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Case Study

CBCT Technology, The Cornerstone of Prosthetically Guided Implant Planning

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Abstract

Cone Beam Computed Tomography (CBCT) has become a cornerstone in modern dental implantology, particularly in prosthetically guided implant planning. This advanced imaging technology provides three-dimensional insights into bone anatomy, nerve pathways, and spatial relationships, enabling precise treatment planning. By offering detailed visualization of the alveolar ridge and surrounding structures, CBCT enhances diagnostic accuracy, facilitates optimal implant positioning, and reduces the risk of surgical complications. This article explores the role of CBCT in implant planning, highlighting ist role in an in-depth analysis of bone volume, the alveolar ridge, and the relationship between the future prosthetic restoration, adjacent teeth, and soft tissues.

Keywords: Cone Beam Computed Tomography (CBCT); Teeth; Computed Tomography (CT)

Brief History of the Transition from 2D to 3D

Dental radiography, invented in 1896, is considered the most frequently used diagnostic tool in everyday dental practice, with over a quarter of all medical radiographs in Europe being performed by dentists. Since their discovery 120 years ago, dental X-rays have been the primary diagnostic source for the oral and maxillofacial region. However, two-dimensional (2D) imaging technology cannot accurately represent the three-dimensional (3D) anatomy of anatomical structures and associated pathologies [1].

In the 1990s, there was a growing trend toward using 3D information for the diagnosis and treatment of dental-maxillofacial conditions. The invention of the cone beam computed tomography (CBCT) scanner in 1995 in Venice by Italian researchers Mozzo and Taconi—originally designed for angiography—along with its adaptation and introduction into dental practice in 1998, further fueled this trend by enabling its use in specialized clinics [2]. At the same time, 3D imaging applications for implant planning and intraoral treatment transfer became increasingly common. Initially, 3D images were obtained using conventional computed tomography (CT), but CBCT quickly gained popularity due to its compact size, lower radiation doses, shorter exposure time, ease of use, and lower acquisition costs compared to CT [1,3].

Equipment and apparatus, principle of operation

CBCT is a modified version of conventional CT, utilizing a conical X-ray beam, which significantly reduces scanner size, radiation dose, and scanning time. There are multiple types of CBCT units, with exposure performed in a seated, supine, or standing position [4].

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The CBCT unit operates based on two main components mounted diametrically opposite each other on a rotating arm: an X-ray source and a detection sensor. The cone of ionizing radiation emitted by the source passes through the region of interest (ROI) toward the detection sensor. The rotating arm completes either a full (360°) or partial (180°-270°) rotation around the patient's head, which is stabilized on a support. During this process, multiple sequential 2D images, similar to lateral cephalometric radiographs, are captured within a selected field of view (FOV) based on the ROI. These images are then digitally reconstructed into a comprehensive 3D representation (axial, sagittal, and coronal views). Since a single exposure captures the entire FOV, one rotation is sufficient to gather enough data for image reconstruction. Partial exposures have gained popularity because they provide sectional 3D images while further reducing radiation doses for patients [5,6].

Software utilization and the virtual patient

Each CBCT unit comes with dedicated software for acquiring and viewing 3D data. Manufacturers enable clinicians to visualize and interact with the captured images for diagnostic and treatment planning purposes. There are four key methods for viewing 3D data: axial, cross-sectional, panoramic, and 3D reconstruction. Each method is equally important, providing different levels of detail. When combined, they offer the most comprehensive representation of the patient's anatomy. The data can be exported in DICOM format ("Digital Imaging and Communications in Medicine"), which can then be used in various interactive treatment planning applications equipped with innovative tools to enhance the diagnostic and treatment planning process [7,8].

One reason for CBCT's increasing use in dental practice is the rising popularity of guided surgery, which relies on high-quality CBCT images combined with intraoral and extraoral scans (STL and OBJ formats) to create a virtual patient. This virtual patient integrates datasets (DICOM, STL, and OBJ) into a craniofacial model within a virtual environment, making it easier to plan implant positions while considering aesthetic, prosthetic, and surgical requirements [9,10].

For optimal data processing, the FOV dimensions and positioning of CBCT scans must align closely with intraoral and extraoral scans. Most software applications require specific reference points, preferably on hard dental tissues, to align datasets accurately [11,12]. Using CBCT-generated data to create a virtual patient allows the clinician to predict surgical outcomes before treatment begins. The software helps determine the appropriate implant type and size, its relationship to adjacent teeth and vital structures, and the characteristics of the underlying bone. CBCT data is precise and cost-effective, improving communication among the dental team and facilitating better treatment planning. The virtual patient model also allows clinicians to explore multiple treatment scenarios to achieve the optimal aesthetic and functional outcome. Additionally, visualizing the final result using the virtual patient enhances communication with both the patient and the dental technician [13-15].

CBCT indications

The radiation dose produced by 3D diagnostics using CBCT is higher than that emitted by conventional 2D radiological techniques. The risks associated with exposure to imaging procedures are justified only if they are lower than the risks of performing treatment without knowing certain case details that can only be obtained through these diagnostic methods - Primum non nocere (First, do no harm) [16].

CBCT devices are used for diagnostics, treatment planning, and transferring information from these stages to surgical and prosthetic procedures. Initially, CBCT was introduced into dental practice due to its indispensable role in implantology. However, it is now successfully used in oral surgery, orthodontics, endodontics, sleep apnea treatment, joint disorders, periodontology, ENT (ear, nose, and throat), and more [3].

Current standards for replacing missing teeth with dental implants involve both functional requirements and satisfactory aesthetics. Optimal implant placement based on prosthetically driven decisions is essential for meeting these requirements. Prosthetic restorations on implants, if designed following the prosthetically driven implant concept, will yield excellent aesthetic and functional results, along with easier hygiene maintenance, increasing long-term success rates [17].

CBCT produces 3D images that facilitate the transition from the diagnostic phase to image-guided treatment. Some key uses of CBCT in implantology, as mentioned in various professional guidelines, include: identifying critical anatomical areas, preventing neurovascular trauma, addressing challenges in the anterior aesthetic zone, determining the morphology, quantity, and quality of edentulous ridge bone, locating the correct implant placement sites, assessing the relationship between planned implants and adjacent structures, planning and designing surgical guides [18,19]. A CBCT evaluation is also recommended post-treatment for monitoring the success of bone grafts and implant osseointegration, as the benefit far outweighs the risk of radiation exposure [20].

Advantages and disadvantages of CBCT

Digital implant planning and guided implant surgery offer numerous advantages related to optimizing surgical and prosthetic treatment preparation, ensuring successful and predictable implementation. Compared to medical CT scans, CBCT devices are not only more compact and widespread in dentistry but also offer higher accuracy with lower radiation doses and costs, in a much shorter time [5].

Treatment planning with CBCT provides significant benefits for clinicians, allowing implants to be placed without raising mucosal periosteal flaps. This technique benefits not only doctors but also patients, who experience significantly reduced intra- and post-operative discomfort and pain. Detailed preoperative planning ensures a procedure free of unforeseen complications, allowing the clinician to focus on the patient and tissue handling [17].

However, digital implant planning and guided implant placement come with high costs, both for the 3D imaging itself and for designing and manufacturing surgical templates. Additionally, the technical effort required is considerable, requiring not only hardware and software resources but also highly specialized expertise. Thus, experienced and responsible clinicians, along with competent technicians, are essential. They must be aware of the possibilities and limitations of this technology to avoid complications and make reasonable use of CBCT's undeniable advantages for the benefit of the patient [21].

CBCT in modern implantology

Modern oral implantology and implant-supported prosthetics rely on comprehensive diagnostics and precise planning to achieve the desired outcomes for both the patient and the clinician. In this context, digital implant planning using advanced 3D imaging and specialized software is an excellent tool for gathering information and preparing for the procedure based on the projected final result. These methods enhance surgical accuracy and safety, while prosthetic rendering ensures predictability in both aesthetics and function [22,23].

Although 2D imaging, such as panoramic radiography, is useful for assessing a patient's eligibility for implant-supported prosthetic treatment, additional imaging is necessary if treatment is pursued. The growing use of CBCT allows for multiple 3D perspectives, which help determine the correct implant size and placement [24].

CBCT has become a standard in implantology, enabling 3D evaluation and accurate visualization of anatomical structures surrounding the implant site. It allows for an in-depth analysis of bone volume, the alveolar ridge, and the relationship between the future prosthetic restoration, adjacent teeth, and soft tissues. CBCT scanners feature an X-ray source designed to target the head and neck, producing digital DICOM image files that can be analyzed using dedicated software. This allows interactive visualization of the scanned area in three planes (axial, transverse, and coronal), along with a full 3D reconstruction [4].

Within CBCT software platforms, implants can be virtually positioned and analyzed in relation to the anticipated prosthetic outcome, considering adjacent bone structures. The clinician can determine whether the initial bone height will support the final implant restoration or if bone augmentation is necessary [25].

When an implant is placed near a vital structure, 2D radiographs provide limited information, and their inaccuracies can lead to complications, sometimes resulting not only in implant failure but also in severe conditions such as nerve paresthesia. In such cases, patient dissatisfaction may lead to seeking a second opinion from another specialist or even filing a malpractice claim [26].

Clinical Case Report 1

A 35-year-old male patient, without health problems, presents in our clinic with an edentulous space following the extraction of tooth 4.6 approximately four months ago and tooth 4.5 several years ago. It is observed that the adjacent teeth have not migrated to close the gap. Closing the space using an orthodontic appliance was not considered a viable solution, as it would have involved a lengthy and complex procedure of mesializing two mandibular molars with large implantation surfaces. Additionally, it would have left tooth 1.8 without an antagonist, which could have necessitated its extraction—despite being healthy—to prevent it from migrating in search of dental contact. A dental bridge was also not a preferred option, as it would have required the preparation of healthy teeth as abutments. Thus, placing two implant-supported crowns was deemed the best solution, as it is both efficient and avoids unnecessary tooth reduction. The treatment plan with all the options was presented to the patient, who accepted the better version and signed an informed consent, also approving the publication of all case details and any accompanying photos.

A CBCT scan with a small FOV was performed in the right mandibular hemiarch, and the inferior alveolar nerve pathway was traced while measuring bone availability (Figure 1).

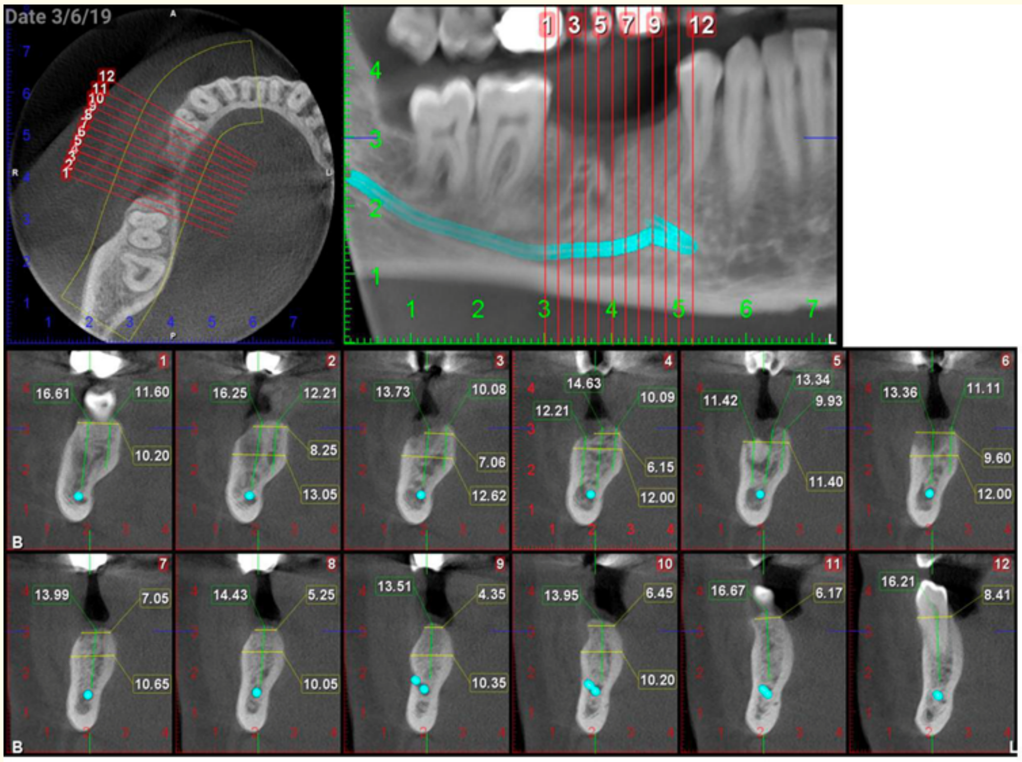


Figure 1: CBCT scan of the right mandibular hemiarch.

The following lengths have been observed:

- The length of the edentulous gap (mesial-distal) of 20 mm.
- The height of the alveolar ridge, measured from the mandibular canal to the crest apex, ranged between 11.42 - 16.67 mm, and at the level of the lingual cortex, between 9.93 - 12.21 mm.
- The width of the alveolar ridge (buccal-lingual) varied between 4.35 - 10.20 mm coronally and 10.05 - 13.05 mm apically, above the mandibular canal.

In the bone area corresponding to the roots of tooth 4.6, a retained root fragment was noted, which was to be extracted during the surgical procedure (Figure 2).

A sufficient space for the prosthetic crowns was assessed. After confirming the proper fit of the future crown within the dental arch, the bone availability was analyzed, and it was decided to insert:

- One implant with a diameter of 3.75 mm and a length of 11.5 mm in the 4.5 position.
- Two implants with a diameter of 3.75 mm and a length of 10 mm in the 4.6 position, to support the molar crown and counteract the increased forces acting on it.

The bone density was assessed as D3 type (thin cortical bone, porous, and dense trabecular bone) with a thin cortical layer in some areas and thick, strong trabecular bone, ensuring excellent vascularization in the implant sites. Primary stability can be im-

Figure 2: Retained root fragment in the area of tooth 46.

proved by using implants with wide threads. The implant axis will pass through the middle of the prosthetic crown, ensuring parallelism with the adjacent teeth. The screw of the restoration will be placed in the central fossa, allowing access to the implant if needed. At this stage, the clinician can order the necessary implants and proceed with the surgical procedure, either using the free-hand technique or by overlapping CBCT data with a digital scan impression to create a surgical guide for guided insertion.

We can observe that the procedure was carried out as planned. The periapical radiograph taken approximately two months after surgery confirmed successful osseointegration of the implants (Figure 3).

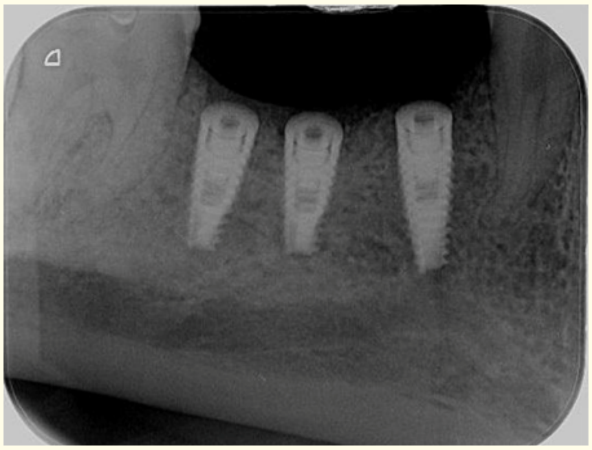


Figure 3: Osseointegration of the implants, two months after surgery.

Three months after the procedure, the implants were uncovered, and healing abutments were placed (Figure 4).

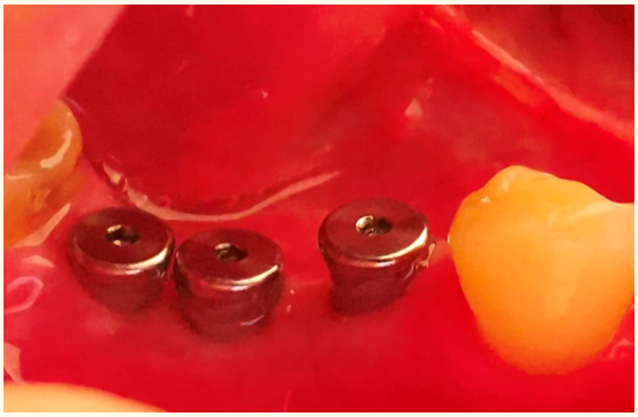


Figure 4: Healing abutments placed on the implants.

Clinical Case Report 2

A 37-year old male patient, without health problems, presents in our clinic with two old single-tooth edentulous spaces: one on the left mandibular arch and the other on the right mandibular arch (Figure 5). These mirror-image edentulous spaces correspond to teeth 3.6 and 4.6, with adjacent teeth that tend to shift into the space due to the absence of dental contact.

It is known that the first permanent molar is the most commonly lost tooth at an early age due to its distal position relative to the

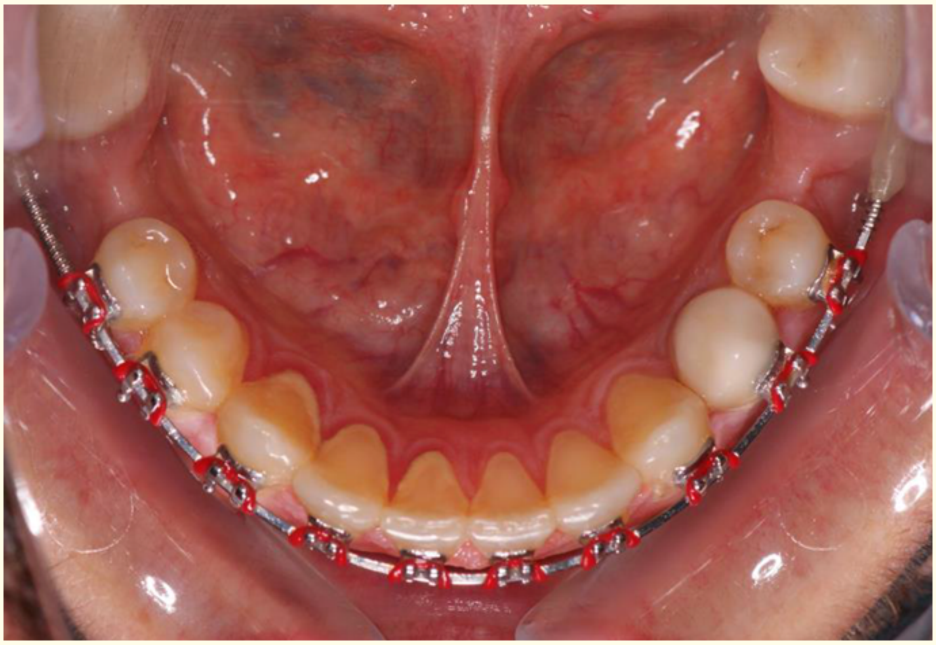


Figure 5: Edentulous spaces corresponding to teeth 3.6 and 4.6.

primary dentition, more challenging access for oral hygiene, and the young age at which it erupts (around six years old—hence the name "six-year molar"). Early loss of the first molar leads to various disturbances, including the migration of opposing teeth and those adjacent to the edentulous space, as well as alveolar ridge atrophy.

In the case of this patient, complete orthodontic closure of the first molar edentulous spaces by mesializing the second mandibular molars was not feasible, as this would have left the second maxillary molars without contact. Therefore, the most suitable solution was orthodontic widening of the edentulous space to create room for an implant-supported crown. A dental bridge could have been considered, but this procedure would have required extensive removal of healthy dental tissue from the abutment teeth. Our team presented all the options treatment and the patient agree with the best one, signing an informed consent, also approving the publication of all case details and any accompanying photos.

After the orthodontic widening of the edentulous space, a CBCT scan was performed with a medium-sized FOV at the mandibular level to plan the insertion of dental implants that would support the future prosthetic restoration. The CBCT imaging was analyzed by tracing the path of the inferior alveolar nerve and measuring bone availability (Figure 6, 7).

For the 3.6 space:

- The length of the edentulous gap (mesio-distal) was 6 mm.
- The alveolar ridge height, measured from the level of the mandibular canal to the ridge apex, ranged between 14.4 and 15.8 mm.
- The alveolar ridge width (vestibulo-lingual) ranged from 5.1 to 5.9 mm coronally and 10 to 10.3 mm apically, above the mandibular canal.

For the 4.6 space:

- The length of the edentulous gap (mesial-distal) was 7 mm.
- The alveolar ridge height, measured from the level of the mandibular canal to the ridge apex, ranged between 13.9 and 15.6 mm.
- The alveolar ridge width (buccal-lingual) ranged from 5.3 to 6.6 mm coronally and 9.5 to 10.7 mm apically, above the mandibular canal.

The available space was deemed sufficient for the prosthetic crowns. Although the long-standing edentulous condition resulted in slight bone resorption, the ridge dimensions were satisfactory both mesial-distal and buccal-lingual. Additionally, a distance of more than 1 cm from the gingival level to the occlusal plane was observed for both edentulous spaces, allowing for easy placement of the planned prosthetic restorations within the dental arch.

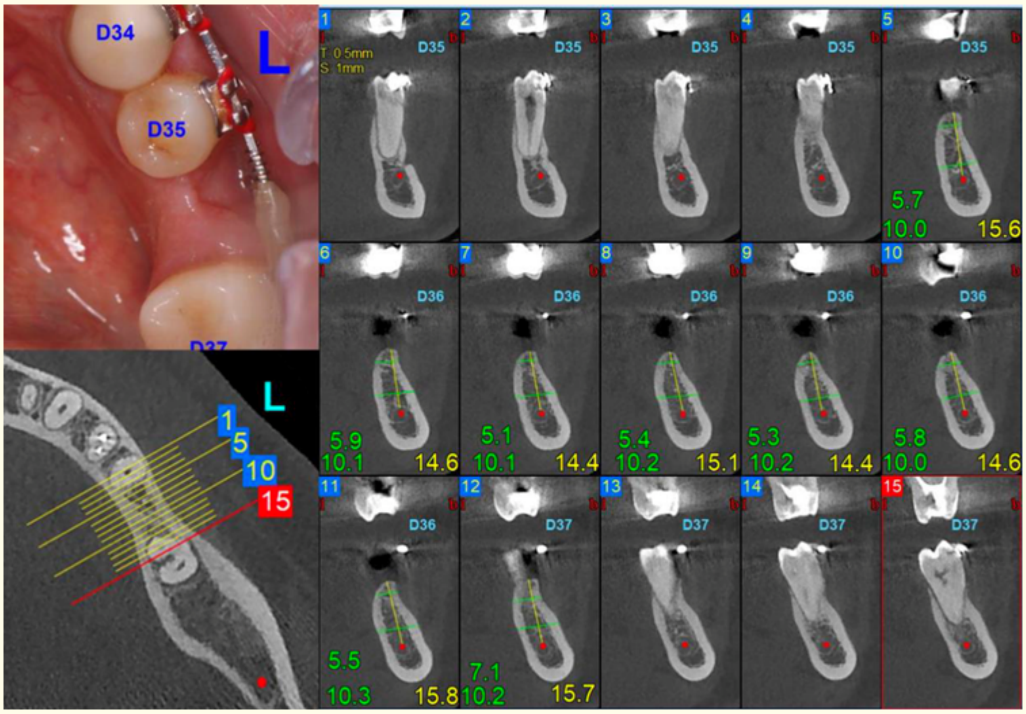


Figure 6: The CBCT imaging of the left side.

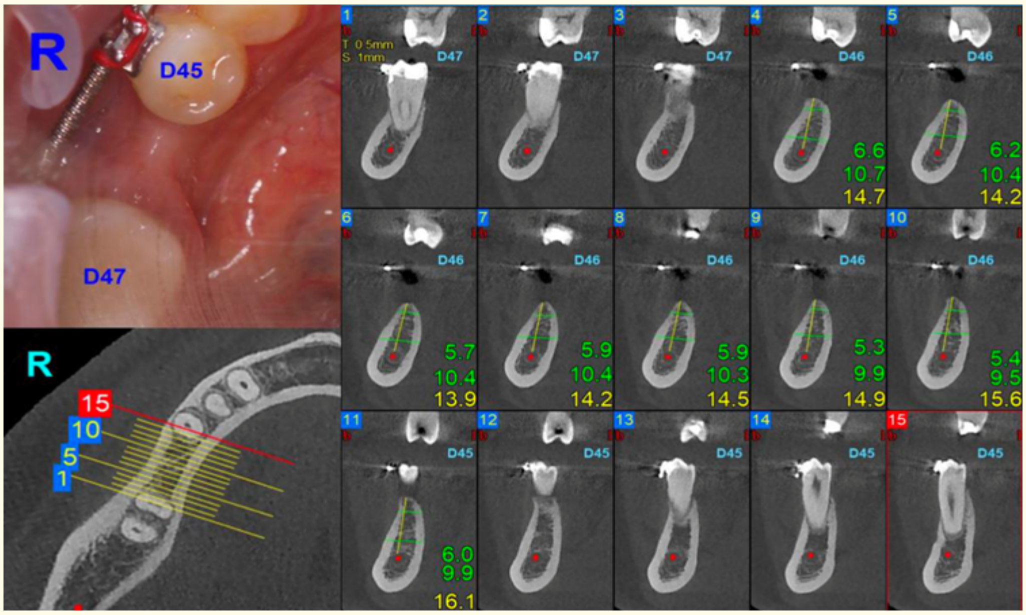
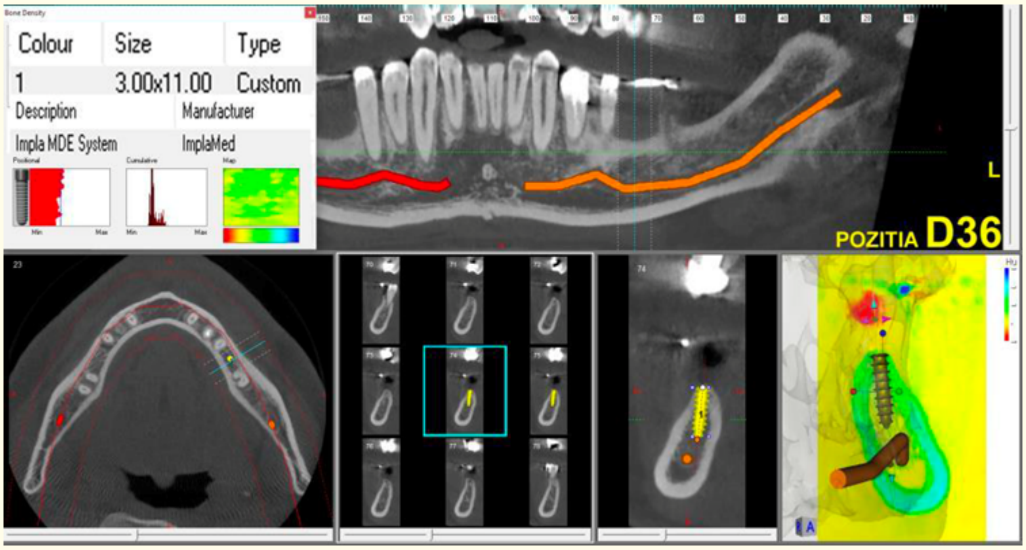


Figure 7: The CBCT imaging of the right side.

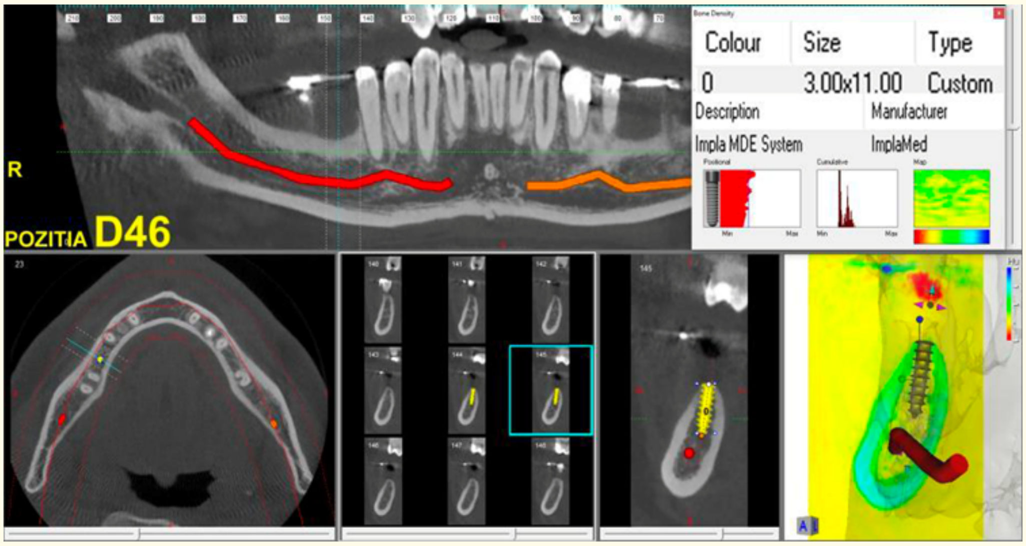
After confirming that there was enough space for the future crowns and assessing the bone availability, it was decided to insert two identical dental implants (Figure 8, 9), each with a diameter of 3 mm and a length of 11 mm, ensuring a safety distance of more than 2 mm from the inferior alveolar nerve. The bone density was classified as D2, providing excellent conditions for osseointegration due to satisfactory vascularization. To ensure good primary stability, implants with fine and dense threads at the neck (corresponding to the cortical bone) and wide threads at the body (corresponding to the cancellous bone) can be inserted.



Colour	Size	Type
1	3.00x11.00	Custom

Description	Manufacturer
Impla MDE System	ImplaMed

Figure 8: Dental implant, 3 mm diameter x 11 mm length mm on the position of tooth 36; the safety distance of more than 2 mm from the inferior alveolar nerve.



Colour	Size	Type
0	3.00x11.00	Custom

Description	Manufacturer
Impla MDE System	ImplaMed

Figure 9: Dental implant, 3 mm diameter x 11 mm length mm on the position of tooth 46; the safety distance of more than 2 mm from the inferior alveolar nerve.

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The implant axes will pass through the middle point of the prosthetic crowns and run parallel to the axes of the adjacent teeth. The screw access hole is designed to be located in the central fossa, ensuring access to the implant if needed.

With the treatment plan prepared, the clinician can order the necessary implants for insertion using the “free-hand” technique or proceed with digital impression-taking of the prosthetic field to perform the procedure with the help of a surgical guide for a more accurate and safer approach.

Discussion

The two cases presented in this study, while both aiming for prosthetic rehabilitation using implants for the edentulous first mandibular molar, required distinct planning approaches tailored to the unique characteristics of each patient. Factors such as the duration of edentulism, the condition and positioning of adjacent teeth, and the forces exerted on the edentulous area were carefully considered in the planning process. Restoring a single missing tooth in the mandibular molar region presents significant challenges, particularly due to the limited space available for implant placement. The migration of adjacent teeth into the edentulous gap further complicates the procedure, necessitating precise planning to ensure proper implant positioning and functional restoration.

One of the key advantages of CBCT-assisted implant planning is its ability to accurately trace the path of the inferior alveolar nerve and measure the bone distance from the ridge crest [27]. This critical information helps avoid potential nerve injury during implant placement, thereby enhancing the safety and success of the procedure.

The use of digital implant treatment planning, particularly the “crown-down” technique, offers the clinician a strategic advantage by allowing the prosthetic restoration to be digitally designed first [28]. This approach not only ensures that the final restoration meets functional and aesthetic goals but also allows for the subsequent adaptation of implant positions to accommodate the ideal prosthetic outcome.

Furthermore, the implementation of a 3D workflow significantly enhances intraoperative efficiency [29]. The additional diagnostic insights provided by this technology streamline the treatment process and improve the overall quality of care, especially during the initial treatment stages. The success of implant placement hinges on achieving primary stability and proper osseointegration. By ensuring these factors are met, the long-term success of the implant is secured. Effective planning plays a crucial role in preventing potential intraoperative complications, as it enables precise placement and reduces the risk of errors.

Finally, the use of a virtual model in treatment planning promotes collaboration among multidisciplinary teams [30], facilitating comprehensive care and ensuring that the restorative outcome is optimized across all aspects of the procedure.

Conclusion

3D imaging, particularly CBCT, offers significant advantages over traditional 2D radiographs by providing highly detailed, three-dimensional views of the implant site. This advanced imaging technology enables precise manipulation along all three axes, allowing for optimal implant placement within the available bone while ensuring a safe distance from critical anatomical structures.

The integration of CBCT technology, paired with specialized software, has been instrumental in enhancing the success and predictability of dental implant procedures. As a result, dental implants have become an increasingly reliable solution for prosthetic restorations, with CBCT playing a central role in the growing field of implantology. This advancement allows clinicians to make more informed decisions, ultimately improving the safety and efficiency of surgical procedures.

While CBCT does involve additional costs, the technology provides considerable value by preventing complications that could lead to more expensive interventions or even malpractice claims. The precision and risk mitigation offered by CBCT result in long-term cost savings and better patient outcomes.

Furthermore, the accurate transfer of computer-generated treatment plans into the clinical setting remains crucial to successful implant placement. Surgical guides derived from these digital plans serve as essential tools, ensuring that the treatment protocol is carried out with precision and improving the overall success of the procedure.

The incorporation of CBCT and digital planning has become an essential component of modern implantology, significantly enhancing the predictability, safety, and outcomes of dental implant treatments.

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