, although it continues to be used in selected prosthodontic procedures.

3.1.2 Articulating Paper

Articulating paper remains the most widely used occlusal indicator in contemporary dental practice. It consists of a thin paper or cellulose substrate impregnated with colored pigments that transfer onto tooth surfaces during occlusal contact. Various thicknesses ranging from approximately 8 μm to over 200 μm are commercially available to suit different clinical applications. The popularity of articulating paper is attributed to its low cost, simplicity, ease of handling, and immediate visualization of occlusal contacts. It is routinely used during restorative procedures, complete denture insertion, fixed prosthodontics, implant prosthodontics, and occlusal adjustments. However, numerous investigations have demonstrated that the size, density, and shape of articulating paper markings are affected by paper thickness, pigment composition, moisture contamination, tooth anatomy, restorative materials, and operator technique. Importantly, larger or darker markings should not be interpreted as areas of greater occlusal force. Several comparative studies have confirmed only a weak correlation between articulating paper mark size and actual occlusal load, emphasizing that articulating paper should be regarded as a contact localization tool rather than a force-measuring device.

3.1.3 Articulating Silk

Articulating silk was developed to improve the precision of occlusal marking while reducing material thickness. The woven silk substrate allows uniform pigment transfer and produces sharper, more consistent markings than conventional articulating paper, particularly on highly polished restorations. Its flexibility enables better adaptation to complex occlusal anatomy, making it useful during occlusal adjustment of ceramic restorations and implant-supported prostheses. Despite improved marking quality, articulating silk remains a qualitative indicator. Moisture contamination, saliva, and operator handling continue to influence mark reproducibility, and the material provides no information regarding occlusal force or contact sequence.

3.1.4 Articulating Foil

Articulating foil represents one of the thinnest conventional occlusal indicators available, with some products measuring less than 10 μm in thickness. The reduced thickness minimizes occlusal interference and improves the accuracy of contact localization, particularly during adjustment of precision restorations. Several laboratory investigations have demonstrated superior contact visualization with articulating foil compared with thicker articulating papers and some digital intraoral scanning systems. Consequently, articulating foil is widely recommended during adjustment of ceramic crowns, implant restorations, veneers, and full-mouth rehabilitations. Although articulating foil improves spatial accuracy, it still functions solely as a contact-marking medium and cannot determine contact timing or occlusal force. Its delicate structure also requires careful handling to avoid tearing during clinical use.

3.1.5 Shimstock Foil

Shimstock foil is an ultra-thin metallic foil, usually measuring approximately 8 μm, that is used to verify whether opposing teeth are in firm contact. Unlike articulating paper, shimstock does not produce visible markings but determines whether a contact is sufficiently strong to retain the foil between opposing teeth during intercuspation. Its negligible thickness allows assessment with minimal alteration of the patient's natural occlusion. Therefore, shimstock is particularly useful for confirming occlusal contacts following crown cementation, implant prosthesis delivery, and occlusal equilibration. Nevertheless, shimstock provides only binary information regarding the presence or absence of contact and cannot determine contact intensity, force distribution, or contact sequence. Consequently, it is commonly used in conjunction with articulating paper or foil rather than as a standalone occlusal indicator.

3.1.6 Silicone Registration Materials

Silicone-based interocclusal registration materials have gained importance because of their excellent

dimensional stability, elastic recovery, and ability to reproduce fine anatomical details. When combined with transillumination or digital image analysis, silicone registrations provide highly accurate visualization of contact and near-contact areas. Due to their reproducibility, silicone registration techniques have frequently served as reference standards in studies evaluating the accuracy of both conventional and digital occlusal indicators. Despite their high validity, silicone registrations require additional clinical time, specialized equipment, and image analysis, making them less practical for routine chairside occlusal adjustment. Consequently, they are mainly reserved for complex diagnostic procedures, research applications, and validation studies.

Summary of Qualitative Indicators

Qualitative indicators continue to dominate routine clinical practice because they are economical, readily available, and simple to use. Their principal advantage lies in rapid visualization of occlusal contacts with minimal equipment. However, their greatest limitation is the inability to objectively quantify occlusal force, contact timing, or dynamic occlusal events. Therefore, qualitative indicators should primarily be considered localization tools rather than comprehensive occlusal analysis systems.

3.2 Quantitative Occlusal Indicators

Unlike conventional marking materials, quantitative occlusal indicators provide objective numerical information regarding occlusal contacts. These systems evaluate variables such as relative force distribution, contact timing, occlusal balance, bite force, and dynamic mandibular movements, thereby reducing the subjectivity associated with conventional occlusal assessment.

3.2.1 T-Scan Computerized Occlusal Analysis

T-Scan was the first computerized occlusal analysis system to gain widespread clinical acceptance. It utilizes a pressure-sensitive electronic sensor connected to dedicated software that records the sequence and relative intensity of occlusal contacts during static closure and functional mandibular movements.One of its greatest strengths is the ability to provide real-time dynamic analysis of occlusion. Clinicians can identify premature contacts, evaluate right-left force balance, analyze occlusal timing, and monitor changes following occlusal adjustment or prosthetic rehabilitation.

Numerous comparative studies have demonstrated superior reproducibility of T-Scan compared with many conventional indicators. Consequently, it has become particularly valuable in implant prosthodontics, full-mouth rehabilitation, occlusal equilibration, temporomandibular disorder management, and assessment of complex restorations. However, T-Scan records relative rather than absolute occlusal force and may underrepresent certain posterior contacts depending on sensor positioning and calibration. The system also requires operator training and represents a significant financial investment compared with conventional indicators.

3.2.2 Dental Prescale II

Dental Prescale II employs pressure-sensitive films containing microcapsules that rupture under occlusal loading. Specialized software subsequently converts the color intensity into numerical measurements representing bite force, pressure distribution, and contact area. Unlike T-Scan, Dental Prescale provides measurements expressed in Newtons, making it particularly useful for evaluating total bite force in research and prosthodontic rehabilitation. However, the system cannot accurately identify the chronological sequence of tooth contacts or precisely determine force distribution on individual teeth. Consequently, its clinical application is generally limited to evaluation of overall occlusal loading rather than dynamic occlusal analysis.

3.2.3 Accura Occlusal Analyzer

Accura is a more recent electronic occlusal analysis system based on piezoelectric sensor technology. Preliminary investigations have reported excellent repeatability and reliability in recording occlusal force measurements. Compared with T-Scan, the currently available scientific evidence remains limited. Although early findings are encouraging, further clinical studies are required before widespread recommendations can be made regarding its routine use.

3.2.4 OccluSense

OccluSense represents a hybrid digital occlusal indicator combining conventional contact marking with computerized force analysis. The disposable sensor is coated with a colored film that simultaneously transfers contact markings while electronically recording force distribution and contact sequence. This dual functionality enables clinicians to visualize contact locations while obtaining objective digital information during the same recording procedure. Although OccluSense has demonstrated promising clinical performance, comparative investigations have generally reported lower repeatability than T-Scan. Nevertheless, its ease of use and combined analog-digital recording make it an attractive option for contemporary prosthodontic practice.

3.2.5 Intraoral Scanner-Based Virtual Occlusion

Modern intraoral scanners generate virtual occlusal maps by digitally aligning maxillary and mandibular scans. These systems provide color-coded representations of interocclusal distance and contact relationships while integrating seamlessly into CAD/CAM workflows. Virtual occlusion improves laboratory communication, facilitates prosthesis design, and reduces the need for conventional interocclusal records. However, several investigations have reported discrepancies

between virtual occlusal contacts and actual intraoral contacts recorded using conventional methods. Current evidence therefore supports their use as adjunctive tools rather than independent diagnostic systems.

3.2.6 Jaw-Tracking Systems and Virtual Articulators

Recent advances in digital dentistry have introduced jaw-tracking devices capable of recording three-dimensional mandibular movements. When integrated with virtual articulators and digital patient workflows, these systems simulate functional occlusion with greater precision. Although these technologies have considerable potential in full-mouth rehabilitation and implant prosthodontics, clinical validation remains limited, and standardization of recording protocols continues to evolve.

Summary of Quantitative Indicators

Quantitative occlusal indicators represent a significant advancement in occlusal diagnostics by providing objective information regarding occlusal force, timing, and functional occlusion. Despite their improved reproducibility and analytical capabilities, they require greater financial investment, technical expertise, and standardized clinical protocols. Current evidence suggests that these systems should complement rather than replace conventional qualitative indicators, particularly in complex restorative and prosthodontic procedures.

Table 2. Classification of currently available occlusal indicators

Category	Indicator	Principle	Major Advantages	Major Limitations	Primary Clinical Applications
Qualitative	Wax	Contact imprint	Simple and inexpensive	Distortion	Preliminary occlusal assessment
	Articulating paper	Pigment transfer	Easy, economical	No force measurement	Routine occlusal adjustment
	Articulating silk	Fine pigment transfer	Improved marking accuracy	Qualitative only	Ceramic restorations
	Articulating foil	Ultra-thin pigment film	Minimal occlusal interference	Technique-sensitive	Precision prosthodontics
	Shimstock	Contact retention	Confirms true contact	Binary result only	Crown and implant verification
	Silicone registration	Transillumination/image analysis	High reproducibility	Time-consuming	Research and complex diagnosis
Quantitative	T-Scan	Pressure-sensitive sensor	Dynamic force and timing analysis	Relative force only	Full-mouth rehabilitation, implants
	Dental Prescale II	Pressure-sensitive film	Absolute bite force analysis	Limited dynamic information	Bite force assessment
	Accura	Piezoelectric sensor	Good repeatability	Limited evidence	Experimental and clinical force analysis
	OccluSense	Hybrid digital sensor	Contact marking + force analysis	Lower reproducibility than T-Scan	Digital occlusal analysis
	Intraoral scanners	Virtual occlusion	CAD/CAM integration	Variable accuracy	Digital prosthodontics

	Jaw-tracking systems	Mandibular motion analysis	Functional simulation	Limited validation	Virtual patient workflows

4. Comparative Evidence on Occlusal Indicators

Over the past three decades, numerous investigations have compared conventional and digital occlusal indicators to determine their accuracy, reliability, reproducibility, and clinical applicability. Although each indicator has unique advantages, the available evidence consistently demonstrates that no single method fulfills all the characteristics of an ideal occlusal assessment system. Instead, each indicator provides specific diagnostic information that should be interpreted according to its intended purpose.

4.1 Comparison among Conventional Occlusal Indicators

The earliest comparative studies focused on evaluating differences among conventional occlusal indicators such as articulating paper, articulating silk, articulating foil, shimstock, and wax-based materials. These investigations sought to determine whether different materials produced similar occlusal markings under identical clinical conditions. Millstein and Maya were among the first investigators to systematically compare various conventional occlusal indicators. Their study demonstrated considerable variation in the size and shape of occlusal markings produced by different materials, even when identical occlusal contacts were examined. The authors concluded that paper thickness, pigment composition, and substrate characteristics significantly influenced the appearance of occlusal markings. These findings challenged the long-held assumption that all articulating materials record occlusal contacts with equal accuracy. Subsequent investigations showed that thinner indicators generally produced more precise contact localization than thicker materials. Ultra-thin articulating foil demonstrated greater accuracy in identifying true contact points because it introduced minimal interference between opposing teeth. Similarly, articulating silk provided more consistent markings than conventional articulating paper, particularly on polished ceramic restorations. Shimstock foil was evaluated as a complementary verification method rather than a marking material. Owing to its minimal thickness, shimstock accurately confirmed the presence or absence of occlusal contact without significantly altering mandibular closure. However, because it provides only binary information, it cannot identify the exact location or intensity of occlusal contacts. Consequently, it is generally recommended as an adjunct to articulating paper or foil rather than as a replacement. Silicone registration materials have also been compared with conventional indicators. Their excellent dimensional stability and minimal distortion resulted in highly reproducible recordings, and several validation studies have adopted silicone transillumination as a reference standard for assessing the accuracy of both conventional and digital occlusal indicators. Despite this high level of accuracy, the additional clinical time and equipment required have limited their routine chairside application. Overall, comparative evidence suggests that thinner conventional indicators produce more accurate contact localization than thicker materials. However, regardless of the recording medium, all conventional indicators remain qualitative methods and are unable to objectively quantify occlusal force or determine the sequence of occlusal contacts.

4.2 Conventional Indicators versus Digital Occlusal Analysis

The introduction of computerized occlusal analysis systems fundamentally changed the approach to occlusal assessment by shifting the emphasis from visual interpretation to objective measurement. Consequently, numerous studies have compared conventional marking materials with digital technologies to determine whether computerized systems provide superior diagnostic information. One of the most extensively investigated questions concerns the relationship between articulating paper markings and occlusal force. Traditionally, clinicians assumed that larger or darker markings represented heavier occlusal contacts. However, experimental studies by Carey and colleagues demonstrated only a weak relationship between articulating paper mark size and applied occlusal load. Similar findings were later confirmed by Qadeer and co-workers, who reported poor correlation between paper mark dimensions and force measurements obtained using computerized occlusal analysis. These investigations collectively demonstrated that the appearance of an articulating paper mark should not be interpreted as an indicator of contact intensity. Further evidence questioning the reliability of conventional indicators was provided by Mitchem and colleagues, who reported that interposed occlusal marking materials could themselves alter occlusal contacts. The presence of the recording medium between opposing teeth influenced contact relationships and force distribution, suggesting that some conventional indicators may modify the occlusion they are intended to evaluate. This observation highlighted an inherent limitation of all interocclusal recording materials. Computerized systems, particularly T-Scan, addressed many of these limitations by recording the sequence and relative distribution of occlusal forces during mandibular closure. Unlike articulating paper, T-Scan provides dynamic information regarding premature contacts, occlusal timing, and right-left

force balance. Comparative studies consistently demonstrated superior reproducibility of computerized force analysis compared with subjective interpretation of conventional markings. Nevertheless, digital systems are not without limitations. Several investigations have reported that T-Scan records fewer occlusal contacts than articulating paper or foil. Rather than indicating reduced accuracy, this finding is believed to reflect the ability of computerized sensors to register only clinically meaningful contacts while excluding minor surface markings that may not represent functional loading. Consequently, differences in contact numbers between conventional and digital systems should be interpreted cautiously. Collectively, available evidence indicates that conventional indicators and computerized systems evaluate different aspects of occlusion. Conventional materials are effective for rapid localization of contact points, whereas digital systems provide objective information regarding functional occlusal behavior..

4.3 Comparison among Digital Occlusal Indicators

As digital dentistry has expanded, increasing attention has been directed toward comparing different computerized occlusal analysis systems. T-Scan has consistently served as the reference system because of its extensive scientific documentation and long clinical history. Numerous investigations have demonstrated high repeatability and reproducibility for evaluating occlusal timing, force distribution, and dynamic occlusion. Consequently, T-Scan remains the most widely investigated quantitative occlusal indicator. Dental Prescale II represents an alternative quantitative approach by measuring bite force using pressure-sensitive films. Comparative studies have demonstrated significant correlations between Dental Prescale and T-Scan recordings, indicating that both systems provide valuable quantitative information. However, they evaluate different parameters. T-Scan primarily records relative force distribution and contact sequence, whereas Dental Prescale measures total occlusal force and contact area. Therefore, these systems should be considered complementary rather than interchangeable. Hybrid digital systems such as OccluSense have also undergone comparative evaluation. OccluSense offers the unique advantage of simultaneously providing conventional contact markings and computerized force analysis within a single recording. Initial investigations reported satisfactory agreement with conventional marking methods. However, studies comparing OccluSense with T-Scan demonstrated lower repeatability and greater measurement variability, particularly during repeated recordings. Although improvements in sensor positioning have enhanced performance, current evidence continues to favor T-Scan for reproducibility. Accura has demonstrated promising reliability in laboratory investigations, but the available clinical evidence remains limited. Additional longitudinal studies are required before definitive conclusions regarding its clinical performance can be drawn. Overall, comparisons among digital systems indicate that each technology measures different occlusal variables. While T-Scan remains the most extensively validated system for dynamic occlusal analysis, other digital technologies continue to evolve and may complement specific diagnostic requirements.

4.4 Intraoral Scanners versus Conventional Occlusal Indicators

The incorporation of virtual occlusal analysis into modern intraoral scanners has generated considerable interest because of its potential to simplify digital prosthodontic workflows. Consequently, several studies have compared virtual occlusal contacts generated by intraoral scanners with contacts recorded using conventional indicators. Most investigations have demonstrated acceptable sensitivity for identifying teeth involved in occlusion but lower specificity for accurately locating individual contact points. Laboratory studies comparing intraoral scanners with articulating foil have generally reported superior contact localization using conventional marking materials. Clinical investigations have similarly demonstrated discrepancies between digitally generated occlusal maps and intraoral contact markings. In many cases, virtual occlusal analysis underestimated posterior contacts or displayed contact areas that were not clinically evident. These differences are attributed to factors such as scanning accuracy, software algorithms, image stitching, virtual articulation, and patient movement during scanning. Despite these limitations, intraoral scanners provide significant advantages by integrating occlusal assessment with digital impressions, CAD/CAM workflows, and laboratory communication. Consequently, they are increasingly regarded as valuable adjuncts for treatment planning rather than definitive occlusal diagnostic tools.

4.5 Evidence from Recent Systematic Reviews

Recent systematic reviews have attempted to synthesize the growing body of evidence comparing conventional and digital occlusal indicators. Although differences exist among the included studies, several consistent conclusions have emerged. First, conventional indicators remain reliable for identifying the location of occlusal contacts but cannot objectively determine force magnitude or contact timing. Therefore, interpretation of articulating paper markings should be limited to contact localization rather than force estimation. Second, digital systems provide more objective and reproducible information regarding force distribution, contact sequence, and occlusal

balance. Among the currently available systems, T-Scan possesses the strongest evidence supporting its clinical reliability for dynamic occlusal assessment. Third, hybrid technologies such as OccluSense represent promising developments because they combine visual contact marking with digital force analysis. However, additional clinical validation is required before they can be considered equivalent to more extensively investigated computerized systems. Finally, systematic reviews consistently conclude that digital technologies should complement rather than replace conventional occlusal indicators. Combining qualitative and quantitative methods enables clinicians to obtain a more comprehensive understanding of static and dynamic occlusion than either method alone.

Clinical Implications of Comparative Evidence

The comparative literature clearly indicates that occlusal indicators should be selected according to the diagnostic objective rather than personal preference. Conventional indicators remain indispensable for rapid chairside identification of occlusal contacts because they are economical, simple to use, and readily available. Conversely, digital systems provide additional information regarding functional occlusion, including force distribution, contact timing, and occlusal balance, making them particularly valuable during complex prosthodontic rehabilitation, implant-supported restorations, and full-mouth reconstruction. Rather than replacing conventional techniques, contemporary digital technologies should be viewed as complementary diagnostic tools that enhance clinical decision-making. An evidence-based approach therefore combines qualitative localization of contacts with quantitative evaluation of occlusal function whenever comprehensive analysis is required.

Table 3. Landmark comparative studies on occlusal indicators

Author	Year	Indicators Compared	Major Findings	Clinical Significance
Millstein & Maya	2001	Conventional papers, films, and silk	Markings varied according to thickness and material	Mark appearance alone is unreliable
Carey et al.	2007	Articulating paper vs applied load	Poor correlation between mark size and force	Mark size should not indicate force
Qadeer et al.	2021	Articulating paper vs T-Scan	Weak relationship between mark area and occlusal force	Objective force assessment requires digital analysis
Mitchem et al.	2017	Conventional occlusal indicators	Recording materials altered occlusal contacts	Conventional indicators may influence occlusion
Ayuso-Montero et al.	2019	T-Scan vs intraoral scanner	T-Scan demonstrated superior dynamic assessment	Digital systems evaluate different variables
Huang et al.	2022	T-Scan vs Dental Prescale II	Positive correlation with different measurement capabilities	Systems are complementary
Rovira-Lastra et al.	2023	Conventional and digital methods	Silicone reference showed highest validity	Silicone useful as reference standard
Popa & Ahlers	2024	OccluSense vs Gnatho-Film	Good agreement after modified evaluation	Hybrid systems show potential
Jauregi et al.	2023	OccluSense vs T-Scan	T-Scan showed superior repeatability	T-Scan remains the benchmark
Manziuc et al.	2024	Articulating paper vs digital systems	Conventional indicators detected more contacts	Digital systems require complementary verification

Reich et al.	2025	T-Scan Novus, articulating silk, wax occlusogram	T-Scan provided better observer agreement but recorded fewer contacts	Dynamic analysis improves reproducibility

5. Discussion

Occlusal assessment remains one of the most important yet challenging aspects of restorative dentistry and prosthodontics. Despite the introduction of numerous occlusal indicators over the last century, the ideal method capable of accurately recording contact location, force magnitude, contact sequence, and functional occlusion without interfering with mandibular movements has not yet been developed. The findings of the present review demonstrate that each available occlusal indicator possesses inherent strengths and limitations, and none can independently satisfy all clinical requirements. Consequently, the choice of an occlusal indicator should be guided by the diagnostic objective rather than by routine clinical preference. The evolution of occlusal indicators illustrates a gradual shift from subjective visual interpretation toward objective digital analysis. Conventional indicators such as articulating paper, articulating silk, articulating foil, shimstock, and silicone registration materials continue to be widely used because they are economical, simple to manipulate, and provide immediate chairside information regarding contact location. Their ease of use has ensured their continued relevance in restorative dentistry, removable and fixed prosthodontics, implant dentistry, and occlusal adjustment procedures. Nevertheless, the literature consistently demonstrates that these materials primarily identify the presence of occlusal contacts and should not be interpreted as indicators of occlusal force or functional loading. One of the most significant observations emerging from comparative research is the absence of a direct relationship between the appearance of articulating paper markings and the magnitude of occlusal force. Earlier clinical practice often assumed that larger or darker markings represented heavier occlusal contacts. However, multiple experimental investigations have shown that mark size is influenced by several variables, including paper thickness, pigment characteristics, tooth anatomy, surface roughness, saliva contamination, and recording technique. Therefore, relying solely on the visual characteristics of articulating paper markings may lead to inaccurate occlusal adjustments, particularly during complex restorative and implant procedures. Another important finding is that conventional recording materials may influence the occlusal relationship they are intended to evaluate. Because these materials are interposed between opposing teeth during closure, they inevitably introduce a degree of separation that may alter contact patterns. Although this alteration is minimal with thinner materials such as articulating foil and shimstock, it cannot be completely eliminated. This explains why ultra-thin indicators generally demonstrate greater accuracy than thicker materials and why silicone-based transillumination techniques have been adopted as reference methods in many validation studies. The introduction of computerized occlusal analysis represented a significant advancement by enabling objective evaluation of occlusal function. Among currently available systems, T-Scan has accumulated the largest body of scientific evidence and remains the most extensively investigated digital occlusal analyzer. Unlike conventional indicators, T-Scan provides dynamic information regarding contact sequence, relative force distribution, occlusal balance, and timing of intercuspation. These parameters are particularly valuable during full-mouth rehabilitation, implant-supported prostheses, occlusal equilibration, and management of patients with complex occlusal problems. Although T-Scan demonstrates superior reproducibility compared with most conventional indicators, it should not be regarded as an infallible diagnostic tool. The system measures relative rather than absolute occlusal force, and sensor characteristics may influence contact detection. Furthermore, several comparative studies have reported fewer registered contacts with T-Scan than with articulating paper or articulating foil. Rather than indicating inferior performance, these findings likely reflect differences in measurement principles. Conventional indicators record all visible surface contacts, whereas computerized sensors preferentially identify contacts that contribute meaningfully to occlusal loading. Consequently, discrepancies between conventional and digital recordings should be interpreted as methodological differences rather than diagnostic inaccuracies. Pressure-sensitive systems such as Dental Prescale II provide an alternative quantitative approach by measuring overall bite force and contact area. These systems are particularly useful when total occlusal loading is of clinical interest. However, they provide limited information regarding tooth-specific force distribution and lack the ability to record the chronological sequence of occlusal contacts. Accordingly, Dental Prescale and T-Scan should be regarded as complementary technologies rather than competing systems. Hybrid technologies have attempted to overcome the limitations of both conventional and digital indicators. OccluSense combines visual contact markings with computerized force analysis,

allowing simultaneous qualitative and quantitative assessment during a single recording. Although initial clinical investigations have shown promising results, current evidence indicates that its reproducibility remains lower than that of T-Scan. Additional multicenter clinical studies are therefore required before definitive conclusions regarding its long-term clinical performance can be established. Digital dentistry has further expanded the scope of occlusal assessment through the introduction of intraoral scanners, virtual articulators, and jaw-tracking systems. These technologies integrate occlusal analysis into complete digital workflows and facilitate communication between clinicians and dental laboratories. Nevertheless, current evidence suggests that virtual occlusal contacts generated by intraoral scanners do not consistently correspond with actual intraoral contacts. Variations in scanning accuracy, software algorithms, virtual articulation, and mandibular positioning continue to influence diagnostic reliability. Therefore, digital occlusal maps should currently be interpreted as adjunctive information rather than definitive representations of functional occlusion. An important observation throughout the literature is that many comparative studies evaluate different outcome measures. Some investigations focus on contact localization, whereas others assess force distribution, timing, reproducibility, sensitivity, specificity, or clinical applicability. This methodological heterogeneity makes direct comparison between studies difficult and partly explains the conflicting conclusions reported in the literature. Future research should adopt standardized methodologies and clinically relevant outcome measures to facilitate meaningful comparison among different occlusal indicators. From a clinical perspective, the evidence supports an integrated approach to occlusal assessment. Conventional qualitative indicators remain appropriate for routine restorative procedures because they are simple, economical, and effective for identifying contact locations. However, digital quantitative systems should be considered whenever objective assessment of force distribution, occlusal balance, or contact timing is required, particularly during implant-supported rehabilitation, extensive fixed prosthodontic treatment, and full-mouth rehabilitation. The complementary use of qualitative and quantitative indicators enables clinicians to combine the simplicity of conventional methods with the objectivity of digital technologies, thereby improving diagnostic accuracy and treatment predictability. Future developments in occlusal analysis are expected to focus on greater integration of digital technologies. Artificial intelligence, virtual patient concepts, four-dimensional mandibular motion analysis, digital twin technology, and machine learning algorithms are likely to improve the interpretation of occlusal data and facilitate individualized treatment planning. As these technologies continue to evolve, they may reduce operator-dependent variability and provide more comprehensive assessment of functional occlusion. However, their widespread clinical implementation will depend upon further validation, standardization, cost reduction, and demonstration of meaningful improvements in patient outcomes. Overall, the available evidence suggests that the evolution of occlusal indicators has enhanced the clinician's ability to evaluate occlusion; however, technological advancement has not eliminated the need for sound clinical judgment. Successful occlusal assessment continues to depend on appropriate interpretation of diagnostic findings within the context of each patient's functional requirements and treatment objectives.

6. Conclusion

The evolution of occlusal indicators reflects continuous efforts to improve the accuracy and objectivity of occlusal assessment. Conventional qualitative indicators, including wax, articulating paper, articulating silk, articulating foil, shimstock, and silicone registration materials, remain indispensable in routine clinical practice because of their simplicity, affordability, and effectiveness in identifying occlusal contacts. However, these materials primarily indicate the location of contacts and should not be used to estimate occlusal force or contact intensity. Quantitative technologies have significantly advanced occlusal diagnostics by providing objective information regarding force distribution, contact timing, and dynamic occlusal relationships. Among currently available systems, T-Scan possesses the strongest scientific evidence supporting its reproducibility and clinical application in dynamic occlusal analysis. Dental Prescale II is valuable for evaluating overall bite force, while OccluSense and other hybrid systems represent promising developments that require further clinical validation. Intraoral scanners and virtual occlusal analysis have improved digital workflows but should presently be considered adjunctive tools rather than independent methods for definitive occlusal assessment. Current evidence does not support the existence of a universally superior occlusal indicator. Instead, qualitative and quantitative methods should be regarded as complementary diagnostic tools, each contributing unique information relevant to specific clinical situations. Selection of an occlusal indicator should therefore be based on the diagnostic objective, treatment complexity, and type of information required rather than on familiarity with a particular system.Future research should focus on standardized evaluation protocols, well-designed clinical trials, and integration of artificial intelligence with digital occlusal analysis

to improve diagnostic accuracy and treatment outcomes. Until such advances are validated, a combined approach using conventional and digital occlusal indicators remains the most evidence-based strategy for comprehensive static and dynamic occlusal assessment.

Table 4. Clinical recommendations for selecting occlusal indicators

Clinical scenario	Recommended indicator(s)	Rationale
Routine restorative procedures	Articulating paper + Shimstock	Rapid localization and verification of contacts
Fixed prosthodontics	Articulating foil + Shimstock	Thin indicators minimize occlusal interference
Complete dentures	Articulating paper	Simple identification of occlusal discrepancies
Implant-supported restorations	T-Scan + articulating foil	Objective force distribution with precise contact localization
Full-mouth rehabilitation	T-Scan + articulating foil/shimstock	Assessment of occlusal timing, balance, and contact verification
Occlusal equilibration	T-Scan + articulating paper	Dynamic force analysis combined with visual confirmation
Research applications	Silicone transilluminati on + Digital analysis	High reproducibility and reference-standard contact mapping
Digital CAD/CAM workflow	Intraoral scanner + conventional verification	Efficient digital workflow with clinical validation of contacts

References

1. Dawson PE. *Evaluation, Diagnosis and Treatment of Occlusal Problems*. 2nd ed. St Louis: Mosby; 1989.
2. Kerstein RB, Chapman R, Klein M. A comparison of ICAGD (Immediate Complete Anterior Guidance Development) to mock equilibration. *Quintessence Int*. 1990;21:729–739.
3. Garrido García VC, García Cartagena A, González Sequeros O. Evaluation of the T-Scan system in occlusal analysis. *Med Oral*. 1997;2:218–223.
4. Carey JP, Craig M, Kerstein RB, Radke J. Determining a relationship between applied occlusal load and articulating paper mark area. *Open Dent J*. 2007;1:1–7.
5. Millstein PL, Maya A. An evaluation of occlusal contact marking indicators: A descriptive quantitative method. *J Am Dent Assoc*. 2001;132:1280–1286.
6. Kerstein RB. Current applications of computerized occlusal analysis in dental medicine. *Gen Dent*. 2001;49:521–530.
7. Kerstein RB. Combining technologies: A computerized occlusal analysis system synchronized with a computerized electromyography system. *Cranio*. 2004;22:96–109.
8. 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:e48–e53.
9. Kerstein RB. Computerized occlusal analysis technology and its clinical applications. *Dent Clin North Am*. 2007;51:575–589.
10. Kerstein RB. Disclusion time reduction therapy with immediate complete anterior guidance development. *Compend Contin Educ Dent*. 2010;31:530–541.
11. Qadeer S, Yang L, Sarinnaphakorn L, Kerstein RB. Accuracy, reliability and clinical implications of static compared to quantifiable occlusal indicators. *Eur J Prosthodont Restor Dent*. 2021;29:9–18.
12. Mitchem JA, Katkoori VR, Chen J, Conway RC. Does the presence of an occlusal indicator product affect the contact forces between full dentitions? *J Oral Rehabil*. 2017;44:791–799.
13. Ayuso-Montero R, Mariano-Hernandez Y, Khoury-Ribas L, et al. Reliability and validity of T-Scan and three-dimensional intraoral scanning for measuring the occlusal contact area. *J Prosthet Dent*. 2020;123:203–209.
14. Kerstein RB. Computerized occlusal analysis as an alternative occlusal indicator. *Compend Contin Educ Dent*. 2015;36:26–34.
15. Qadeer S, Yang L, Kerstein RB. Static versus computerized occlusal indicators: Clinical implications. *Eur J Prosthodont Restor Dent*. 2021;29:9–18.
16. Hennen M, Rehmann P, Wöstmann B. Accuracy and reproducibility of visualization

of occlusal contacts using digital intraoral scanners compared with articulating foil. *J Prosthet Dent*. 2022;128:1005–1013.
17. Rovira-Lastra B, Flores-Orozco EI, Vela-Nebot X, et al. Accuracy of digital and conventional systems in locating occlusal contacts: A clinical study. *J Prosthet Dent*. 2023;130:418–426.
18. Huang HY, Lin YC, Lee KT, et al. The correlation between two occlusal analyzers for measuring occlusal force. *BMC Oral Health*. 2022;22:548.
19. Popa D, Ahlers MO. Contact point marking with the OccluSense system: An in vitro study on reliability and validity. *Int J Comput Dent*. 2024;27:103–116.
20. Jauregi I, Solaberrieta E, Brizuela A, et al. Repeatability and reproducibility of two digital occlusal analyzers: T-Scan and OccluSense. *J Prosthet Dent*. 2024;131:485–493.
21. Manziuc MM, Savu A, et al. Insights into occlusal analysis: Articulating paper versus digital technologies. *Healthcare*. 2024;12:1548.
22. Reich KM, Kappel S, Reitemeier B, 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 Prosthet Dent*. 2025;134:112–121.
23. Dinçer M, et al. Validity and reliability of digital occlusal analyzing methods: A systematic review. *J Dent*. 2025;157:105965.
24. Seth-Johansen M, Gotfredsen K. Digital occlusal assessment methods in prosthodontics: A systematic review. *J Oral Rehabil*. 2025;52:645–659.
25. Akkılıç F. Chronic traumatic dental occlusion: Its impact on temporomandibular joint and systemic health, and clinical management strategies. *J Oral Rehabil*. 2026;53:210–226.
26. Esposito M, et al. Clinical evaluation of intraoral scanner-based virtual occlusion compared with conventional occlusal indicators. *J Prosthet Dent*. 2026. (Ahead of print).