Optimized implant planning:
DICOM-STL matching

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_Introduction

On the basis of three-dimensional X-ray images, in the 1990s the first software programmes allowed a navigated insertion of dental implants. But the digitisation of dental processes started even earlier, namely in the mid-1980's. Imaging techniques allowed the production of components based on virtual construction. Today, this principle is well established both in the dental-clinical field and especially in the dental laboratory. Meanwhile, 3-D data sets of objects are created not only by normal camera shots, but there are also special 3-D scanners in use. In particular, today's desktop scanners are so precise in their resolution accuracy that they are able to exactly reflect the real model or oral situation. Simultaneously with the capturing process, different methods have been developed to transfer the acquired 3-D data sets back to reality. While initially this was a milling and prototyping process, currently the sintering and printing processes are favoured. For a long time, navigated implantology and 3-D scanning has been developed in parallel, where at best surgical templates were fabricated by prototyping on basis of X-ray data sets.

Goal: optimal implant position

In recent years, the matching of 3-D X-ray data sets (DICOM) and 3-D model data sets (STL) has begun. The goal was and still is to find the optimal surgical and prosthetic implant positions for navigated insertion to provide an optimal solution for the patient. In addition, the production of temporary dentures and in individual cases an immediate treatment is so much better and much more reliable and predictable. At the same time, an objective quality control of both the planning and the result is practicable through matching of DICOM and STL data sets. By means of some case studies, we show which diagnostic and technical possibilities have been feasible since the establishment of the diagnostics and navigation system CTV in 2005 in the following article.

_Implant planning with CTV

X-rays are subject to the laws of physics. Therefore, all the resulting images are generally afflicted with an error regarding distortion, diffraction and interference. Because these errors have their origin in the radiological density changes of the object, some areas cannot be represented or are misrepresented. Particularly critical are movement-induced distortions in CBCT images. They cannot be completely avoided or even predicted. A further increase in accuracy solely from radiological data does not seem to be possible currently. The solution is to collect additional data by using independent methods to achieve a "rectification" and detail enhancement through combination with the radiological data. For example, the line of the gingiva and other surface structures in the 3-D X-ray image cannot be traced precisely. The solution here is the correct matching

Fig. 1_Planned implant with full-guided drill sleeve; gingiva line set by the clinician according to X-ray image (pink); by matching obtained with the situation model – real – gingiva line (yellow).
Fig. 2a_ Virtual matching in 3-D X-ray; planned implants with a situation model (red). Image cut: orthogonal ridge section with gingiva line (yellow) from the situation model.
Fig. 2b_Virtual matching in 3-D X-ray, implants planned with aesthetics wax up (green); image: orthogonal ridge section with tooth line (yellow) of aesthetic wax up.

Fig. 1

Fig. 2a

Fig. 2b
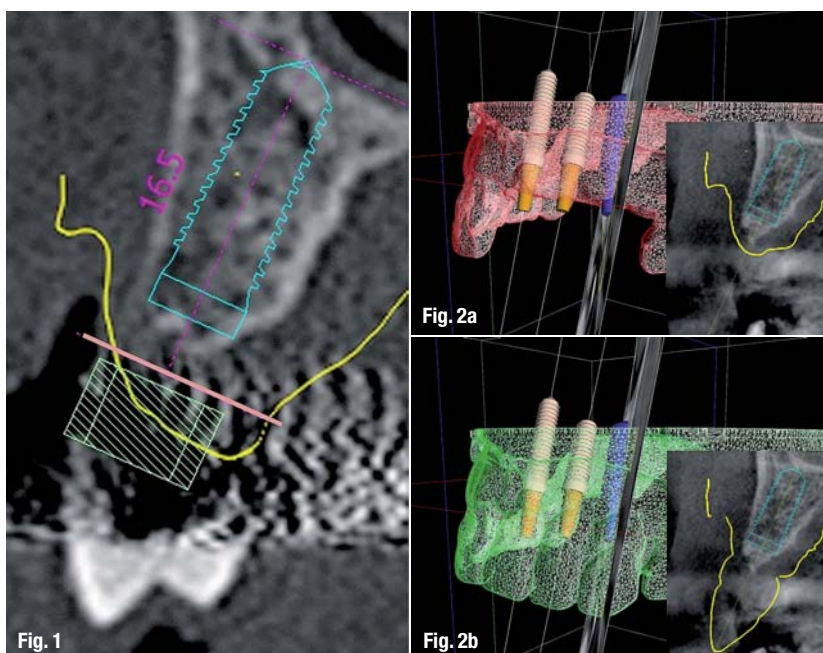
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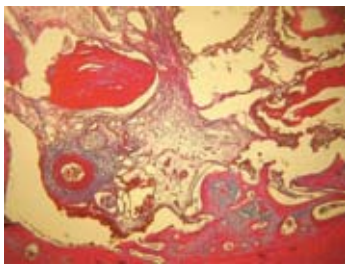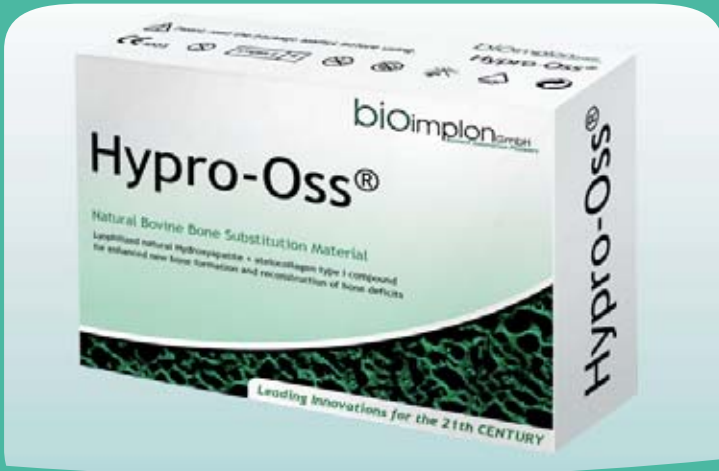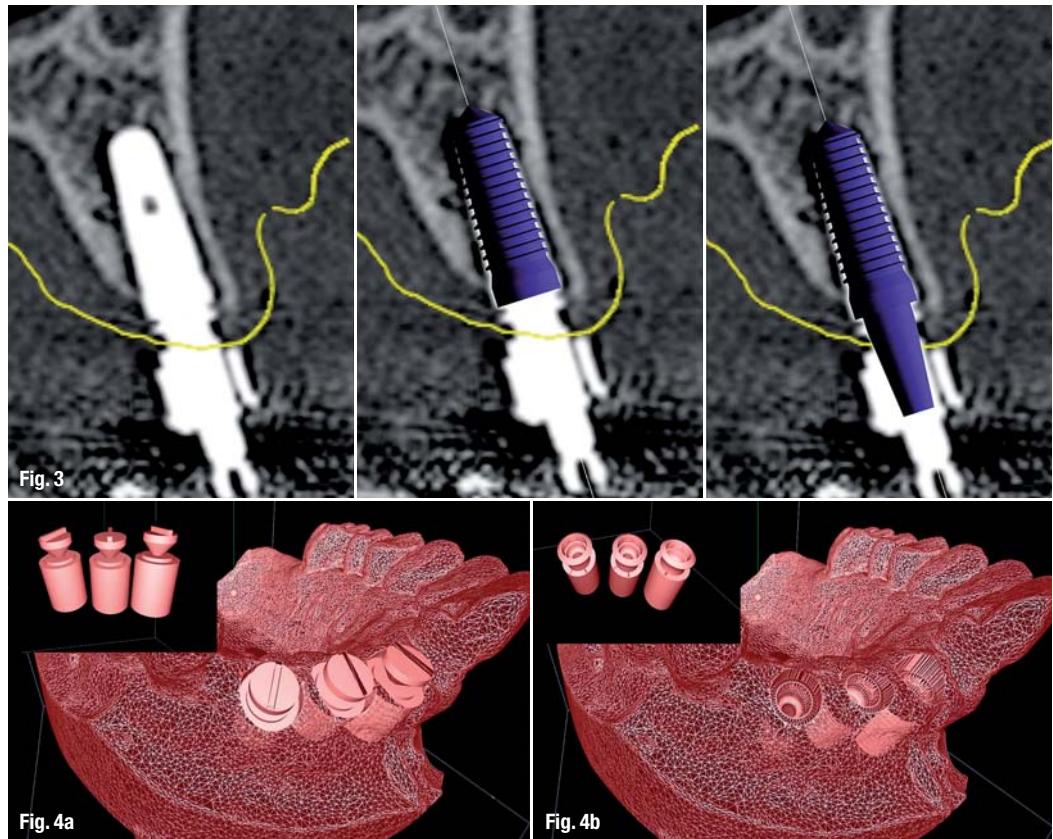
Histology after 4 weeks.
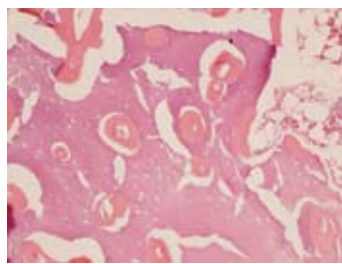
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Fig. 3

Fig. 4a

Fig. 4b

of DICOM data sets with the digital capture of the associated surface structures, e.g. anatomical model. With the situation model the real surface profile is obtained. If an aesthetic modelling (wax-up) is scanned and matched additionally, the planned position of the implants both in axial direction as well as in mesial/distal orientation can be determined optimally (Figs. 1, 2a & b).

3-D data matching

The comparison of the real positions of the inserted implants in the jaw with the virtual planning is done by matching the 3-D X-ray planning capturing with the post-op 3-D picture. Here it is irrelevant whether the planning and the post-op 3-D capturing come from the same device type (DVT/CT) or not. This method also allows for a standardised follow-up (Fig. 3).
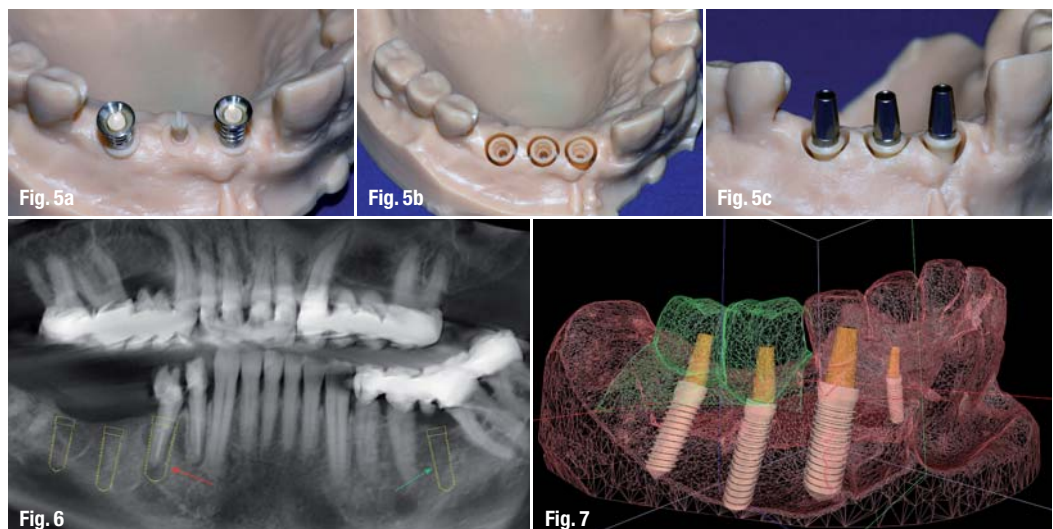
DICOM and STL data matching

For the manufacturing of surgical templates, for models to produce temporary restorations in navigated implantations and planning of definite dentures (backward-planning) matching data sets from

Fig. 5a

Fig. 5b

Fig. 5c

Fig. 6

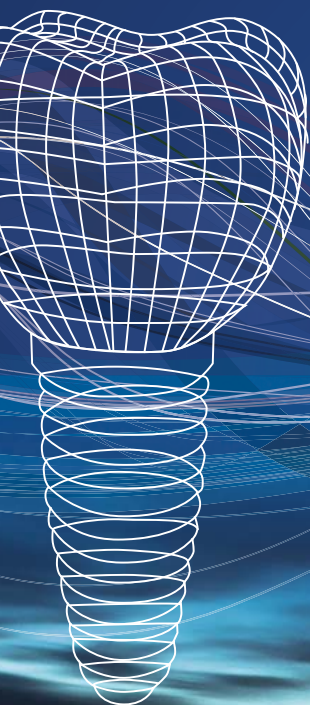Fig. 7

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DICOM and STL data are used. Virtual models can be designed with exactly positioned sleeves for full-guided systems and or with laboratory analogues of the planned implants. This range can be extended, provided that the STL data sets of components to be designed are available, such as implant abutments. The thus created virtual model is transferred by milling, printing, sintering, etc. back to reality and can then be used e.g. in the laboratory for the production of temporary dentures or surgical guides. The more accurate the replications process the better the models (Figs. 4a–b, 5a-c).

Safe implant-planning

It is also possible to safe implant-planning make with still incorporated metal structures, even if the X-ray image at these locations with radiation artifact areas is insufficiently evaluable. In the described case, the usage of a non-optimal DVT had been assumed, due to extensive metal restorations. Alternatively, the structures would have to be removed. Because of many opportunities in the CTV system, a virtual planning for minimally invasive, navigated implantation is almost unrestricted. (Figs. 6–8c)

Complex planning

For complex planning, even when there is not an optimal bone situation and accompanying surgical services (e.g. sinus lift) are needed, the matching processes of the CTV system support the surgeon. By virtual articulation of the scanned models and matching with the X-ray data, a position and axial direction of the planned implants and their subsequent supra structure in relation to the remaining dentures or natural teeth are determined and other accompanying, necessary surgical procedures can be pre-planned (Figs. 9a–g).

Comprehensive matching process

Last but not least, quality controls, such as of the finished surgical drilling template, are carried out with these comprehensive matching processes. In order to achive this, the template is scanned and matched as best as possible with the planning images for covering. Ideally, there are no deviations. If differences occur, the implantologist must decide whether he can use this template or a new preparation will be necessary. In this way, failures in implantation and subsequent prosthetic treatment are avoided (Figs. 10a–e, 11a–c).

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Fig. 10a_STL mesh of the real drilling template (green) and DICOM data with the planned implants maxillary anterior region.
Fig. 10b_Planned implant positions of maxillary anterior area with evaluated positions for drill sleeves (full-guided) and surface line of the scans of the real drilling template (green, regio 11).
Fig. 10c-e_Orthogonal cross-sectional images with planned implants (aqua), associated full-guided drilling sleeves (dark green), orange line: surface profile (gingiva) of situation model, green line surface during the scan of the template: line "based" on the virtual sleeve edges.
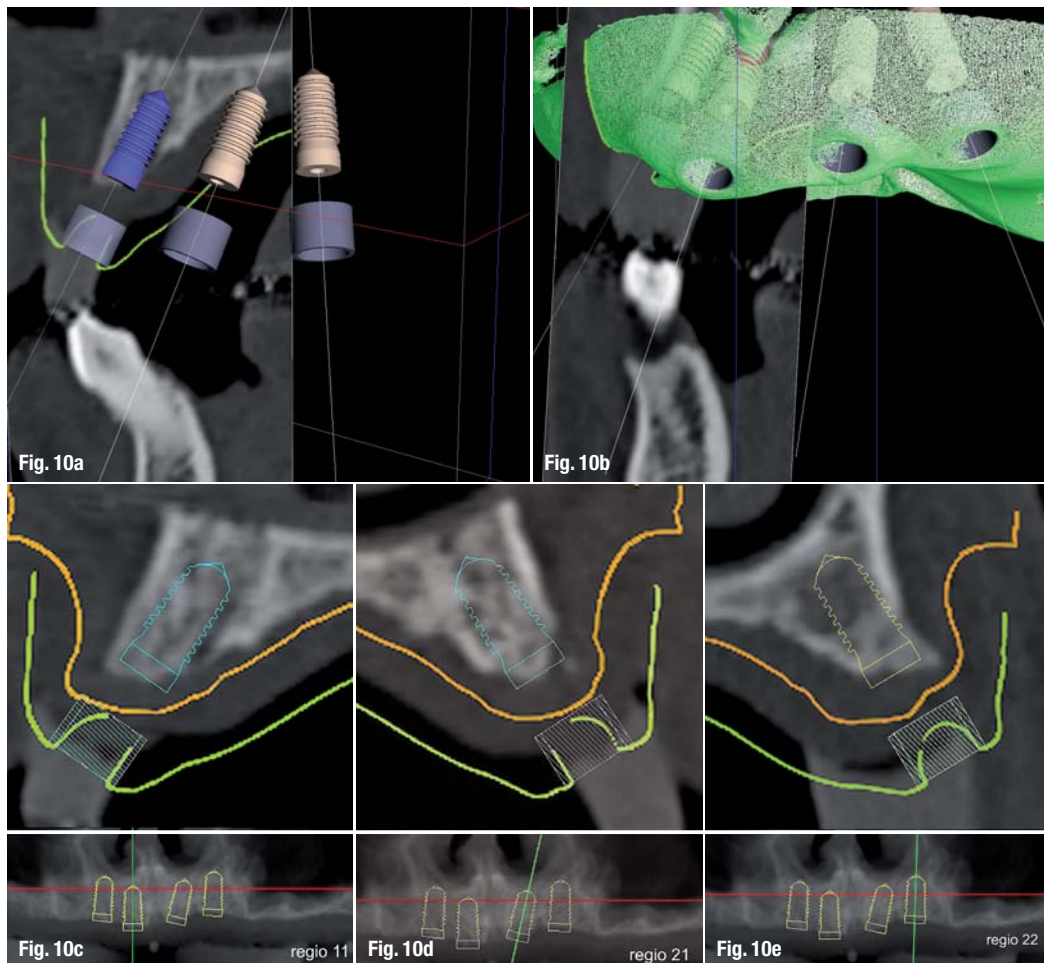
_Conclusion

The procedures for overlay of DICOM and STL data contained in the CTV system allow a comprehensive planning of implant positions regarding surgical, prosthetic and aesthetic aspects. Due to the diversity of options, shortcomings of X-ray or model data sets can be fairly settled. This method eliminates the need of a special transfer device for the implementation of the design positions from the virtual to the real world. Thus, the described approach is independent from the existing dental infrastructure as the data exchange with freely selectable machining centres can be done via internet. The goal is to enable a consistent minimally invasive surgical-implantological procedure, to reduce failure rates and to meet the often high demand for prosthetics and aesthetics from the patient's perspective._

_contact   implants

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Fig.11a_STL mesh of situation model (red) and wax-up (green) with the planned implant and abutment.
Fig.11b_STL mesh with designed drilling sleeves of the replica model for the production of the surgical guide.
Fig. 11c_Orthogonal cross section regio 45 with planned implant and sleeve position; orange line: surface profile situation model (gingiva); green line: surface contour wax-up; aqua line: real surface of drilling template.
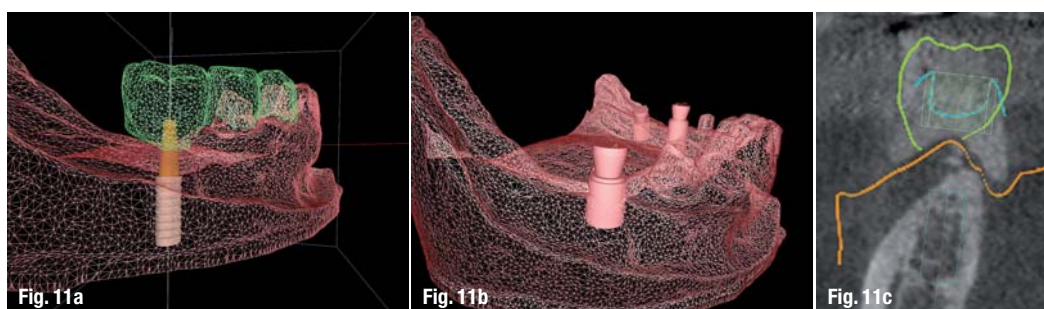
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