STL subtraction:

A new method for digital treatment planning

When combined with traditional treatment planning methods, digital tools can offer a more conservative approach and more predictable final results[3, 6]. The merging of 2D designs and 3D digital models allows prosthetic constructions to be completed digitally[1], and scanned models can now be transferred to the final design of the restoration[17]. Detailed functional analysis of dentition using provisionals to change or adapt the smile design is also needed[4, 16]. The success of an aesthetic treatment relies on good planning and screening of patients; this is the case whether it is a crown-lengthening procedure or implant treatment. Optimal aesthetic results require a suitable smile design which fulfils the patient's expectations[10, 11].

When planning a crown-lengthening procedure, the volume of soft and hard tissues which needs to be removed should be carefully calculated. 3D surgical guides can assist with this, allowing us to visualise and measure the alveolar bone; plan the positions of prosthetic designs; and produce wax-ups and mock-ups inside the patient's mouth.

Initially, implant therapy was surgically-led and implants were placed according to the amount of available bone which was detected using traditional radiography. This approach often led to incorrect positioning of prostheses because implants were placed in the wrong 3D position. The consensus today is that the starting point for treatment planning should be the final design of the prosthesis, and the use of digitally planned surgical guides is common.

This paper describes a fully digital protocol which allows clinicians to plan, visualise, and functionally test designs, enabling the design of digital surgical guides and provisional constructions for complex aesthetic cases before irreversible dental procedures are carried out.

Material and methods

For this prospective study, patients requiring complex aesthetic therapy (including crown-lengthening and/or implant treatment) were recruited. Our procedure involved surgical guides using digital subtraction. Patients were selected at random, although the following groups were excluded: those with medical conditions which could compromise treatment results; pregnant women; anyone with a drug addiction or strong smoking habit; anyone suffering from a mental disorder; or anyone currently undergoing chemotherapy. All patients signed a declaration of informed consent. The treatment planning protocol consisted of two stages: 2D digital planning and 3D digital planning.

2D digital planning

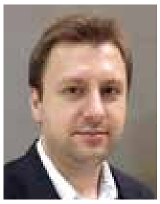
We used VisagiSMile software to create 2D digital designs of restorations which reflected patients' requests and expectations[3, 6, 15]. The 2D design was used as a guideline for creating a diagnostic mock-up of the patient's mouth. This was done with the edges of the central incisors aligned.

Two photographs are required to create designs with VisagiSMile: one of the patient's full face with a forced smile showing their dentition, and another of the upper jaw with lips retracted against a contrasting black background. These were captured, and patients were filmed while going from resting to smiling. Patients were also asked to discuss their expectations and concerns about the aesthetic outcome.

VisagiSMile employs facial analysis and a short interview to gauge the patient's personality type and calculate the main parameters of an individual's smile frame. Various features are measured, including: the incisal projection; tooth inclination; dominance; and shape[8, 9]. Patients' preferences regarding the design are taken into consideration.

Once the position of the incisal edge of the central incisors was defined, we used the 2D design to create new tooth proportions, extending the length of the tooth in coronary or apical directions with periodontal surgery. By analysing the position of the incisal edge of the central incisors in the patient's picture we could define the new position (Figure 1).

The proportions provided by the software are highly personalised and optimised for each case. Final designs can be exported as PDF, PNG or STL files containing detailed information of size, correlation, inclination and shapes of teeth, as well as the whole composition. A diagnostic wax-up was created based on the treatment plan provided by the software's



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Top; Figure 2: Position of the incisal edge superimposed with 2D VisagiSMile design – initial situation.
Left; Figure 3: Position of the incisal edge superimposed with 2D VisagiSMile design – mock-up.

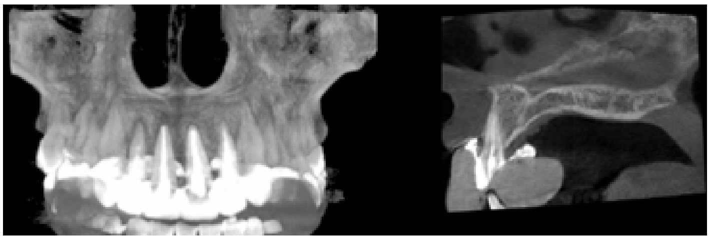

Figure 5: CBCT of the patient in front view and sagittal view before treatment.

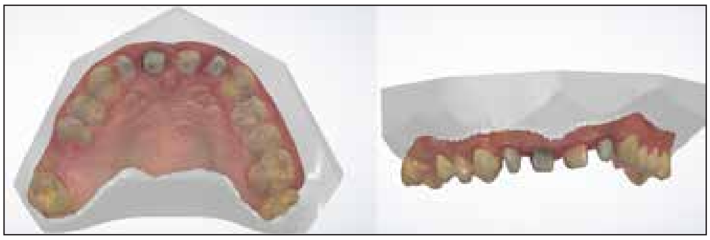

Figure 6: TRIOS 3Shape scans of initial situation, occlusal and front view.

digital proposal. Based on this, the first additive composite mock-up was made. Prototypes were made on wax models using silicone keys with high durability. Bis-acryl self-cured composite was applied to the silicone keys and the design was recreated in the mouth using a composite mask over the patient's natural, non-prepped teeth (Figures 2 and 3).

New full-face and intraoral pictures were taken; any changes were discussed with the patient by comparing the relevant before and after mock-up pictures[7] (Figure 4). Once the patient had given consent, the treatment plan was finalised[7].

Conventional crown-lengthening approaches include manufacturing the surgical guide from thermal vacuum adapted film or silicon. The level of the alveolar bone is measured by sounding and mapping[2, 13]. However, these methods generally lack geometrical accuracy and 3D buccolingual data. Therefore, innovative 3D studies are necessary to allow visualisation and measurement of the alveolar bone and position-planning for future prosthetics. The use of conventional impression and model materials is considered one of the main reasons for differences between planned and achieved positions of implants and surgical guides[2].

Surgical guides can be made with CAD/CAM technology by using 3D images from CBCT scans and 3D printing. Treatment planning with surgical guides allows prosthetic construction or repair to be carried out in the patient's mouth immediately after surgery.

3D digital planning

We performed CBCT (ProMax 3D Mid, Planmeca) with contrast and resolution of 200 microns along with 3D intraoral scanning of the initial situation. Using data from these scans we created a design in the patient's mouth. Studies on the use of intraoral scanners in the production of surgical guides are limited and so it is our hope that this research will contribute to a greater understanding of their use/advantages[5] (Figures 5–7).

3Shape scans (with and without crowns) were processed and converted into STL files by Ortho Analyzer software and imported using SimPlant Pro (Materialise NV) (Figure 8). The intraoral images were superimposed in all three planes along the contours of the CBCT model.

All models were imported into CAD 3-matic (Materialise NV) software. The highly detailed intraoral images allowed exact repositioning on the CBCT model. Repositioning was done along the contours of the STL files over the direct outlines of the same structures (Figure 9).

Two types of digital subtraction were performed: first, a 3D intraoral model was subtracted from the 3D model without crowns. This created a 'shell' STL model of the crowns (Figure 10). The STL model of the CBCT scan was then united with the scanned 3D model without crowns (Figure 11). Second, the shell model was subtracted from the united model.

The results are either positive or negative. When the residual amount of subtraction is from intraoral scanner values, the results are negative; in cases where the volume of the residual subtraction is part of the CBCT it is a positive value (Figure 12).

Comparing the results of the subtraction allows us to estimate the difference between the root surfaces and crowns. The visual definition of the residual volume of the subtraction allows the identification of the measured areas.

Figure 13 shows the visualisation of the ideal preparation of the teeth so that the veneers can lie flat on the root surface.

Digital planning allows us to create stereolithographic (SLA) printer guides to perform the gingivectomy; osteotomy; selective tooth preparation; and the printing and fixing of the temporary veneers in one clinical procedure.

We converted the file into an STL open format. The final prosthetic was milled using CAD/CAM technology with biocompatible acrylic material and completed by manually adding details and effects (Figures 14–16).

Detailed functional analyses of the dentition were made with diagnostic provisional constructions. Occlusal relationships between both jaws were verified and occlusal contacts were adjusted where necessary (Figure 17).

Conclusion

The proposed methodology improves diagnosis, digital planning and the visualisation of created designs. It also provides completely digital surgical guides and provisional constructions for complex aesthetic cases in one clinical step.

Figure 17: Functionally adjusted provisional 3 days after surgery.

Figure 9: STL file repositioned over CBCT model along tooth outlines.

Figure 12: United model combined with shell STL model.

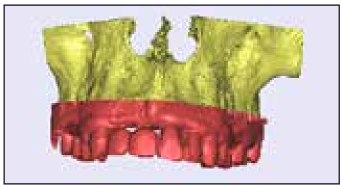

Figure 19.1: STL model of the CBCT united with 3D scanned model.

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