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Smartphone-Based Augmented Reality Application for Dental Implant placement: A Technical Innovation

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

All authors contributed to the technical note conception and design. Material preparation, conceptualization, data collection and analysis were performed by TS, RM, FT, CvS and DT. The first draft of the manuscript was written by PG and FP-M and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Ethics approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The study protocol was approved by institutional Ethics committee. Informed consent was obtained from all individual participants included in the technical note.

Consent to participate

The patient received a thorough explanation of the proposed report, gave his oral and written informed consent to be included in this report as well as for publication of these case, anonymous data, and pictures. A copy of the written consent is available for review by the Editor-in-Chief of this journal on request.

Consent to publish

The authors confirm that the patient gave informed consent for publication of the images.

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ABSTRACT

Accurate dental implant fixture placement is critical for optimal restorative functional and esthetic outcomes. Computer-assisted implant surgery (CAIS), including static (sCAIS) and dynamic (dCAIS) systems, improves accuracy compared to freehand techniques. Augmented reality (AR) offers further benefits by integrating preoperative planning with real-time intraoperative visualization, enhancing surgical results and providing valuable tools for training future implantologists. However, high costs and technological complexity have limited its widespread adoption.

This technical note presents the first clinical application of a mobile-visualized AR navigation system. While the intraoperative interface operates on a smartphone, the system is built upon a comprehensive digital workflow involving CBCT imaging, intraoral scanning, photographic data, and bite registration for dynamic implant navigation in the anterior maxilla. Postoperative analysis showed maximum deviations of 2.0 mm in implant apex position and 9.15° in angulation from the planned trajectory. These results confirm accurate implant placement and support the feasibility of smartphone-based AR as a cost-effective, accessible solution for digital navigation in implantology. Further research with larger sample sizes is warranted to validate these preliminary findings.

KEYWORDS

dental implant; augmented reality; computer-assisted surgery; esthetic zone; smartphone; technical innovation.

INNOVATION

The purpose of this technical report is to describe the first clinical use of a smartphone- augmented reality (AR) guidance system, with intraoperative visualization executed via a smartphone interface, integrated into a dynamic computer-assisted implant surgery (dCAIS) workflow that includes CBCT, intraoral scanning, photographic, and occlusal data acquisition. This innovative approach enables real-time intraoperative visualization and guidance during dental implant placement, while leveraging the cost-effectiveness and accessibility of mobile technology.

Accurate dental implant placement, which is key to achieving the desired esthetic outcomes and ensuring optimal prosthetic function and long-term durability,^{1,2} has been significantly improved by advancements in digital technologies such as computer-assisted implant surgery (CAIS).³ These technologies, developed specifically to reduce error rates, have demonstrated superior outcomes when compared with freehand techniques.^{4,5} The utilization of three-dimensional (3D) datasets not only facilitates the optimization of implant position prior to surgery but also enables the integration of virtual visualization of anatomical structures, intraoral conditions, and prosthetic objectives.^{6,7}

These plans are implemented either statically (sCAIS)⁸ using surgical guides or dynamically (dCAIS)^{9,10} using real-time tracking systems. The sCAIS technique uses a pre-made guide template to facilitate CAIS.¹¹ The dCAIS method uses a fixed optical tracking system to monitor the position of surgical instruments and the patient in real time and display these data on a screen, which enables intraoperative adjustments and reduces spatial requirements, offering a more flexible approach to implant surgery.^{12,13}

Augmented reality (AR) enables the overlay of digital surgical plans directly onto the physical operative field, enhancing visual guidance during implant placement.^{14,15,16}

This integration enables real-time visualization of preoperatively planned implant position and angulation and calibration of surgical instruments and anatomical structures, such as the mandibular inferior alveolar nerve, thereby reducing the risk of complications and allowing a more personalized and precise approach for satisfactory treatment outcomes.^{6,17} Moreover, the technology can better explain interventions to patients through visualization, thus potentially increasing patient satisfaction.

Besides improved surgical outcomes, AR offers great potential in educating and training surgical procedures, such as dental implant surgery. Students and surgical residents are able to practice and refine their skills virtually through immersive simulations and training without any limitations before performing the procedure on an actual patient. The detailed visualization of complex anatomical structures in real-time deepens their understanding of the procedures, enabling more precise planning and execution. Their ability to react to unforeseen circumstances improves as they engage in continuous scenario-based training, which in turn, can contribute to an increase in both confidence and performance efficacy in terms of actual procedures.^{14,18}

However, implementing AR is associated with high costs and technological complexity, including the need for hardware components such as displays, cameras, sensors, often virtual reality (VR) glasses, and software. Nevertheless, modern smartphones now provide sufficient hardware with advanced cameras and displays and

increased computing power. Therefore, smartphone applications (Apps) and software can be considered relatively cost-effective and easily accessible for implementing AR in dentistry and implantology.^{14,18}

ADVANTAGE

Compared to conventional AR and dCAIS systems, the smartphone-based application offers a cost-effective, accessible, and user-friendly solution that integrates seamlessly into clinical workflows. The presented approach leverages smartphone technology as a portable, accessible interface for visualizing digitally planned implant procedures. However, it operates in conjunction with a structured workflow comprising CBCT imaging, intraoral and facial scans, and digital prosthetic planning software.

SIGNIFICANCE

The presented approach holds significant potential for expanding access to digital surgical navigation in dental implantology. By leveraging widely available smartphone technology, the system enables cost-effective and scalable AR-assisted guidance without requiring specialized equipment.

Clinically, this may improve the accuracy of implant placement, reduce procedural errors, and enhance patient outcomes. Additionally, the system facilitates immersive preclinical training and surgical education, offering students and residents a low-barrier entry into digital navigation systems.

Its compatibility with standard clinical workflows and mobile hardware further supports adoption in both high-resource and underserved settings, aligning with broader efforts to democratize access to advanced surgical technologies.

A pre-operative cone-beam computed tomography (CBCT) scan of the patient's edentulous site was taken using ProMax 3.9.4 (Planmeca, Helsinki, Finland) to provide the App with basic restorative and surgical planning information. Romexis® 6.0.1.812 (Planmeca, Helsinki, Finland) was used to accurately align the planned implant position with a comprehensive reference provided by the 3D image. The implant position in relation to the 3D image was exported in standard tessellation language format. The teeth, implant axes, and different structures were then color-coded. The resulting digital model and axes were exported in Filmbox (FBX) format for subsequent integration into the navigation system.

The data and implant positions were transferred to the App, which uses the smartphone's built-in camera with autofocus to create an AR environment that transfers the virtual implant plan to a realistic counterpart. The App was then installed on a Samsung Galaxy s22 mobile phone (Samsung, Seoul, South Korea). We used an AI-based solution (Vuforia) that enabled single-camera tracking from multiple angles and distances, eliminating the need for the more conventionally extensive and complex dCAIS setups.

The patient's condition was first tested and trained using a 3D-printed patient model on a phantom head to exclude technical and practical error rates for dental implant insertion.

A digitally designed training model, inspired by the Frasaco model (Frasaco, Tettang, Germany), was developed using Autodesk Netfabb 2021.1 (Autodesk, San Francisco, USA). This model was specifically designed to simulate a Kennedy Class IV. A key feature of the design was the incorporation of a recess within the edentulous space, facilitating the placement of a milled Sawbone component (Pacific Research Laboratories, Inc., Vashon, USA). The model was produced using a 3D printer (Varseo L; BEGO, Bremen, Germany) with Varseo-Wax Model material (BEGO, Bremen, Germany), achieving a resolution of 50 microns. Similarly, the Sawbone component (Pacific Research Laboratories Inc., Vashon Island, USA) was precisely milled using a Pocket NC V2-10 milling machine (Penta Machine Company, Belgrade, USA) with a resolution of 6.1 μm .

Uniform lighting conditions were achieved using two Andoer MS-30 L LED lights (Shenzhen Tomtop Technology Co., Shenzhen, China). After demonstrating the functionality and practical implementation of the App, it was used in this subsequent clinical technical note.¹⁸

To ensure practical usability and clinical confidence, the AR interface was designed to provide clear visual guidance of the planned implant position and angulation in real time. This includes the projection of the digital implant axis, alignment markers, and spatial cues relative to surrounding anatomical landmarks. During the clinical application, the visual information was displayed continuously on a tablet within the surgeon's field of view. This setup allowed the operator to validate alignment intuitively and adjust instrument positioning accordingly. Nonetheless, further refinements and validation studies are necessary to optimize the interface design and ensure consistent interpretation across users with varying levels of digital experience.

EVIDENCE

A 52-year-old male patient presented with the request for implant-supported restoration in the anterior maxilla. The maxillary right central incisor was previously extracted, and the adjacent maxillary left central incisor had a poor prognosis (Figures 1A and 5A). Both lateral incisors were part of a failing four-unit bridge and were deemed non-restorable due to chronic apical periodontitis. All four teeth were extracted under local anesthesia (articaine 4% with 1:200,000 epinephrine) following elevation of a mucoperiosteal flap and thorough curettage. Guided bone regeneration was performed using a cancellous particulate allograft and a bovine pericardium membrane to preserve ridge volume. The site was closed with non-resorbable polypropylene sutures.

Prior to tooth extraction, diagnostic impressions of both arches were taken (Figures 1B and 5B). A removable temporary restoration was fabricated to maintain esthetics and function during healing. Eight months post-extraction, and following clinical and radiological evaluation, four implants were planned for placement at the positions of both maxillary central and lateral incisors.

Preoperatively, an intraoral digital scan, CBCT scan, and facial photographs were acquired. Planning was performed using digital backward planning software based on CBCT and intraoral scans, photographs, and occlusal data. The processed output was then transferred to the AR interface on the smartphone for intraoperative guidance. A phantom model simulating the patient's anatomy was fabricated using additive and subtractive manufacturing techniques to validate the AR workflow and minimize potential sources of error.

Implant placement was performed under local anesthesia as part of a live demonstration in an educational setting. The surgical procedure was guided entirely using the smartphone-based AR application displayed on a tablet positioned in the operator's visual field (Figures 2A and 2B). A mucoperiosteal flap was raised from canine to canine, and osteotomies were prepared under AR guidance. All four implants (BEGO S-Line, 11.5×3.25 mm) were placed according to the visual overlay of the preoperative plan. Cover screws were inserted and the site was closed with polypropylene sutures.

Postoperative healing was uneventful (Figure 1C). Sutures were removed after 10 days, and uncovering of the implants occurred after seven months. A digital prosthetic workflow followed, including intraoral scanning, facial scanning, and virtual articulation. Individual zirconia crowns were fabricated and delivered approximately ten months after surgery. Tooth-supported restoration of the maxillary right canine, which had served as an abutment for the temporary appliance, was completed thereafter. (Figures 3A, 3B, and 5C).

To assess the accuracy of implant placement, a postoperative CBCT scan was superimposed onto the preoperative planning dataset using a standard image registration and alignment protocol. Deviations in implant apex position and angular orientation were calculated by comparing the planned and actual implant positions in three-dimensional space. The measurements included linear deviation (in mm) at the implant apex and angular deviation (in degrees) between planned and placed implant axes. The mean apex deviation was 1.38 ± 0.51 mm (range: 0.86–2.00 mm), and the mean angular deviation was $5.31^\circ \pm 3.44^\circ$ (range: 0.95° – 9.15°) (Figure 4). According to commonly accepted thresholds in dental implantology (<1 mm linear and $<3^\circ$ angular deviation), three of the four implants were within these limits, while one implant exceeded both thresholds. These results indicate variable accuracy across sites and demonstrate the feasibility of AR-guided navigation using a smartphone-based system in a clinical setting.

CHALLENGES

Despite its promising results, the clinical implementation of a smartphone-based augmented reality (AR) system for dynamic implant navigation presents several challenges.

First, the system remains dependent on the user's ability to correctly interpret and align the AR overlay in real time. Variability in lighting conditions, as experienced in our case, can affect the projection quality and result in brief mismatches between the virtual and actual anatomy. Although easily recognized and corrected by an experienced surgeon, such issues underline the importance of visual awareness and consistent intraoperative validation. Given the system's current sensitivity to lighting conditions, its preferential use in the anterior region is recommended, where visibility and access are generally more favorable. This aligns with the clinical case presented in this report.

Second, while smartphones are broadly available, their use as surgical AR tools requires mounting systems that do not disrupt the clinical workflow. Extended procedures may lead to ergonomic strain if the device must be handheld or awkwardly positioned. Integrating fixed mounts or lightweight head-mounted displays could address this concern, but these additions require careful balancing of cost, usability, and sterility.

Furthermore, although the application interface was designed to be intuitive, there remains a learning curve—especially for clinicians unfamiliar with digital workflows or AR environments. Broader adoption would require structured training modules and possibly certification pathways to ensure safe and effective use.

Finally, data protection and cybersecurity concerns must be addressed before large-scale deployment. In this initial case, the application was installed via a direct connection without internet dependency. However, future integration into clinical environments will require secure data handling, compliance with data protection regulations, and possibly the use of encrypted or institutionally managed devices.

TIME

The implementation of smartphone-based AR for dynamic implant surgery could be realized in clinical practice within a relatively short time frame. As the system relies exclusively on widely available consumer hardware, such as smartphones or tablets, the technical barriers to deployment are low. The application can be installed offline and does not require specialized equipment, making same-day implementation possible in clinics already familiar with digital workflows.

However, broader integration into routine practice depends on several factors. These include the development of standardized mounting solutions, integration into existing surgical protocols, and the creation of training programs to ensure proper use. With institutional support and minimal regulatory obstacles, pilot adoption in educational or digitally oriented clinics could begin immediately, with widespread use achievable within 12–24 months.

The rapid evolution of mobile technology and AR development platforms supports a favorable outlook for timely adoption. As user interfaces become more intuitive and real-time visualization improves, smartphone-based AR has the potential to become a mainstream tool in guided implantology within the near future.

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

All authors contributed to the technical note conception and design. Material preparation, conceptualization, data collection and analysis were performed by TS, RM, FT, CvS and DT. The first draft of the manuscript was written by PG and FP-M and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Ethics approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The study protocol was approved by institutional Ethics committee. Informed consent was obtained from all individual participants included in the technical note.

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Consent to publish

The authors confirm that the patient gave informed consent for publication of the images.

FIGURE LEGENDS

Figure 1.

Cone-beam computed tomography scan before surgical removal of the maxillary lateral and central incisors (A), after guided bone regeneration (B), and after implant insertion at the sites of both maxillary lateral and central incisors (C).

Figure 2.

The position and angulation of the pilot and the further depth drills were executed according to the augmented reality app's guidance (A + B).

Figure 3.

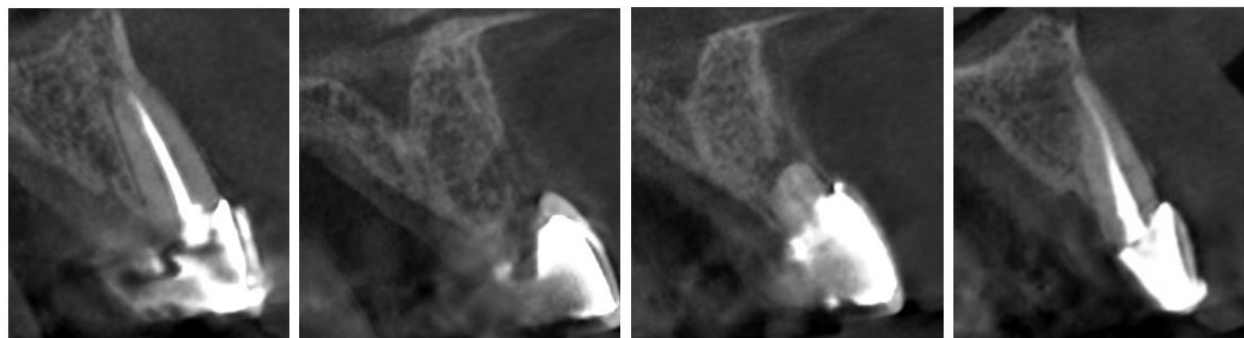
Clinical pictures after handover of the prosthetic treatment (A + B).

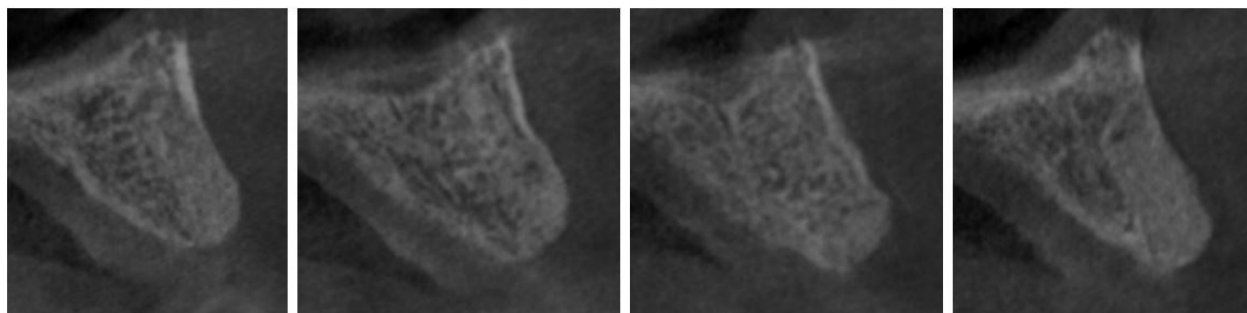
Figure 4.

Illustration of the deviations between the planned and actual implant positions in the maxillary lateral and central incisor regions: right lateral incisor (A), right central incisor (B), left central incisor (C), and left lateral incisor (D).

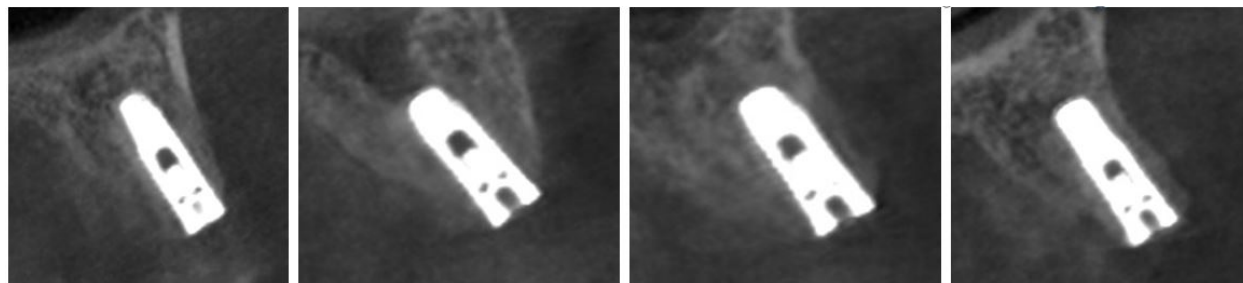
Figure 5.

Orthopantomographic course before surgical removal of the maxillary lateral and central incisors (A), after guided bone regeneration (B), and after implant placement in the same regions (C).





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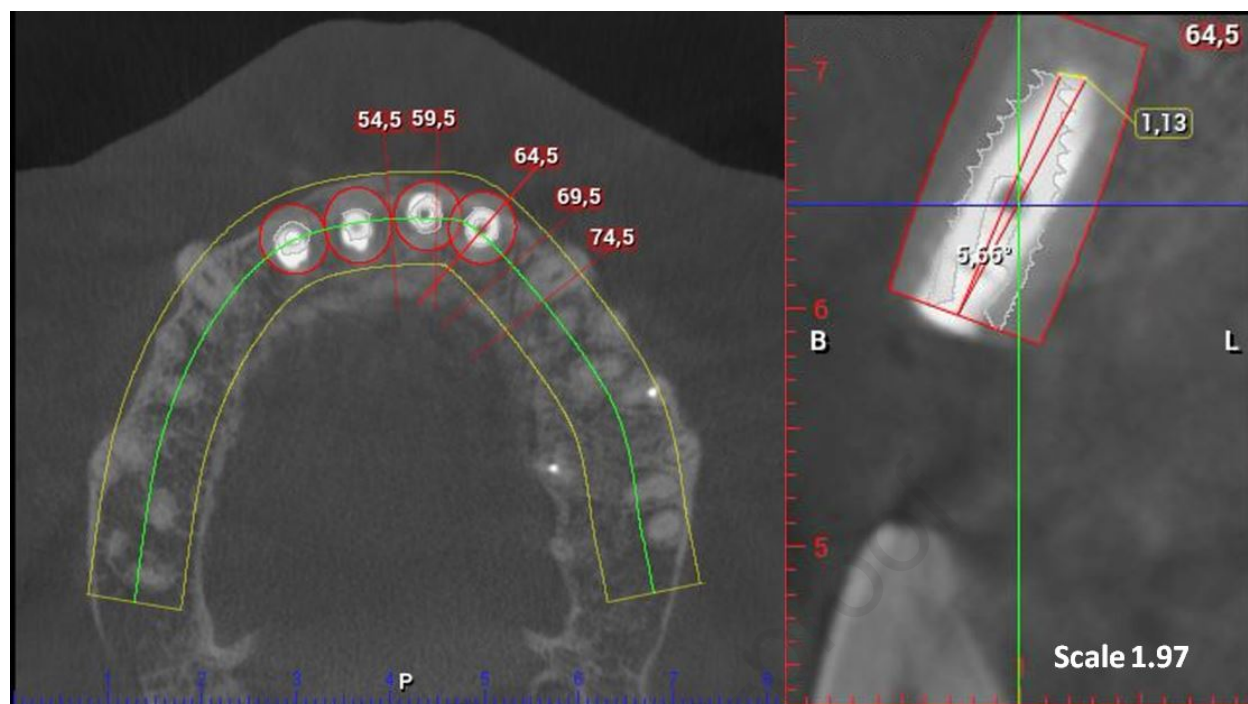


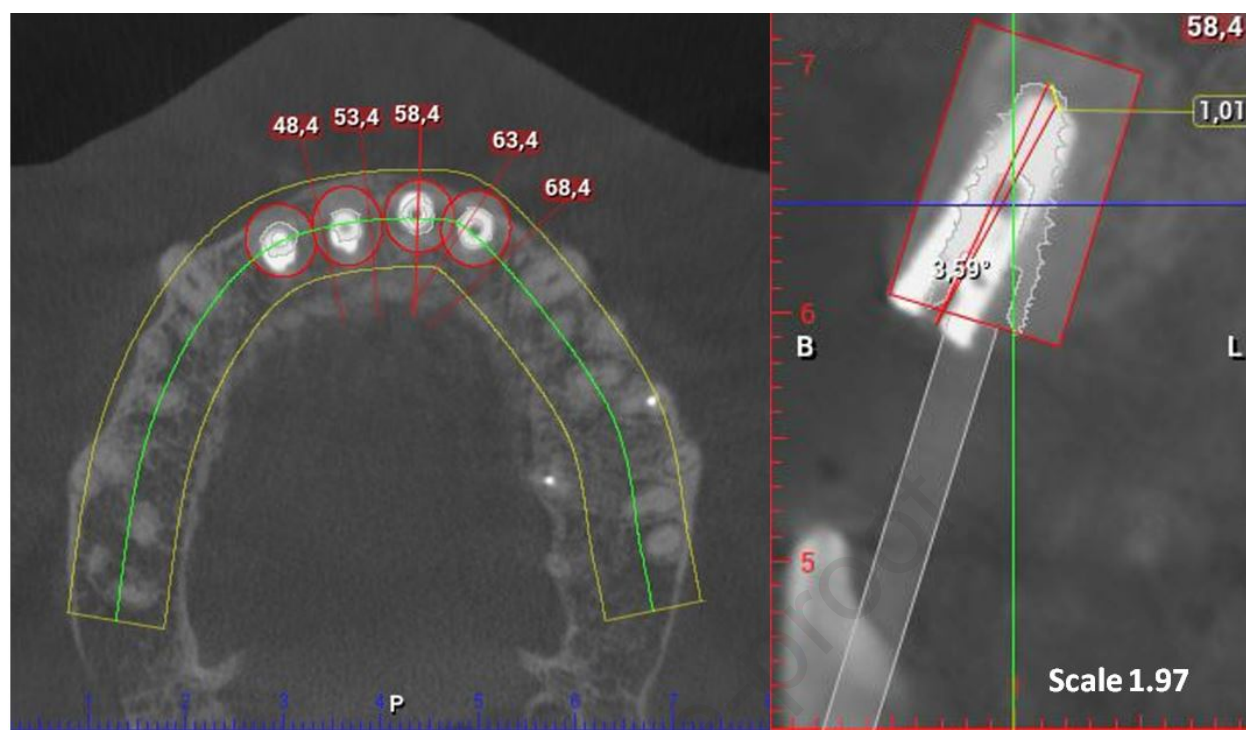


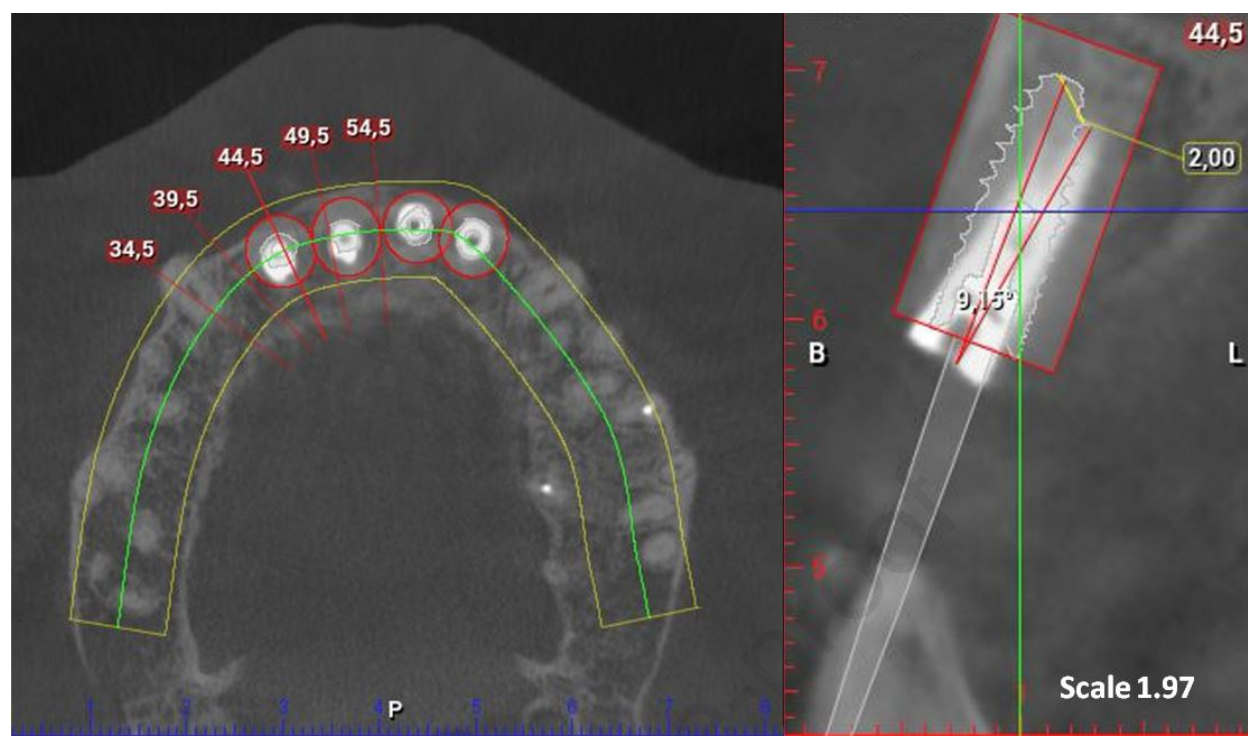
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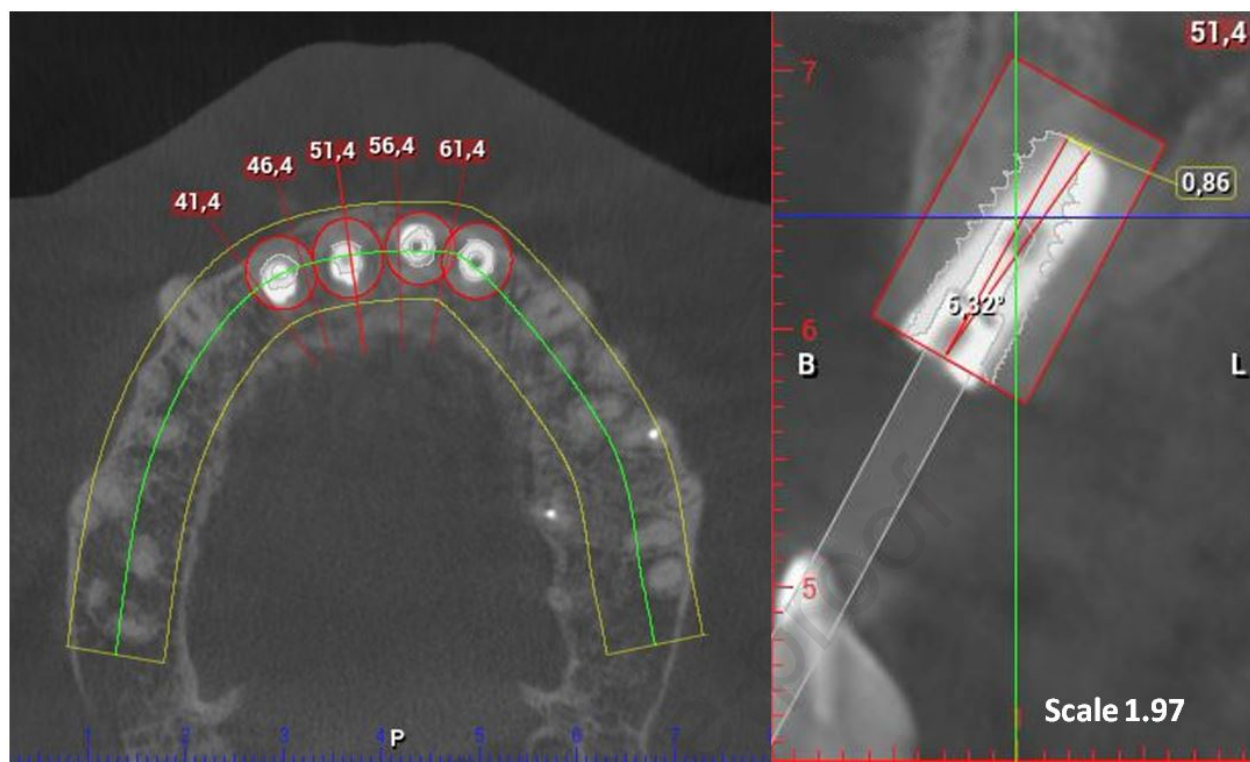


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