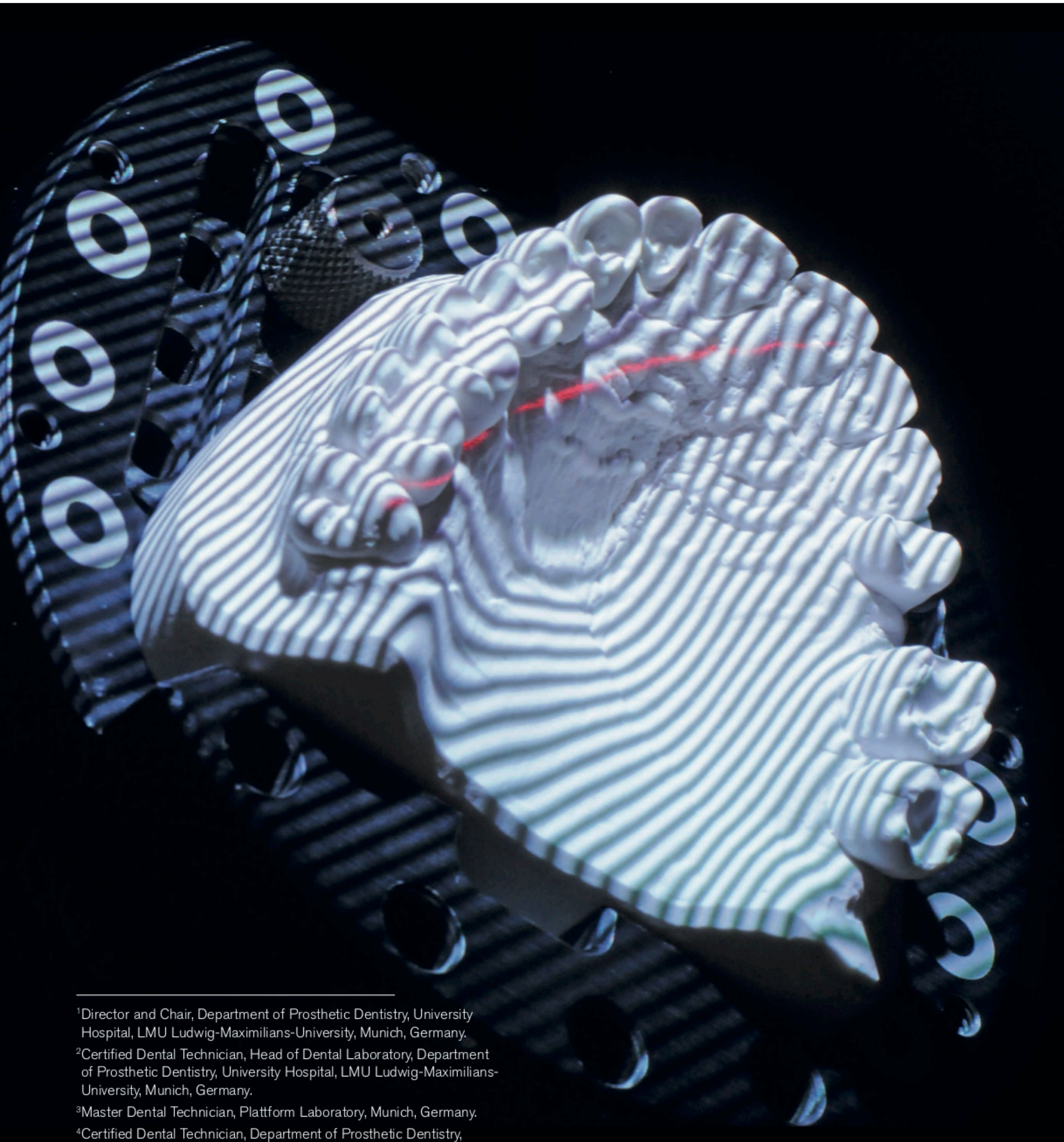

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CAD/CAM Splints for the Functional and Esthetic Evaluation of New Defined Occlusal Dimensions

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Splint therapy is generally the initial treatment step in functional therapy, as it is able to quickly reduce the tone of the masticatory muscles and to provide a reversible correction of occlusal anomalies.[1] In general, occlusal splints and other occlusal appliances can be differentiated on the basis of their indications.[2] Occlusal splints are primarily designed to clinically test a newly defined static and dynamic occlusion.[1] This will in most cases be preceded by a functional and esthetic evaluation based on an analytic wax-up.[3] Traditionally, the different types of occlusal splints are custom-shaped at the dental laboratory using an autopolymerizing polymethyl methacrylate (powder-liquid system) on blocked-out plaster casts, then polymerized in a pressure pot.[4]

This method of splint production is very common and has been proven for clinical application over a pretreatment period of several months. Nevertheless, it has numerous laboratory and clinical disadvantages compared to more contemporary alternatives. At the laboratory, the inevitable polymerization shrinkage that is an integral aspect of the production process will adversely affect the fit of the splint. Remakes are difficult because the working casts are usually damaged in the fabrication process. Patients, in turn, frequently complain about the unfavorable shape and transparent shade that preclude the use of the splints in a professional or social environment.[1,5] In addition, abrasive particles and monomer vapors arising from the conventional manufacturing process are thought to be a health hazard for the dental technician. Residual monomer can have negative health effects on patients.[6,7] These properties of conventional occlusal splints have a negative impact on patient compliance and treatment efficacy, which are crucial for a successful treatment.[8]

CAD/CAM technology allows prefabricated components to be made from standard materials used in conventional manufacturing techniques. As the standardized production chain is associated with higher quality and greater reproducibility, this will in many cases result in an expanded

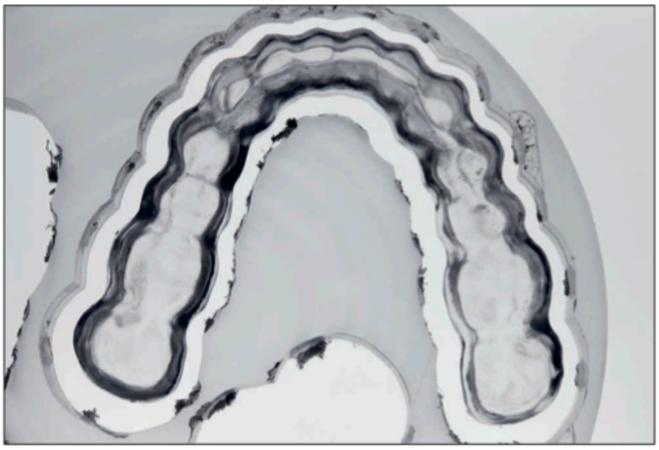


Fig 1a Milled removable occlusal splint made of transparent PMMA. CAD/CAM manufacturing avoids monomer fumes and polymerization shrinkage, reduces the residual monomer content to a minimum, and ensures easy reproducibility.

Fig 1b Conventional occlusal splints are less accepted by patients due to esthetic and phonetic challenges they pose. The treatment process is constantly interrupted, reducing the efficacy of the treatment.

range of indications. Since they are fabricated to industrial production standards, splints made from high-performance polymers exhibit material properties that are superior to those of conventionally made splints. The availability of tooth-colored CAD/CAM polycarbonate seems to provide an interesting alternative for different types of splints.[9–11] Due to their higher flexibility compared to polymethyl methacrylate (PMMA), polycarbonate splints are less susceptible to fracture and can be fabricated extremely thin. This provides a clear benefit for the patient—the material allows less bulky shapes that approach the target (anatomic) morphology.

Furthermore, in situations requiring extensive changes to the vertical dimension of occlusion (VDO), there is now the option to use two splints—maxillary and a mandibular—that reproduce the occlusal contours of the wax-up and therefore reflect not only the newly defined bite but also the associated newly designed static and dynamic occlusion. The authors' clinical experience has shown that very good patient compliance can be achieved with these tooth-colored occlusal splints. Not unlike a removable provisional restoration, they can be worn permanently in business and home environments alike, thanks to their acceptable esthetic appearance and tooth-like morphology. The only time they cannot remain in place is while eating, due to the insufficient retention (hence their designation as "23-hour splints").

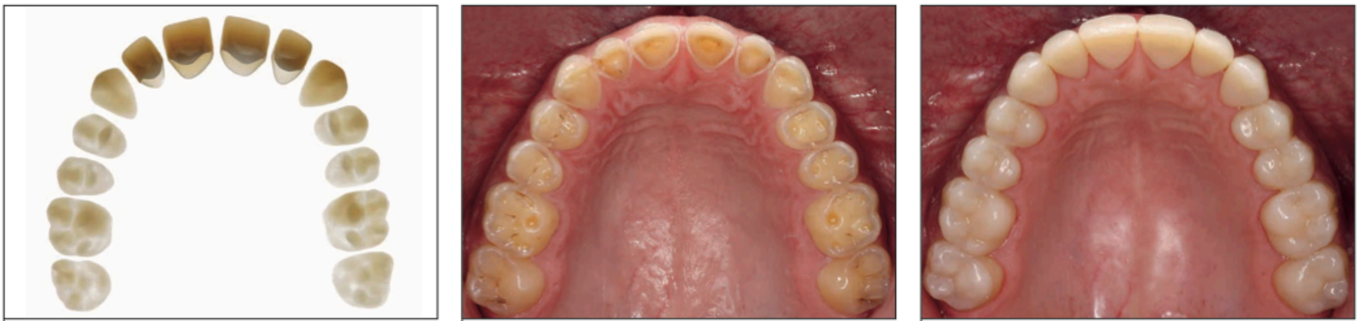
The objective of this report is to present, step by step and based on clinical case reports, the use of occlusal splints made of tooth-colored polycarbonate in a patient with an extremely reduced VDO.

PRETREATMENT CONCEPTS FOR A NEW VDO

Generally speaking, there are three pretreatment concepts for functional evaluation of a newly defined VDO:

1. *Conventional removable repositioning splints.* Made of transparent PMMA and usually inserted in only one arch, these splints exhibit a limited occlusion pattern with the entire change in VDO represented in a single splint.[4] This leads to an occlusal plane position that is either too high (splint placed in the mandible) or too low (splint placed in the maxilla). Owing to their intermittent use, limited occlusion patterns, and occlusal plane location, as well as to their compromising appearance and shape, these splints are associated with significant esthetic and phonetic disadvantages.[5] Because of their lower cost, these types of splints continue to be the choice for initial treatment for pain relief and functional rehabilitation. They can be produced by CAD/CAM today (Figs 1a and 1b), avoiding the problems associated with polymerization shrinkage. A patient dataset, once obtained, ensures nearly unlimited reproducibility at low cost, as remakes require no new impression/scan and no additional design (CAD) steps.
2. *Tooth-colored removable CAD/CAM splints made of polycarbonate.* Based on a classic or virtual wax-up, these full anatomic splints approximate the definitive restoration in terms of their esthetics, phonetics, and function, including the new defined occlusion pattern and adequate occlusal plane location. These delicate

2a 2b 2c



3a 3b 3c

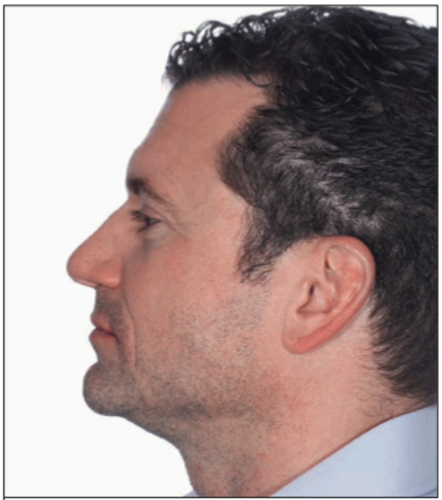
Figs 2a to 2c *(a)* Milled removable occlusal splint made of tooth-colored polycarbonate. The material exhibits an extremely high degree of flexibility and, even when fabricated extremely thin (0.3 mm), a high fracture resistance. This type of splint results in significantly greater compliance ("23-hour splint"). *(b)* Preoperative situation of the maxilla of a 16-year-old patient with deciduous tooth persistence (FDI 53,54,55,63, 64, 65) as a result of multiple congenital tooth agenesis (FDI 015, 014, 013, 012, 022, 023, 024, 025s). *(c)* Tooth-colored removable polycarbonate splint after insertion for the functional and esthetic evaluation of the new occlusion, defined by the wax-up.

Figs 3a to 3c *(a)* Milled repositioning onlays and veneers made of tooth-colored CAD/CAM polymer (PMMA) for adhesive insertion. *(b)* Maxillary teeth with pronounced generalized biocorrosive defects due to permanent and excessive consumption of acidic drinks. *(c)* CAD/CAM polymer repositioning restorations were manufactured separately using a purely additive process, without any preparation, to provide a "fixed splint" adhesively bonded to the compromised tooth structure.

tooth-like repositioning splints can be applied in one or both arches **[au: editing OK?]** and enjoy significantly greater patient acceptance (Figs 2a to 2c).[5] The properties of the materials used permit very thin splint layers (0.3 mm) to be produced. Experience has shown, however, that a "two-splint concept" is feasible only in the context of more significant changes in VDO, increasing the height of the incisal pin of the articulator by about 4 mm or more. As the splints are milled from already polymerized blanks, polymerization shrinkage is again avoided, and an existing dataset ensures nearly unlimited reproducibility at lower cost.

3. *Fixed tooth-colored repositioning veneers and onlays made of PMMA.* These are fabricated based on a wax-up, either conventionally or by using a CAD/CAM system. They closely approximate the definitive restorations in terms of their function and esthetics (Figs 3a to 3c).[12,13] As these splints are usually adhesively bonded in the form of single-tooth restorations, the cost is relatively high, but the splints correspond almost exactly to the attained restorative goal. Bonded tooth-colored splints provide a pleasant esthetic, phonetic, and functional evaluation experience in terms of a 24-hour treatment. Patients can even eat with these restorations in place, which makes the evaluation period as realistic as possible. However, the restorations are difficult to modify intraorally; the original situation is more difficult to restore if needed, meaning that the reversibility of this treatment is limited.[14] Moreover, the cost is significantly higher than for removable splints, and adhesive placement requires a high expense of time.

4a



4b

Figs 4a and 4b Preoperative situation of a patient with severe abrasions and traumatic contacts in the anterior dentition. As a result, the anterior teeth exhibit a fan-shaped spreading with small gaps and significant changes in proportions. The lateral view shows a pronounced chin groove as a result of a loss of vertical dimension of occlusion.

CASE PRESENTATION

A 45-year-old man presented with extensive tooth defects and asked for treatment options to restore the associated changes in his occlusion. He reported an increasing sensitivity to chemical and thermal irritations and complained of significant functional and esthetic impairments caused by the appearance of his extremely compromised teeth. Compared to the position of his teeth when he was a young adult, he had observed significant changes in shape and increasing gaps between the maxillary incisors (Figs 4a and 4b), as earlier photographs amply demonstrated. During the extraoral examination, an extremely strong masseteric muscle hypertrophy associated with a shortening of the lower facial third and a pronounced chin groove were identified (Fig 4b). Intraoral findings included clear signs of parafunctional habits in the form of generalized wear facets and traumatic anterior contacts that were identified as the main cause of a generalized loss of tooth structure.[15] The patient also reported significant phonetic and masticatory problems due to the extreme changes in tooth morphology.

Special challenges of this complex rehabilitation included reconstructing the VDO, restoring adequate function and esthetics, and meeting the patient's desire for a rapidly improving clinical situation.

Treatment Planning

Primary treatment goals included—in addition to the esthetic rehabilitation of the dental morphology—restoration of a dynamic occlusion with anterior/canine guidance and reconstruction of the VDO. The lost tooth structure was later to be replaced by adhesively cemented restorations following an additive design. The patient's priority was for high durability of the restorations with as few esthetic compromises as possible. The patient consented to accept full-contour precious metal–based restorations in the less esthetically salient molar regions subject to higher masticatory loads, given their higher strength and favorable abrasion behavior. All the remaining teeth and three implants (Screw-Line, Camlog) at sites 15, 25, 36 (FDI) were to be restored with all-ceramic restorations made of monolithic lithium disilicate (IPS e.max Press Multi, Ivoclar Vivadent) or CAD-on (Ivoclar Vivadent). This decision was made to facilitate esthetic and functional replacements for lost tooth structures using minimally invasive methods.

To convey a first impression of the situation to the dental technician, extraoral (portrait) and intraoral photographs were taken. Alginate impressions of both arches were taken for the laboratory to prepare diagnostic casts. Furthermore, a centric record was taken and an arbitrary facebow transfer was performed.

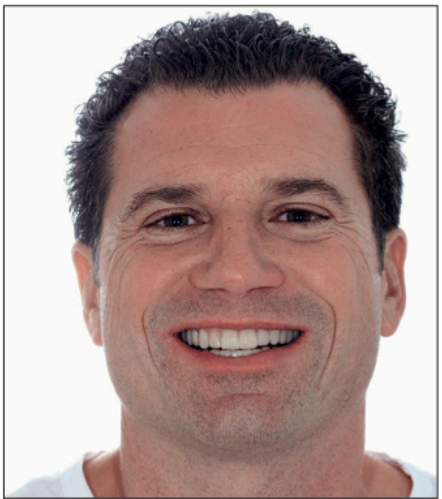
Following the laboratory and clinical assessment and having considered the benefits and risks of alternative restorative options, the patient and the treatment team agreed on the following treatment plan:

- Creation of a diagnostic wax-up to reconstruct an esthetically and functionally adequate tooth morphology (Fig 5)
- Intraoral esthetic evaluation of the wax-up by the patient using a diagnostic template (Fig 6)

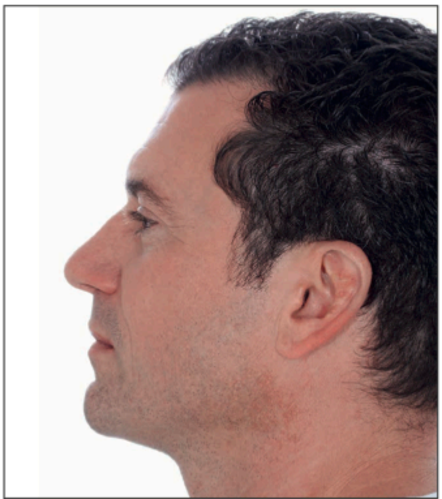
Fig 5 Analog wax-up procedure.

Fig 6 The wax-up is transferred in a gypsum model and the wax-up areas blocked out with silicone. A transparent **polyester sock down foil [Au: is this correct?]** (0.5 mm Duran; Scheu Dental) was applied and the blocked-out areas were filled with Matrix-Flow (Anaxdent). This index will be used for intraoral try-in of the wax-up. In this case, the procedure was repeated twice until the wax-up was finished for the scanning procedure.

Figs 7a and 7b Esthetic evaluation of the wax-up. In addition to restoring the anterior proportions and closing the gaps, the soft tissue profile was significantly improved by raising the lower part of the face and reducing of the chin groove (lateral view).



7a



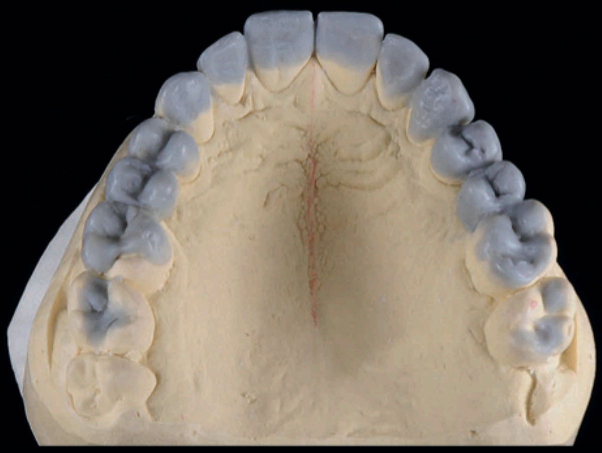
7b

- Transfer of the wax-up with the reconstructed VDO to bimaxillary tooth-colored polycarbonate full-anatomic splints; functional evaluation with optional modifications (Optiglaze, GC)
- Following a complication-free evaluation phase of 3 months, segmental transfer of the evaluated jaw relations into definitive restorations by quadrant-by-quadrant preparation and reciprocal transmission with separated occlusal splints

Clinical Procedure

First, the diagnostic wax-up was evaluated intraorally using a diagnostic stent filled with a bisGMA-based direct temporary restorative material (Figs 7a and 7b).[14] This first step also allows a preliminary inspection of the newly defined static and dynamic occlusion using shim stock foil. After this intraoral analysis and having obtained the patient's consent for the preliminary restorative goal, precision impressions (Impregum, 3M) were taken of both arches and sent to the dental laboratory.

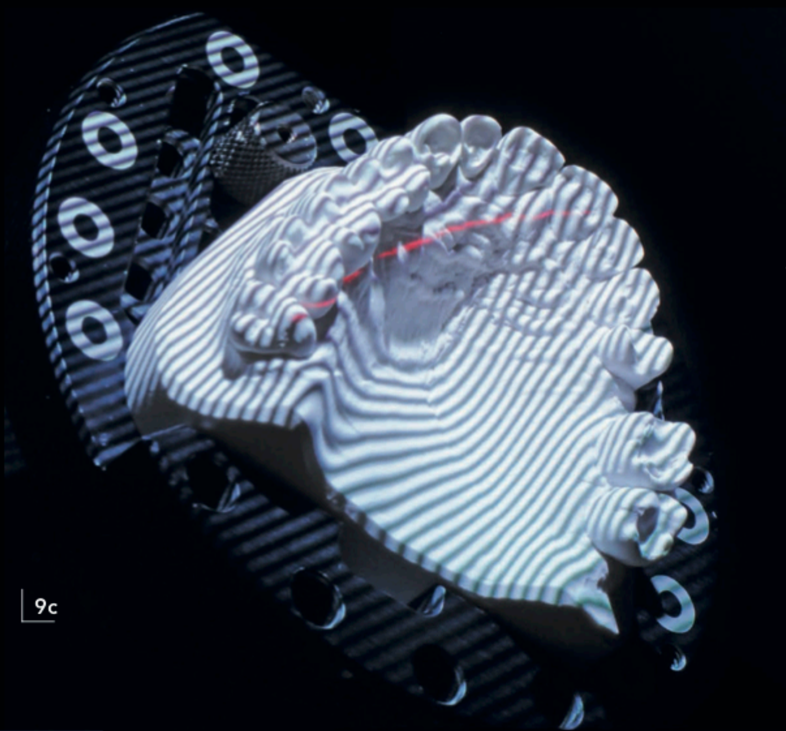
8a



9a

8b

9b

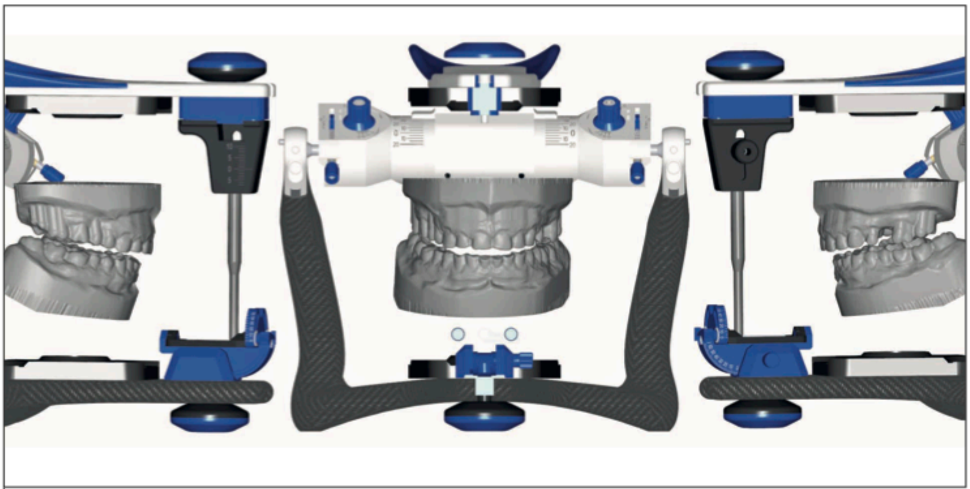


9c

Figs 8a and 8b Maxillary and mandibular baseline model prior to scanning procedure.

Figs 9a and 9b Maxillary and mandibular wax-ups in centric relation prior to scanning procedure.

Fig 9c Scanning of the models by optical strip-light scanner S600 ARTI (Zirkonzahn).



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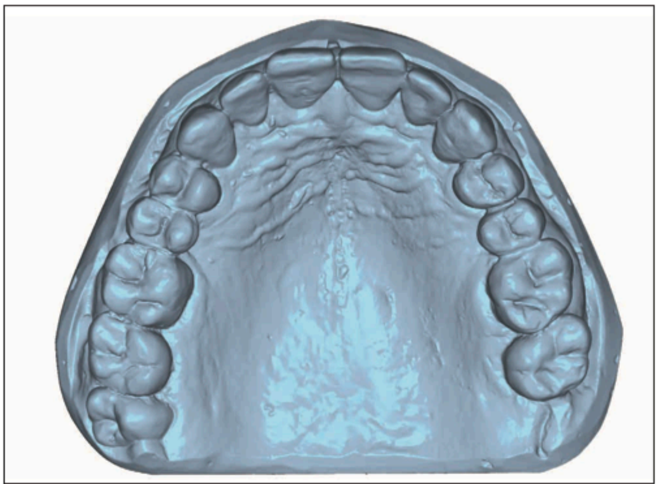

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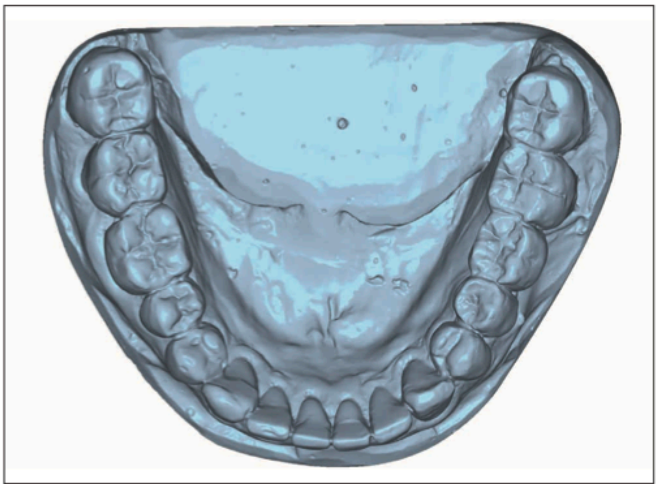


9f

Fig 9d Cranially oriented transfer of the model position to the digital articulator.

Figs 9e and 9f Models of maxilla and mandible after scan procedure.

Laboratory Procedure

Scanning the Casts

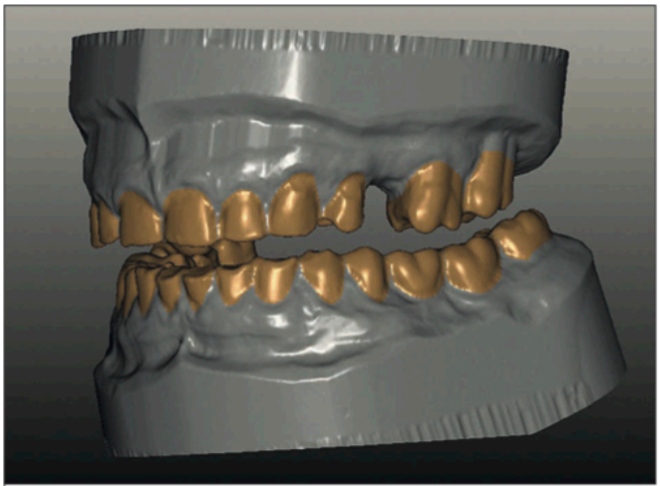
In the dental laboratory, the master casts representing the baseline situation as well as the duplicate casts of the diagnostic wax-ups made in them were poured in dental stone and scanned (Figs 8 and 9). This digital sampling step was performed using the S600 ARTI optical strip-light scanner (Zirkonzahn).[10]

To position the models in the virtual articulator in relation to the cranium, the model scans were carried out with the "Model Position Detector" (Zirkonzahn). Here, a separate overview scan obtained by scanning the entire articulator was proven to be advantageous.

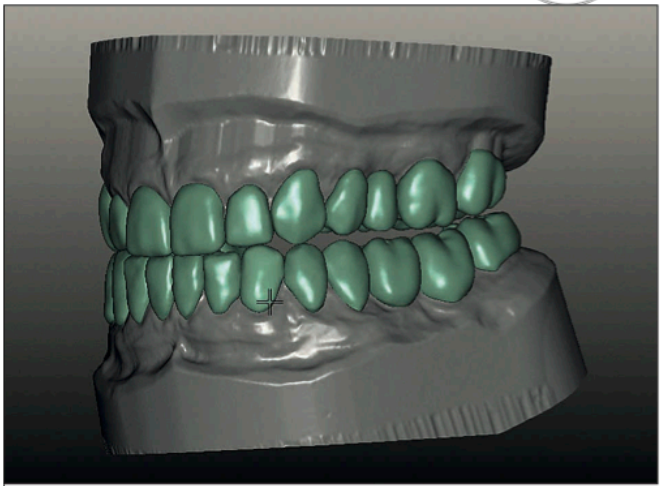
CAD Design of the Splints

In the first CAD design step, the "preparation margins" were calculated for each tooth of both arches, which determine the length of the splint in a cervical direction. For better control, the original diagnostic model can be loaded as a "general visualization" model at this point, featuring a semi-transparent representation of the "thermoforming material model" that clearly highlights the exact contours of the gingival margin.[10]

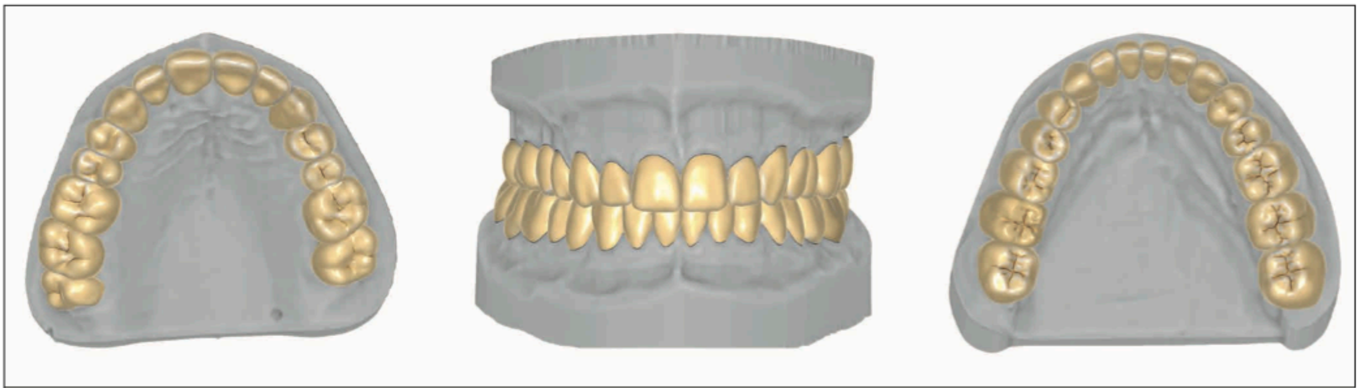
Next, the insertion path and fitting parameters, such as the thickness of the cementing gap, were determined. During the scanning process, the "virtual spacer" had already ensured the necessary space for inserting the splints, so the cementing gap could be set to a width of zero (Figs 10a and 10b).



10a



10b



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Figs 10a and 10b CAD step after delineating the extension of the splints *(a)* and completed design *(b)* as visualized STL data.

Fig 11 CAD versions of both splints after finishing of the design.

In order to obtain sufficient friction for the splints on the dentition, a value for undercuts of 0.1 mm was defined in the CAD software (Zirkonzahn Modellier, Zirkonzahn).

The actual splint design was based on the anatomical structures of teeth from the tooth library. These were positioned on the existing teeth in an ideal position above the tooth, while their external surfaces were adapted to the tooth surfaces on the scanned wax-up (Fig 11).

The static and dynamic occlusion had already been developed with the help of the analog wax-up but were rechecked in the CAD design using the virtual articulator to achieve an optimal result and to correct any premature contacts.

CAM Calculations and Production

Next, the milling strategies and associated tools were defined. Zirkonzahn has developed a single-edge milling bur specifically for processing flexible high-performance polymers, whose geometric shape and surface structure prevent resin from sticking to it and allow an efficient, secure, and accurate processing of these materials. After the tool paths were calculated and the NC files created, the splints were fabricated on the Zirkonzahn M5 Heavy Metal 5-axis CNC milling unit (Figs 12 and 13).

Finishing the Splints

The splints were separated from the milling blank after CNC machining, and the supporting sprues were severed and smoothed using cross-cut burs. The static and dynamic occlusions were reviewed in a SAM 2PX semiadjustable articulator, and the anterior/canine guidance was inspected. To efficiently polish the polycarbonate splints and to achieve a sufficient luster, they were pre-polished with a goat-hair brush and Acrypol polishing paste (Bredent) and

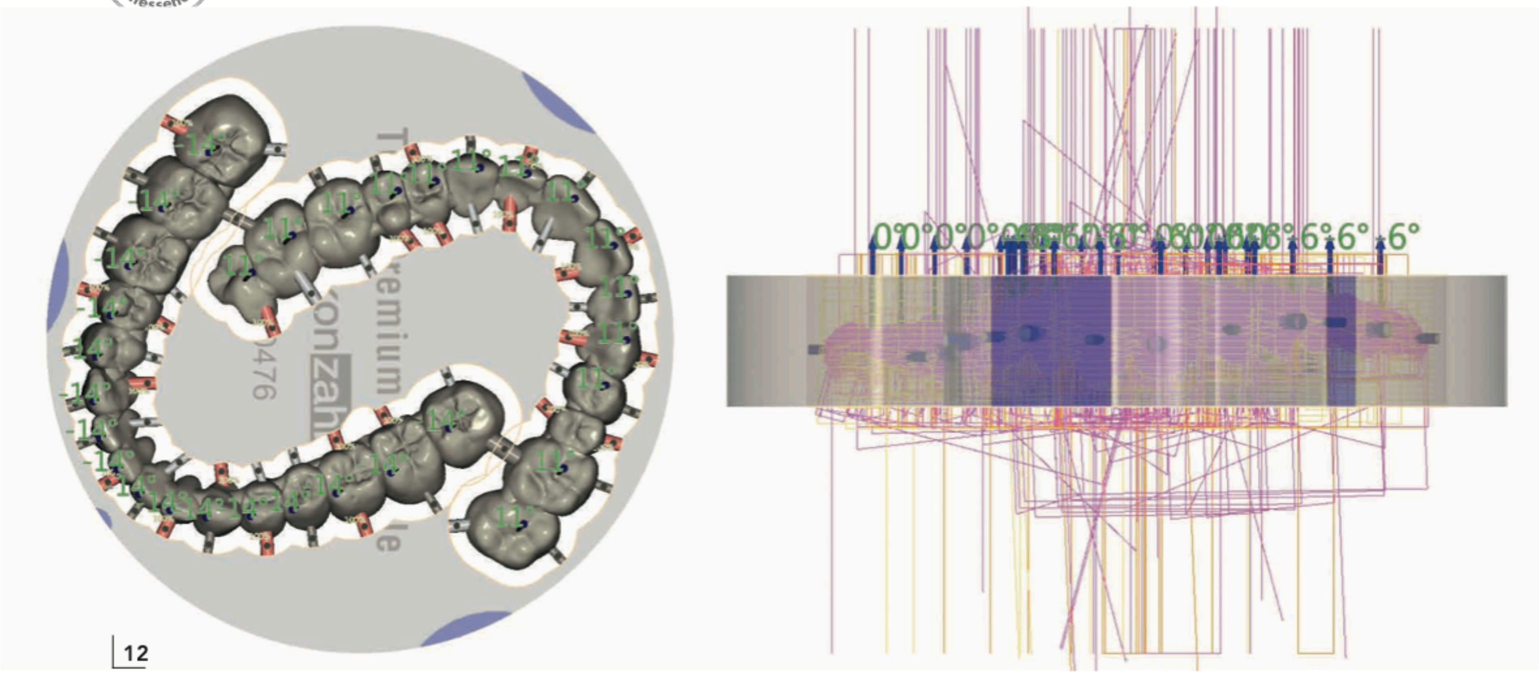

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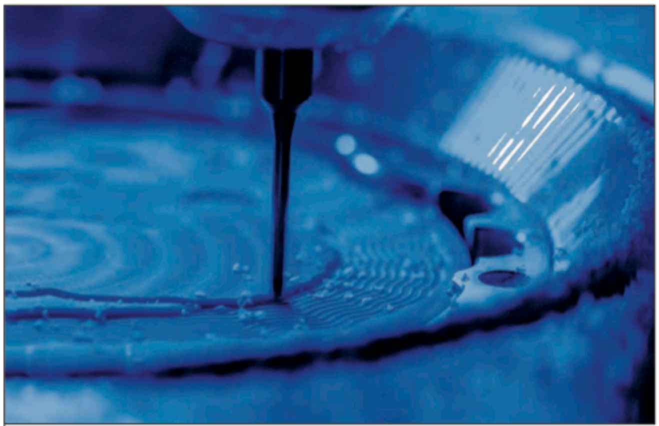
Fig 12 Positioning of the CAD constructions in the milling blank and calculation of the tool passes by CAM software.

Fig 13 The milling procedure was conducted without water application.



13

then polished to a high luster with a polishing buff and paste (Abraso Starglanz, Bredent).[10]

Try-in and Delivery

The polished occlusal splints have a tooth-like shade and are relatively flexible under load (Figs 14a to 14d). At the first intraoral try-in, the splints showed a very good fit and adequate retention on the residual tooth structure, without tilting on point loading or unilateral loading. The most salient aspects were the reconstructed portions of the maxillary anterior teeth.

The patient felt no tension caused by the occlusal splints and was highly pleased with their tooth-like appearance. He described the insertion and removal of the splints as completely unproblematic. No premature contacts occurred in the posterior region during phonetic testing, although the production of sibilants (S and Z sounds) remained somewhat challenging during the initial wearing period. When examining the static occlusion with shim stock foil, the contacts were still slightly too tight in the anterior region. This was successfully alleviated by careful reduction with a fine cutter. The modified areas of the splints were repolished and the splints were delivered (Figs 15a and 15b). The patient was scheduled for frequent recalls, at which primarily esthetic and functional adjustments were performed.

After the existing pontics 15 and 36 were removed, implants were placed at sites 15, 25, and 36 (Screw-Line, 3.3 mm, at sites 15 and 25, and Screw-Line Promote plus, 4.3 mm/13 mm, at site 36; Camlog). An attempt was made to revise the endodontically treated tooth 46, and all existing

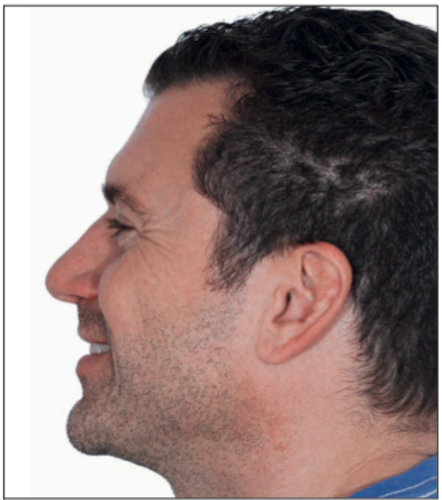

14a


14b


14c


14d


15a


15b


16

Figs 14a and 14b Both polycarbonate splints were CAD/CAM-fabricated according to the second version of the wax-up, which has been modified following the patient's demands. The main increase of the VDO was applied to the mandibular splint (higher thickness of the splint in the mandible).

Fig 14c Frontal view of both splints in a protrusive position after finishing procedure.

Fig 14d Slight individualization of the splints with Optiglaze Color.

Figs 15a and 15b Situation after delivery of the two CAD/CAM-fabricated polycarbonate splints. The splint delicately covers aspects of the teeth in order to achieve a certain amount of retention and thus a secure fit (snap effect). Patient acceptance is very good. The "test drive" can begin.

Fig 16 Facial view after esthetic and functional fine-tuning of the splints, assisted by the patient. The modification of the maxillary anterior display, eg, with specific staining (Optiglaze, GC), has resulted in a very satisfactory situation.


17a


17b

Fig 17a Transfer to the definitive restoration can now proceed in segments, using the reciprocal transfer method for the newly defined jaw relation. For this purpose, the right quadrant was prepared and the splint separated in half with a separating disk.

Fig 17b With the left half of the splint inserted in the still unprepared left quadrant, the jaw relation could be recorded using a high-precision bisacrylate-based registration material (Luxa Bite, DMG), which can be corrected with Aluwax (American Dental Systems).


17c

Fig 17c In a second step, the left quadrant was prepared and the existing bite registration extended by using the right-side record as a reference.

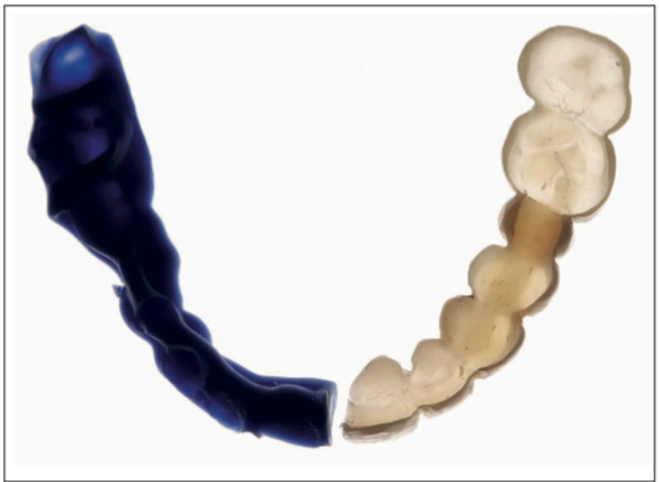

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Fig 18 Extraoral view of the situation in Fig 17b. The tooth-colored splint was divided in the middle. After preparation of the first quadrant and inclusion of the left splint and the mandibular splint, the jaw relation was determined using a high-precision registration material.

fillings and restorations were replaced underneath the splints without adversely affecting the patient's appearance. In addition, the CAD files of the splints could be used for 3D implant planning and the transfer into the surgical templates. Within the pretreatment phase, segments of the splints were modified by adjustment and relining. To improve the optical separation of the anterior display, the facial surfaces of the splints were stained with a special varnish (Optiglaze, GC) (Fig 16).

At the end of the implant healing phase, a segmented conversion to the final restoration was performed. The maxillary right quadrant was prepared first and the splint was separated in half and retained in the unprepared maxillary left quadrant only (Fig 17a). Referring to the separated splint, the jaw relation could now be obtained precisely in the prepared right quadrant (Fig 17b). Next, the maxillary left quadrant was prepared, and the existing bite record for the right quadrant was used as reference for extending the jaw relation record to the left quadrant (Fig 17c). The separated splints as well as the jaw relation record made of a bisacrylic material (LuxaBite, DMG) can then be passed along with the impressions of the prepared maxillary arch and the lower rail **[Au: the term "rail" is unclear]** and the facebow to the dental laboratory for the manufacture of the first part of the final restoration (Fig 18).

Fig 19 The maxillary restorations were fabricated of IPS e.max Press Multi (Ivoclar Vivadent) and in the molar area of gold alloy (J4-PF, Jensen Dental).

Fig 20 Facial view of the restorations. The details were expressed predominantly by the surface and the positions (tooth axis) of the monolithic restorations.

Fig 21 Following delivery of the definitive maxillary restorations, treatment of the mandible proceeded in the same way as described for the maxilla.

It is recommended to correct the LuxaBite jaw relation record with Aluwax (American Dental Systems) for improved accuracy.[16]

An advantage of this segmented approach, among others, is that any required minor adjustments to the static and dynamic occlusion of the final restorations in the maxilla can be made to the antagonistic splint, leaving the newly inserted restorations intact. After adhesive insertion of the definitive restorations in the maxilla, the restoration of the mandible can be performed following the same principles as described for the maxilla (Figs 19 to 23).

Fig 22 The definitive restorations for the mandible were made of IPS e.max Press Multi (Ivovlar Vivadent) and gold alloy (J4-PF, Jensen Dental) for the third molars.

Fig 23 Patient 3 months after final placement of the definitive restorations.

DISCUSSION

The main benefits of tooth-colored occlusal splints are that they are rapidly produced and they meet esthetic and functional expectations in terms of a noninvasive and reversible initial therapy—they might be termed "removable provisionals." Fine-tuning and modifications as well as a gradual approximation of the treatment goal are easily achieved with this variant at relatively low cost. Advantages of tooth-colored polycarbonate splints include the possibility of performing surgical (extractions), periodontal (crown lengthening, root coverage), and implantological interventions as well as endodontic and restorative treatments (endodontic revisions, filling replacements) during the pretreatment phase. This can be performed underneath the splint without affecting the esthetics and function of the previously defined outer contour.

Another aspect worth mentioning is the excellent compliance observed in the many patients treated to date, which is owed not least to the delicate design of the splints. Thus, it is possible to "test-drive" a reversible and modifiable prototype of the final restoration in a virtually risk-free manner. This design option is made possible by the CAD/CAM-related high quality of the materials and the flexible behavior of the polycarbonate material used (Temp Premium Flexible, Zirkonzahn). This material was developed primarily for the fabrication of temporary crown and bridge frameworks in the anterior and posterior region and exhibits a modulus of elasticity of 2,400 MPa (PMMA: 1,800 MPa) and a bending strength of 100 MPa (PMMA: 55 MPa).[17]

By providing removable tooth-colored occlusal splints made of this material, the reconstructed VDO can be clinically tested for up to one year, achieving a high level of predictability for complex definitive restorations. Especially when extensive corrections have to be made to shades, shapes, and positions in the esthetic zone, longer pretreatment periods are essential—important factors such as the influence of lip position and dynamics on the smile line and the influence on phonetics cannot be fully anticipated by the laboratory technician.[3]

Tooth-colored occlusal splints, therefore, not only serve a functional purpose during the pretreatment phase. They also constitute the communication medium for the patient, the dentist, and the dental technician in fine-tuning the restorative design.[18] This pretreatment phase could be extended, if specifically desired by the patient, by milling a further splint based on the existing dataset once the inserted splint had reached the end of the maximum wear period. This advantage of digital reproducibility lowers the cost for each subsequent splint, since no additional impression/scanning or CAD steps are required.

The use of separate splints for the maxilla and mandible that reproduce the occlusal morphology embodied in the wax-up also simplifies the segment-by-segment transfer of a complex rehabilitation plan to the definitive restorations, but it does require a minimum increase of the VDO of 4 mm in the region of the incisal pin of the articulator. After several uneventful months of functional evaluation, the maxilla can be prepared step by step in quadrants, accurately transmitting the jaw relationships reciprocally with a separated splint.[14]

Once the final maxillary restorations are delivered, the patient will be wearing only the mandibular splint. The mandible can then be definitively restored in the same manner at an opportune time. This provides a high degree of discretion during treatment planning and the treatment itself, particularly in the high-cost complex restorations described, as economic considerations can be better taken into account through the risk-free extension of the pretreatment phase.

In principle, CAD/CAM-generated occlusal splints could also be produced by 3D printing as an additive process.[19] In the present case, a subtractive production process was chosen, ie, milling from an industrially prefabricated and prepolymerized blank. Based on 4 years of clinical experience with tooth-colored occlusal splints made of polycarbonate, the authors believe that their choice is currently still supported by higher precision and better quality of the material used in a subtractive process.

CONCLUSION

Over the past 6 years, the authors have increasingly worked with CAD/CAM-fabricated tooth-colored occlusal splints made of polycarbonate. Their clinical experience has shown the following benefits of the functional pretreatment phase:

- Timely and reversible implementation of functional, phonetic, and esthetic changes, which offer simplified options of evaluation
- High patient compliance during the trial phase because the splints resemble a full-fledged restoration ("23-hour splint," "removable provisional")
- Significant benefits in the pretreatment phase for both the restorative team and the patient by facilitating conservative, surgical, periodontal, and restorative interventions underneath the splint without affecting the esthetic and functional situation
- Simplification of complex rehabilitations with the option of a segment-by-segment transfer to the definitive restorations using the bimaxillary (maxillary and mandibular) splint concept
- Option of gradually approximating the treatment goal through individual modifications of the digital dataset
- Quick and easy reproducibility in case of loss or fracture of the occlusal splint based on the existing digital data

Disadvantages include the relatively high cost and the fact that the indication is limited to extensive VDO changes.

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