A Fully Digital Workflow to Achieve Predictable Esthetic and Functional Outcomes: A Case Series

Hongseok An, DDS, MSD¹
Christine Marie Fischer, DDS²
Stephanie Elizabeth Miller, DDS³
Kinan Malik Al-Bitar, DDS, MS⁴
Paul Gerard Luepke, DDS, MS⁵

Various types of digital dental technologies have been successfully implemented as a part of dental treatment to improve predictability and efficiency of dental procedures. Virtual smile design can be used to enhance predictability from an esthetic perspective, and the virtual articulator can be a useful tool to create a desired occlusal scheme. This case series describes a fully digital workflow that can predictably achieve desired esthetic and functional outcomes. The proposed protocol also includes other currently available digital technologies, such as intraoral scanning, computer-aided design, milling, and 3D printing. Three clinical cases are presented to describe the workflow in detail. Int J Periodontics Restorative Dent 2022;42:165–174. doi: 10.11607/prd.5328

Because restoring proper function and esthetics is the primary goal when providing dental care to patients with damaged dentition, both esthetics and occlusion should be considered essential parts of treatment planning. Treating only occlusion or esthetics without considering the other aspect treats only half the patient.¹

Creating the correct individual tooth size and establishing a harmonious positional relationship between teeth and other facial components have been emphasized as critical parts of treatment planning to achieve desired esthetic outcomes.²,³ In particular, determining the position, inclination, and gingival levels of maxillary anterior teeth should be some of the first steps of comprehensive treatment planning, because the esthetic outcome could be compromised or even disastrous if a treatment plan does not begin with a clear view of its esthetic impact.⁴,⁵ Various types of computer-aided design (CAD) systems are available for virtual smile design. Virtual smile design helps clinicians make a treatment plan with higher predictability by allowing them to visualize the esthetic impact of restorative and surgical treatments before they begin the treatment procedures.⁶

Traditionally, a dental articulator has been used to create a desired
occlusal scheme for prosthodontic reconstructions. Recently, as digital dental technologies are used for more extensive prosthodontic treatment, the role of a virtual articulator has also become very important. A dynamic virtual articulator that is capable of replicating the function of mechanical articulators is available for most current dental designs.\(^7\)

This case series demonstrates a digital workflow to generate excellent and predictable esthetic and functional outcomes. Three clinical cases are presented to elaborate on the application of digital technologies at each step.

### Treatment Protocol

**Step 1: Data Collection**

Diagnostic digital impressions of maxillary and mandibular arches were acquired by using an intraoral scanner (Trios 3, 3Shape; or 3M True Definition, 3M ESPE). Facial and close-up photos with smile and retracted lips were taken. The digital impressions and facial photos were imported to dental CAD software (Dental System 2019, 3Shape). Four to six common reference points were selected on the maxillary digital impression and the facial photos. The maxillary digital impression and the facial photos were then superimposed using the selected reference points. Location of the reference points were adjusted until the outline of visible teeth in the digital impression and the facial photos matched with a good accuracy.

**Step 2: Virtual Design**

Maxillary teeth were virtually designed on the digital impression to achieve the ideal tooth size, proportion, and shape. Facial esthetics of the virtual design were evaluated using the superimposed facial photos and modified to create a harmonious appearance in relation to the face and the lips. The digital impressions were virtually mounted in an average position. Condylar element settings of the virtual articulator were programmed using the following average values: 8-degree Bennett angle, 30-degree horizontal condylar inclination, 0-mm immediate mandibular lateral translation, and 0-degree incisal table inclination.\(^8\)–\(^11\) The maxillary and mandibular teeth were designed according to the occlusal scheme planned for the case.

If gingivectomy or surgical crown lengthening was planned, a 1.0- to 1.5-mm–thick surgical guide was designed by tracing the gingival margins of the proposed design. The surgical guide was 3D-printed (Objet500 Connex3). A thermoplastic vacuum-forming machine (Biostar, Scheu Dental) was used on the 3D-printed model to fabricate tooth reduction guides. Small holes were drilled using a no. 4 round bur on the buccal and lingual surfaces of teeth to measure the amount of reduction using a periodontal probe. When desired, a putty matrix (Aquasil Easy Mix Putty, Dentsply Sirona) for intraoral mock-up was created by copying the 3D-printed model.

**Step 3: Fabrication of Provisional Shells and Tooth Reduction Guides**

Teeth were virtually prepared in the CAD software, and a 0.5-mm–thick shell was designed and milled for the provisional restoration using the five-axis dental milling machine (DWX-52D, Roland DGA) and high-density polymethyl methacrylate (PMMA; TruTemp, 3DBioCAD). Maxillary and mandibular models of designed restorations were 3D-printed (Objet500 Connex3). The premade putty matrix and the injectable resin (Integrity Temporary Crown and Bridge Material, Dentsply Sirona) were used to create a direct intraoral mock-up. The mock-up was evaluated by the patients and the dentists. If a mock-up was modified to improve patient satisfaction, another digital impression of the mock-up was made to be used as a guide for final restoration design. Teeth were prepared for all ceramic crowns under proper anesthesia. The premade reduction guide was used to verify a proper reduction of tooth structure. Maxillary and mandibular digital impressions and buccal bite scans were made using an intraoral scanner.
The premade provisional shell was adjusted until completely seated and was relined using autopolymerizing polyethyl methacrylate (Snap, Parkell). The provisional restorations were trimmed, polished, and delivered using the noneugenol temporary luting agent (Ultra-Temp, UltraDent).

**Step 5: Design and Fabrication of Definitive Restorations**

The digital impressions were mounted on the virtual articulator using the average settings described above. The initial diagnostic design was used as the design guide when no adjustments were made to the initial diagnostic design. If a significant adjustment was made either to the intraoral mock-up or the provisional restoration, a digital impression of the adjusted mock-up or provisional restoration was made and used as the design guide. Definitive restorations were designed by copying the design guide. Only minor modifications were made to perfect esthetic and occlusion. Models with individual dies were 3D-printed. Definitive restorations were manufactured using lithium disilicate glass ceramic (IPS e.max CAD, Ivoclar Vivadent) and the 4-axis milling machine (DWX-4W, Roland DGA). Manual contouring, crystallization, staining, and glazing were performed according to the manufacturer’s recommendation. Facial cut-back and ceramic layering (IPS e.max Ceram, Ivoclar Vivadent) were performed when desired.

**Step 6: Delivery of Definitive Restorations**

After try-in and occlusal adjustments, the intaglio surface of the restorations was treated with hydrofluoric acid (IPS Ceramic Etching Gel, Ivoclar Vivadent) and silane (Monobond Plus, Ivoclar Vivadent). The dual-cure resin cement (Multi-link Automix, Ivoclar Vivadent) was used for cementation of the ceramic crowns.

**Case Reports**

**Case 1**

A 76-year-old man presented with chief concerns of broken anterior teeth, an unesthetic smile, and generalized sensitivity (Fig 1). The patient had a history of gastroesophageal reflux disease, and clinical examination revealed multiple lesions consistent with tooth damage from acid erosion. He had a Class I canine relationship, with an end-to-end anterior relationship due to incisal wear, and compensatory supra-eruption. Potential loss of vertical dimension was observed, and the incisal display at rest and during smile was significantly decreased due to short clinical crowns. After discussing several treatment options, the patient elected to restore a premolar occlusion. Full coverage restorations on maxillary anterior teeth, maxillary premolars, and mandibular premolars were planned, as well as composite resin restorations on mandibular incisors.

All collected images were imported to the CAD software, and the initial diagnostic design was made (Figs 2 and 3). Shallow canine guidance was designed using the virtual articulator. The provisional shell and the reduction guide were fabricated based on the diagnostic design (Fig 4).
Teeth were prepared for all ceramic crowns, and provisional restorations were fabricated. Mandibular incisors were restored with composite resin to create even occlusal contacts. Maxillary and mandibular digital impressions and bite scans were made. The provisional restorations were delivered and scanned to serve as a design guide.

The definitive restorations were designed using the scanned provisional restorations as a design guide (Fig 5). Monolithic lithium disilicate ceramic restorations were fabricated and inserted. The patient was satisfied with the result (Fig 6).

Case 2

A 29-year-old woman presented with a chief concern that her anterior teeth were very sensitive to cold (Fig 7). She had been diagnosed with Sjögren’s syndrome and suffered from dry mouth. Direct
Composite resin restorations were present on the facial surfaces of her maxillary and mandibular anterior teeth. A significant amount of tooth structure loss and dentin exposure was observed on the lingual surfaces of her maxillary and mandibular anterior teeth. She had an Angle Class I occlusal relationship with an anterior open bite. She did not have a proper anterior guidance, and eccentric mandibular movements were guided only by her second molars. The wear patterns that are consistent with acid erosion were found on her anterior and posterior teeth. Signs of attrition were also found on her second molars. The definitive treatment plan included fluoride therapy, full coverage restorations for anterior teeth and first premolars of both arches, and direct composite restorations for second premolars and molars.

The diagnostic virtual design was made using the digital impression and facial photos (Fig 8). The provisional shell and tooth reduction guide were fabricated (Fig 9). Teeth were prepared for all ceramic crowns, and provisional restorations were fabricated by relining the shell (Figs 10 and 11). Digital impressions were made using a single cord technique.

After using the provisional restorations for 2 months to test the new occlusal scheme, the provisional restorations were scanned again to be used as a design guide. Definitive restorations were designed by copying the provisional restorations (Fig 12). Monolithic lithium disilicate ceramic crowns were fabricated and inserted (Fig 13). Hypersensitivity on the anterior teeth was resolved, and the patient was satisfied with the result.

**Fig 5** The digital impression of prepared teeth was merged with the scanned image of provisional restorations, and the definitive restorations were designed by copying the provisional restoration.

**Fig 6** Clinical views at the 6-month follow-up. (a) Facial view. (b) Smile.
Fig 7 Case 2. Initial presentation.

Fig 8 Diagnostic design. (a) The facial photo with the retracted lips is a useful tool for leveling an occlusal plane. The full smile photo was also used to determine the incisal plane. Maxillary incisors were lengthened 1 to 2 mm to have ideal proportions and to make their incisal edges parallel to the lower lip. (b) Eccentric movements (protrusion and laterotrusion) were evaluated on the virtual articulator. Mandibular incisors were also lengthened to create ideal anterior guidance. Shallow canine guidance was created using the virtual articulator.

Fig 9 Milled polymethyl methacrylate (PMMA) provisional shells (left), the 3D-printed model (top right), and the tooth reduction guide (bottom right).
Case 3

A 34-year-old woman presented with a chief concern of short teeth and interproximal gaps (Fig 14). Her anterior teeth were short, and a significant loss of tooth structure was observed. The broad enamel concavities on the facial surfaces indicated that this was most likely due to acid erosion.\textsuperscript{12,13} The palatal surface of the maxillary anterior teeth also had a considerable amount of wear from erosion and attrition. Her posterior teeth and lower incisors were intact. She had an Angle Class II canine and molar relationship with a 6-mm vertical and horizontal overlap. She had excessive gingival display during smiling and was diagnosed as altered passive eruption. Crown lengthening and full coverage restorations for six maxillary anterior teeth were planned.

Digital impressions and facial photos were taken, and six anterior teeth were virtually designed. The crown lengthening guide was designed and 3D-printed based on the diagnostic design (Fig 15) and...
served as a guide during the crown-lengthening surgery (Fig 16).

After 12 weeks of healing, the data collection and virtual design procedures were repeated to fabricate the provisional shell and tooth reduction guide (Fig 17). After making the intraoral mock-up, the patient approved the design (Fig 18). Six maxillary anterior teeth were prepared for all ceramic crowns, and the provisional restorations were made by relining the shell. Digital impressions were made, and the bite scan was made at the maximum intercuspal position.

Fig 15 Diagnostic design (blue) and crown lengthening guide (orange). Maxillary anterior teeth were lengthened both gingivally and incisally to achieve a harmonious esthetic. The crown lengthening guide was designed based on the diagnostic design.

Fig 16 The 3D-printed surgical guide was used during the crown lengthening surgery. Osseous reduction on the left side was completed first.

Fig 17 The virtual articulator was used to produce a planned occlusal scheme. The articulator was programmed using average values.

Fig 18 An intraoral mock-up was performed by copying the 3D-printed model of the proposed design.
Definitive restorations were made using the diagnostic design as a design guide. Bilayered lithium disilicate ceramic crowns were fabricated and inserted with minor adjustments (Fig 19). The patient was satisfied with the result.

Discussion

In earlier years, virtual smile design used line drawings and a virtual caliper on facial photos. Then, diagnostic wax-up was necessary to transfer the proposed design to a physical model. This may cause some information loss, as it relies on the clinician's ability to reproduce the 3D objects based on drawings made on the 2D photos. As recent virtual design software allows direct superimposition of digital impressions to 2D facial photos or 3D facial scans, it is possible to transfer the proposed design to the 3D-printed model with greater precision. In the present case series, digital impressions were superimposed to 2D facial photos for virtual smile design. The limitation of this approach is that it allows evaluation of facial esthetics only from the angle that the photos were taken. However, the cases presented herein show that virtual smile design using 2D photos still can provide an excellent prediction of the final result.

For all patients in the present case series, the planned occlusal scheme was successfully reproduced using the virtual articulator. The digital impressions were mounted in an average position, and the condylar components of the virtual articulator were programmed using the average values. Although accuracy of the virtual articulator is comparable to that of mechanical articulators, some occlusal errors can be generated when using the average settings. If a considerable amount of occlusal adjustment is expected, the 3D-printed models can be mounted on a mechanical articulator using traditional facebow transfer and interocclusal records for laboratory occlusal adjustment prior to the delivery appointment.

The guides for clinical procedures can be fabricated in various ways. In the present case series, the tooth reduction guides and the crown lengthening guide were fabricated using 3D printing and thermoplastic templates. The provisional shells were also fabricated to precisely transfer the predetermined design to the provisional restorations. Using proper guides helps clinicians perform clinical procedures precisely based on the predetermined design, and they play a critical role in transferring the predetermined design to the final result.

Conclusions

The use of the protocol presented in this case series will help clinicians predictably achieve optimal esthetic and functional outcomes. The virtual diagnostic procedures can be used to make a treatment plan and diagnostic design. Prefabricated guides, such as a tooth reduction guide or a crown-lengthening guide, can be made based on the diagnostic design and used to precisely reproduce the guide during clinical procedures.
Acknowledgments

The authors declare no conflicts of interest.

References