3-D Planning, Navigation, and additional Questions concerning practical Dentistry

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It is the aim of this paper to reveal those patient cases where implantological prosthetic treatment with three-dimensional imaging by means of digital volume tomography (DVT) or computer tomography (CT) should be applied in order to analyze and eliminate errors. It is made clear that the increasing population with implants also requires an exact determination of the implant localization and diagnostic imaging of long term integrated implants.

_Not only do 3-D illustration facilities contribute to the increase of indications and thus to a rise in restorations with implants, but a major need for three-dimensional imaging for control and complication management purposes is also given. The fast-paced development of computer techniques, hard and software, storage media, the compatibility of programmable devices with sensors and optics, can also be applied in many fields of dentistry. In the past years, technical, and especially computer-supported methods for dental diagnosis and therapy have been refined significantly. Innovations in digital technologies show promising and interesting improvements in regard to their application. Anyway, a pragmatic, time-saving and user-oriented application of particular programs is of great importance. This in fact is the real improvement of the current development. The chance of co-operation also offers adequate possibilities to integrate this technique into general dental offices without major investments. At the same time, modern data transfer and multiple means of communication improve time management as well. The indication for the use of DVT or CT has to be checked separately for every single case. This holds true for all medical therapies, and it guarantees a better realization of therapy in view of individual needs. It has to be evaluated if the enhanced complexity and the resulting higher costs will be refunded by official and private health insurance companies. It is of great significance, how three-dimensional planning with appropriate methods and materials can be put into practice. Crucial and pathbreaking improvements can be shown here.

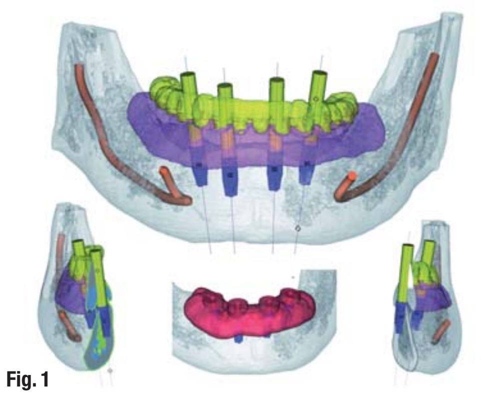
Fig. 1

Fig. 1_ Virtual planning with SimPlant®, Materialise Dental GmbH, Oberpfaffenhofen, Germany.

_Imaging techniques

In 1917 the Austrian mathematician Johan Radon developed a mathematical method by means of which one could calculate the projection image of an

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X-ray that had been weakened by materia. This was a purely mathematical gain of insight and far away from any applicability. However, radon transformation is nowadays the basis for the calculation of non-destructive spatial images of an intact object and all its inner structures. From 1975 on, CT technology found its way into medical diagnostics. All body tissues weaken the penetrating X-rays differently. The technician Godfrey Hounsfield defined a attenuation value for objects, the so called Hounsfield unit (HU) was named after him.

The various values are: for air 1,000 HU, adipose tissue from 200 to 50 HU, and water 0 HU. Bone values start with 300 HU to 2,000 HU (teeth), metall around 3,000 HU. By using gray-scale value filters for special HU values, body tissues can be segmented and shown separately from any other tissue structures. CBDVT is the abbreviation for a cone beam digital volume tomograph. This apparatus is a new development for reconstruction purposes, which has only become possible thanks to high performance computer systems and the latest mathematical algorithms. This image taking method works as follows: An X-ray source formed like a "cudgel" or pyramide X-ray with an opposing detector unit circles around the patient. Thus, approximately 300 X-ray images can be taken from different positions. The X-ray tubes can be compared with an orthopantomogram (OPG) or they may even be identically equal. Only the exposure time (due to the necessary high number of projections) and the anode current (in order to achieve a good penetration) are elevated. A difference has to be made between pulsed and non-pulsed radiation methods. A non-pulsed tube continously emits rays, which on the one hand facilitates the steering of the device, but on the other hand implies a higher X-ray dose for the patient.

The pulsed tube only emits X-rays, when definitely taking an X-ray image. Thereby an unnessecary exposure to X-rays can be avoided, which is favorable for patients in regard to the total exposure to radiation. It has to be noted that in the moment of power-up some X-ray tubes also emit low voltage X-ray radiation (between 20 kV and 50 kV), which has a higher biological damaging effect.

Some DVT manufacturers have already solved this problem. The detector unit transforms the X-ray projection information into an image data file, which will be saved temporarily on a recontruction computer. There are two kinds of technologies for detector units: 1.) Image amplifiers function with a special electron tube. By means of a scintillator layer X-ray radiation is transformed into visible light, reinforced by the tube, and then digitalized by a camera chip. Image ampliers are a bit more sensitive to X-rays than surface detectors, their purchase is cheaper for manufacturers, but there are some important disadvantages that have to be mentioned. Image geometry displays heavy distortions in the bordering area, which have to be mathematically corrected, and which limit the use of the whole detector surface. During the course of time the image quality decreases significantly, which makes repeated recalibration necessary, and finally requires an exchange of the image amplifier. Meanwhile this method has become obsolete. 2.) The impinged X-ray radiation of semi-conductor surface detectors will be digitalized directly without any geometrical distortions. The (still) high purchase price for flat panel detectors (FPD) is to the disfavor of DVT manufacturers. Thanks to this recent DVT technology the mechanical effort and the size of the devices can be kept on a very low level. Besides, it can be adapted to the appearance of the usual panoramic radiography. Furthermore, cone beam methods minimize the development of scattering artifacts (e.g. on crowns), which poses a big problem for normal CT images of the cranial region. For practical issues, it should be mentioned that those DVT devices applied in dentistry have been reduced to an exclusive use for the cranial region. Therefore, dentists are allowed to operate such devices, whereas CTs can only be operated by radiologists. The discussion about advantages and disadvantages of both device groups is factual, though sometimes a bit polemic. It is undisputed that CTs compared to DVTs have a lower sensitivity to movement but are more prone to scattering artifacts. Various DVT devices require different positioning of the patients during image taking, e.g. reclined, seated or standing up.

Since movement artifacts are illustrated much more dramatically on DVT images, imaging is principally better in a reclined position, though due to this position patients may suffer from deglutition reflexes provoked by saliva. Devices designed for image taking of patients in seated or standing up positions are convincing, because of the minimal required space. The discussion about the exposure to radiation of the various devices and techniques has to be judged differentially. The comparability of the present studies is often not given, because of different evaluations of biological effects on human organs. There is no doubt about that DVTs have lower radiation than CTs, though there are great differences among DVT devices. The new CT generation enables a significant reduction of exposure to radiation by applying so called low dose protocols. On the whole, the exposure to radiation is low in all modern devices, but its radiation dose still multiply surpasses that of OPGs. An important criterium in regard to exposure to radiation is the avoidance of repeated image taking. Above all, the necessary image quality and processability depend on the specialized staff, the maintenance of the devices and the competence of the device operator.

_Three-dimensional planning and navigation

Adequate software should provide illustration facillities into the three main scanning directions (axial, coronal, sagittal) so they are readable for the user. Most programs solve this by parallel projection on the monitor of a panorama analog image, a jaw cross section and a transversal section. Normally a three-dimensional image of the jaw can also be visualized. However, this is a rather close to reality animation and not an exact realistic image. By moving the cursor, a change of the cutting level can be obtained in all images, so that anatomical anomalies can be pursued into every cutting direction. In addition to this optimized image the programm also includes auxiliary means and tools, which make the work easier and give practical help to users. Apart from simple facilities used for the measurement of length, angle and density there are imaging programs, which show the course of the mandibular nerve canal, and the insertion of planning axes and of implant forms from different manufacturers and their product line. The first planning system on this basis, which implied much of the corresponding pioneering, was developed by SimPlant®-System (nowadays the Belgian company Materialise Dental). It was introduced in Germany in the early nineties, and sponsored by the German Association of Dental Implantology. In the last few years, many innovations have been made to improve this development. A wax-up of the prosthetic planning or a duplication of the existing prosthesis can be transferred to a so-called scan prosthesis composed of X-ray opaque substitution teeth. The virtual positioning of the implants into the jaw bone will be carried out in compliance with the location of the X-ray opaque substitution teeth. Afterwards this virtual planning will be digitally transferred and a drilling guide will be produced. Based directly on the 3-D-data of CT or DVT a drill guide, which can be mucosa-, tooth- or even bone-supported, will be calculated and finally materialized with a laser beam, which solidifies a liquid UV-curable resin.

With this in mind, 30 years ago German implantology pioneers have started working "minimally invasive" and "atraumatically" on single-phase implants. However, they had to rely on palpation, experience and intraoperative control when positioning their implants. From the forensic point of view this way of proceeding is considered to be obsolete. In case of failure the documentation of the way of proceeding will be required, and checked in terms of safety. Hence, a respective three-dimensional image of the jaw situation is necessary for a minimally invasive implantation. On its basis implantology possibilities will be checked, then the planning can be done, and finally the positioning of the implant can be determined. New and precise navigation systems, which are routinely used especially in neurosurgery, where they are of vital importance for the patients, have also found their way into dentistry.

In the last few years navigation techniques have been improved, in order to adapt them to the requirements for application in dentistry. Navigation systems have also become available for dental implantology purposes, due to the development of specialized software and instruments. By means of this direct navigation, previously combined DVT or CT data will be combined and visualized on a monitor, and reference points for the localization of the jaw und the driver tip will be optically recorded. The current drill position will be displayed in color. It can be controled by the program based planning. On the contrary to the already described way of proceeding in regard to drilling jigs, the system, however, has to be ready to use in the dentist's office during the operation. A comparable exactness cannot be achieved in "free-hand style" without navigation. Schermeier et al. (2002) concluded in their study that skilled surgeons could not achieve aberrations below 2–3 mm, whereas the maximal failure using navigation was detected between 0.6 and 0.8 mm.

_Hazard to anatomical structures

Though thanks to "backward planning" in modern implantology, anatomical risks can be avoided by preimplantological augmentative and other surgical methods, anatomical knowledge still plays an important role in regard to successful implantations. Within therapy planning, the three-dimensional image taking with CT and DTV techniques provides an exact and distortion-free image of important anatomical structures, both in bones and soft tissues (Lenglinger et al.

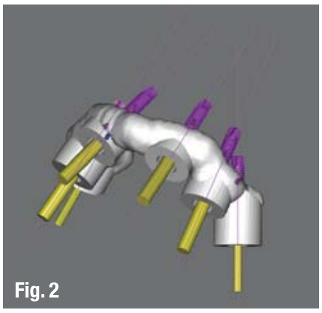

Fig. 2

Fig. 3

Fig. 2_ Virtual bone-supported SurgiGuide® drill guide, as calculated by the SimPlant®-Software, Materialise Dental GmbH, Oberpfaffenhofen, Germany.
Fig. 3_ Bone-supported SurgiGuide® drill guides with ascending diameters on stereolithographic bone model, Materialise Dental GmbH, Oberpfaffenhofen, Germany.

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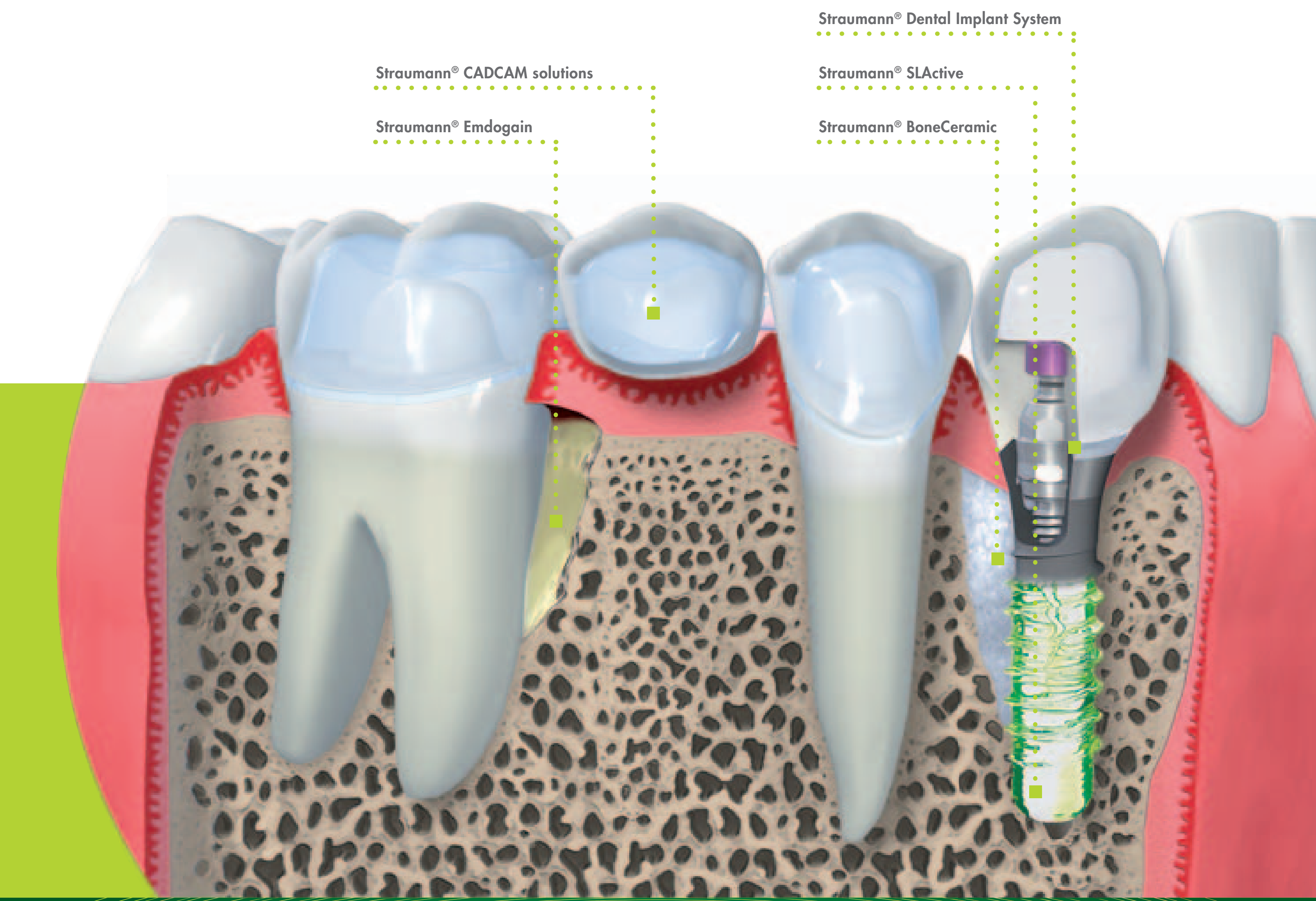

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1999, İplikçioğlu et al. 2002, Rubio Serrano et al. 2008). Thus, possible anatomical "snares" can easily be detected. However, one has to re-evaluate the anatomical situation from the perspective of the conventional two-dimensional radiological method compared to the three-dimensional method. This significantly simplifies the transmission of computer-supported implant planning to the operative site (Rupprecht 2007).

A multicentric retrospective study of 1,202 placed implants proved that thanks to navigated implantology none of the endangered anatomical structures was damaged (Bier et al. 2006). Three-dimensional representation facilitates the demonstration of anatomical structures before an autologous bone extraction, e.g. of the lower jaw (Aalam and Nowzari 2007) or the detection of pathological alterations (İplikçioğlu et al. 2002) in general. Due to tooth loss, there are numerous anatomical problems zones, which can mainly be found in heavily atrophied jaws (Gruber et al.1993, Pietrokovski et al. 2007). A quantitative "bone mapping" of the different jaw regions, carried out in order to evaluate the existing bony structures and dimensions (Juodzbalys and Raustia 2004), as well as the detection of bone densities and qualities (Gomes de Oliveira et al. 2008) is facilitated by computer-supported diagnosis and the imaging of the different anatomical cutting levels (sagittal, coronal, axial). Zones of interest in oral implantology are in the upper jaw the maxillary sinus, especially its floor region, the floor of the nasal cavity, in the lower jaw the course of the mandibular nerve canal, the mental nerve at the mental foramen, and the structures belonging to the lingual side of the bone (Gruber 1993, van der Zypen 1994, Lenglinger et al. 1999, Sharawy and Misch 1999, Machado et al. 2001). There are abounding variations and risks e.g. the maxillary sinus septa (Kim et al. 2006), position and course of the foramina, the neurovascular bundle at the lingual side of the mandible, and in the anterior palatinal region of the maxilla (Jacobs et al. 2007), a mylohyoid ridge, which can reach the hight of the resorbed alveolar ridge at the atrophic posterior mandible. Undercut bone areas (Gruber 1993) or anatomical variations of the mental foramen (position, number, size etc., see Greenstein and Tarnow 2006). It is well known that conventional radiological methods do not always display the mandibular nerve canal reliably, which is of great importance for implantological purposes (Kieser et al. 2005). During the course of planning, many navigation programs offer nerve canal detections with a determined collision warning. It is important to verify the real size and the marking in order to also document irregular courses or doublings like they can be found in dentate and especially in toothless patients (Sharawy and Misch 1999). Also the course and the extension of the intra-osseous anterior loop of the mental nerve ("mentalis-siphon", "anterior loop"), which can vary between 1 to 7 cm (Machado et al. 2001) can hardly be detected in an OPG (dental panoramic radiograph). 3-D planning also enables the detection of probable deviations, e.g. towards inferior, seen from the course of the loop from mesial buccal cranial, and then distal buccal (Hu et al. 2007, Uchida et al. 2007). As shown in the following case studies, 3-D planning also is of advantage for the localization of retained teeth or of inserted implants, and the relation between implants and neighboring natural teeth concerning implant restoration in partially dentate patients.

_Costs

Though implant navigation provides considerable diagnostic and operative advantages, dentists and patients are consistently concerned about the costs. Implant navigation is always coupled with additional expenses. In the past, official and private health insurances considered these costs as "luxury treatment" and thus as non-refundable. This may change. According to an adjudgment of the Local Court Dortmund (verdict dated September 21, 2008, file number: 421 C 9664/07) the costs for implantation navigation have been admitted for the first time by a private health insurance company. It remains to be seen, how health insurance companies will orient themselves by this adjudgment, or if other courts will follow the legal concept of the Local Court Dortmund. The Local Court Dortmund considered the implantation navigation in a concrete sense to be a "medically necessary treatment" according to the conditions of private health companies. After asking for an expert opinion, the court was convinced that the implantation would have been too risky without the supporting navigation technique, due to the very complicated anatomical anomalies of the patient, who filed this suit.

The patient's jaw showed considerable anatomical anomalies. The alveolar process in both inferior posterior tooth regions of the patient showed a knife-edged jaw ridge. This was heavily translocated lingually and the alveolar process was considerably atrophied at this level. The lingual wall of the mandibular margin below the mylohyoid ridge proceeded strongly angled, so the risk of perforating the lingual cortical plate when drilling the implant bone supporting area was given. Therefore, a drilling direction had to be chosen, which was different from the natural tooth longitudinal axis, especially when drilling in the posterior lower jaw area. The implant axis was heavily inclined to lingual. Without implantation navigation there would have been considerable risks of damaging nerves

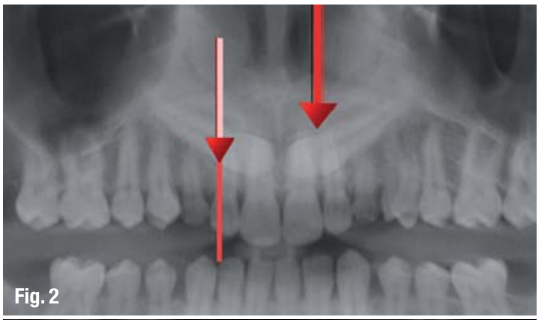
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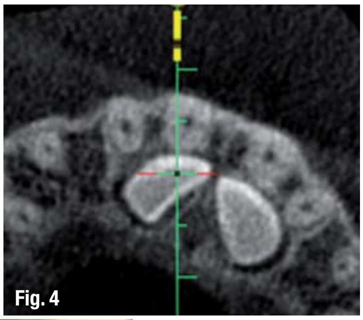
Fig. 3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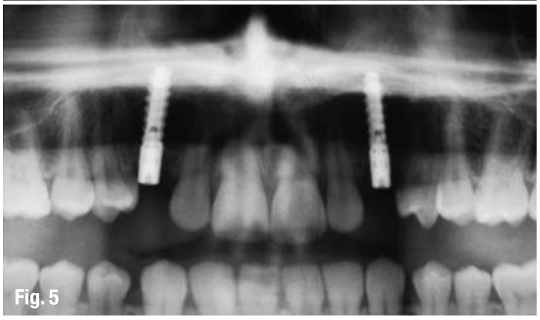


Fig. 5


Fig. 6

Case 1

Fig. 2_ Panoramic display of retained canine teeth in the upper jaw.

Fig. 3_ The narrow spatial position in relation to the incisors indicates the subsequent operative procedure.

Fig. 4_ Also the transveral section illustrates the complicated retention form.

Fig. 5_ Panoramic display after implantation as immediate implantation after extraction of deciduous canine teeth.

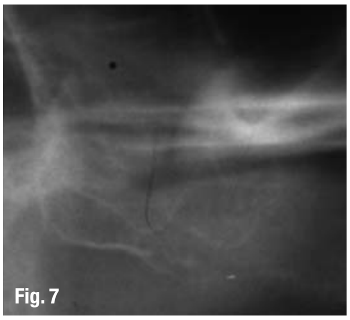
Fig. 6_ Clinical appearance four weeks after the implantation and extraction of the deciduous teeth.

and muscles, and of perforating the lingual cortical plate. The verdict of the Local Court Dortmund has two consequences for the practical work of implantologists. On the one hand, every patient should be checked thoroughly in order to see, if there are any clinical or "conservative" radiological findings, which may indicate significant anatomical anomalies. This would justify the necessity to apply implantation navigation. The consequence of the case decided upon by the Local Court Dortmund would be e.g. if a dentist does not make use of implantation navigation he might be charged for a medical error, and thus becomes liable. On the other hand it has to be checked before carrying out implantation navigation, if in case of existing anatomical anomalies, this treatment will be refundable. According to the verdict of the Local Court Dortmund, this would be the case if implantation navigation is estimated to be medically necessary. In case of existing anatomical anomalies it is recommendable to clarify the reimbursement of costs beforehand with the patient's health insurance company. In view of a possible intended reimbursement, all clinical findings, which favor implantation navigation, should be meticulously documented for each case.

_Indications and case studies

Case study 1:

A 22 year old male patient presented himself with two persisting and meanwhile loose deciduous teeth. The dental panoramic radiograph showed that the remaining teeth were retained and ectopic. The dentist, who had treated the patient before, had recommended to leave the retained canine teeth like they are in order not to risk any damages that might be caused by an operation. Since the deciduous teeth started loosening we had to elaborate on a new concept. In addition, the patient wanted an implant restoration for his neighboring teeth, but this could not be done since the retained teeth were still existent. After thoroughly informing the patient he decided upon having a 3-D image taken in order to exactly determine the position of the remaining canine teeth, and to be able to judge the possibilities to integrate them or to find an alternative treatment. The image revealed that due to the form of retention an orthodontic treatment would be very time-consuming and expensive. The retained teeth had no direct contact to the roots of the other remaining teeth. The decided operative extraction could be carried out in a very precise way, thanks to the three-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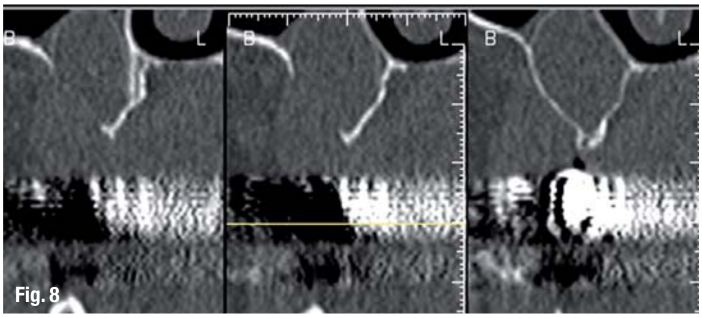
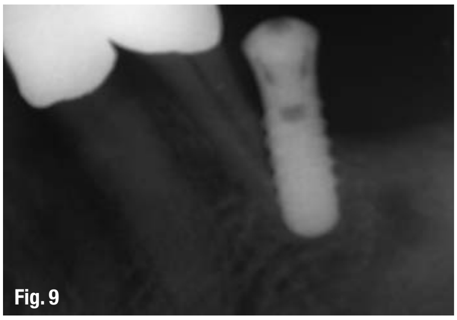


Fig. 8

Case 2

Fig. 7_ Panoramic display of the right upper jaw. Thereupon the evaluation of the sinus floor was planned.

Fig. 8_ The cross section of the three-dimensional image shows the bony defect and an opacification of the maxillary sinus.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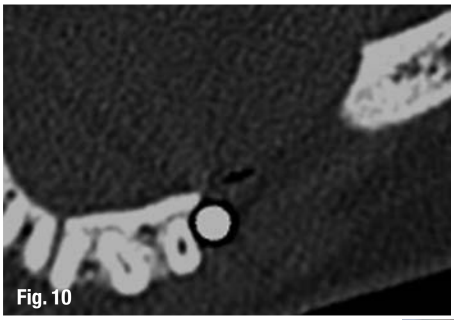
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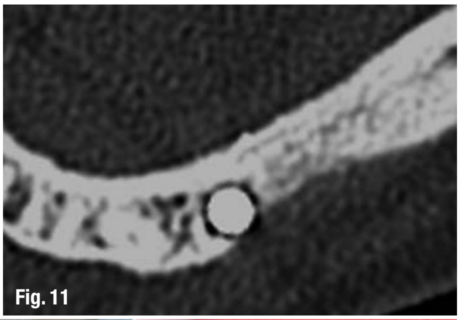


Fig. 11


Fig. 12


Fig. 13

Case 3

Fig. 9_ The contact between implant and tooth cannot clearly be proven due to the two-dimensional X-ray image. Root and implant apex may lie one behind the other.

Fig. 10_ In the medial transversal section implant and root still lie next to each other.

Fig. 11_ The contact and damage can be clearly seen at the implant's apex. A large part of the root has been cut off beyond the pulp cavity.

Fig. 12_ The extracted tooth provides the ultimate proof.

Fig. 13_ The removed implant can be exactly repositioned.

Case 4

Fig. 14_ The ceramic anchor implant is completely surrounded by soft tissue.

Fig. 15_ The inferior alveolar nerve can allusively be seen on the right, next to the soft tissue. It proceeds through the soft tissue of the posterior implant region.

Case 5

Fig. 16_ A significantly reduced area of 45° inclination can be seen under the mylohyoid line.

dimensional image. Due to the great loss of tissue we waited four months until we placed the implant. On the occasion of the extraction of the deciduous canine teeth we carried out an immediate implantation.

Case study 2

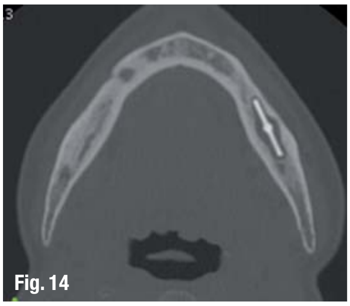
The upper and lower jaw of a 49 year old female patient had to be restored with implants. Since a sinus lift was necessary for the upper jaw anyway, there was no need for another X-ray image. Due to the low bone volume in the lower jaw it was agreed with the patient to have a three dimensional image taken. Also, the radiologist could nearly display the complete upper jaw and thus enabled the evaluation of the maxillary sinuses. The evaluation showed a missing bony floor in the maxillary sinus in the area of the posterior teeth of the right upper jaw, which could therefore be considered for the operative procedure. The patient could not give any anamnestic information about this. The bone loss might result from an earlier extraction of a molar.

Case study 3

A 51 year old female patient presented herself with a letter of referral for restoration of the unilateral free-end situation in the left lower jaw. Some time ago an implant 34 had been angularly inserted directly behind tooth 33. In order to avoid nerve damages an insertion was carried out angularly to the mesial direction, without previous three-dimensional planning. The dental panoramic radiograph suggested a lesion of tooth 33, for the tooth did not show any sensitivity reactions, no percussion pain and no apical alterations. This could not have been shown so clearly in a two-dimensional image. All the same, the implant apex (could also have been located directly behind the root apex. Since the patient required further treatment and more certainty in regard to diagnosis, a 3-D image was taken, which proved a root apex lesion of tooth 33. Thus, tooth and implant were removed and a new restoration had to be planned.

Case study 4

About 25 years ago a ceramic anchor implant was placed in the left lower jaw of the today 67 year old female patient and the free-end situation was restored with a composite bridge. The prosthesis was no longer preservable, the implant was heavily loosened and surrounded by soft tissue, which could clearly be seen in the dental panoramic radiograph. The inferior posterior course of the anchor implant was directly above the mandibular nerve canal. At first, a three-dimensional image was taken for a better diagnosis, since the implant had to be removed in any case. The image displayed that the periimplant soft tissue in the anterior area was separated from the root canal course. In the mesial and posterior areas the soft tissues could not be separated from the inferior alveolar nerve. The anchor implant could be carefully removed intraoperatively. It was then tried to totally remove the granulation tissue from the defected area under magnifying glass control, which did not work out, due to con-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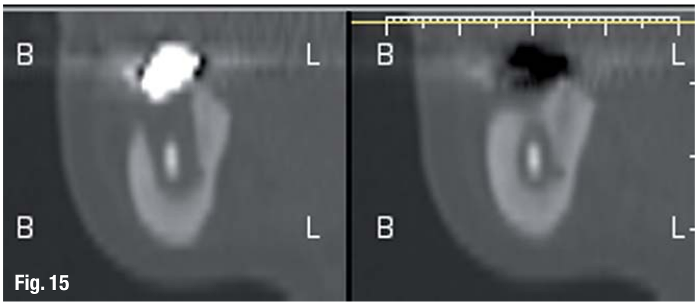

Fig. 15

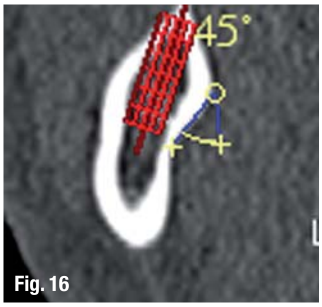

Fig. 16

Fig. 17_ Clinical appearance of the final dental restoration.

crescences on the floor of the bony defect. In order not to damage the nerve, and considering the anatomical facts, the granulation tissue of the mesially defected area was removed, and mesially and distally clearly separated from the remaining soft tissues on the bottom of the defect. The extracted tissue was histologically examined. The patient was informed that radiological control examinations of the remaining defect should be carried out regularly.

Case study 5

Implantation planning for the posterior teeth area of a heavily degenerated jaw. The 44 year old male patient required a restoration of the free-end situation with implants on both sides. Due to the clinical diagnosis, which had revealed heavily degenerated areas, a three-dimensional image had to be taken. Degenerated areas of almost 45° were displayed. However, the dimension of the jaw bone was sufficient for implant placement and restoration with angled abutments. An implant angle of 25° was sufficient. In exact compliance with the planning, the implantation was carried out with navigation support using a corresponding template.

_Acknowledgements

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The reference list can be requested from the editorial office.

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