1.5 T MRI with a Dedicated Dental Signal-Amplification Coil as Noninvasive, Radiation-Free Alternative to CBCT in Presurgical Implant Planning Procedures

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Purpose: Cone beam computed tomography (CBCT) is considered both reliable and safe and provides reproducible results in guided dental implant planning procedures. However, it has weaknesses in soft tissue contrast and is associated with radiation exposure. Recent studies showed promising results with magnetic resonance imaging (MRI) as a possible noninvasive, radiation-free, alternative imaging modality for dental indications. The purpose of this study was to evaluate the quality of 1.5 T MRI with a dedicated dental signal-amplification coil in comparison to CBCT for dental implant planning procedures. Materials and Methods: Sixteen subjects undergoing preoperative MRI (3D HR T1w TSE and 3D HR T1w FFE) and CBCT were included in this prospective study. All imaging data were used for dental implant planning procedures using commercially available software. Two experts scored the planning as “ideal,” “improvable,” or “unacceptable.” Furthermore, quantitative distances according to EuCC recommendations were collected. Finally, discrepancies between CBCT and 3D HR T1w TSE were analyzed. Statistical analysis was performed using the Mann-Whitney U test and analysis of variance (ANOVA). Results: The dental implant planning procedure was technically feasible using all imaging data. CBCT allowed for “ideal” placement in all cases. Ratings for 3D HR T1w TSE and 3D HR T1w FFE were 81.9%, 18.1%, and 0% and 54.2%, 30.0%, and 15.3% for ideal, improvable, and unacceptable, respectively, identifying 3D HR T1w TSE as superior compared with 3D HR T1w FFE. Head-to-head comparison between CBCT and 3D HR T1w TSE revealed no significant differences regarding the apical position of the implant of 1.2 ± 0.7 mm and 1.3 ± 0.5 mm coronally, respectively (P = .287). The deviation of the placed angle was 3.0 ± 1.2 degrees. In these merged data sets, the distance to the mandibular canal was significantly higher with 1.3 ± 0.8 mm, indicating better utilization of the existing bone. Conclusion: Within the limits of this pilot study, it can be reported that the dental image planning procedure is feasible using 1.5 T MRI with a dedicated dental coil and specific MRI sequences. Int J Oral Maxillofac Implants 2021;36:1211–1218. doi: 10.11607/jomi.8103

Keywords: cone beam computed tomography (CBCT), magnetic resonance imaging (MRI), dental signal amplification coil, surgical guide, dental implant surgery

A 3D dental implant planning procedure is done to determine the best achievable prosthetic result with optimal use of the available bone. For reliable, safe, and reproducible results, it is an indispensable prerequisite to clearly depict adjacent anatomical structures of functional importance, such as nerves, vessels, sinuses, and teeth as well as the cortical bone. This can be achieved by detailed imaging of both hard and soft tissue. For guided implant planning procedures and oral surgical treatments, the standard diagnostic imaging modality is cone beam computed tomography (CBCT), due to its high resolution and contrast in the treatment area at a low radiation dose. An implant planning procedure based on CBCT data allows reduction of the risk of harming anatomical structures and avoidance of critical proximity in multiple implantations.

Yet, CBCT is still associated with ionizing radiation, which is known to cause tissue-damaging effects. In light of dental imaging, the negative effects on the highly radiosensitive lens need to be highlighted; beyond that, radiation may further lead to thyroid carcinomas or meningiomas. Therefore, the demand for radiation-free 3D imaging modalities has always been present.
Moreover, imaging of soft tissues, such as the inferior alveolar nerve in the posterior mandible, has limitations in CBCT. Here, reliable nerve imaging is limited by the blooming of bone and the intrinsically low soft tissue contrast in CBCT.

Recent studies showed promising results with magnetic resonance imaging (MRI) as a possible alternative imaging modality for dental indications.\textsuperscript{12,13} Yet, MRI data acquisition is time-consuming, requiring a tradeoff between image quality and acquisition times. Higher field strength, dedicated coil systems, and optimized sequences rendered MRI a promising imaging modality in dental implantology.\textsuperscript{12,14–17} Pulse sequences suggested for use in dental imaging include (1) 3D high-resolution T1-weighted turbo-spin echo sequences (3D HR T1w TSE), which allow for acquisition of anatomical images while demonstrating little susceptibility toward image artifacts; and (2) 3D high-resolution T1-weighted fast field gradient echo sequences (3D HR T1w TSE), which allow for fast acquisition of anatomical high-resolution 3D data sets while being more susceptible toward artifacts. All images are stored in the so-called Digital Imaging and Communications in Medicine files (DICOM format), allowing for standardized postprocessing using a variety of software solutions.

The aim of this study was to evaluate if the routinely used MRI sequences for dental application allow sufficient 3D implant planning procedures in comparison to standard CBCT data sets.

**MATERIALS AND METHODS**

The institutional review board approved this single-center, prospective study (No. 14-413). Written informed consent was obtained from all individuals.

**Inclusion criteria were as follows:**

- Study period: January 1, 2016 to December 31, 2017
- Age > 18 years
- Clinically indicated need for CBCT-based implant planning procedures due to an edentulous tooth span

**Exclusion criteria were as follows:**

- Lacking ability to provide informed consent
- No clinical indication for CBCT
- Contraindication for MRI (ie, patients with cardiac stimulators, pregnancy or claustrophobia, ferromagnetic implants [eg, retainers, unremovable piercings, prosthetic crowns, osteosyntheses], or tattoos)
- ASA score > 3

CBCT and MRI diagnostics were obtained for each patient within a time frame of 24 hours to 6 months.

**CBCT Imaging**

All CBCT scans were performed using a clinically available CBCT (GALILEOS Comfort CBCT, Dentsply Sirona) with 85 kV, 5 to 7 mA, and radiation exposure between 10 and 42 mAs. The effective exposure time ranged from 2 to 14 seconds. The radiation detector consists of a 9-inch (23-cm) image amplifier and a CCD camera system with a volume of 512 × 512 × 512 pixels with 0.3-mm voxels generating a spherical volume of 15 cm as field of view. A complete rotation took 14 seconds.

**MRI**

MRI data sets were obtained by a 1.5 tesla (T) MRI system (Philips Achieva, Philips Health Systems). Here, a special modified version of an orbital 4-channel coil (Dental 4-channel coil v2, Noras) was placed directly on the skin of the maxilla and mandible. Parasagittal 3D HR T1w TSE and 3D HR T1w FFE sequences were acquired using a constant pulse sequence (Table 1).

**Postprocessing**

In total, 22 implants were virtually positioned using commercially available implant planning software (SiCAT Implant, SiCAT) in both CBCT and MRI (3D HR T1w FFE and 3D HR T1w TSE sequences, respectively) data sets (Figs 1 to 3), resulting in a total of 66 planning procedures: 22 implants in three image data sets (CBCT, 3D HR T1w TSE, and 3D HR T1w FFE).

**Qualitative Assessment**

Two highly experienced oral surgeons (A.G., N.P.) evaluated the implant planning procedures using standardized criteria based upon surrounding anatomical
landmarks adhering to principles of the 9th European Consensus Conference (EuCC). Following EuCC, an ideal implant position requires a visual safety distance of 2 mm to the mandibular canal, 3 to 5 mm to the mental foramen, and 1 mm to adjacent tooth roots on the apical level and 1.5 to 2 mm on the coronal level. The implant axis and apicocoronal position were determined by these distances.

Eventually, the implant positions were rated as ideal, improvable, or unacceptable based on consensus agreement by both experts. Improvable implant position means a position worse than ideal but without damaging surrounding anatomical landmarks, for example, the mandibular canal or adjacent tooth roots. Not acceptable means an implant position without prosthetic fitting or with damaging surrounding anatomical landmarks.
In addition, the implant planning procedures performed on the 3D HR T1w TSE sequence were merged with the CBCT volume data to allow evaluation of the quality of the MRI-based planning within the information context of the CBCT. The quality of the MRI-based surgical planning is described by the quantity of deviation compared with CBCT-only planning. This approach facilitates an unbiased comparison of the implant position quality achievable in CBCT and MRI. This discrepancy was quantified as follows: A two-step spatial registration process was applied to determine the relative positions of the corresponding anatomy in MRI and CBCT scans and to transform implant positions and orientations between them. First, the pulps of three different teeth near the implant site were identified as landmarks in both MRI and CBCT. Afterward, these corresponding landmarks were coarsely matched in both volumes. This coarse registration was fine-tuned using Brainsfit software (Center for Research in Biological Systems), which performs multimodal volume registrations based on a gradient-descent-type optimization of the Mutual Information metric between MRI and CBCT scan data (Fig 4). The region of interest taken into account by Brainsfit was restricted to either the maxillary or mandibular region, depending on the implant site to be evaluated. This introduces robustness to different arch positionings between CBCT and MRI image acquisitions. Within the planning software, for each plan, an xml file with the spatial information of the implants could be transformed into the CBCT data set of each patient using this procedure. Afterward, the aforementioned metric criteria of the MRI 3D HR T1w TSE–based plan were additionally determined in the merged CBCT data set.

Statistical Analysis

All statistical analysis was performed using SPSS (SPSS Statistics 24.0, IBM). Descriptive statistics are provided, and 95% confidence intervals are reported as appropriate. For categorical variables, the Mann-Whitney U test was conducted. Intergroup comparisons were conducted using analysis of variance (ANOVA) following assessment by the Mauchly sphericity test. P values < .05 were considered to indicate significance.

RESULTS

In total, 16 patients (19 to 78 years of age) were included. Of these, 5 were women (31.3%), while the others were men (68.7%).

Qualitative Assessment

The implant planning procedure was technically possible in all image data sets (CBCT, 3D HR T1w TSE, and 3D HR T1w FFE). All planning conducted on CBCT received the highest rating for all criteria (ie, ideal), while for the 3D HR T1w TSE, this rating was only given in 81.9% of the examined criteria (n = 59), while 18.1% were rated improvable (n = 13). Using the 3D HR T1w FFE sequence, 54.2% (n = 39) of implant criteria showed ideal positions, and in 30.0% (n = 22), planning criteria were rated improvable; however, in 15.3% of cases, the criteria were rated not acceptable (Fig 5).

Quantitative Assessment

Analyzing the distances of the planned implant positions to relevant anatomical structures showed that all were within the range of the recommended values. A statistically significant difference between CBCT and MRI sequences could not be established (Table 2, Fig 6).

The results of the quality assessment identified the parasagittal 3D HR T1w TSE sequence as significantly superior for dental implant planning procedures in comparison to the 3D HR T1w FFE sequence. Due to the superior results of the 3D HR T1w TSE sequence, only implant planning procedures performed in this...
sequence were merged with the CBCT data sets; however, this cross-validation was only possible in 16 out of 22 cases due to technical reasons. The difference of the two planning procedures showed a mean value of a few tenths of a millimeter for the structures “vestibular” and “oral bone,” “root tip,” “tooth coronal,” and “sinus.” Only for the distance to the mandibular canal or to the inferior alveolar nerve, respectively, the difference was significantly higher in CBCT compared to MRI with 1.3 ± 0.81 mm to the horizontal parameters (Tables 3 and 4, Fig 7). The deviation of the planned angle was 3.0 ± 1.15 degrees (Fig 8). Of note, in this sub-sample analysis, planning procedures could have been improved in 12.5% of cases. This demonstrates that the improved visualization of the inferior alveolar nerve on MRI allows closer planning of the implant with better use of the available bone.

**DISCUSSION**

This exploratory study investigated the utility of 1.5 T MRI using a dedicated dental signal-amplification coil in comparison to CBCT for dental implant planning procedures. First, the implant planning procedure was technically successful using either CBCT or MRI; however, only CBCT allowed for “ideal” planning for all examined criteria in all cases, while 3D HR T1w TSE and 3D HR T1w FFE only allowed for “ideal” planning in 81.9% and 54.2%, respectively, of the observed criteria. Furthermore, planning was unacceptable in 15.4% of cases using 3D HR T1w FFE.

Readers found that the boundary between cortical bone and adjacent soft tissues was challenging to depict on MRI compared with CBCT in some cases, relevantly impairing implant planning. This is also illustrated by a larger discrepancy between CBCT and either MRI sequence, particularly in EuCC parameters relating to bony structures. Of note, neither planning inaccuracy in the MRI-based planning procedure would have resulted in injury of anatomically important neighboring structures in the case of actually performed implantation.

Regarding trading off between the use of MRI and/or CBCT, besides cost and radiation dose, it needs to be considered that while CBCT allows for a high-resolution depiction of bony structures that enable an indirect anticipation of associated nerves, the direct visualization of these structures is superior using MRI. Although the direct visualization of bone is a well-known constraint of MRI, several studies demonstrated before that MRI allows for a reliable and precise modality with regard to the imaging of bone and dental structures.17,21–23
These findings are in line with earlier studies on MRI for dental implant planning procedures. An experimental study showed the possibility of performing fully guided implant surgery using MRI data acquisition with clinically acceptable accuracy. Other ex vivo investigations furthermore demonstrated that MRI allows for more accurate visualization of periodontal structures compared with CBCT. MRI was also reported to be helpful in the case of carious lesions and injury to the mandibular nerves causing paresthesia and/or anesthesia after oral implant placement. Surprisingly, a recent study demonstrated that MRI imaging is even possible in the presence of dental implants, particularly if zirconia implants are used. In vivo, fewer studies on the utility of MRI for implant planning procedures have been conducted. Flügge et al concluded that the accuracy of MRI-based guided implant placement was comparable to CBCT in vitro. Hilgenfeld et al concluded, in a feasibility study on a 3 T MRI, that dental MRI could be reliable and sufficiently accurate for surgical guide production.

Generally, MRI is characterized by high soft tissue contrast and is therefore considered the gold standard for soft tissue imaging. These findings are in line with earlier studies on MRI for dental implant planning procedures. An experimental study showed the possibility of performing fully guided implant surgery using MRI data acquisition with clinically acceptable accuracy. Other ex vivo investigations furthermore demonstrated that MRI allows for more accurate visualization of periodontal structures compared with CBCT. MRI was also reported to be helpful in the case of carious lesions and injury to the mandibular nerves causing paresthesia and/or anesthesia after oral implant placement. Surprisingly, a recent study demonstrated that MRI imaging is even possible in the presence of dental implants, particularly if zirconia implants are used. In vivo, fewer studies on the utility of MRI for implant planning procedures have been conducted. Flügge et al concluded that the accuracy of MRI-based guided implant placement was comparable to CBCT in vitro. Hilgenfeld et al concluded, in a feasibility study on a 3 T MRI, that dental MRI could be reliable and sufficiently accurate for surgical guide production.

Generally, MRI is characterized by high soft tissue contrast and is therefore considered the gold standard for soft tissue imaging. With its help, it is, for example, possible to visualize even the smallest branches of the inferior alveolar nerve throughout the mandible. Inspired by these observations, in this study, a comparison in which the T1w TSE planning results were merged with the CBCTs was conducted. Here, a significantly smaller distance of the implant to the mandibular canal

<table>
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<tr>
<th>Table 3</th>
<th>Descriptive Statistics for Difference of Distances to Various Structures Between CBCT and MRI</th>
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<td>n</td>
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<td>Vestibular bone</td>
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<td>Oral bone</td>
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<td>Tooth coronal</td>
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<td>(I) structure</td>
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<td>Mandibular canal</td>
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*Statistically significant.

Fig 7 Differences between planning in CBCT and 3D HR T1w TSE (mm) from different anatomical structures.

Fig 8 Apical and coronal differences between planning in CBCT and 3D HR T1w TSE (mm).
or inferior alveolar nerve was found, respectively. This suggests that improved visualization of the inferior alveolar nerve on MRI allows more accurate planning of the implant with better utilization of the existing bone.

MRI limitations arise primarily from susceptibility artifacts in the case of metal-containing structures, such as metal dental crowns, implants, and orthodontic appliances. These limitations of MRI technology with regard to susceptibility artifacts in patients with fixed metal prosthetics were confirmed by the presented findings. Depending on the alloy and size of the prostheses, smaller or larger artifacts occurred. These artifact formations can be largely compensated by selecting examination protocols with ultrashort echo times, as recommended in the literature. In addition, recent studies evaluating special high spatial resolution, artifact-suppressed dental prototype sequences show promising results in terms of artifact reduction and implant accuracy. In MRI, ceramic implants showed fewer artifacts than in CBCT, where ceramic implants often limit the use of a scan for implant planning procedures.

Pertaining to pulse sequences used in MRI, data from the literature suggest that FFE sequences are particularly useful in imaging of nervous tissue; however, the data presented suggest that this strength plays a minor role in dental implant planning procedures. Furthermore, even the isotropic 3D HR advantage of the sequence is mitigated by the poor signal-to-noise ratio and related poor image contrast. Hence, it can be concluded that the 3D HR T1w TSE sequence is more suitable for implant planning procedures compared with the 3D HR T1w FFE sequence.

This study features some limitations that need to be acknowledged. First, only a small subset of study subjects were included to demonstrate general feasibility. Second, pulse sequences that were established in routine imaging protocols were used, while further optimization of pulse sequences was out of the scope of this study despite its potential. Finally, all images were acquired using a 1.5 T MRI scanner, despite the current widespread availability of 3 T MRI systems. However, this may even be considered a particular strength of this study for three reasons: (1) many patients cannot undergo 3 T imaging due to implants, pacemakers, etc; (2) the vast majority of MRI systems are indeed 1.5 T systems; and (3) image quality from 3 T MRI is generally considered superior; hence, this demonstration of feasibility will likely upscale to more advanced systems.

**CONCLUSIONS**

Within the limits of this pilot study, it can be reported that dental implant planning procedures are feasible using 1.5 T MRI with a dedicated dental coil and specific MRI sequences.

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**REFERENCES**


