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Artificial Intelligence-Assisted and Conventional CAD Software for Occlusal Splint Design: A Narrative Review

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Abstract

Artificial intelligence (AI) is increasingly integrated into dental computer-aided design (CAD) workflows, offering automated restoration and occlusal device design with reduced operator input and potentially higher efficiency. In parallel, conventional CAD systems remain the standard for digital occlusal splint fabrication, relying on rule-driven algorithms, tooth libraries, and virtual articulation to generate splint geometry. Emerging AI-assisted platforms, such as Medit Splints and 3Shape Automate, extend concepts originally developed for crown design to occlusal splints, automatically generating complete devices from articulated digital models with minimal manual adjustment. However, the extent to which these systems match or exceed established CAD software in terms of geometric accuracy, occlusal morphology, and reproducibility remains unclear. This narrative review summarizes current evidence on AI-assisted and conventional CAD software for occlusal splint design. Early in vitro data suggest that AI-generated splints can achieve clinically acceptable intaglio fit and occlusal contact patterns, with precision comparable to technician-designed or conventionally designed controls. Larger, well-designed clinical studies are required to determine whether AI-assisted splint design offers meaningful advantages in clinical performance, patient comfort, and long-term outcomes beyond gains in efficiency and standardization.

Keywords: Artificial intelligence, Occlusal splints, Computer-aided design, Digital workflow.

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1. Introduction

Temporomandibular disorders (TMD) and parafunctional habits such as bruxism are prevalent conditions that can lead to pain, functional impairment, and accelerated tooth wear, often necessitating long-term conservative management strategies [1-2]. Occlusal splints have become a cornerstone of such management, serving diagnostic, therapeutic, and protective roles by stabilizing the mandible, redistributing occlusal forces, and protecting teeth and restorations from overload [3-6]. Among these, stabilization splints of the Michigan type, designed to provide uniform contacts and smooth anterior guidance, remain the most widely used for myogenous TMD and bruxism, with substantial evidence supporting their effectiveness in symptom reduction and functional improvement [7-10]. Traditionally, these appliances were fabricated using fully analog techniques, including conventional impressions, stone models, wax-up, and heat-cured acrylic processing, followed by labor-intensive occlusal adjustment. While clinically successful, conventional workflows are time-consuming, operator-dependent, & susceptible to cumulative inaccuracies from each manual step, potentially affecting fit, stability, and occlusal schemes [3-4-8]. The introduction of digital technologies has transformed this process, enabling intraoral scanning, virtual articulation, computer-aided design (CAD), and computer-aided manufacturing (CAM) of splints through milling or three-dimensional (3D) printing, which together improve standardization, reproducibility, and turnaround time [9-13]. In parallel, artificial intelligence (AI) has rapidly entered dental diagnostics and prosthodontics, first through deep-learning-based detection and classification systems, and more recently through AI-assisted design tools capable of automatically generating restorations and occlusal devices [14-20]. Early work focused on AI-driven crown design using generative adversarial networks (GANs) and convolutional neural networks (CNNs), demonstrating that automatically generated crowns can match or surpass conventional CAD designs in morphological fidelity and internal fit while reducing design time [14-21-23]. Building on these advances, new software platforms now offer AI-assisted occlusal splint design, automatically producing splint geometries from articulated scans with minimal user intervention [15-23-24]. Despite this progress, the relative merits of AI-assisted versus conventional CAD software for occlusal splint design have not been clearly established. Geometry-based workflows rely on rule-driven algorithms, tooth libraries, and explicit occlusal philosophies, offering predictable and explainable outcomes but limited adaptability to highly individualized morphology [25-27]. Machine-learning–based systems, by contrast, infer patterns from data and can generate complex occlusal surfaces, yet their behavior may be less transparent and highly dependent on training data quality and coverage [18-20-26-28]. This narrative review aims to summarize current evidence on AI-assisted and conventional CAD software for occlusal splint design, with particular emphasis on design principles and digital workflows. The review first outlines the evolution from conventional to digital splints, then contrasts conventional digital workflow and machine-learning-based CAD paradigms (Figure 1).

2. Occlusal splints: from conventional to digital and AI-assisted design

2.1. Conventional occlusal splints and their clinical roles

The concept of occlusal splints has evolved over more than a century, originating as simple bite plates designed to protect teeth from wear caused by bruxism. Early 20th-century clinicians recognized that separating the dental arches could relieve excessive forces on the teeth and provide comfort for patients experiencing jaw fatigue. Over time, as understanding of the temporomandibular joint (TMJ) and masticatory muscles grew, splints began to be appreciated not only for protection but also for their therapeutic potential in managing temporomandibular disorders [3-29]. By the mid-20th century, occlusal appliances were increasingly incorporated into treatment plans aimed at stabilizing occlusion and reducing muscle hyperactivity. Dawson emphasized the use of splints as diagnostic and therapeutic tools, allowing clinicians to assess centric relation, evaluate occlusal stability, and plan restorative interventions in a controlled, reversible manner [4]. Okeson [3] later formalized their role in the management of temporomandibular disorders, highlighting that splints could reduce muscular pain, protect dentition, and serve as an adjunct to behavioral and rehabilitative strategies.

Today, occlusal splints come in several forms, each with distinct indications. Stabilization splints, often called Michigan splints, cover the full dental arch and are designed to provide uniform contacts and optimal anterior guidance, reducing muscle hyperactivity and stabilizing the mandible. Anterior bite planes, such as Lucia jigs, focus on disengaging the posterior teeth to relax the elevator muscles and facilitate accurate centric relation registration. Anterior repositioning appliances guide the mandible forward, improving disc-condyle coordination in patients with internal derangements. Soft or resilient splints are commonly used for comfort and bruxism protection, although their effect on muscle relaxation is variable [3-5]. Occlusal splints relieve myofascial pain by reducing hyperactivity in the masseter and temporalis muscles and provide a reversible means of testing whether symptoms originate from muscular or joint sources. In addition, they are used diagnostically and therapeutically prior to extensive restorative or orthodontic treatment, allowing clinicians to identify a stable mandibular position and plan interventions with minimal risk [6].

They also play a preventive role in patients with parafunctional habits, protecting teeth and restorations from wear and fracture. The evidence supports the effectiveness of splints particularly in managing muscular TMD. Stabilization splints reduce pain, improve function, and are most beneficial when combined with education, behavior modification, or physiotherapy. Anterior repositioning splints can temporarily alleviate symptoms of disc displacement with reduction, though prolonged use may risk occlusal changes. Even in cases of disc displacement without reduction or chronic joint inflammation, splints can provide comfort and reduce muscular tension, although they do not reposition the disc permanently [7]. Through the decades, occlusal splints have transitioned from simple protective devices to sophisticated tools that integrate diagnosis, therapy, and prevention. They illustrate the evolution of dental practice from purely mechanical interventions to evidence-informed, patient-centered care that addresses both the musculoskeletal and functional aspects of the stomatognathic system.

2.2. From analog fabrication to digital workflows

Historically, occlusal splints were fabricated entirely using conventional, manual techniques, which involved taking elastomeric impressions of the patient's arches, pouring stone models, and constructing the appliance using wax-ups followed by heat-cured acrylic processing, the technician would manually shape, adjust, and polish the splint to achieve desired occlusal contacts and vertical dimension, often requiring multiple chairside try-ins to ensure comfort and function [3-4]. Despite being widely used for decades, conventional fabrication introduced several sources of variability, including impression distortion, polymerization shrinkage of acrylic, porosity, and operator-dependent differences in occlusal adjustment. These factors could affect fit, stability, and overall effectiveness, necessitating frequent adjustments and, in some cases, remakes. While reliable in skilled hands, conventional splints are time-consuming, labor-intensive, and less reproducible compared to modern digital workflows [8]. The development of occlusal splints over recent decades reflects how advances in digital dentistry transformed what was once a labor-intensive manual process into a streamlined, precise, reproducible workflow, as digital tools matured, a fully digital workflow emerged, including intraoral scanning of the maxillary and mandibular arches, CAD design of the splint geometry, and manufacturing via milling or 3D printing, using stereolithography or DLP. Figure 2 shows the typical workflow of conventional splint design using DentalCAD (Exocad GmbH, Darmstadt, Germany; version 3.0, Galway release). This evolution not only reduces human error but allows rapid production, easier duplication, and standardized quality control [9].

Accuracy studies similarly support digital methods, while milled splints generally show slightly higher conformity to the virtual design, 3D-printed splints still achieve clinically acceptable accuracy for functional use, with deviations influenced by the resin selection, printing orientation, and post-processing. Thus, digital splints are sufficiently precise for clinical application when proper protocols are followed [11]. However, material properties remain a key limitation, systematic reviews analyzing mechanical and chemical characteristics of contemporary splint materials concluded that PMMA-based splints, whether conventional or CAD/CAM milled, consistently exhibit superior hardness, wear resistance, and overall durability compared with many 3D-printed resins, conversely, 3D-printed resins may be more prone to water absorption, lower polymerization, and reduced mechanical longevity, could compromise their performance in patients with heavy parafunctional habits. Clinicians are therefore advised to carefully select materials and manufacturing methods for long-term use [30]. Digital occlusal splints represent significant advance over conventional splints in terms of workflow efficiency, reproducibility, patient comfort, and integration with modern digital dental practice. When designed and manufactured correctly, they offer comparable clinical efficacy and acceptable mechanical performance. Nevertheless, careful material selection, meticulous manufacturing protocols, and long-term follow-up remain essential, as technology and materials continue to improve. Digitally fabricated splints are likely to become standard for contemporary TMD management, bruxism protection, and occlusal therapy, particularly in clinics aiming for precision, efficiency, & comprehensive digital cares [12].

2.3. Design principles for effective splints

A properly designed occlusal splint must establish a stable, reproducible mandibular position in centric relation, allowing the condyles to seat physiologically and the masticatory muscles to function without strain [4]. In this position, the splint should provide even, simultaneous contact across the arch so that each tooth contacts uniformly, distributing forces efficiently and minimizing muscle hyperactivity [3-4]. Effective splint design must also incorporate smooth anterior guidance during protrusive and lateral movements to ensure immediate posterior disclusion, which protects posterior teeth and reduces excursive loading [4-31]. Balanced occlusal contact across the dental arch (i.e. simultaneous, uniform contact of all or most teeth when the mandible closes) is frequently presented in the literature as an ideal design goal for stabilization splints, because it distributes occlusal forces evenly, reduces overload on individual teeth, and helps stabilize the neuromuscular system and temporomandibular joints [32-34]. In classical descriptions of stabilization splints such as the “Michigan” type, authors recommend a smooth acrylic surface against which all opposing teeth contact with equal intensity in centric relation (CR), maximal intercuspation (MIP), or adapted-centric position (ACP).

This simultaneous occlusal contact aims to minimize deflective contacts, prevent occlusal interferences, and reduce parafunctional muscle hyperactivity [32]. In clinical practice, several studies report that properly balanced splint contact schemes, when verified and adjusted, can reduce symptoms in temporomandibular disorder (TMD) patients, likely through improved force distribution and muscle relaxation [35]. Digital workflows can reproduce these requirements when accurate scans, reliable jaw-relation records, and carefully planned occlusal surfaces are used; CAD-based investigations demonstrate that properly designed digital splints can achieve clinically acceptable fit and accurate occlusal schemes [11]. Clinical verification remains essential, as refinement of contact timing and anterior guidance often aided by computerized occlusal analysis, ensures that the delivered splint achieves true even contact and functional mandibular movement. Together, these principles highlight that occlusal splint effectiveness depends on the combination of sound occlusal philosophy, precise digital design, and careful clinical adjustment [36].

3. Artificial intelligence and conventional CAD in prosthetic and occlusal device design

Artificial intelligence (AI) can effectively design dental restorations and occlusal devices with high reproducibility and accuracy, comparable to traditional human-designed and digital methods. AI-designed crowns showed excellent marginal fit and reduced design time, highlighting the potential to improve efficiency in clinical practice. Overall, AI offers a promising approach to streamline the fabrication of dental prostheses while maintaining precision and quality, making it a valuable tool in modern restorative dentistry [37]. Moreover, recent work has focused particularly on deep learning methods such as convolutional neural networks and generative adversarial networks. It highlights applications ranging from diagnostics and imaging analysis to treatment planning and prosthetic design, where AI improves accuracy, efficiency, and reproducibility. By automating tasks such as margin detection, data integration, and digital modeling, AI reduces operator-dependent variability and supports more reliable outcomes. At the same time, the article notes challenges related to data quality, standardization, and the need for clinical validation before widespread adoption [38].

Convolutional Neural Networks (CNNs) learn by extracting features from data in a hierarchical way. Early layers capture simple elements such as edges or contours, while deeper layers combine these to recognize more complex patterns. This process allows CNNs to automatically identify relevant features and improve prediction accuracy without manual intervention. These learning principles are particularly useful in dentistry, where AI can analyze detailed 3D scans and support the design of precise, customized occlusal splints. Tomaka and Luchowski’s computer-aided design method for personalized occlusal positioning splints exemplifies a purely geometry-based approach in the context of occlusal devices. Their workflow reconstructs a virtual patient from multimodal 3D data (intraoral scans, CBCT, and facial scans) registered into a common coordinate system, defines the therapeutic mandibular position as a rigid transformation matrix, and generates the splint through successive geometric operations including dilation, Boolean virtual impression, and mesh editing to resolve interferences. All steps are described analytically, and no machine-learning components are used for either morphology prediction or decision-making, emphasizing the deterministic nature of geometry-based splint design.

Similar deterministic behavior characterizes conventional CAD modules in commercial software (e.g., traditional Exocad or 3Shape Dental System workflows), where occlusal morphology is derived from libraries and adjusted by rule-based occlusal adaptation and virtual articulators whose movements and guidance parameters are explicitly set by the user [25]. From a metrological standpoint, accuracy in these geometry-based workflows is governed by input scan quality, registration accuracy, articulator settings, and the numerical properties of the CAD operations used to generate and refine surfaces. When the same parameters and design steps are applied repeatedly to comparable cases, the systems exhibit high reproducibility, meaning that the resulting devices display very similar morphology and measurable precision. At the same time, the reliance on predefined templates and rules can limit the ability to capture highly individualized occlusal morphologies or complex multimodal relationships, especially when patient anatomy falls outside the assumptions built into the libraries and algorithms [26-28].

3.1. Machine-learning–based AI and generative design

Machine learning–based artificial intelligence, particularly deep learning, presents a fundamentally different paradigm where dental knowledge is learned from large datasets rather than being directly programmed into the CAD engine. In this context, supervised learning models such as convolutional neural networks (CNNs), transformers, and ensemble methods are trained on large datasets of images or 3D meshes to perform tasks including caries detection, lesion segmentation, margin identification, occlusal classification, and automated prosthetic design. For occlusion-related applications, recent deep-learning models have been developed to classify molar and canine relationships and overbite from intraoral photographs using CNN- and transformer-based architectures, demonstrating that occlusal schemes can be recognized with high accuracy directly from image data. In parallel, CNNs have been used to detect and number teeth on occlusal photographs, further illustrating the capability of deep models to interpret occlusal morphology from two-dimensional projections [16-18].

Beyond classification, generative deep-learning models such as generative adversarial networks (GANs), StyleGAN variants, and related architectures have been applied to reconstruct or synthesize occlusal surfaces and tooth morphologies. Studies using conditional GANs and StyleGAN-based frameworks have shown that occlusal surfaces of molars can be partially reconstructed or fully generated based on partial crown data and opposing-arch information, with close preservation of cusp anatomy, groove patterns, and functional occlusal relationships. A recent review of generative deep learning in dental restoration design reported that such models can achieve morphological fidelity and stress distributions comparable to or better than conventional CAD designs, suggesting that data-driven generative approaches may be particularly well suited to complex occlusal morphology. These generative techniques provide a conceptual foundation for future deep-learning–based occlusal devices, in which the cameo surface of a splint or night guard could be synthesized by a model that has learned desirable contact patterns and guidance schemes directly from large clinical datasets [19-20].

3.2. Evidence from AI-driven crown design and implications for splints

Machine-learning–driven CAD has already entered clinical practice for single-tooth restorations. Xie et al. [14] performed a morphological comparison between AI-driven and manual CAD designs for single posterior crowns using an AI service (3Shape Automate) and technician-designed crowns as comparators. Three-dimensional deviation analysis against clinically approved reference crowns showed no significant difference in overall surface trueness between AI-generated and manually designed restorations, although AI designs exhibited significantly higher maximum pointwise deviations in some complex occlusal and proximal regions. These findings indicate that machine-learning–based AI can match expert CAD in global morphology while revealing potential local discrepancies, highlighting need for clinician oversight in critical morphological areas. Reviews of AI in prosthodontics implant dentistry similarly conclude that deep-learning–based systems can reduce design time and operator variability while providing acceptable or superior marginal and internal fit, but emphasize issues of data bias, generalizability, & requirement for robust clinical validation. For occlusal splints, these findings imply that AI-assisted systems may be capable of generating splint surfaces with adequate occlusal morphology and contact distribution, provided that underlying models have been trained on appropriately curated datasets and that clinicians retain oversight for final adjustment. At same time, observation of localized discrepancies in AI-generated crowns indicates need for detailed 3D evaluation of AI-designed splints, not only in terms of global fit but also in critical contact regions where small geometric differences may influence patient comfort and therapeutic efficacy [15-21-23].

3.3. AI-assisted occlusal splint design

Artificial intelligence (AI) is beginning to transform occlusal splint fabrication by automating the design phase and enabling clinicians to generate a complete splint design from digital scans with minimal manual input. Recently, software packages such as Medit Splints and 3Shape Automate have been developed. These programs allow the user to import digitally articulated maxillary and mandibular scans and automatically produce an occlusal device design that can be exported as an STL file for milling or 3D printing. This represents a major step beyond conventional manual design techniques and beyond standard CAD workflows and may reduce operator dependence and shorten design time [24]. In an in vitro study, researchers compared splint designs made by experienced dental technician with those generated automatically by two AI programs, Medit Splints and 3Shape Automate, using identical design parameters and the same printing material. Figure 3 illustrates the typical workflow of AI-assisted splint design using commercially available software Medit Splints (Medit Corp., Seoul, Korea; version 1.1.3), from scan import through parameter selection to final design output. AI systems successfully produced complete occlusal device designs without human intervention.

Although measurable discrepancies found b/w AI generated designs and technician's design in the intaglio and occlusal surfaces and in overall STL geometry, differences remained within clinically acceptable limits. Reported RMS values for occlusal discrepancies were below 100 micrometers. Precision of AI-generated designs across repeated trials was similar to human designed controls, which indicates that AI can reliably reproduce consistent designs [15]. Early practical reports support the feasibility of incorporating AI-generated splints into routine clinical workflows. A digital method paper described the use of AI-powered design software integrated with an additive manufacturing protocol.

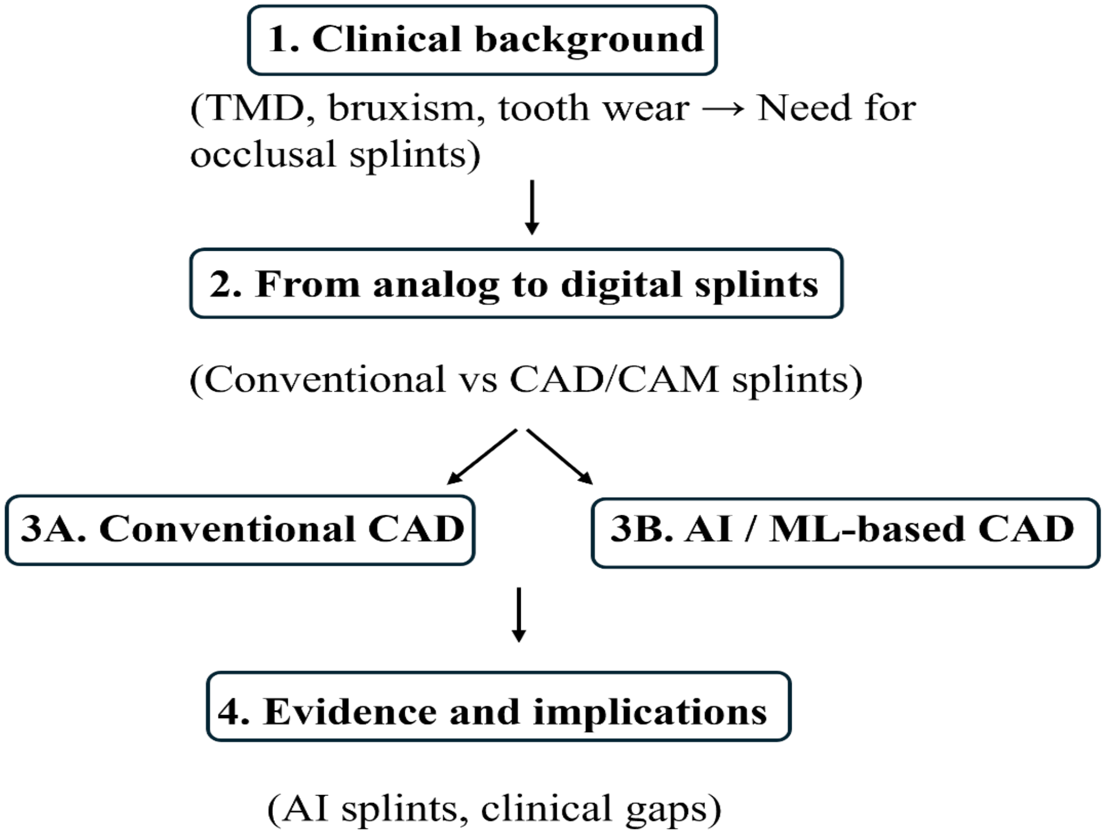

Figure 1. Schematic overview of the narrative review, from clinical indications for occlusal splints to analog and digital workflows, CAD paradigms, and current evidence on conventional and AI-assisted occlusal splint design.

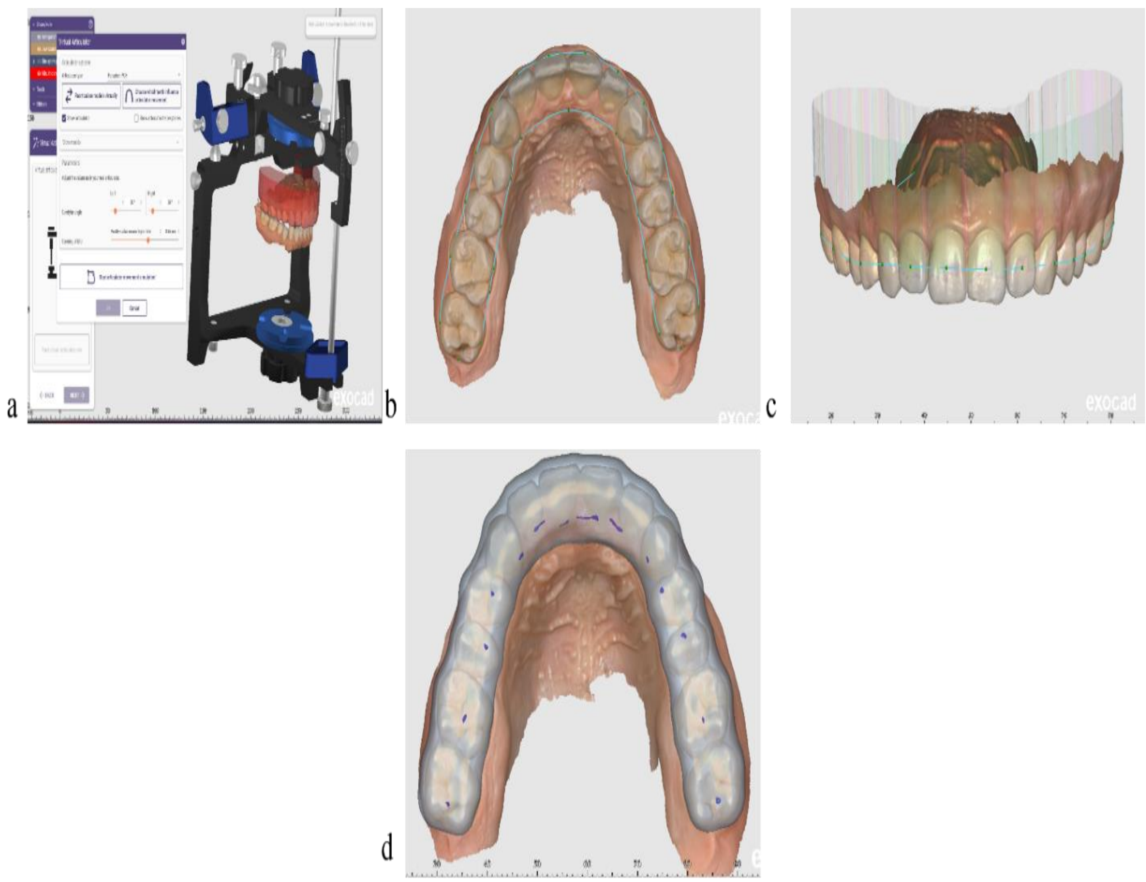

Figure 2. Procedures of conventional Exocad workflow. (a) Upper and lower arches mounted on virtual articulator. (b) Palatal extension of occlusal splint. (c) Buccal extension of occlusal splint. d, Occlusal contacts.

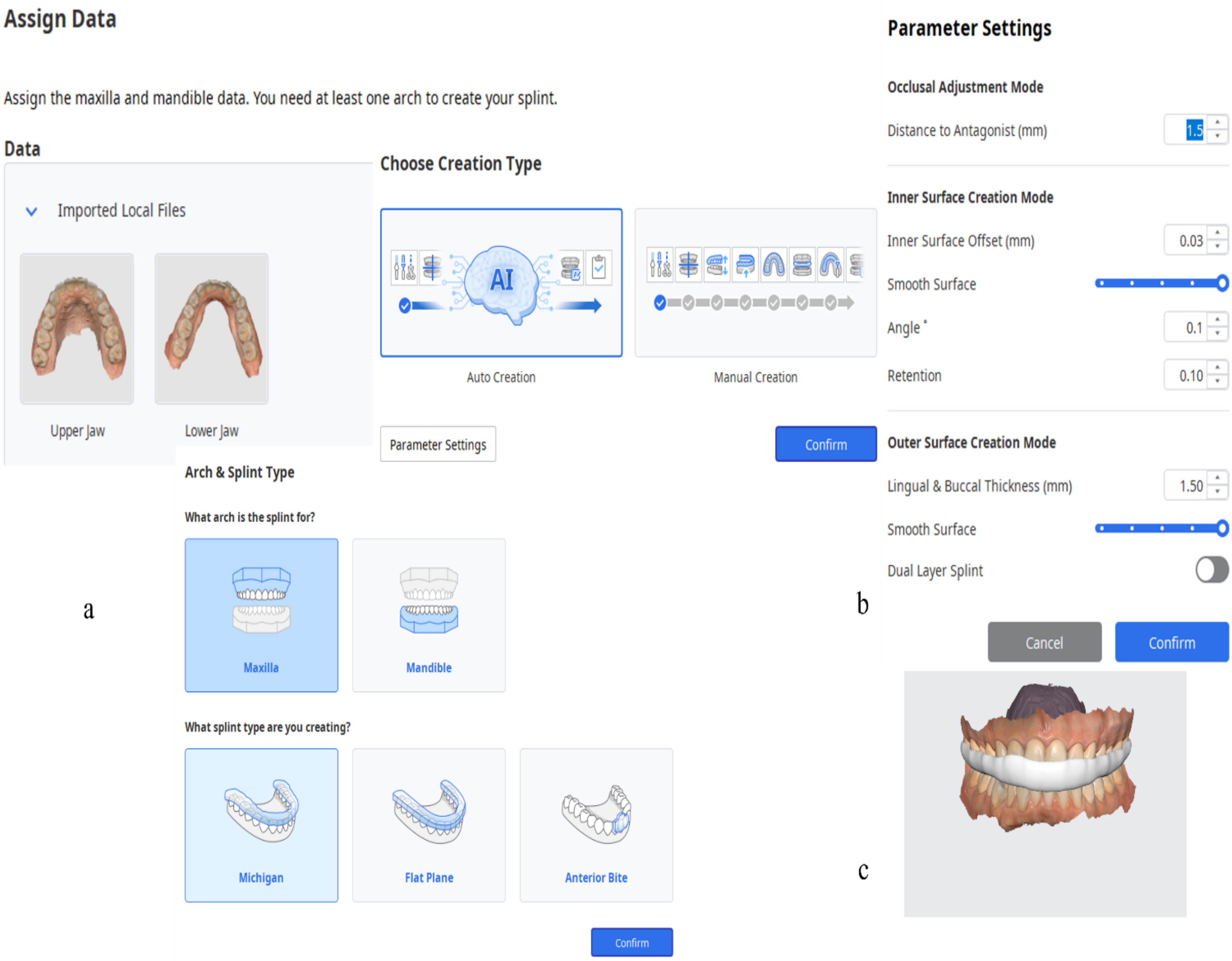

Figure 3. Workflow of AI-assisted occlusal splint design in Medit Splints: (a) Importing maxillary and mandibular scans for designing. (b) Parameters settings of Medit Splints. (c) Designed occlusal splint

Table 1. Advantages and limitations of conventional CAD and AI-assisted software for occlusal splint design

Aspect	Conventional CAD software	AI-assisted CAD software
Design Time	Longer, multiple manual steps	Shorter overall time once data are imported
Reproducibility	Depends on individual operator and protocol	High internal reproducibility for same settings and input data
Occlusal morphology	Direct control by technician; follows explicit occlusal philosophy	Learned from data, can reproduce complex morphology but may show local discrepancies in critical contact areas
Implementation requirements	Widely available, well understood	Newer, may require cloud services and software updates
Clinical implications	Proven workflows; predictable if occlusal principles are followed	Promising for efficiency and standardization, but requires clinician oversight and more clinical validation

The authors reported that AI-based design reduced the number of manual modeling steps and shortened overall design time in comparison to conventional CAD techniques. The resulting splints required minimal adjustment during clinical try in and presented acceptable occlusal contacts and functional fit [24]. These findings suggest that AI-assisted design may improve standardization and efficiency in splint fabrication. Despite these promising developments, there is still limited scientific evidence regarding the clinical performance of AI-designed occlusal splints. Large scale clinical trials comparing AI-designed splints with conventionally designed digital splints or technician designed splints have not yet been published. Existing studies consist mainly of in vitro accuracy assessments, methodological reports, and small case series [15-24]. Therefore, although AI is capable of producing splint geometries and reducing laboratory workload, it remains uncertain whether the small geometric differences relative to human design influence patient comfort, therapeutic efficacy, or long-term clinical outcomes. It is also important to note that AI-generated splints are influenced by the same downstream factors that affect any digitally designed splint. The quality of the manufacturing method, the accuracy of the printer or milling machine, and the post processing protocol all influence the final appliance. AI algorithms create digital geometry, but clinician oversight is still required to verify and adjust occlusion, evaluate the intaglio surface clinically, and validate the final design prior to delivery [15].

AI-assisted splint design may play a significant role in future of digital dentistry. As AI algorithms continue to evolve, they may integrate with functional jaw tracking, facial scans, and dynamic occlusal analysis, allowing for personalized splints that better reflect patient-specific mandibular movement patterns. However, widespread adoption of AI-designed splints cannot occur until well-controlled clinical studies confirm their effectiveness and safety. Nevertheless AI-designed occlusal splints represent a promising advancement within the digital workflow and may improve efficiency, reproducibility, and standardization. Table 1 summarizes the key advantages and limitations of conventional CAD and AI-assisted approaches to occlusal splint design. Current evidence from in vitro and methodological studies supports feasibility and consistency of AI-generated designs, but clinical performance and long-term outcomes must be further investigated. Until more evidence becomes available, clinician judgment and thorough verification remain essential [15-24].

4. Conclusion

AI-assisted occlusal splint design represents a promising extension of digital dentistry that can enhance efficiency and standardization while delivering geometrically accurate devices. Current evidence supports its feasibility and consistency but does not yet demonstrate clear clinical superiority over conventional CAD workflows. Continued clinician oversight, rigorous ISO-based accuracy evaluation, and high-quality clinical research will be key to realizing the full potential of AI in occlusal splint therapy and ensuring that technological advances translate into meaningful benefits for patients.

5. Clinical implications and future directions

1. The emergence of AI-assisted occlusal splint design presents both opportunities and challenges for clinicians working within digital prosthodontic workflows. AI-driven systems promise to reduce design time, standardize key design steps such as occlusal surface generation, and provide consistent device morphology across operators and clinics.
2. For clinicians, a prudent approach is to view AI-assisted splint design as an adjunct to, rather than a replacement for, sound occlusal principles and careful clinical verification. Regardless of how the splint is designed, accurate diagnostic assessment, appropriate case selection, and meticulous adjustment of contacts and guidance remain critical determinants of clinical success.
3. AI-generated designs should be examined critically, with attention to intaglio fit, occlusal contact patterns, and patient comfort, and modified as needed to meet established therapeutic goals.
4. Further integration of AI with multimodal digital data, such as functional jaw tracking, electromyography, and facial scanning, may enable more personalized, functionally optimized splint designs that better reflect individual mandibular movement patterns and neuromuscular behavior.

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Conflict of interests

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