Digital workflow for the rehabilitation of the excessively worn dentition

Wael Att, DDS, Dr med dent, PhD
Professor and Chair, Department of Prosthodontics, Tufts University School of Dental Medicine, Boston, MA, USA

Udo Plaster, MDT
Master Dental Technician, Plaster Dental Technology, Nurnberg, Germany

Miha Brezavscek, Dr med dent
Private Practice, Radolfzell, Germany

Aikaterini Papathanasiou, DMD
Associate Professor and Director, Advanced Education in Esthetic and Operative Dentistry Program, Department of Prosthodontics, Tufts University School of Dental Medicine, Boston, MA, USA

Correspondence to: **Prof Dr Wael Att**
Professor and Chair, Department of Prosthodontics, Tufts University School of Dental Medicine, One Kneeland St, Suite 220, Boston, MA 02111, USA; Tel: +1 (617) 636-6575, Fax: +1 (617) 636-6583; Email: wael.att@tufts.edu

Abstract

Excessively worn dentition is a clinical condition that mainly impacts the esthetic appearance of patients. In many cases, this may even extend to affect their psychologic condition and social interaction, and consequently reduce their quality of life. The treatment steps of such cases involve comprehensive evaluation and diagnosis, a rigid rehabilitation plan, and a careful and well-structured treatment execution. To facilitate long-term success, patient compliance and a strict recall program should be implemented. The case report presented in this article provides a step-by-step description of the treatment of an excessively worn dentition with the aid of the digital workflow.
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Introduction

The incidence of tooth wear is noticeably increasing, which not only affects the esthetic appearance of patients but may also impact their quality of life. Although there is no specific information, the global prevalence of tooth wear shows a large variation and has been estimated at between 3% at the age of 20 years and 17% at the age of 70 years.[1] For erosive tooth wear, estimates show an even greater range, between 20% and 45% for adults.[2] The increasing levels of tooth wear are significantly associated with age, habits, and the consumption of acidic foods and drinks.[1,2]

It is generally accepted that tooth wear mainly occurs due to attrition, abrasion, and erosion.[3] According to the Glossary of Prosthodontic Terms, attrition is the mechanical wear resulting from mastication or parafunction, limited to contacting surfaces of the teeth.[4] Abrasion is the abnormal wearing away of the tooth substance caused by factors other than mastication. Erosion is the progressive loss of tooth substance caused by chemical processes that do not involve bacterial action, producing defects in the form of wedge-shaped depressions, often in the occlusal, facial, and cervical areas.[3,5]

While parafunction, namely bruxism, and toothpaste/toothbrush abuse have been described as factors that cause abrasion, erosion results from regurgitation, soda swishing, and fruit mulling. In these cases, tooth wear is often observed to be the result of a combination of several issues and its etiology can be multifactorial.[1,2,6-8] In other words, clinicians often observe a combination of attrition and erosion or abrasion and erosion.

Bruxism is typically characterized by a planar wear pattern on the incisal and occlusal surfaces of the teeth. The tooth structure loss is gradually greater on the anterior rather than the posterior teeth because of leverage changes that are due to eccentric posterior interferences. In patients with bruxism, it has been suggested that the leverage system changes as the temporomandibular joint (TMJ) stops being at the fulcrum point, resulting in increased anterior forces.[3,9] However, the scientific evidence on this point has not been validated.

On the other hand, patients with regurgitation or reflux show tooth wear from erosion. Usually, the most affected areas are the palatal surfaces of the maxillary anterior teeth due to the acidic vomitus and the low protection provided by the tongue position. This is followed by the palatal surfaces of the maxillary posterior teeth, and lastly the mandibular posterior teeth. The position of the tongue protects the mandibular anterior teeth against the acidic environment. These teeth therefore almost never show signs of erosion. Cupping or cratering is quite common in regurgitation patients and can easily be observed in occlusal areas where resin-based fillings exist. The fillings appear elevated and are surrounded by a depressed area of hard tooth substance.[2,8,10]

Furthermore, patients who have the habit of swishing with carbonated drinks usually show a wear pattern of significantly affected posterior compared with anterior teeth due to the position of the tongue during swishing. In these cases, the mandibular first molar is usually the most affected tooth.[2,11] Another clinical manifestation of this condition is tooth cupping or cratering with sharp enamel edges. In contrast, when there is tooth cupping or cratering with abraded enamel edges, the wear can be due to fruit mulling. Patients who have the habit of fruit mulling have wear lesions mainly located on the occlusal surfaces of the maxillary and mandibular posterior teeth.[2,3,11]

Considerations for the rehabilitation of worn dentition

While many approaches for the treatment of excessively worn dentition have been proposed,[6,10,12-21] several basic steps are recommended in the workflow to facilitate a successful treatment outcome. The clinician should obtain and analyze all patient information. More specifically, the first step should be comprehensive charting involving the following evaluations:

- Medical and dental history.
- Extraoral analysis.
- Esthetic analysis (facial and dental).
- Intraoral and dental evaluation.
- Periodontal evaluation.
- Radiographic evaluation.
- Functional analysis.
- Phonetic analysis.

While details of the necessary evaluations are described elsewhere,[12,14,15,22,23] attention should be given to the incisal edge position, interocclusal rest space, overbite, clinical crown height, vertical dimension of occlusion (VDO), and gingival display. The related analyses help to define the need for both the manipulation of the VDO and the lengthening of the teeth coronally, cervically or both.[12,14,15,22] Further important parameters include, but are not limited to, the length and activity of the upper lip, overjet, tooth proportions, and soft tissue architecture.

Determinants for the manipulation of the VDO

Based on the analyses performed, the next steps include determining the diagnosis and treatment plan. While the majority of cases involving excessive tooth wear necessitate the manipulation of the VDO, it is important to understand the global indications for this procedure:[12,14,15,22]

1. To improve esthetics (tooth exposure, esthetic tooth proportions, etc).
2. To create an adequate space for the restorative materials.
3. To improve the incisal and occlusal relationships, not function.
4. To preserve tooth structure by guiding tooth preparation and implementing minimally invasive procedures.

Other indications that have been advocated for the manipulation of the VDO (namely, the treatment of TMJ symptoms, improvement of masticatory function, improvement of phonetics, etc) can be described as misbeliefs that lack any scientific evidence. The clinical steps for the manipulation of the VDO are described later in this article.

After the treatment plan has been finalized, the steps performed in the clinic and in the laboratory should be planned and communicated among the treatment team.

Digital workflow for the rehabilitation of the worn dentition

The digital workflow for the rehabilitation of the worn dentition follows the general workflow for reconstructive dentistry.[24] It comprises three main components: data acquisition; followed by data processing and planning; and finally, the execution of the treatment or fabrication (Fig 1).

Data acquisition is the first step in the transformation of the patient information into digital data that can be used for further steps such as analysis, treatment planning, and processing/planning. The available techniques that are most commonly used include digital charting, intraoral or desktop scanning, digital radiography, digital photography, and video recording. The use of digital photographs and video recordings with the appropriate software and online or cloud-based communication platforms can be used as a part of the comprehensive

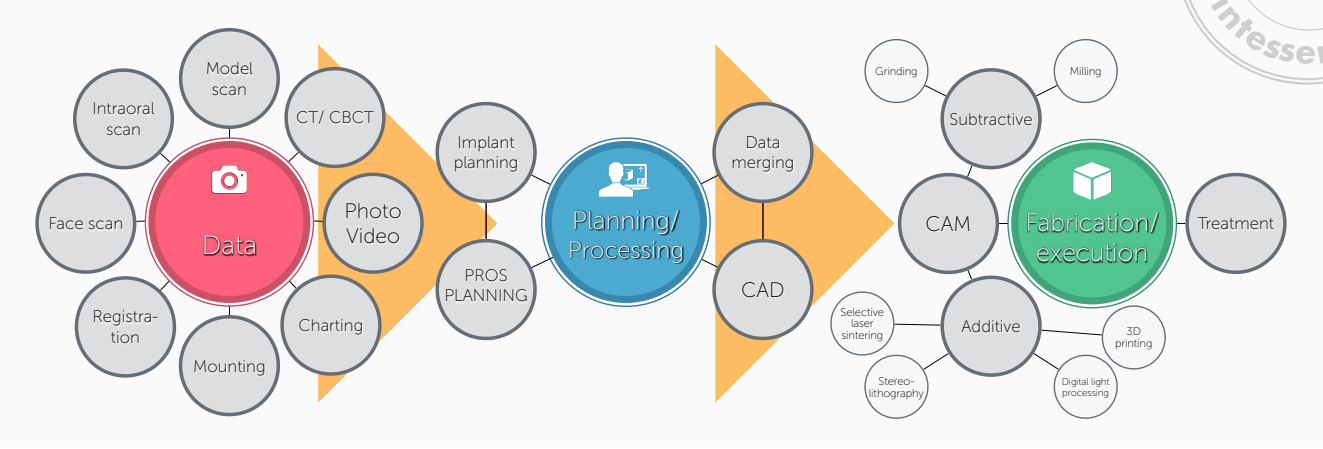


Fig 1 Overview of the digital workflow in reconstructive dentistry.

treatment and esthetic analysis as well as an important communication tool among the clinician, the dental technician/s, and the patient. Intraoral scanners (IOSs) used for computer-assisted impressions are predictable and fast tools for digitizing and manufacturing small-unit reconstructions.[24-27]

The next step of the digital workflow is the *processing/planning* of the collected data to create the virtual patient, finalize a treatment plan or design a restoration. Data obtained from different acquisition tools (eg, intraoral scans, CBCT images, or patient photographs superimposed onto model scans) can be merged or superimposed using specific planning software to enhance the information on the computer screen for the clinician or dental technician.[24,28]

The last step of the digital workflow is the *treatment and fabrication*, where the planned treatment or production of the prosthesis takes place by means of CAM. The CAD data is imported into the CAM software to manufacture the appliances and/or restorations.[24]

To date, the digital workflow for the rehabilitation of worn dentition has focused more or less on the implementation of chairside technologies to deliver segmental treatment rather than on the treatment as a whole. The presented case provides a step-by-step description of the treatment of an excessively worn dentition with the aid of the digital workflow.

Case presentation

A 38-year-old male patient presented for consultation and treatment. His chief complaint was the overall unpleasant appearance of his teeth, which were extremely short and dark. Due to his tooth appearance, the patient said that he avoided smiling and socializing. In addition, he stated that he had several old restorations that required replacement (Fig 2).

The patient's medical history revealed no significant general conditions or allergies. He was a heavy smoker (30 cigarettes per day) and consumed approximately 1.5 liters of carbonated soft drinks per day. He was not under any medication. The patient's dental history revealed several restorations delivered over the years, the extraction of tooth 46, and extreme wear possibly associated with his lifestyle. His oral hygiene was average and he did not visit a dentist on a regular basis.

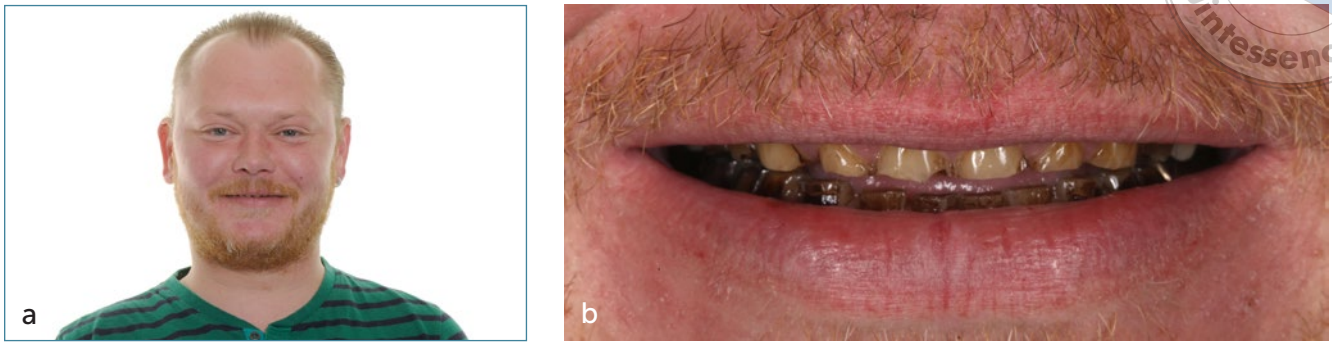


Fig 2 Initial extraoral and smile photographs. (a) The teeth appear barely visible during a social smile. (b) A forced smile reveals short and discolored maxillary and mandibular teeth, reflecting a jeopardized esthetic appearance.

Examinations

The extraoral examination revealed minor facial asymmetry and compromised esthetics. Regarding the esthetic and smile analyses, the smile was rated as unpleasing, with the teeth barely visible during a discrete smile. A forced smile revealed extremely short and discolored teeth in both jaws (see Fig 2).

The intraoral and comprehensive dental examination and analysis revealed generalized extremely worn dentition with heavily discolored teeth and multiple insufficient restorations. Due to wear, discoloration, and multiple lesions, the general esthetic appearance of the teeth was compromised. The wear was characterized by a combination of a planar enamel and shallow dentin wear, denoting generalized attrition (Fig 3). Furthermore, multiple cupped lesions on the occlusal and incisal surfaces were observed, as were elevated and insufficient composite fillings. Apparently, these lesions were directly related to the excessive consumption of acidic soft drinks.

Due to secondary caries, the existing crowns on teeth 16, 24, and 36 as well as the fixed partial denture (FPD) on teeth 45 to 47 were deemed insufficient (see Fig 3). The periodontal assessment depicted localized gingival inflammation (Fig 4).

The radiographic examination revealed insufficient root canal treatments on teeth 16 and 25 as well as periapical lesions on teeth 16 and 25 (Fig 5). The functional examination showed multiple contacts during maximum intercuspation, with group guidance during lateral and protrusive movements. The overbite was 3 mm, the overjet was 3 mm, and the interocclusal rest space was 3 to 4 mm. The patient's centric relation coincided with his maximum intercuspation position, and he depicted anterior and canine guidance. The TMJ function was within normal limits, showing neither discomfort for the patient nor limitations or deviations.

Diagnosis

Based on the comprehensive charting and analyses performed, the following diagnosis was established:

- Extraoral: minor facial asymmetry, compromised esthetics.
- Intraoral: n/a.
- Dental: multiple missing teeth, extensively worn dentition, multiple insufficient restorations with secondary caries.

Fig 3a to e Anterior, vestibular, and occlusal views of the initial situation. The teeth appear extremely worn and discolored, along with multiple insufficient restorations and secondary caries.

[Authors to please check, on previouus page tooth 25 is mentioned as also having a periapical lesion?]

- Periodontal: localized gingivitis.
- Functional: anterior and canine guidance.
- Prosthetic: insufficient fixed prosthetic rehabilitation.
- Radiographic: insufficient root canal treatments on teeth 16 and 25. Periapical lesion on tooth 16.

Treatment options

Except for tooth 16, all teeth in both jaws were given a fair prognosis.

Based on the diagnosis and tooth prognosis, several treatment options were proposed and discussed, including direct resin-based restorations, conventional single crowns and FPDs, and minimally invasive prosthetic procedures (MIPP) using an additive approach.

Table 1 serves as a treatment planning decision aid, showing the advantages and disadvantages of the various treatment options to provide guidance about the most favorable option. A rating approach is used

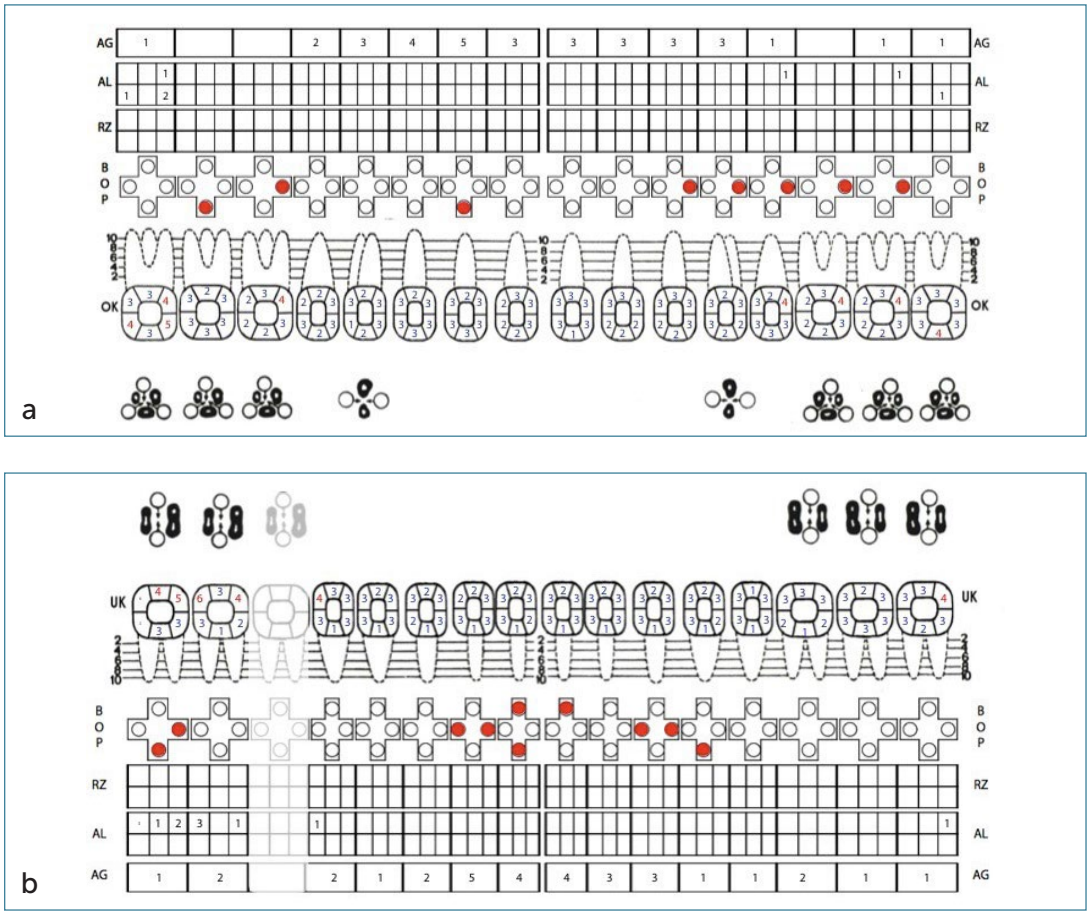
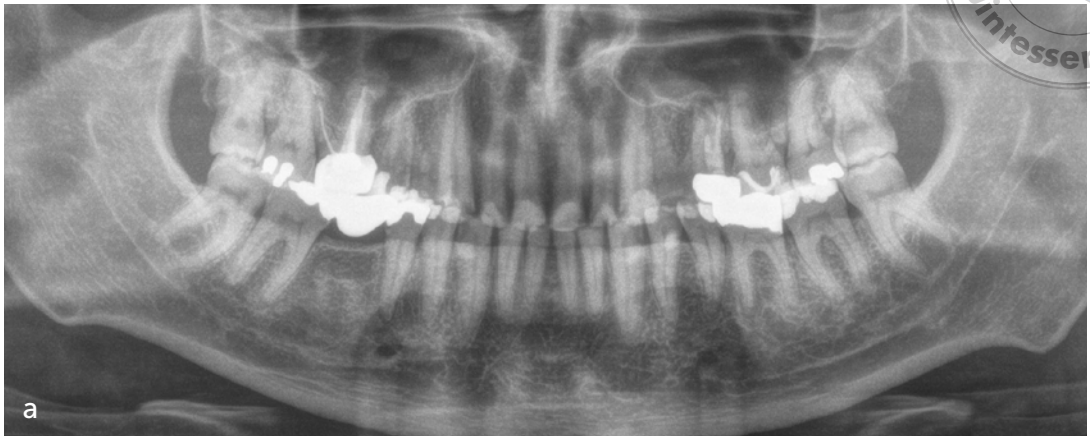


Fig 4a and b Periodontal charting depicting probing depths, bleeding on probing (BOP), attachment loss (AL), attached gingiva (AG), and recession (RZ). No furcation involvement was recorded.

Table 1 Treatment planning decision aid

	TREATMENT OPTIONS		
Parameters	**Composite**	**Crown & FDP**	**Minimally invasive**
Patient comfort	+	+	+
Quality of life	+	+	+
Esthetics	+/–	+	+
Invasiveness	+	–	+
Fabrication complexity	+/–	+	+
Extensibility/reparability	+	–	–
Oral hygiene performance	+	+/–	+
Economics	+	–	–
Long-term clinical performance	–	+	+

+ Advantage; – Disadvantage



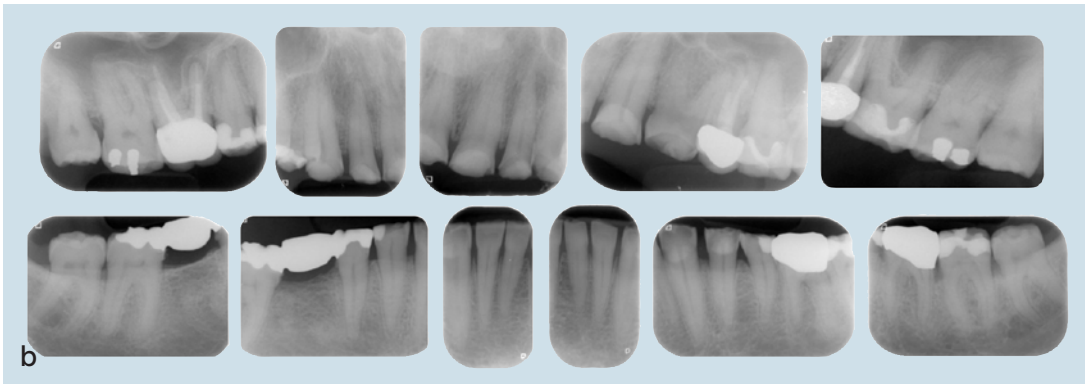


Fig 5a and b The radiographic assessment revealed insufficient root canal therapy on teeth 16 and 25 as well as a periapical lesion on tooth 16.

Note to author: Please make consistent, was there a periapical lesion on tooth 25 too? See previous comment to you.

for the different options to assist in the selection of the most appropriate one for each specific patient.

Rehabilitation with direct resin-based restorations

The use of direct resin-based restorations for the rehabilitation of extremely worn dentitions has been discussed in the literature and advocated as the most conservative treatment option.[29,30] While there are several composite resin systems available that show favorable characteristics in terms of resistance, color stability, and handling, a full-mouth rehabilitation using this technique is not only difficult but also does not guarantee the accurate inclusion of the patient-relevant parameters in the final rehabilitation. While some clinicians advocate this approach as being an esthetic, fast, economical, and reliable one, the final outcome solely depends on the clinician's skills, and in many cases yields a compromised result.[31-33] Additionally, long-term data to support the performance of such restorations are not available. In fact, most studies in the literature are case series. Overall, the survival rates for vertical bite reconstructions using composite resin are between 93.1% to 98% after 3.3 to 5.5 years (Table 2).[16,34,35]

Conventional crowns and FPDs

It is widely accepted that a fixed prosthetic rehabilitation shows a very good long-term

clinical performance.[36-40] More specifically, studies have demonstrated that the 10-year survival rate of conventional single crowns and FPDs is 93% and 89.2%, respectively.[36-40] Although it remains debatable, the selection of a specific restorative material does not seem to play a significant role in restoration survival rates (see Table 2). In other words, the current data does not favor the use of one specific material over any other to facilitate better longevity. In fact, studies on the outcome of different restorative materials have excluded patients with parafunctions, meaning that the outcome of different materials in excessive wear cases is yet to be evaluated. Currently, the decision to use a specific material seems to be based on the preference of the clinician and the experience of the dental technician. Nevertheless, monolithic ceramic restorations, primarily lithium disilicate or zirconia seem to be preferred by many clinicians because they offer favorable esthetic properties and bypass the inherent issues with the fracture and chipping of veneering ceramics, especially in the case of veneered zirconia-based restorations (see Table 2).

Minimally invasive prosthetic procedures

These procedures have previously been described as a method to preserve tooth structure and establish an esthetically pleasing, harmonious, and functional rehabilitation.[14,15] In addition to ceramic veneers, onlays and tabletops, the concept of MIPP also includes crowns and FPDs.[41-43] This approach has the advantage of being less invasive than conventional crowns and FPDs because the rehabilitation relies on an additive approach via the manipulation of the VDO in combination with minimal tooth preparation.[14,15] The survival rates of restorations manufactured through the MIPP approach appear to be very good and show fewer complications than other types of rehabilitations (see Table 2).[41-47]

Treatment plan and execution

After evaluating the possible treatment options and patient-related factors for the present case, the final treatment plan was decided, which included minimally invasive single crowns and FPDs made out of a monolithic zirconia-based material. As

Table 2 An overview of the mid- and long-term outcomes of various treatment options favors ceramic-based over composite-based restorations

Prognosis of treatment options (survival rates)			
Crowns (after 5 years)[39,40]	FDPs (after 5 years)[37,38]	Minimally invasive restorations	Composite
Metal-ceramic 95.7%	Metal-ceramic 94.4%	Veneers 91–100% after 3–21 years[41-43]	Veneers 80.1–87% after 3.5 years[29,30]
Lithium disilicate 96.5%	Glass-ceramic 89.1%	Ceramic onlays 93–100% after 3–10 years[41,44-46]	Vertical bite reconstructions 93.1–98% after 3.3–5.5 years[16, 34, 35]
Infiltrated alumina 94.6%	Infiltrated alumina 86.2%		
Zirconia (veneered) 91.2%	Zirconia (veneered) 90.4%		

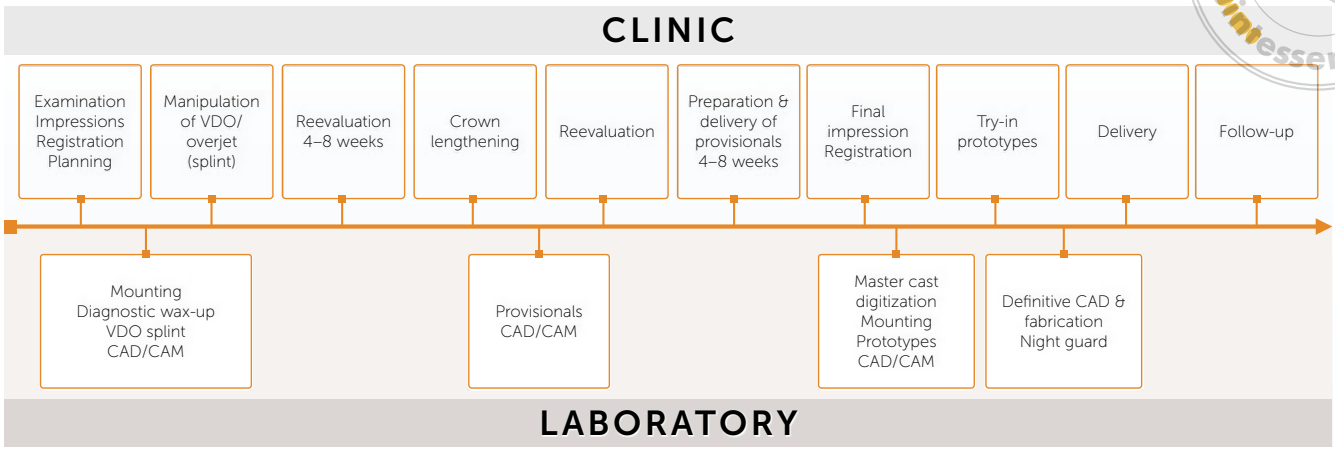


Fig 6 Treatment steps and sequence for both clinical and laboratory sessions with an emphasis on the digital workflow.

the too-short teeth required lengthening for esthetic enhancement, a manipulation of the VDO was planned. Factors that determined this manipulation were esthetics, the remaining tooth structure, and the restorative space needed. A sequence for the treatment steps for both the clinic and laboratory was finalized and discussed with the patient (Fig 6).

The treatment began with the registration of patient-relevant references and planes, for which the PlaneFinder system (Zirkonzahn) was used. Instead of using a conventional facebow, the registration procedure was carried out relative to the patient's natural head position, and was performed with the patient in a standing rather than a seated position.[48] Although it is still unknown whether this technique is more accurate than the conventional procedure, the developer of the system suggests that it offers several advantages over the conventional one. These include a more accurate registration of patient-relevant references and variations, enhancement of the information for the dental technician, the possibility of seamless integration in the digital workflow, and ultimately fewer try-in appointments and modifications. In short, the position of the maxilla as well as patient-relevant planes and references, ie, the ala-tragus plane, the incisal edge position, and the facial and dental midlines were registered relative to the horizontal (zero) plane and to the natural head position. Accordingly, the maxilla was mounted in a calibrated articulator (PS1; Zirkonzahn), which, unlike semi-adjustable articulators, considers the mastoid as the axis for rotation rather than the condyles (Fig 7). A detailed description of this technique is provided elsewhere.[48]

After conventional mounting, the digitization procedure was performed by scanning each cast separately, before scanning the mounted casts together with the articulator (Scanner S600 ARTI; Zirkonzahn). In this way, the analog situation, including the patient-relevant planes and references, was completely digitized.

With the help of the Zirkonzahn.Modellier CAD software (Zirkonzahn), the 2D patient photographs were superimposed onto the 3D models to facilitate the setting of the tooth length during display and the incisal edge position. Following this, a virtual diagnostic wax-up was performed and

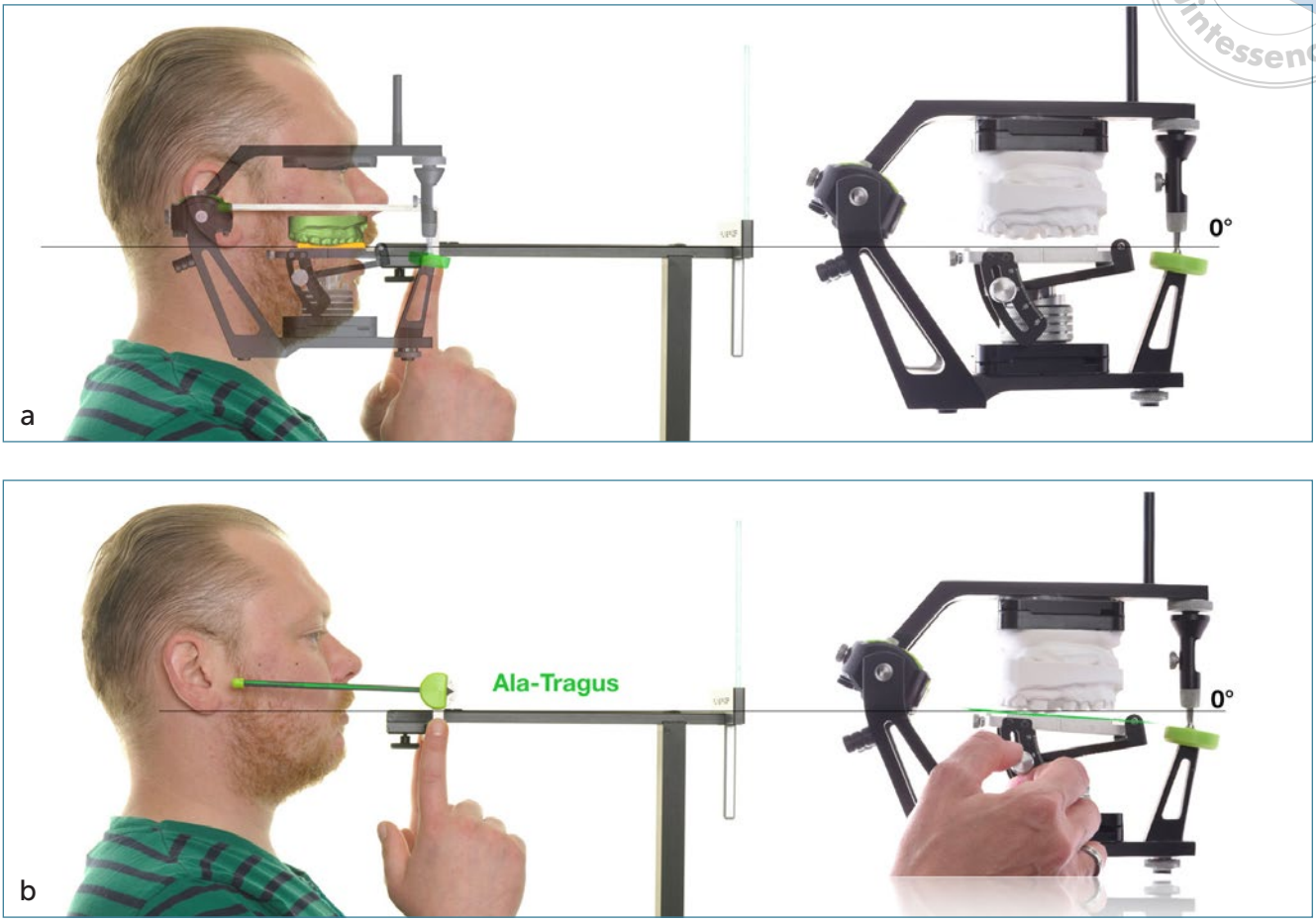


Fig 7a and b The patient-relevant references were registered relative to the natural head position and the horizontal (zero) plane. The registered angle of the ala-tragus plane to the horizontal plane was set in the articulator by modifying the registration table inclination accordingly.

a manipulation of the VDO considered. Accordingly, and prior to tooth preparation, a noninvasive try-in of this manipulation was facilitated using an occlusal splint. The splint was designed using the same CAD software, taking into consideration the amount of space needed for the manipulation of the VDO, and was milled out of a polymethyl methacrylate (PMMA) block. It was then delivered to the patient, who was asked to use it for a period of a few weeks. The anatomical design of the splint from the facial aspect improved the esthetic appearance and restored the patient's confidence when smiling (Fig 8). With the delivered splint, the patient's comfort with the new VDO was evaluated, and the wear patterns helped to track the course of reprogramming the dynamics. The extent of the wear serves as an aid to identify the degree of parafunction (Fig 9).

As the clinical crown height of the maxillary teeth was deemed insufficient to provide an appropriate retention, a selective crown-lengthening procedure focusing on the palatal aspect of the teeth was performed (Fig 10). A healing period of 6 to 9 months is usually recommended after such

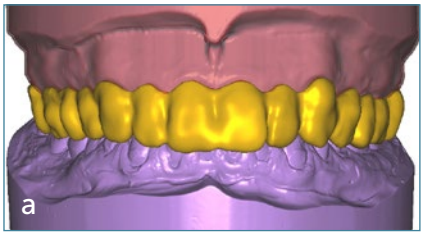


Fig 8a to c The designed and milled PMMA maxillary splint with anatomical features was used as a removable appliance for testing the new VDO, tracking the reprogramming of the patient's dynamic occlusion and temporarily improving esthetics.

Fig 9a and b The extent and pattern of wear of the PMMA splint helps to identify the degree of parafunction, ie, bruxism.

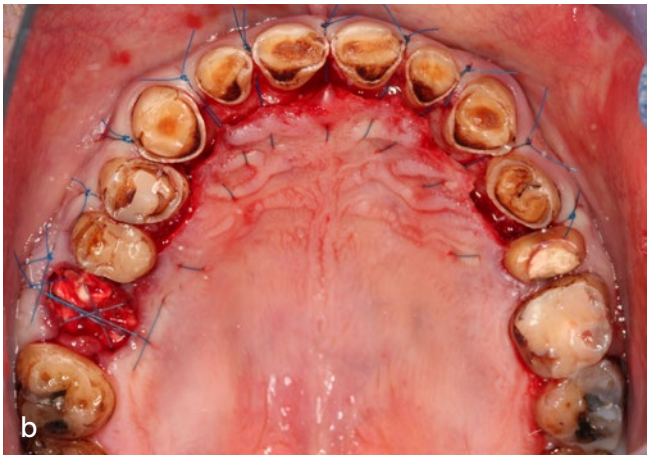


Fig 10a and b Crown lengthening surgery was performed to increase the clinical crown height of the maxillary teeth. Tooth 16 was extracted at the same time that the crown lengthening surgery took place.

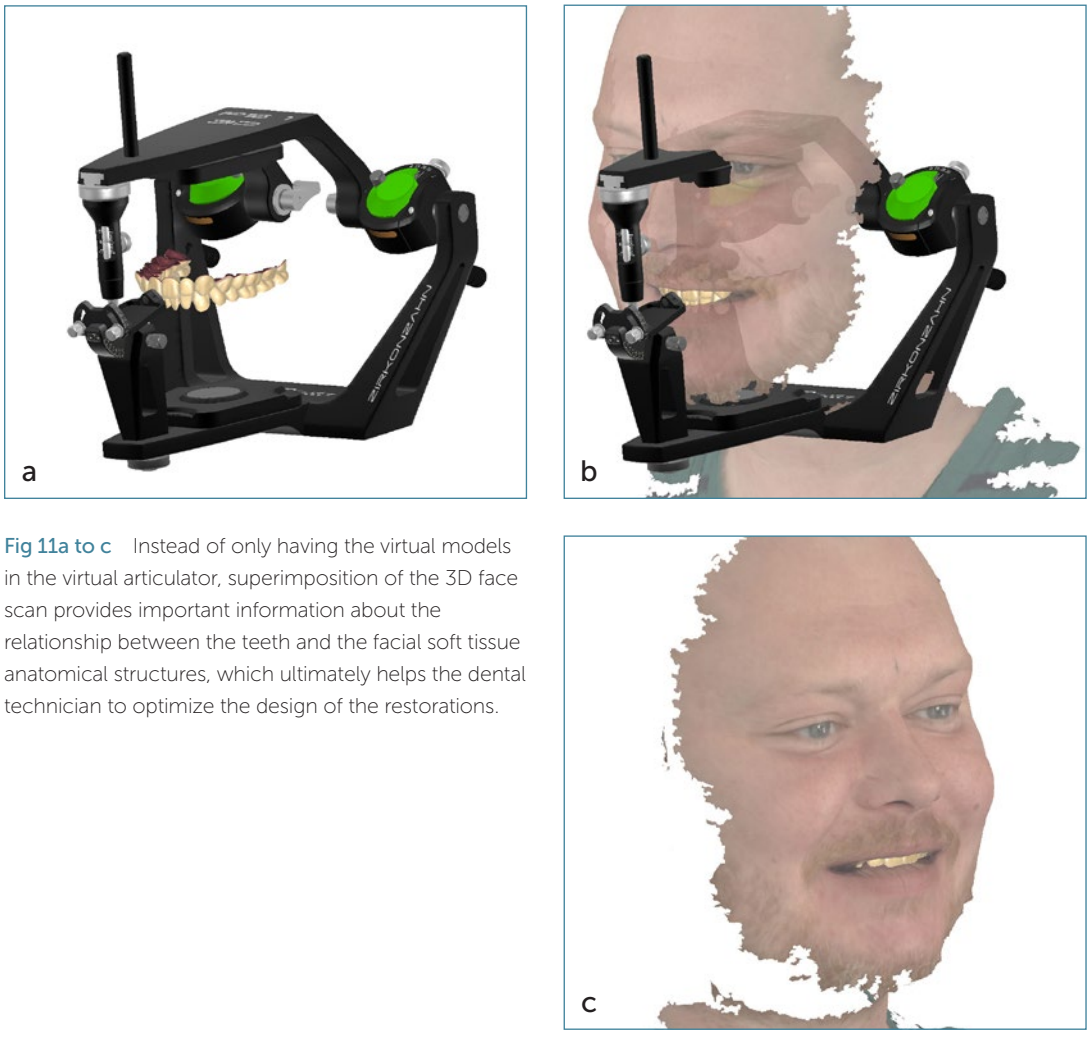


Fig 11a to c Instead of only having the virtual models in the virtual articulator, superimposition of the 3D face scan provides important information about the relationship between the teeth and the facial soft tissue anatomical structures, which ultimately helps the dental technician to optimize the design of the restorations.

a procedure in the anterior zone to ensure proper postsurgical soft tissue maturation and stability.[49-55]

In order to provide the dental technician with more information and to improve communication, a face scanner (Face Hunter; Zirkonzahn) was used to deliver information about the integration between the facial soft tissue and the teeth at different viewing positions. A registration of the jaw relationship with the face was performed with a registration fork, which utilizes software-specific markers that help to align the different data sets of the jaws (model scan) and face scans (Fig 11).

After the successful test drive of the manipulation of the VDO, the virtual design of the shell-type provisional restorations in both jaws was carried out. The provisional restorations were milled out of a PMMA block in a 5+1-axis milling machine (M5; Zirkonzahn), after which they were further refined and characterized manually by the dental technician. A centering device made of a reinforced acetate matrix with a rigid support (hard palate) was fabricated to position the provisional restorations accurately in the oral cavity (Fig 12). After tooth preparation and prior to the relining procedure, the provisional restorations were placed in the

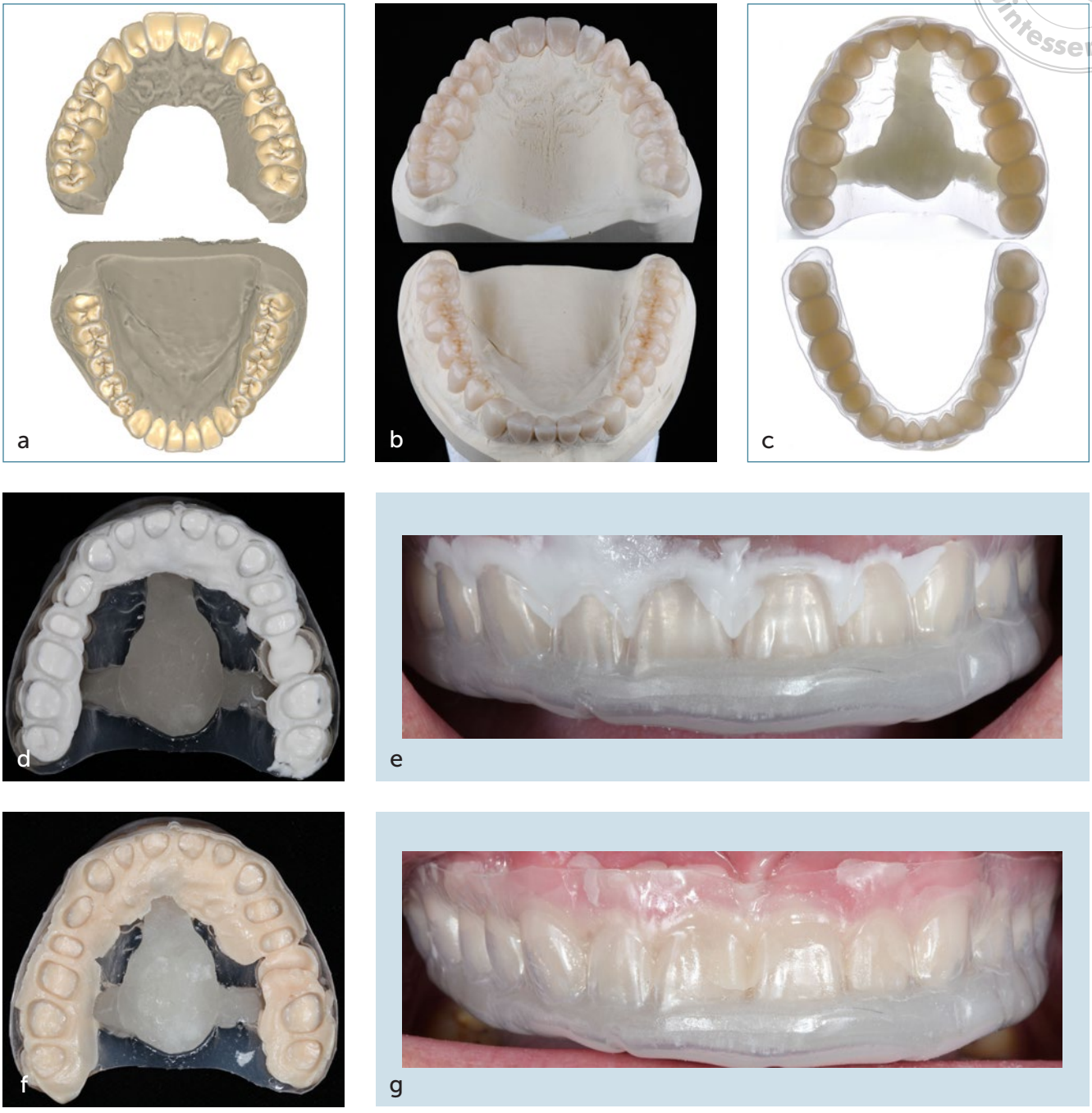


Fig 12a to g PMMA shell-type provisional restorations were milled for the maxillary and mandibular teeth. The centering device helped to secure an accurate position of the restorations along with the relining procedure in both jaws.

Fig 13a to d Delivered provisional restorations in both jaws. The correct registration and mounting procedure, along with the intraoral fitting procedure, is reflected in the accuracy of the resulting occlusal scheme. The esthetic outcome after delivery of the provisional restorations and its impact on the overall appearance of the patient was obvious. The amount of VDO manipulation introduced to achieve proper esthetics and facilitate sufficient material bulk thickness is shown.

centering device and filled with a silicone paste (Fit Checker; GC Dental). Then, with the help of the centering device, the restorations were placed on the prepared teeth to verify the fit on the anatomical landmarks (eg, the soft tissue of the hard palate and gingiva). The provisional restorations were then removed and checked for interferences showing through the silicone paste that might prevent the achievement of a proper fit during the relining procedure. After the elimination of interferences, the aforementioned procedure was repeated.

The next step was to perform the relining procedure using a PMMA resin-based material with the aid of the centering device. After the relining material had set, the relined provisional restorations were retained in the maxilla. In a similar manner to the maxilla, interferences were verified and eliminated in the provisional restorations of the mandible using a centering device. Then, the relining procedure for the mandibular provisional restorations was performed by closing in centric relation, while the properly fitted provisional restorations in the maxilla remained on the maxillary teeth to guide the procedure. Finally, the provisional restorations in both jaws were removed, finished, polished, and delivered using a temporary cement (Fig 13).

Three weeks after the delivery of the provisional restorations, the final impression was carried out with custom-made impression trays and polyether-based impression material (Impregum Penta DuoSoft; 3M ESPE). The master casts were poured and mounted with the aid of the PlaneFinder

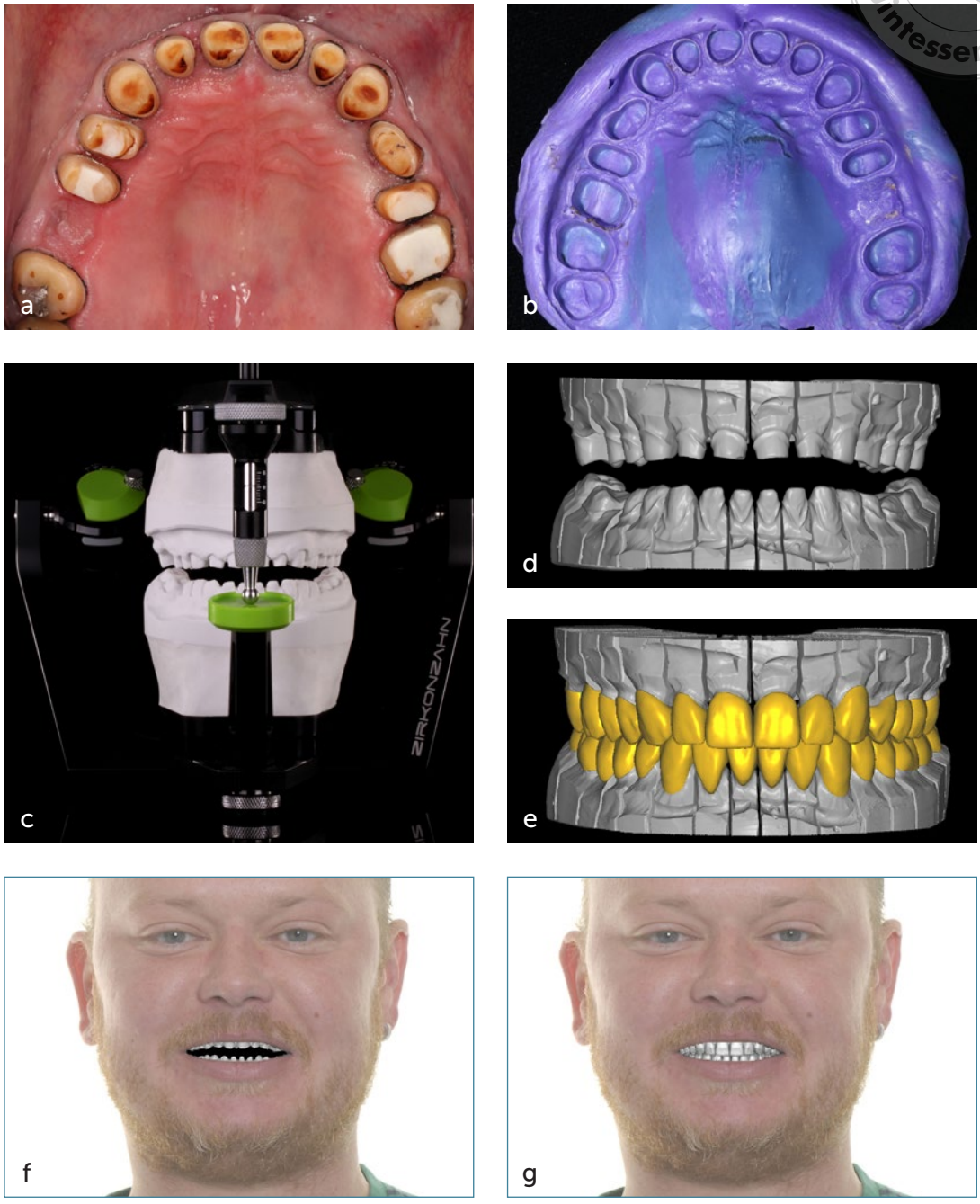


Fig 14a to g After the conventional impressions were performed and the casts were poured and mounted, the initial CAD took place. The 2D extraoral photographs were superimposed onto the 3D virtual models. Based on the configuration of the provisional restorations and the matching procedure, the dental technician was able to set the ideal length of the teeth. Further refinements were performed using matched 3D face scan data together with the 3D virtual models.

system. The casts and the maxillomandibular relationship were then digitized and virtually mounted, as previously explained. Following this, the CAD of the restorations was performed (Fig 14). Based on the virtual design, prototypes of the final restorations were milled out of a PMMA resin block and delivered to the patient for a period of at least 1 week. During this period, esthetics, phonetics, function, and comfort were evaluated, and the patient had ample time to self-test the design and provide feedback. Any necessary modifications were performed directly on the prototypes (Fig 15).

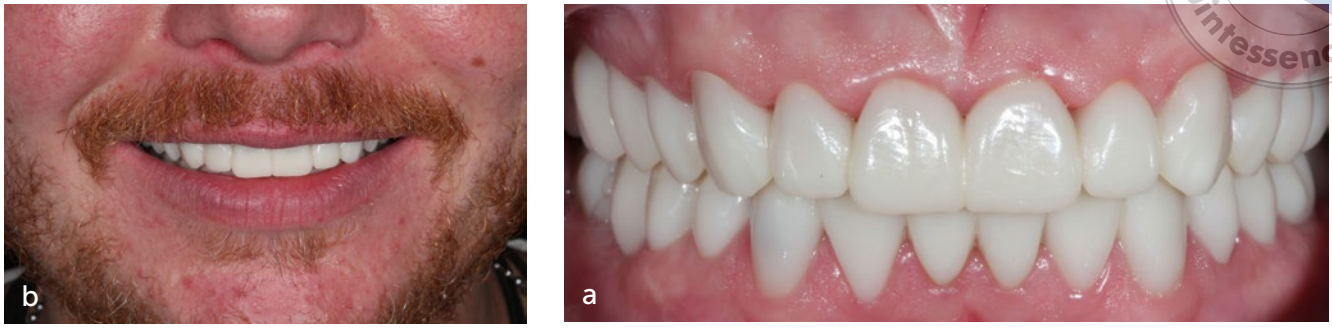


Fig15a and b Prototypes of the final restorations were used to test drive esthetics, phonetics, function, and comfort.

After modification, the prototypes were removed, scanned, and matched with the original design data to implement all the changes and finalize the CAD. The CAD data were then sent to the M5 milling machine to manufacture fully anatomical ceramic restorations out of a translucent zirconia material (Prettau Anterior; Zirkonzahn). The restorations were separated from the zirconia block and refinement procedures were performed manually. The restorations were then individually colored using dedicated coloring liquids (Colour Liquid Prettau Anterior Aquarell; Zirkonzahn). Further individualization was performed using a variety of stains to improve the esthetic outcome (ICE Zirkon 3D Stains; Zirkonzahn). After drying, the restorations were sintered to the fully sintered state in a furnace (Zirkonofen; Zirkonzahn). Finally, the restorations were colored, stained, sintered, and glazed (Fig 16).

The final restorations were tried-in and delivered using a self-curing luting composite (Multilink Automix; Ivoclar Vivadent) (Figs 17 and 18). To guarantee proper function, a canine-protected dynamic occlusion was implemented in the final restoration design (Fig 19). Additionally, a Michigan-type night guard was fabricated and delivered (see Fig 19) that served to distribute the occlusal loads equally and protect the restorations from uncontrolled damaging movements at night. The night guard also functioned as a diagnostic tool to detect and monitor the postdelivery course of parafunction (ie, bruxism). The patient was satisfied with the final outcome and was able to smile and interact socially with increased confidence (Fig 20).

Discussion

As the majority of excessively worn dentition cases necessitate the manipulation of the VDO, the authors emphasize that the rationale for such a treatment is not associated with improvement of masticatory function or the elimination of possible TMJ issues. As pointed out earlier, patients with worn dentition seldom experience issues with mastication, phonetics, or the TMJs.

The manipulation of the VDO necessitates comprehensive evaluation and charting to justify the rationale for treatment.[10,12,17,19] While there are different approaches and clinical steps for such a treatment, the authors recommend a noninvasive test drive of the manipulation as the first step before tooth preparation whenever more than 5 mm of interincisal manipulation is needed.[14,15,22] It is important to start by defining the length of the teeth by setting the incisal edge position of the maxillary

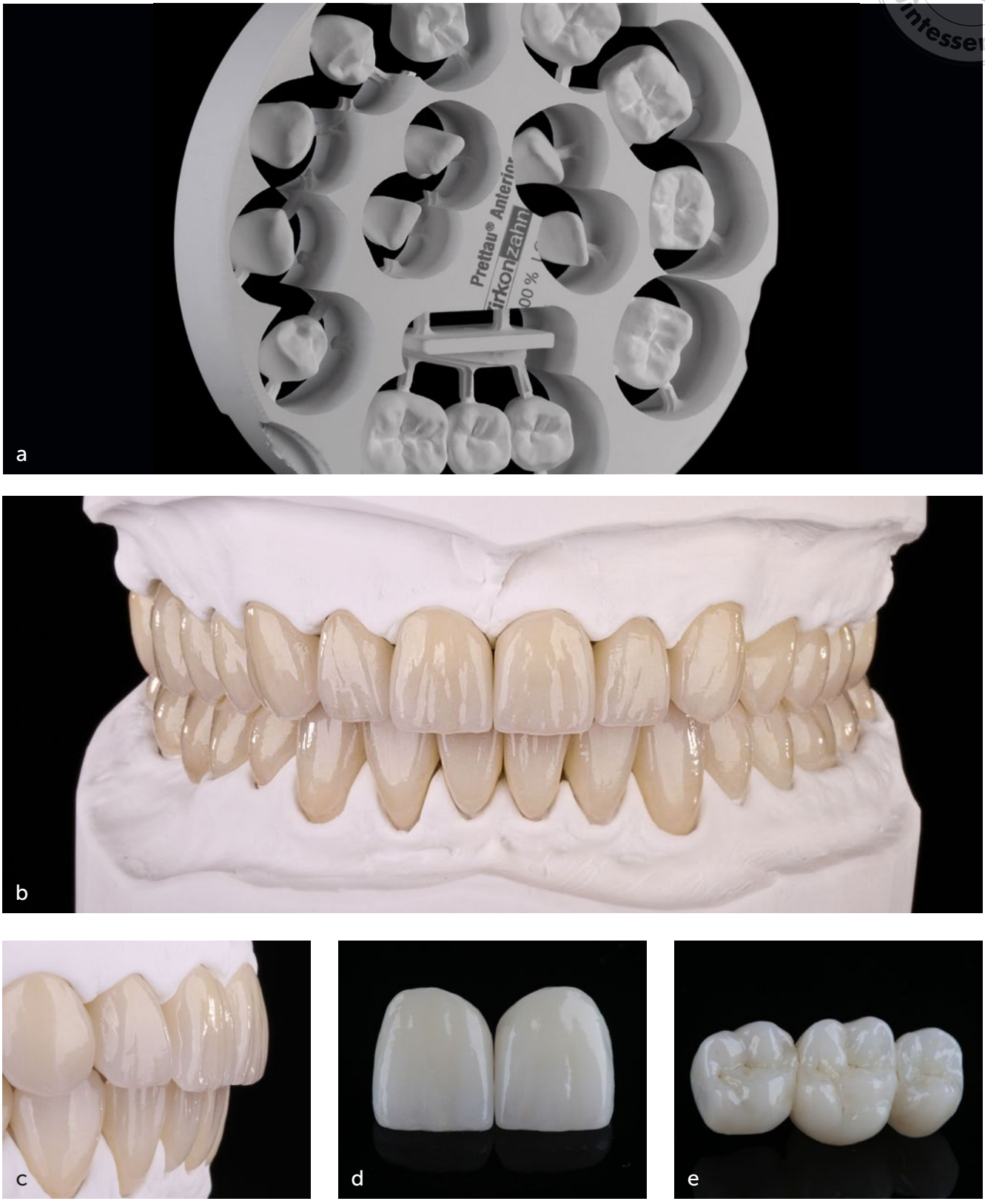


Fig 16a to e The final restorations were composed of milled fully anatomical translucent zirconia crowns and FPDs with individual characterization to mimic the natural tooth appearance.

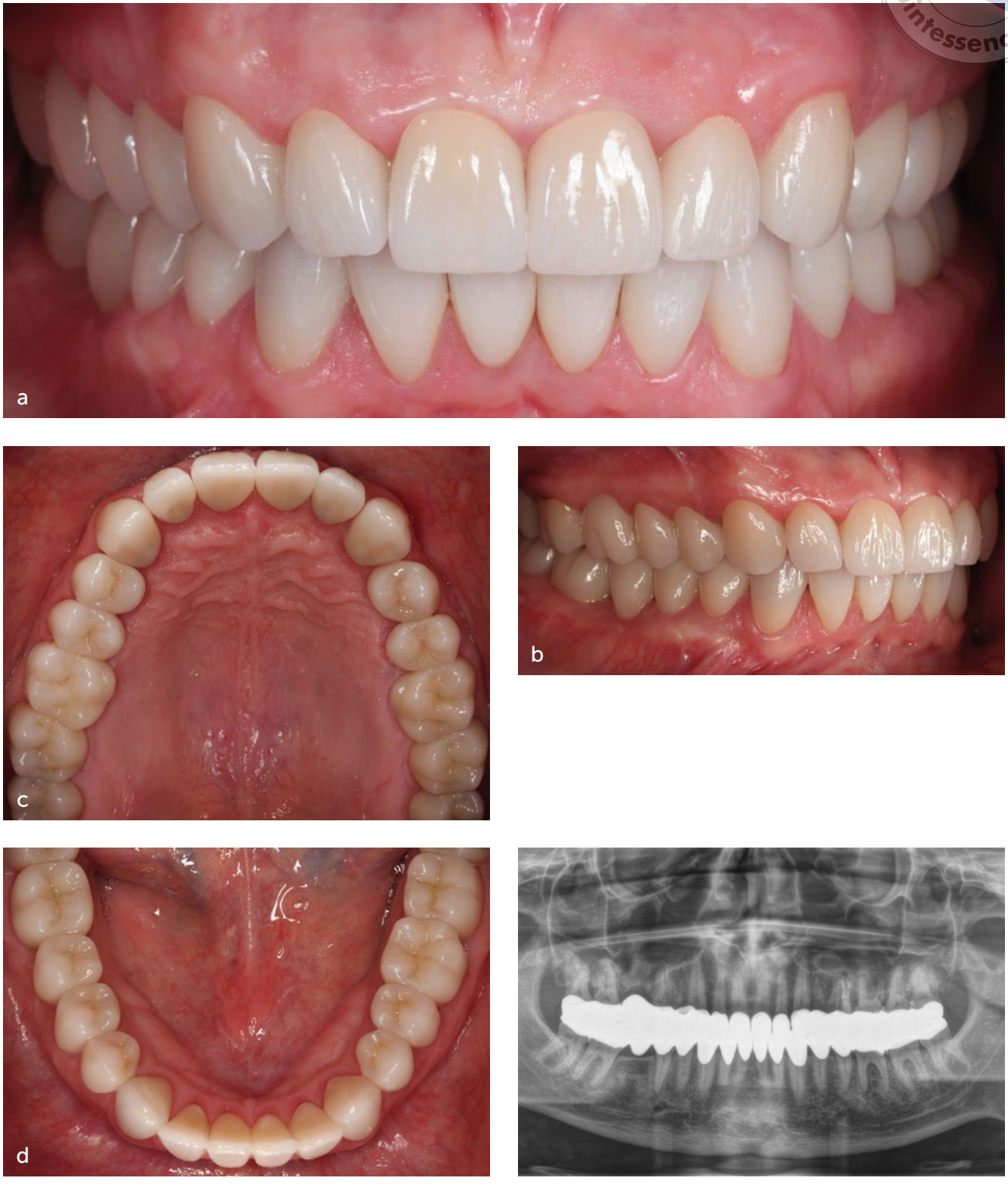


Fig 17a to d Anterior, vestibular, and occlusal images of the final restorations after delivery. The VDO, esthetics, and harmony were restored properly. The amount of VDO manipulation can be identified.

Fig 18 Final panoramic radiograph after the delivery of the restorations.

Fig 19a and b The new restorations implemented a canine-protected dynamic occlusion. The patient was instructed to wear the night guard every night.

Fig 20a and b Extraoral and smile line photographs after the delivery of the final restorations.

central incisors relevant to the position of the lower lip.[15] This procedure guides the full-mouth diagnostic wax-up, which is the key to setting the amount of VDO manipulation needed to accommodate the new tooth length.

Following this step, the occlusal splint can be manufactured accordingly. In addition to the homogenous distribution of occlusal contacts, the splint should incorporate canine-protected dynamic occlusion. Although no clear guidelines have been established to date, the authors recommend that the period of the test drive of the new VDO via the splint should be at least 4 weeks to allow for proper adaptation. This is necessary, as these removable appliances are not worn constantly every day. Also, the test drive allows for the evaluation of the reprogramming of the dynamics and pattern of parafunction.[22,56]

While most cases require a coronal lengthening of the teeth, a surgical crown lengthening is often needed to achieve a clinical crown height of at least 3 mm for proper retention in cases of extreme wear. For surgical crown lengthening, it is important to follow the guidelines for establishing a healthy biologic width without compromising the esthetic outcome (black triangle,

emergence profile irregularities) as well as to meet the restorative challenges (adhesive contraindications on exposed root surfaces).[49-55,57] An alternative method to crown lengthening is orthodontic extrusion. However, due to its long duration and the difficulty of performing it when multiple teeth are involved, this treatment option is not usually chosen by clinicians and patients.

The digital workflow provides numerous advantages over the conventional approach. These can be summarized as improved communication, better coordinated and more efficient treatment (ie, fewer appointments), and ultimately, more controlled and predictable outcomes. Despite its advantages, the implementation of the digital workflow for full-arch rehabilitations is still limited. Apart from initial investment costs and the duration of the learning curve, the limitations of use relate to several other factors, one of which is the limitations of the current technology. For example, the use of IOSs for full-arch digital impressions, when compared with conventional impressions, still does not result in sufficiently accurate data.[58-60] Available studies on the accuracy of IOSs for full-arch scans remain limited to a small number of devices. This means that the results cannot be generalized to all IOSs, and at the same time show unacceptable deviations. Workarounds that have been suggested to overcome full-arch scans is to segment the case, which is not a feasible option when it comes to ease of the treatment process. Even with a sufficiently accurate IOS, a further issue is how to mount the virtual models to include all planes and patient-relevant references. Here, inaccuracies in virtual occlusal contacts that do not represent a clinical reality are a further factor of concern.[61] Moreover, it is important to mention that IOSs implement the so-called advanced virtual articulation, which does not include important references for the rehabilitation such as occlusal plane, facial midline, horizontal (zero) plane, etc. Therefore, the use of physical casts mounted in a real articulator remains the method of choice in order to include patient-relevant planes and references. It can be argued that STL data from IOSs can be used to print models that can be used for the conventional mounting procedure. Nevertheless, 3D printing of full-mouth models still does not show sufficient accuracy.[62] Many clinicians use printed models not for verifying occlusal and proximal contacts, but only for holding the restorations. Therefore, for full-arch cases, the present authors believe that the most accurate method currently is to perform conventional impressions and produce conventional casts, which can be later digitized using a desktop scanner. The conventionally mounted casts can then be digitized using the individual virtual articulation method to transfer all patient-relevant references into the virtual space.[62]

While virtual articulated models facilitate better communication and ease of work for the dental technician, important information remains unavailable, namely, the relationship to the soft anatomical structures. Here, the dental technician can be provided with 2D photographs that can be superimposed onto the 3D virtual models. Most CAD software is capable of performing this matching procedure, which facilitates the determination of tooth display at rest or during smiling as well as the facial midline. Digital smile design features are known to use this approach. However, the superimposition of 2D photographs onto 3D virtual models is practically a combination between a plane and 3D data sets and lacks significant information about the anterior-posterior position as well as the inclination of the teeth. Therefore, this type of data superimposition can be considered as a limited improvement of communication. Clearly, it is better to superimpose 3D face scan data onto the 3D data of the model scan. In this way,

information about the anterior-posterior position and the inclination of teeth can be viewed and incorporated into the CAD. Although the available face scanners are static and do not capture mobility, mimics cannot be incorporated. Consequently, multiple face scans with different positions, such as mouth closed, social smile, extreme smile, etc, are required to incorporate more information for the CAD procedure. In addition, the current CAD software does not feature the so-called morphing function, meaning that facial soft tissue structures (lips) will not adapt according to the new tooth position in the CAD data. Lastly, knowledge is still limited regarding the accuracy of face scan data and that of the superimposition with model scan or intraoral scan data.[63,64]

Along with the improvement of CAM procedures, new restorative materials with improved physical and optical properties are being utilized. Currently, lithium disilicate or zirconia-based ceramics are the most widely used materials to manufacture ceramic restorations. As mentioned earlier, while the material selection remains based mainly on the clinician's preference, the current trend advocates for the use of monolithic restorations. To further enhance esthetics, veneering ceramics limited to the facial aspect of the restorations can be considered. For zirconia-based materials, the authors recommend not to extend the veneering ceramic to the incisal edge to avoid loads that may lead to chip off. Rather, the design of the restoration should facilitate protection of the incisal edge with the zirconia material. While the traditional opaque zirconia materials may jeopardize the esthetic outcome at the incisal edge area, the new generation of translucent zirconia materials shows improved optical properties and enhanced esthetics.

Regardless of the restorative material used, the wear resistance property as well as the wear of the antagonist teeth, especially with patients who experience parafunction, remains an important criterion for selection. While the microstructure of the material has a smaller effect, surface roughness has the greatest impact on the wear of both the material and the antagonist teeth.[65] Regular grinding procedures are known to produce an average surface roughness that easily exceeds 1 µm, whereas that of polished and/or glazed ceramic surfaces is as low as 0.06 to 0.2 µm.[65-67] Hence, intraoral occlusal adjustments of ceramic restorations should always be avoided. This can be achieved through the use of prototypes to test the design of the final restorations and to make any necessary adjustments before finalizing the design and manufacturing of the restorations. If needed, however, occlusal adjustments should only be performed with fine-grain diamond burs and must be followed by a thorough polishing sequence.

Conclusion

The implementation of the digital workflow aims to provide a faster and more predictable treatment. Despite the advances in technology, a combination between digital and conventional procedures is still needed for the treatment of complex cases. For excessive wear cases, the workflow described here enhances communication among the treatment team and the patient and ensures a predictable outcome, provided that the team is well versed in all the elements related to the technologies and the workflow.

[Authors to please check red author names of specific chapter listed, unless this is correct and it is the same as the book editors.]

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