Computer-controlled implantology: Digital workflow facilitates resource-optimised treatment

**Authors** Uli Hauschild, Italy, Dr Albert van Hove, Monaco, Dr Sébastien Rousset, France & Dr Dominik Muylaert, Belgium

The success of dental implant reconstruction depends upon decisions made throughout the treatment process. The patient’s initial situation must be correctly assessed, with full consideration given to all the existing oral structures, including the teeth, bones and soft tissue. The time required for various treatment alternatives must be carefully weighed; time is a resource crucial to the comfort and well-being of the patient and an important cost factor for the whole implant team.

Advancements in computer-based technology, including 3-D imaging and advanced software applications, have made it possible to streamline and optimise the implant treatment workflow in ways that previously were unimaginable. The following comprehensive case illustrates the results that can be achieved when adopting a completely digital approach to treatment planning, implant placement and immediate seating of an aesthetic full maxillary restoration. This approach combines processes that until now have been independent, enabling successful low-pain (morbidity) delivery of an exceptional result.

**Case presentation**

A 65-year-old male patient presented with advanced periodontal disease. All his remaining maxillary teeth were loose (Figs. 1–5). The patient...
explained that he wanted a quick solution, with the caveat that he did not wish to be toothless at any time or to leave the practice with an obvious temporary restoration.

A CBCT scan was obtained, along with a precise impression and bite registration. No major treatment was planned for the mandible. Owing to the fact that all the maxillary teeth required extraction, a treatment plan incorporating immediate seating of a full arch restoration was developed, for which the patient provided informed consent. The laboratory fabricated a maxillary master cast along with a duplicate (Fig. 6), and the teeth were carefully removed preoperatively from the duplicate cast. The objective was to create an impression of aesthetic natural dentition that would not significantly change the patient’s appearance.

A set-up was fabricated, starting in one quadrant and using the other as a guide (Figs. 7 & 8). The second side was then completed. The new teeth were placed in ideal positions, and only minor aesthetic alterations were made. On a conventional denture set-up, the interdental spaces are filled with gingiva-coloured acrylic. In this case, however, the
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... teeth were widened to create more space for the implant abutments. The completed set-up (Fig. 9) was crucial in demonstrating the potential final results and determining the position of the implants. The parameters specified here must not be changed to accommodate both the surgical and restorative phases of treatment. The set-up is therefore also known as the "point of no return". These steps represented the analogue or conventional method of creating the diagnostic wax-up.

The completed set-up was sprayed to facilitate digitalisation of the cast utilising an open laboratory scanner (SinergiaSCAN, Nobil-Metal; Figs. 10–13). The model of the patient's initial oral condition and the edentulous cast on which the set-up was created were both scanned for incorporation into the implant planning software. The CBCT scan DICOM data was first imported into the SIMPLANT interactive treatment planning application (DENTSPLY Implants). The digital workflow continued with the import of the virtual STL files of the digitised stone models (Figs. 14a–c). The STL 3-D volumes were then combined with the patient's CBCT images in the SIMPLANT software, using the Optical Scan module (Fig. 16). The separate datasets are accurately superimposed or combined to allow for improved diagnostics, as they can be easily manipulated by the software. The surface detail of the digitised stone casts and wax-up is far superior to the surface detail of the CBCT scan image.

Using the interactive implant treatment planning module, eight implants were simulated in the patient's bone, each with a virtually elongated axis that helped demonstrate parallel positioning in relation to the proposed restoration as represented by the diagnostic wax-up. In order to achieve the desired surgical and restorative results, various technical aspects must be considered. The length and width of the implants in the bony receptor sites must be sufficient for implant stabilisation and each implant's screw access channel should ideally end in the middle of the planned tooth for a screw-retained prosthetic design (Figs. 16–22). Figures 23 to 26 show the patient's jaw before and after tooth extraction, along with the prosthetic design and the axis projection of the simulated implants.

Owing to the number of extractions in this case, the surgeon opted for a bone-supported surgical guide. Using specific software segmen-
tation, the teeth can be virtually removed from the 3-D reconstructed maxillary arch (Fig. 24). The ability to combine digital datasets allows for unparalleled diagnostic interaction, providing state-of-the-art preoperative assessment of the virtually placed implants, abutments, gingiva and bone. Once the surgeon was satisfied with the virtual plan for the implants, the software was directed to fabricate the simulated bone-supported surgical guide (Fig. 27). The data was then sent via the Internet for stereolithographic (rapid-prototyping) fabrication of the resin surgical guide (Fig. 30). The implant-specific SIMPLANT SAFE surgical guide incorporated drilling sleeves to match the manufacturer’s drilling sequence (Fig. 30). In addition, a 3-D printed model of the situation after implant placement was fabricated for use as a control model during manufacture of the temporary restoration. This optional step provided additional confidence in the accuracy of the temporary restoration. However, it is possible to make a temporary restoration using digital data exclusively (Figs. 33–36).

**Fabrication of the temporary restoration**

The digital workflow as described helps to facilitate the fabrication of a temporary restoration that must fit immediately and accurately after implant placement.
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placement, as readjustment during the operation can be quite difficult, if not impossible. In order to provide a measure of safety, two temporary restorations were fabricated for this particular procedure. The first was produced digitally. The implant planning data was exported as STL files from the SIMPLANT software and imported into the CAD software (exocad DentalCAD; Figs. 33–36). The restoration was then designed in exocad DentalCAD based upon the location of each implant and abutment, and the diagnostic wax-up.

Once the design process had been completed, the CAM process was completed on a CNC milling machine, which milled the restoration from a solid block of PMMA (Figs. 37 & 39). As with most milled restorations, the restoration was not entirely finished when removed from the milling machine but required only a few additional manual steps for completion (Fig. 40). The holes intended to receive the abutment cylinders were designed for cement space of approximately 1 mm so that the temporary restoration could be inserted directly after the operation. The first was produced digitally. The implant planning data was exported as STL files from the SIMPLANT software and imported into the CAM software (exocad DentalCAD; Figs. 33–36). The restoration was then designed in exocad DentalCAD based upon the location of each implant and abutment, and the diagnostic wax-up.

Fig. 37. The milled PMMA temporary restoration.
Fig. 38. The palatal view of the PMMA temporary restoration.
Fig. 39. The abutment cylinders included cement space of approximately 1 mm so that the temporary restoration could be inserted directly after the operation.
Fig. 40. The dental technical working steps are reduced to minimal manual finishing.
Fig. 41. The aesthetically enhanced temporary restoration.
Fig. 42. A comparison of both variations: both the same size but the right-hand piece of work had far greater stability.
Fig. 43. A comparison of both variations: aesthetically no difference was noticeable.
Fig. 44. The clinical situation before the operation under general anaesthetic.
Fig. 45. The sterile surgical guide for implantation.
Fig. 46. The situation after extraction of the teeth.
Fig. 47. The open gingival flap.
Fig. 48. Positioning the SIMPLANT SAFE guide on the edentulous bone.
Fig. 49. Drilling according to the instructions from SIMPLANT.
Fig. 50. Placement of the implants (ANKYLOS C/X) alternately

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The aesthetic appearance (Fig. 41). The second temporary restoration was fabricated by hand in the laboratory utilising the 3-D printed model and was based on a metal substructure (Fig. 42). Each restoration was designed to be worn by the patient throughout the anticipated three to six months of osseointegration. When both restorations were compared, they were the same size, but the hand-made restoration appeared to be distinctly stronger (Fig. 43). When it was placed on the 3-D model, the aesthetic appearance was also satisfactory.

The surgical procedure

Surgery was carried out under general anaesthesia in the Princess Grace Hospital Centre in Monaco. The teeth were extracted and the extraction sockets were meticulously cleaned (Figs. 46 & 47). A gingival flap was reflected sufficiently to allow for the bone-supported surgical guide to be positioned on the alveolar ridge (Fig. 48). It fitted perfectly. The surgeon then followed the implant-specific drilling protocol to prepare osteotomies for the eight implants (ANKYLOS C/X, DENTSPLY Implants; Fig. 49). The implants were placed alternately with the specially designed carriers that allowed for placement through the guide. The implants were strategically positioned and secured to prevent the guide from tipping and then blocking the implants with the positioning aid (Figs. 50 & 51). Once the surgical guide had been removed, Balance Base Abutments (ANKYLOS, DENTSPLY Implants) were connected (Figs. 52 & 53).

and overcrossed to prevent the guide from tipping.

Fig. 51. Blocking the placed implants with the positioning aid.

Fig. 52. The implants with the SIMPLANT SAFE guide in their original position.

Fig. 53. The situation after removal of the surgical guide.

Fig. 54. Securing the Balance Base Abutments. The terminal implants were not immediately loadable, as there was insufficient bone substance in those areas.

Fig. 55. Insertion of the GORE-TEX membrane and replacement of the missing bone with Bio-Oss.
The surgeons judged that the two terminal implants could not sustain immediate loading, as the bone in those areas was too soft (Fig. 54). Bone graft material (Bio-Oss, Geistlich) was filled in around those two implants and covered with a GORE-TEX Regenerative Membrane (Gore Medical; Fig. 55). Cover screws were then placed and the areas were sutured so that the Balance Base Abutments were barely visible under the gingiva (Figs. 56 & 57). According to the original CBCT-derived plan, the remaining six implants had bone in sufficient volume and density to enable immediate loading, and the connection to the two terminal implants would help improve healing. The ANKYLOS retention copings were positioned and tightened (Fig. 58). The surgeons opted to insert the CAM-fabricated PMMA temporary restoration so that the patient would not have to go home without any maxillary teeth (Figs. 59 & 60). It was decided to insert the metal-strengthened long-term temporary restoration the following day. This additional step was necessary because the two terminal implants were not immediately loadable and because it was determined that the PMMA restoration would not be able to provide sufficient stability for six implants long term. This was the first time that the surgeons had inserted a previously manufactured temporary restoration for immediate loading. The fit of the PMMA restoration was excellent and the aesthetic appearance was pleasing, even after the extensive surgery.
The gingiva adapted well to the contour of the restoration and sufficient occlusion was achieved. The temporary restoration was fixed with light-curing composite and the exact position was reconfirmed (Figs. 61 & 62). As planned, the following day, the PMMA restoration was exchanged for the temporary bridge with the metal substructure. Function, aesthetics, and adhesive fixation were all checked, and the patient and the surgical team were all pleased with the results (Figs. 63–65).

**Conclusion**

The application of computer technology and advanced 3-D imaging in implant dentistry using multiple interactive software applications makes it possible to create advanced designs that are multilayered, simultaneous and precise, enabling true resource optimisation. In the clinical case example, the design and production of a complex treatment plan were carried out using a state-of-the-art digital workflow. The data export procedure allowed for simulation of optimal abutment positioning. The CBCT image data was used to position the implants accurately within the desired envelope of the diagnostic wax-up, allowing for the restorative data to be exported for CAD and fabrication of the temporary restoration before the treatment on the patient had even begun. The analogue or manual working steps in the laboratory were replaced by the digital workflow as made possible through advanced computer-aided processes.

Resource optimisation using digital workflow has great advantages for both patients and dental implant treatment teams. When it is possible to deliver an immediate-load restoration supported by sufficient dental implants, our patients can continue their lives with less psychological burden, and implant teams benefit from predictable operating procedures and efficiency. The craftsmanship of a competent dental technical specialist and the skill of a good dental surgeon when combined with 3-D preoperative planning can reduce operator and patient stress to a minimum, reduce patient morbidity and reduce surgical time, even when the operation must be relatively invasive, as represented by the clinical case illustrated._

**Fig. 64** The situation before the insertion of the final piece of work six months after surgery.  
**Fig. 65** A radiograph twelve months after surgery.  
**Fig. 66** The situation after twelve months.