Complete Digital Workflow for Fabricating an Occlusal Device Using Artificial Intelligence–Powered Design Software and Additive Manufacturing: A Dental Method

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Artificial intelligence (AI) has been expanding into areas that were thought to be reserved for human experts and has a tremendous potential to improve patient care and revolutionize the healthcare field. Recently launched AI-powered dental design solutions enable automated occlusal device design. This article describes a dental method for the complete digital workflow for occlusal device fabrication using two different AI-powered design software programs (Medit Splints and 3Shape Automate) and additive manufacturing. Additionally, the benefits and drawbacks of this workflow were reviewed and compared to conventional workflows. *Int J Prosthodont 2024;37(suppl):s275–s284. doi: 10.11607/ijp.8941*

Artificial intelligence (AI) has been expanding into areas that were thought to be reserved for human experts and has a tremendous potential to improve patient care and revolutionize the healthcare field.[1,2] In recent years, the capabilities of AI have expanded into the computer-aided design (CAD) stage, in addition to their usage for diagnostic purposes and treatment outcome evaluations.[3–6] With the aid of commercially available AI-powered dental software programs, the crowns, copings, inlays, models, removable partial dentures, and occlusal devices can be automatically designed.[7–13] Automated restoration design may provide many advantages, such as

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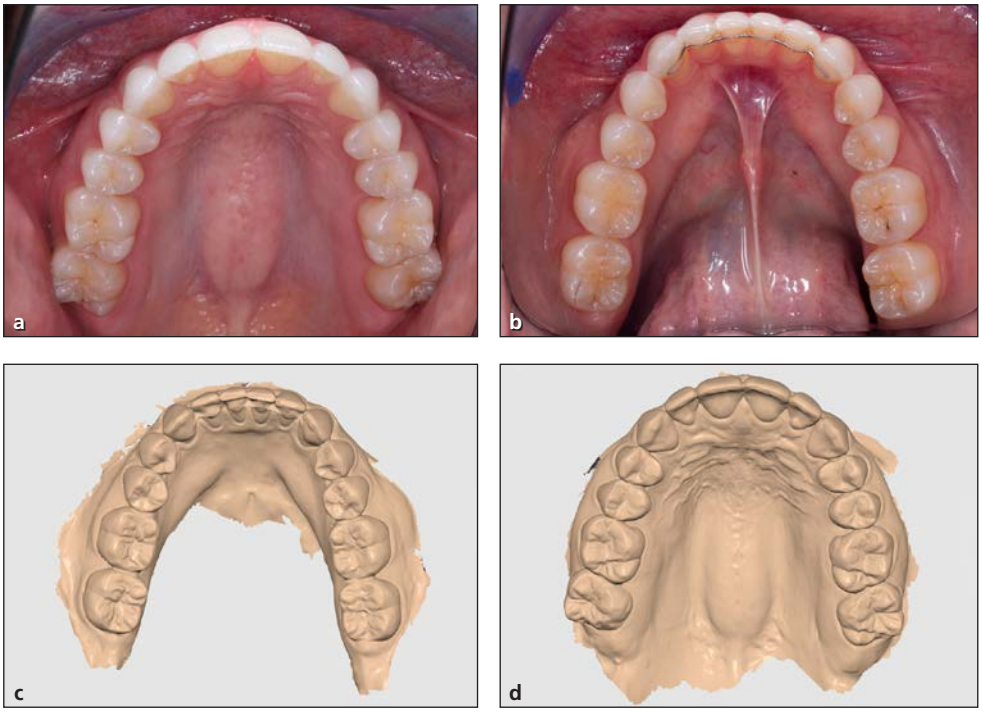


Fig 1 *(a and b)* Intraoral view of the maxilla and mandible, respectively. *(c and d)* Digital scans of the maxilla and mandible, respectively.

the elimination of intensive laboratory work, increased time efficiency, decreased human-related errors, and improved chairside dental treatment procedures.[13,14] Further, this automated design outcome may be adjusted if needed.[13,14] Recently launched AI-powered dental design solutions, such as Medit Splints (Medit) and Automate (3Shape), enable automated designing of occlusal devices.[14] Both software programs use articulated intraoral scan data.[14] Although Automate[15] provides an automated design option only for night guards, Medit Splints[16] provides design options for different occlusal splint types, including Michigan, flat plane (FPS), and nociceptive trigeminal inhibition (NTI) splints.

Regardless of whether the design is analog or automated, computer-aided manufacturing (CAM) technologies, including additive manufacturing (AM) and subtractive manufacturing (SM) methods, can be used to fabricate occlusal devices. CAM of occlusal devices may have advantages such as reduced cost, reproducibility, time-efficiency, and fewer laboratory stages[17–22] than traditional occlusal device–fabrication methods of thermoforming, sprinkle-on, and lost wax techniques. Although SM has been preferred over AM for fabricating occlusal devices for many years due to the better mechanical properties of SM resins,[21] newly introduced 3D-printed resins have promising mechanical properties. Due to AM's several advantages (eg, less material waste, reduced cost, and high productivity by fabricating multiple objects with complex geometries at the same time), AM-generated occlusal devices are increasingly used.[21,22]

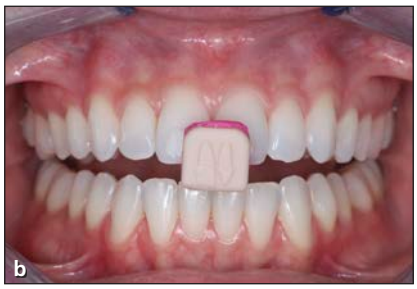
To the present authors' knowledge, there is limited information on the digital workflow for occlusal device fabrication, including automated design with AI-powered software followed by AM. In an in vitro study. Kois et al[14] reported the design discrepancies of occlusal devices made with Medit Splints and Automate compared to the designs of experienced dental technicians. However, the clinical fabrication steps have not yet been reported. Therefore, the purpose of this dental method is to present the complete digital workflow for occlusal device fabrication using two different AI-powered design software programs (Medit Splints and Automate) and AM. Additionally, the benefits and drawbacks of this workflow in comparison to conventional workflow will be reviewed.

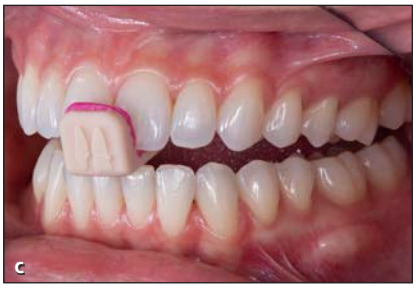
MATERIALS AND METHODS

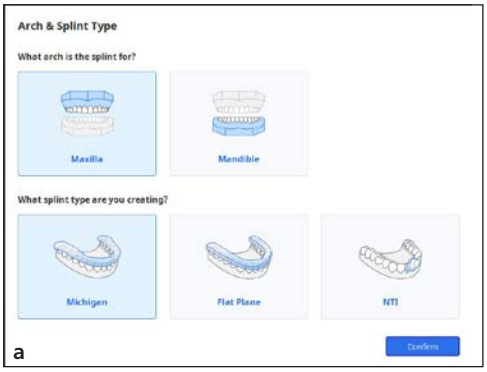
This complete workflow consists of four stages: *(1)* data acquisition, involving intraoral scans and recording the centric relation; *(2)* design (Medit Splints and Automate); *(3)* CAM; and *(4)* device delivery with clinical adjustments.

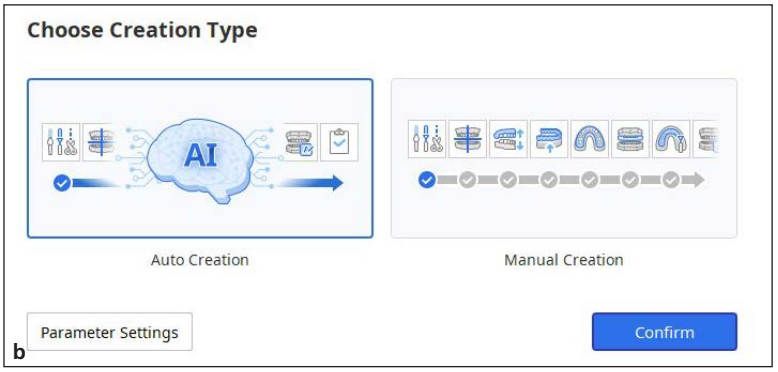
In the data-acquisition stage, first the maxillary and mandibular arches are digitized using an intraoral scanner (Trios4, 3Shape), including the most distal molars, according to the manufacturer's recommended scan protocol (Fig 1). Then, place an anterior deprogrammer (Kois Lucia Jig, Kois Center) on the maxillary incisors and fix it with silicone bite registration material (Prestige Bite, Vannini Dental Industry). Instruct the patient to gradually

Fig 2 *(a)* Anterior deprogrammer. *(b to d)* The anterior deprogrammer was fixed on the maxillary incisors using silicone bite registration material and centric relation registration of the mandible.









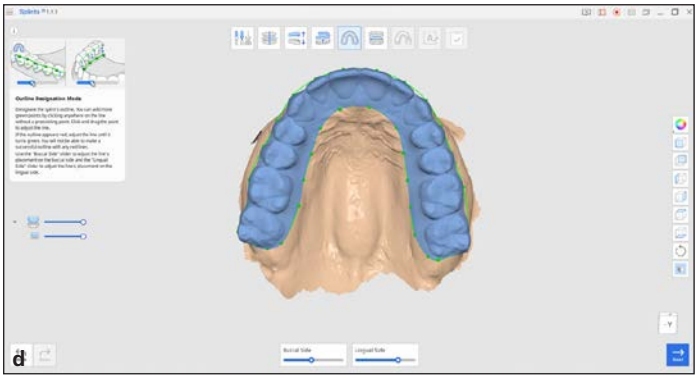


Fig 3 Representative procedures of the Medit Splints AI-powered software: Generating the model. *(a)* Selection of occlusal device type. *(b)* Selection of AI-powered automated design and/or design parameter settings. *(c)* Adjusting the parameter settings. *(d)* Occlusal device margins determined by the software after confirming occlusal device creation.

occlude mandibular incisors on the occlusal plate of the deprogrammer until the posterior teeth have a maximum disclusion of 2.0 to 2.5 mm. Record the centric relation of the mandible and complete the maximum intercuspation scans for both sides (Fig 2). Process the virtual models of articulated maxillary and mandibular arches and export the standard tessellation language (STL) files.

In the design stage, an occlusal device is virtually designed using the AI-powered dental software (Medit Splints version 3.1.3). After creating a new patient in Medit Splints, import the maxillary and mandibular STL files. Then, open the "Medit Splints" tool and assign the maxilla and mandible data using the "Assign Data" tool (Fig 3). The bite scan enables the software program to virtually articulate the intraoral scans of both arches. Select the arch (maxilla or mandible) and device type (stabilization splints; Michigan or FPS and an NTI splint) and confirm. In the present dental method, Michigan

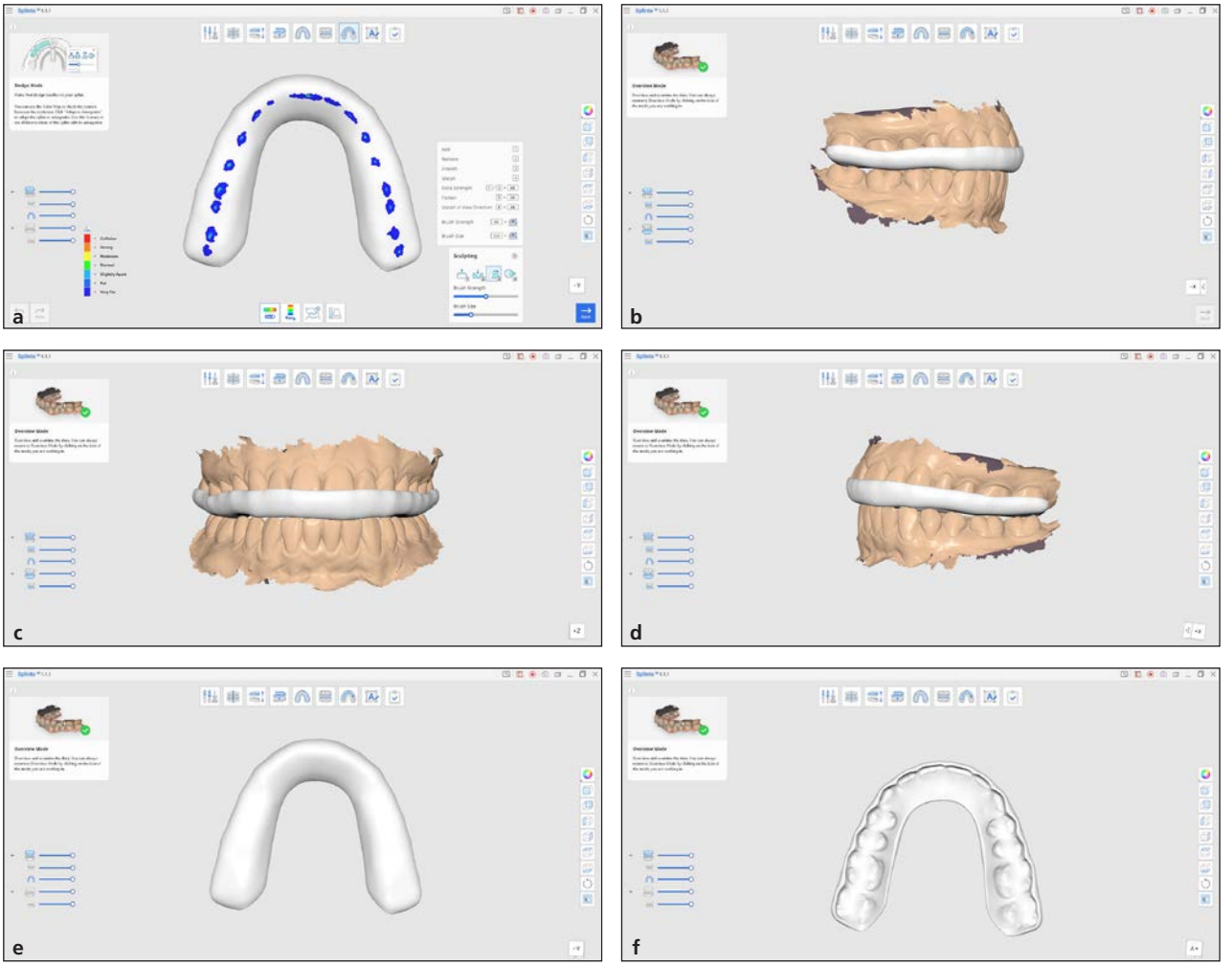


Fig 4 Representative procedures of Medit Splints AI-powered software after the automated design is completed, review of automated design in different 3D views. *(a)* Visualization of the occlusal contacts in static occlusion (occlusal contacts and collisions) with color map. *(b to d)* Visualization of the design from right lateral, frontal, and left lateral views, respectively. *(e and f)* Outside and intaglio surfaces, respectively.

Splint was selected. Then, choose "Auto Creation" and customize design parameters in the occlusal adjustment mode, such as the distance to antagonists (occlusal thickness, 1.5 mm); inner surface creation mode: inner surface offset (0.03 mm), smooth surface (maximum), block out angle (0.1 degrees), retention (0.10 mm); outer surface creation mode: peripheral thickness (1.5 mm), smooth surface (maximum), and dual layer splint (off). Once the virtual device is automatically created, check the device borders. To improve its retention, extensions of the occlusal device should cover the height of the maxillary teeth contour, while borders on the palate should cover a few millimeters of the gingiva.[20] If needed, manually customize the extensions using "Outline Designation Mode." If additional adjustments are made, press "next tool" to recreate the occlusal device. After generating, change the lingual and buccal thickness and smoothness in the "Outer Surface Creation Mode Tool" when needed. Proceed with the "Design Mode" tool by visualizing the occlusal contacts with color maps and making further adjustments, either using the "sculpting" tool (add, remove, smooth, morph) or the "Adjust Distance to Antagonist Tool" as needed (Fig 4). In the presented dental method, no further adjustments were made. Complete the occlusal device design (labeling can be done) and export the STL design file.

In the design stage of the occlusal device using another AI-powered software (Automate, version R1.1), save the maxillary and mandibular STL files as a zipped folder. Open the website, login, and select "Nightguards." Adjust design preferences for the maxilla: occlusal thickness (1.5 mm), inner surface offset (0.03 mm), crevice block out (Moderate), minimum thickness (1.5 mm), inward retention (0.10 mm), CAM orientation (flat was selected in the present study), and select the turnaround time and price of accepted design (10-minute or 10-hour design

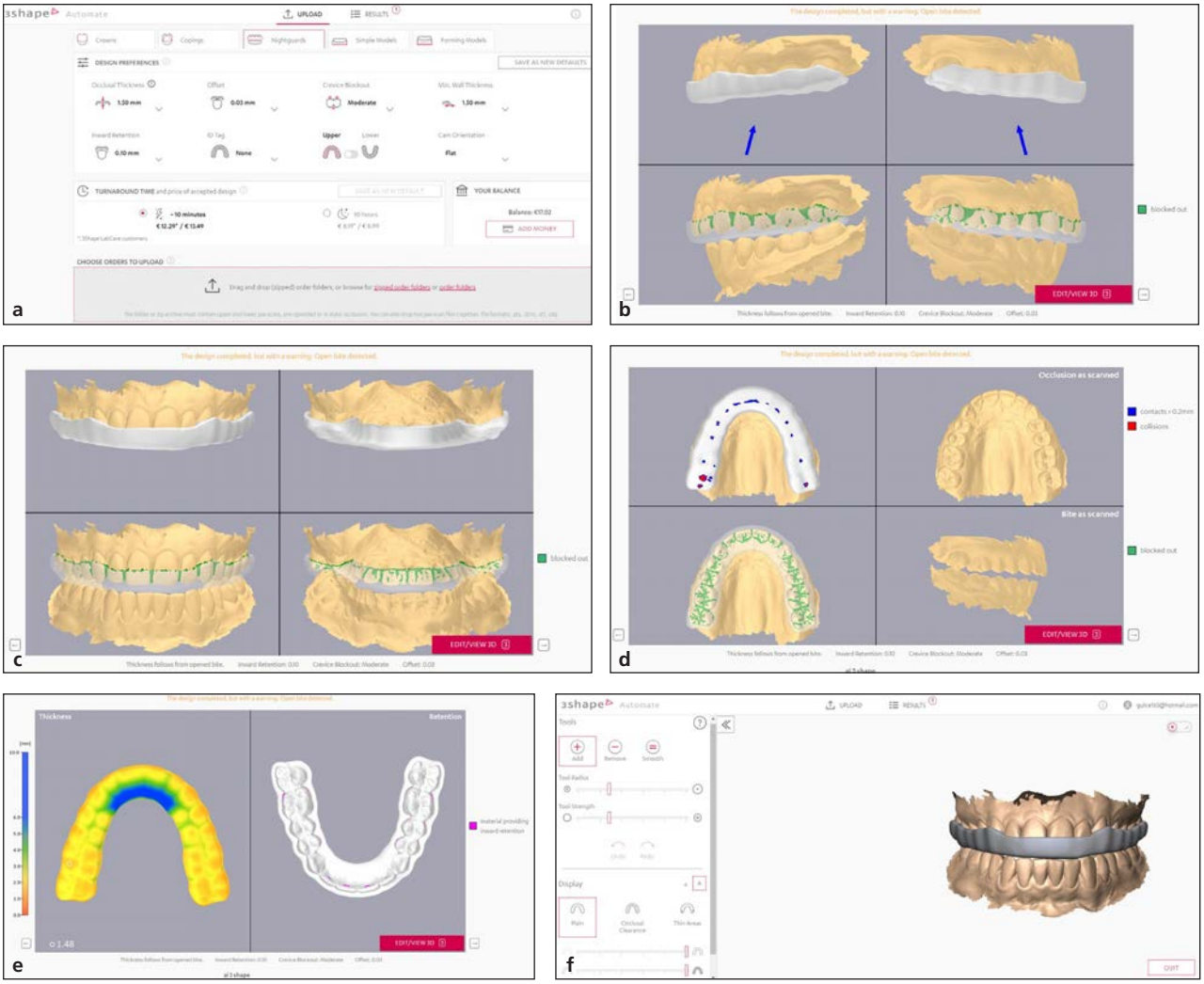


Fig 5 Representative procedures of 3Shape Automate AI-powered software (version R1.1). *(a)* Selection of design preferences. After completion, the automated design can be reviewed in different 3D views in the results tool. *(b)* Path of insertion *(blue arrows)* and blocked-out areas *(green)*. *(c)* Margin lines of the occlusal device. *(d)* Static occlusion (occlusal contacts and collisions). *(e)* Thickness and retention evaluation. The material provides inward deviation. *(f)* The "Further Adjustments" tool can be used if needed.

options) (Fig 5). Then, drag and drop the zipped order folders and wait nearly 3 minutes until the automated design is completed. After, review the automated design in the results tool. In different 3D views, review the path of insertion and blocked-out areas, margin lines of the occlusal device, static occlusion (occlusal contacts and collisions), and thickness and retention (material providing inward deviation). In the presented method, no further adjustments were made. However, when further adjustments are needed, click the "Edit/View 3D" tool. Surface smoothness, occlusal clearance, and thin areas can be adjusted in this step. Then, accept the occlusal device design (labeling can be done if selected in the settings) and export the STL file of the design.

In the CAM stage, the automated-designed occlusal device is fabricated using a digital light processing printer (DLP). Select the occlusal splint resin (Keysplint Hard, Keystone Industries) and layer thickness (100 µm) from the DLP's proprietary software library (Composer, Asiga). Import the STL file of the AI-powered occlusal device designs into the software, orient the outer surface so it is facing and parallel to the build platform, and generate support structures automatically. Control the support structures and add or eliminate them as necessary. Before using the resin, mix it for nearly 1 hour (Resin mixer, Manfredi Reddish Stone) to obtain the appropriate consistency and to prevent bubbles, and allow the resin to reach ambient temperature (20° to 25°C). Print the occlusal device using a DLP-based 3D printer (MAX UV, Asiga). After a 10-minute drip time, remove the occlusal device from the build platform and wash it in an ultrasonic bath of 98% isopropyl alcohol

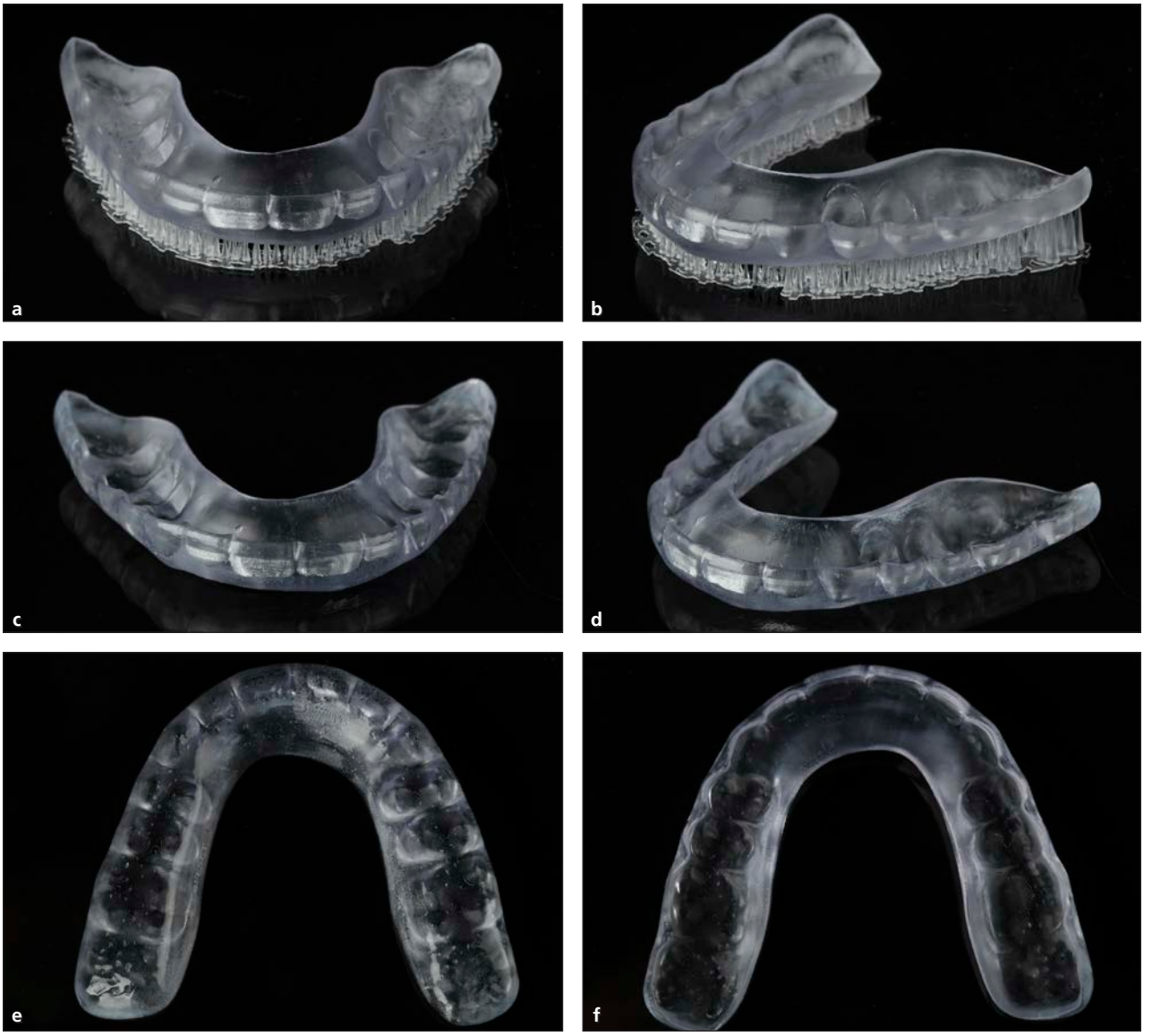


Fig 6 *(a to d)* Frontal, lateral, occlusal, and intaglio surface views, respectively, of the additively manufactured occlusal device.

(IPA) for 3 minutes (Isopropanolum rein, Cristoffel-Apotheke) to remove excess unpolymerized resin parts. Then, wash the device for 2 minutes with fresh isopropyl alcohol (IPA). Use a soft-bristle brush or cotton swab dipped in IPA when excess resin is still present. Dry the occlusal device using an air syringe and allow it to dry for at least 10 minutes to ensure that there is no alcohol residue, then polymerize using a xenon lamp-polymerization unit (Otoflash G171, NK Optik) for 4,000 lighting exposures (2,000 flashes per side without nitrogen gas, allow 5-minute cool-down between the two sets of exposures; Fig 6). After postprocessing, cut support structures using a side cutter and remove remnant printing lines/texture and residual material from the surface using an abrasion disc sanding wheel (Blue 400-grit disc, Keystone Industries). Polish using a pumice slurry under firm and consistent pressure from a cloth wheel (Muslin Buffs, 4"x42, Keystone Industries). Steam-clean the surface and apply prepolishing via a polishing compound and cloth wheel (Tripoli Polishing Compound, Keystone Industries) under firm pressure. Steam-clean the surface again and apply a high-shine polishing compound via cloth wheel (Beige Paste Polish Bar, Keystone Industries) under light pressure (Fig 6).

In the delivery stage, visually inspect the occlusal devices for sharp edges and potential problems. Place the occlusal devices intraorally, and check the borders, fit, and retention. Identify whether any tilting points or axes are present by pressing on four different regions (second molars and lateral teeth).[23] Evaluate the occlusal device's retention and occlusal contacts in static and dynamic

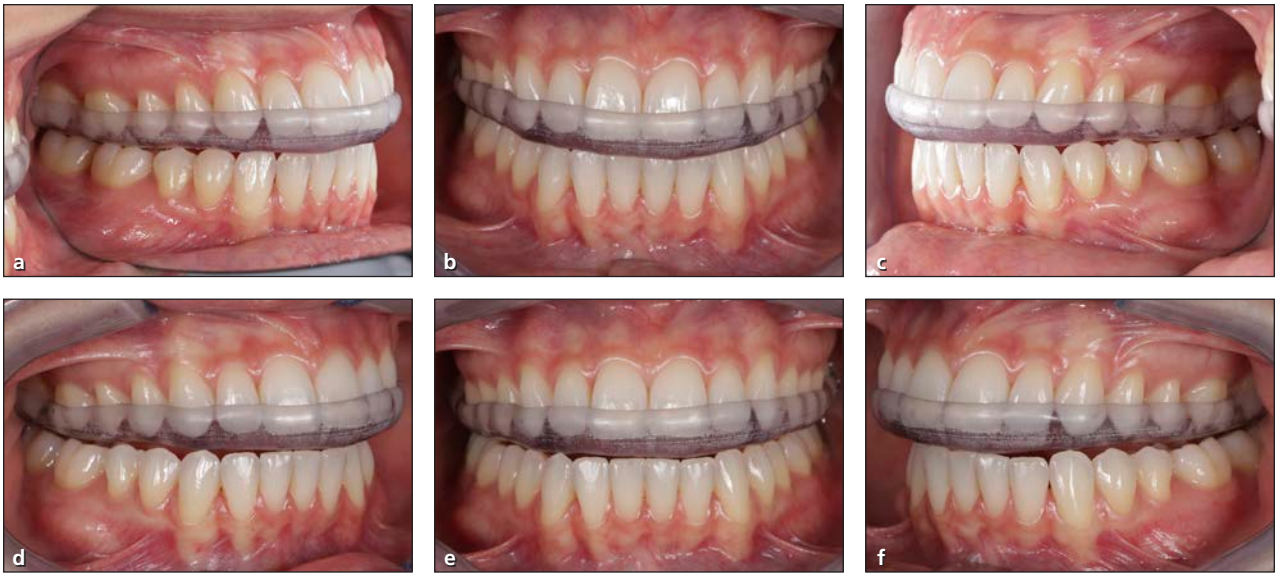


Fig 7 Clinical try-in of an occlusal device designed by Medit Splints AI-powered software. *(a to c)* Right lateral, central, and left lateral views in centric occlusion, respectively. *(d to f)* Right laterotrusion, protrusion, and left laterotrusion views before adjustments, respectively.

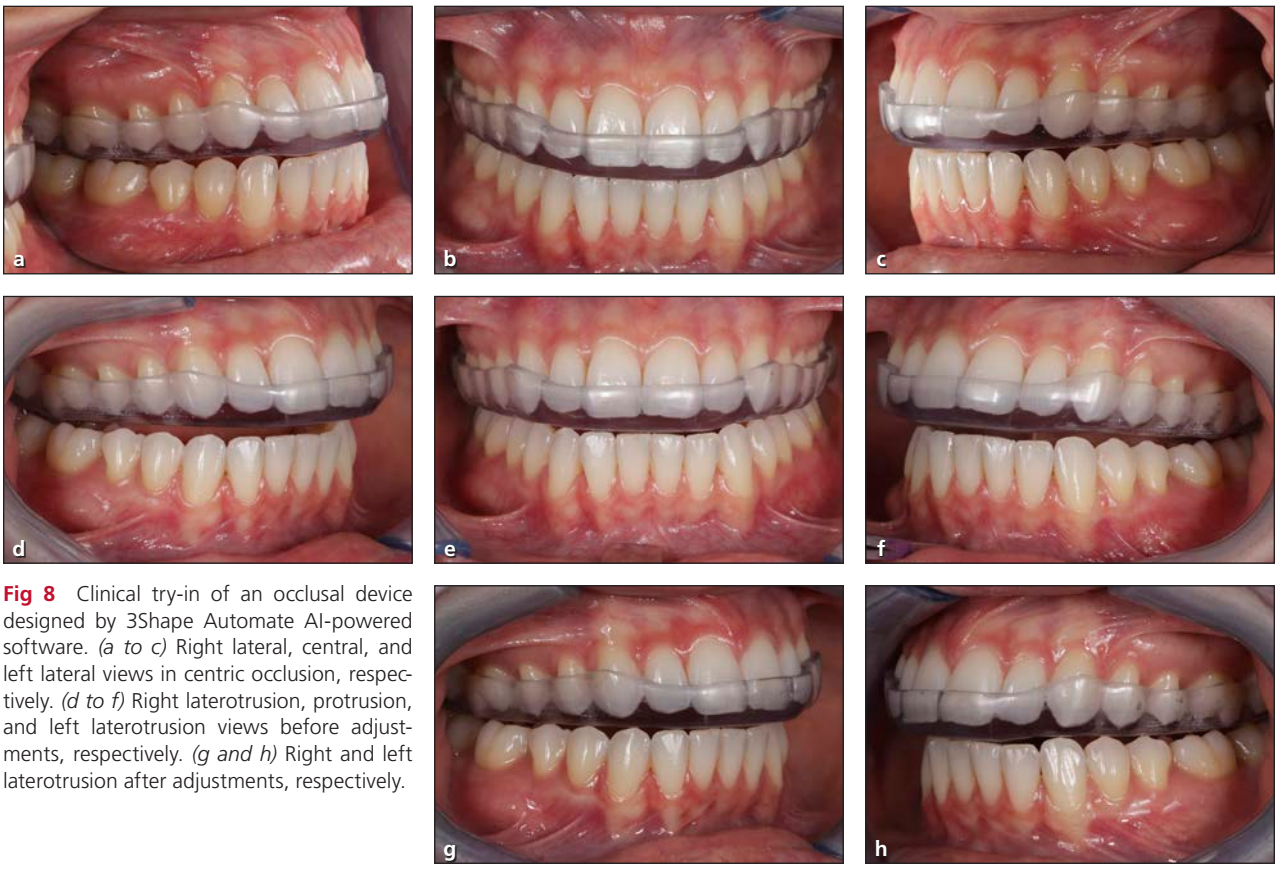


Fig 8 Clinical try-in of an occlusal device designed by 3Shape Automate AI-powered software. *(a to c)* Right lateral, central, and left lateral views in centric occlusion, respectively. *(d to f)* Right laterotrusion, protrusion, and left laterotrusion views before adjustments, respectively. *(g and h)* Right and left laterotrusion after adjustments, respectively.

occlusion (Figs 7 and 8). Instruct the patient to perform all applicable functional movements, including lateral movements, protrusion, retrusion, sipping water, and swallowing. Evaluate the occlusion for any premature contacts and interferences using 40-µm articulating paper (Bausch Arti-Check, Bausch Articulating Papers) and trim using a carbide acrylic bur (HM129FX-023-HP Laboratory Carbide Bur, Meisinger) (Fig 9). Deliver the occlusal device to the patient if there is no tension or pressure.

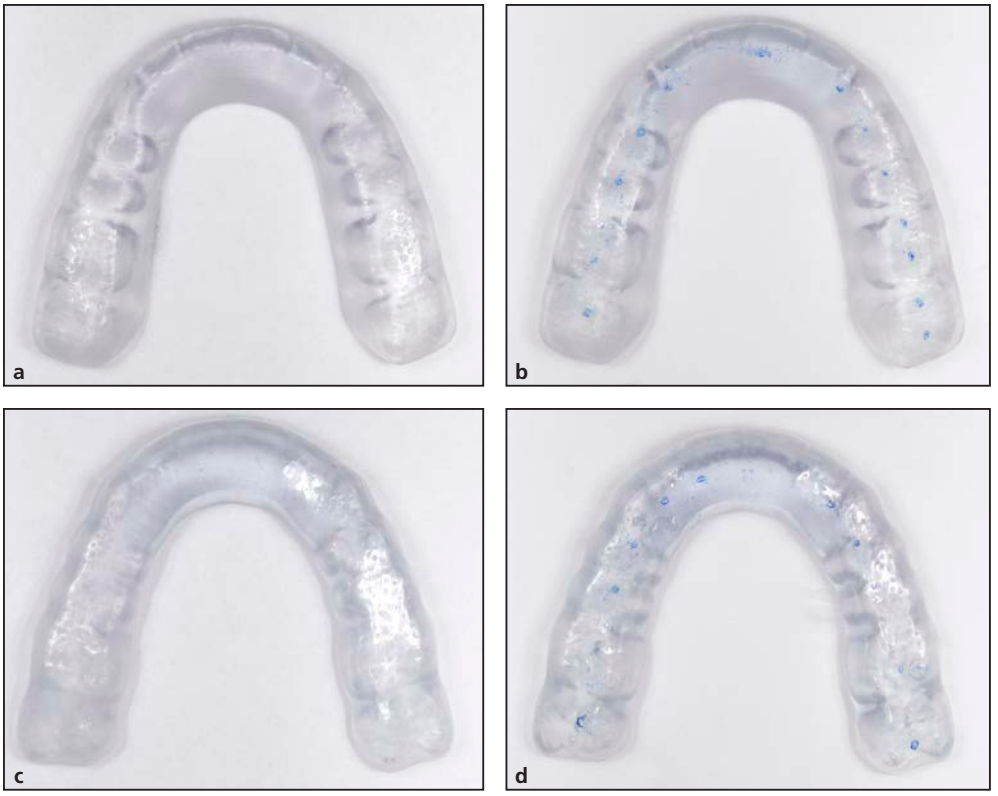


Fig 9 *(a and b)* Occlusal contacts of an occlusal device fabricated with Medit Splints AI-powered software before and after adjustments, respectively. *(c and d)* Occlusal contacts of an occlusal device fabricated with 3Shape Automate AI-powered software before and after adjustments, respectively.

DISCUSSION

The presented dental method describes a process for fabricating an occlusal device supported by AI-powered automated design software. The main advantage of the AI-powered software is the automatic design of occlusal devices within a few minutes of importing maxillary and mandibular scans and selecting design parameters, which simplifies procedures by reducing the time for analyzing undercut areas and blocking out and defining the path of insertion, thereby substantially reducing the working time.[14] In other words, the AI-powered automated design software may ease the burden of an intensive laboratory workload and can be applied chairside.[14] Moreover, the work efficiency of this automated design workflow may be advantageous over conventional human-based workflows, which may depend on the operator's expertise.[13,14] In addition, both AI-powered automated design softwares discussed herein are based on open systems that accept STL files from third-party intraoral or laboratory scanners.[14]

The occlusal devices were fabricated without any further intervention in both tested AI-powered automated software. One contact per tooth was achieved in both occlusal devices. A Michigan splint was selected when using the Medit Splints software. The designed occlusal device provided the following characteristics as defined by the Michigan splint parameters[24]: coverage of all maxillary teeth, flat and smooth occlusal surfaces, balanced and simultaneous occlusal contacts of the mandibular teeth (except incisors), and centric freedom. The Medit Splints occlusal device had no premature contact in static or dynamic occlusion. Therefore, no further adjustments were made, which can help save time. Even though the occlusion type was anterior guidance and the disclusion of mandibular teeth during lateral and protrusive motions was adequate, the canine guidance ramps were not high enough and may need to be manually adjusted in some cases. In the Automate software, premature contacts existed in the second right and left molars in static and dynamic occlusion. The disclusion of mandibular teeth during lateral movement was obtained in the molar region rather than canine teeth and it was > 2 mm before adjustments. After further adjustments, group function occlusion was achieved. For canine guidance, further adjustments should be made in the design to create canine ramps.

In both DLP-based software, the program automatically determined the occlusal device borders, but, they may be further adjusted if necessary. In the presented dental method, the retention of occlusal devices in both DLP-based software was adequate. The extension of the occlusal device may affect its retention and fit. Therefore, further adjustments (including offset values and retention values) may be required if the splint borders are designed to be shorter or if the retention is not

adequate, depending on the CAM procedure. Medit Splints DLP-based software can also be used to design other types of occlusal devices, such as FPS and NTI splints. Even though the occlusal device was designed in maxilla in the present dental method, both software enable design options for the mandible.

Careful clinical data acquisition is required for clinical success. It has been well reported that the maxillomandibular relationship and occlusal device thickness affect treatment outcomes of temporomandibular joint (TMJ) disorders.[20,25,26] Therefore, maxillomandibular relationship records using deprogrammers, jigs, and digital facebows are required for the successful treatment of TMJ diseases.[20] In the present dental method, an anterior deprogrammer was used to define the centric relation record, interocclusal rest space, and correct occlusal device thickness.

One of the limitations of both software programs is the lack information on the type of virtual articulator used in the design or simulation of mandibular movements. Mandibular movement simulation may guide clinicians to visualize the possible interferences in advance and make further adjustments; considering this, both software programs should improve their interface. The type of AM resin material and printer may affect the fit and mechanical properties of occlusal devices, and different results may be obtained with different resin materials and printers. Therefore, clinicians should be careful about the CAM technique and material selection. Nevertheless, in the case of fracture, the presented completely digital workflow has the advantage of digital data-saving and easy refabrication of the occlusal device.

CONCLUSIONS

The incorporation of AI-powered automated design into the digital workflow of occlusal devices can be an alternative to labor-intensive and time-consuming conventional workflows. The occlusal devices designed with the support of AI-powered software showed good fit, good stability, and adequate occlusal contacts. The automated design-integrated digital workflow can also provide a reproducible occlusal design by using previously saved data when needed. The technique fulfills clinical requirements while allowing for a complete digital workflow of the occlusal device. However, future clinical studies should be conducted that investigate the patient-reported outcomes.

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The data that support the findings of this study are available from the corresponding author upon reasonable request. The authors declare no conflicts of interest.

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