

Effect of T1 and T2 Magnetic Resonance Protocols on Bone Volume Measurement and Image Quality During Dental Implant Planning

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ABSTRACT

Objective: Compare magnetic resonance imaging (MRI) protocols (T1- and T2-weighted) with cone beam computed tomography (CBCT) for measurement of bone volume and image quality in edentulous mandible during dental implant planning. *Methods:* A phantom was scanned using CBCT and MRI and two examiners measured bone volume (linear measurements) and assessed image quality (visualization of anatomical structures) with 5-point scale. Linear measurement reliability was assessed with intraclass correlation coefficient, and group differences with Friedman's and Wilcoxon's tests. The image quality ratings were classified as clinically nonvalid (scores \leq 2) or valid (score \geq 3), reliability was assessed with percentage of agreement, and group differences with chi-squared test. *Results:* Reliability of linear measurements was mostly very good for CBCT (0.748–0.981), good for T1-weighted (0.674–0.924), and fair to T2-weighted images (0.201–0.851). Significant differences were observed between imaging exams ($p<.032$) and between T1- and T2-weighted images ($p<.046$), except for alveolar ridge height ($p=.119$). CBCT showed the highest agreement and validity (100%), followed by T2-weighted (80% agreement, 90% validity), and T1-weighted (77% agreement, 82.5% validity), with no significant differences among modalities ($p=.054$). *Conclusions:* Compared to CBCT, T1- and T2-weighted MRI protocols had significantly lower reproducibility and accuracy in measuring bone volume, with reduced image quality, especially for visualizing the mandibular nerve canal.

INTRODUCTION

To develop a comprehensive treatment plan involving dental implants, it is essential to visualize and measure relevant anatomical structures using appropriate imaging techniques.¹ This anatomical evaluation minimizes the risk of surgical failure and other complications. The pertinent structures that must be considered when planning dental implants may include the dimensions and configurations of the teeth, alveolar ridge, maxillary sinus, mandibular nerve canal, and mental foramen.²

Although the cone beam computed tomography (CBCT) has long been considered the reference standard imaging modality for three-dimensional (3D) dental implant planning, recent developments in magnetic resonance imaging (MRI) have demonstrated its promising potential as an alternative treatment workflow.³ MRI technology in dental implant planning offers several

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benefits, such as the absence of ionizing radiation, thus lowering the patient and personnel exposure to radiation. In addition, the enhanced visibility of soft tissues, often poorly represented on CBCT, is advantageous when registering surface-scanned data of edentulous patients.⁴

Dental implant planning is predominantly based on calcified tissues (bone and teeth), which exhibit rapid signal decay on MRI. Therefore, specific sequences, parameters, and coils must be applied to image both soft and hard tissues.^{5,6} In MRI, “weighted” refers to emphasizing specific tissue characteristics, such as relaxation times or proton density, in the resulting images. This is achieved by adjusting MRI sequence parameters, including repetition and echo time. Two common types of images are T1- and T2-weighted, each providing unique information about tissue properties and used for different diagnostic purposes.⁷ For musculoskeletal imaging, T1-weighted images are employed for the evaluation of bone structure, whereas T2-weighted images are designed to facilitate the assessment of functional and pathophysiological processes as well as soft tissues.⁸

Previous studies have assessed the use of MRI for dental implant planning, including bone volume measurements and visualization of relevant anatomical structures.³ However, there is a lack of literature investigating the impact of different MRI protocols on dental implant planning. Therefore, the aim of this study was to compare T1- and T2-weighted MRI protocols with CBCT for measurement of bone volume and image quality during digital implant planning in the edentulous mandible.

MATERIAL AND METHODS

The CRIS Guidelines (Checklist for Reporting In-vitro Studies) were followed⁹ and the construction of the phantom, its imaging with CBCT and MRI and the acquisition of the specimens have been described previously.¹⁰ The study design is summarized in Figure 1.

SAMPLE SIZE CALCULATION

The sample size was determined based on a pilot study using the t-test to compare paired groups, with linear measurements of bone volume as the primary outcome. A minimum of three samples would have been required to detect a mean difference of 0.55 ± 0.16 mm with 90% power and a significance level of 0.05. Therefore, six samples ($n = 6$) were included for the CBCT and T2-weighted groups, and eight samples ($n = 8$) were included for the T1-weighted group. The unbalance sample size was due to the additional availability of imaging protocol that could fit clinical requirements.

PHANTOM AND PROSTHETIC PLANNING

An edentulous human mandible (ethical committee approval 2.253.943) received a 2 mm uniform layer of sanitary silicone (Fischer, Germany) around the alveolar ridge to simulate gingival tissue.¹¹ Polymer fiducial landmarks (myBrick) were used as reference points for registering the CBCT and MRI Digital Imaging and Communications in Medicine (DICOM) files with the Standard Tessellation Language (STL) files. The alveolar ridge surface was scanned with an intraoral scanner (TRIOS 3, 3Shape) according to the manufacturer’s protocol and exported as an STL file. Prosthetic planning consisted of an STL file of a removable complete denture prosthesis (Meshmixer, Autodesk).

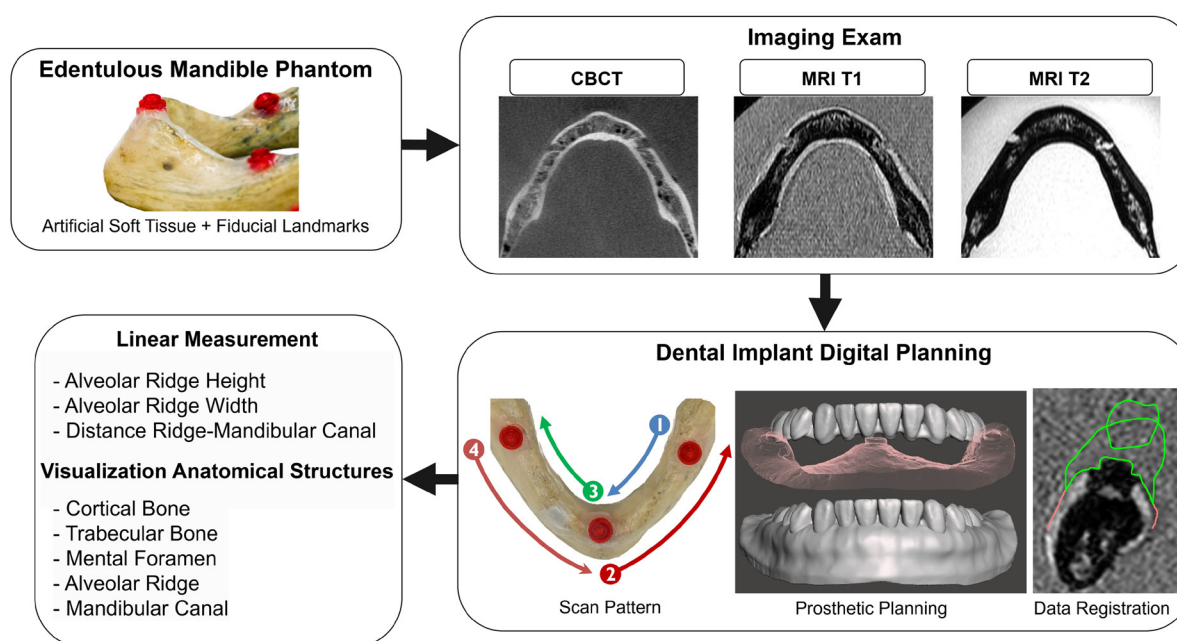


Figure 1: Study design. Figure adapted from Ref 10 because of the different outcomes evaluated.

MAGNETIC RESONANCE IMAGING

The phantom was fixed with soft dental wax (White Periphery Wax, Kemdent) in a plastic container filled with a mixture of water and small amount (<10 ml) of liquid handwash detergent and a contrast agent (0.5 mmol/mL gadolinium) to provide proper voxel intensity surrounding the bone.¹² Imaging was conducted with a 3-Tesla MRI system equipped with a 32-channel head coil (Ingenia CX, R5 V6.a, Philips Healthcare). T1-weighted images were obtained with 3D Fast Field Echo sequencing, 0.5 mm slice thickness, and 4 min acquisition duration. T2-weighted images were obtained with 3D Brain View and Turbo Spin Echo sequencing, 2 mm slice thickness, and 7 to 9 min acquisition duration. Detailed sequence parameters have been described previously.¹⁰ The phantom was imaged three times with T1-weighted and four times with T2-weighted images, and the DICOM files were used twice to match the sample size.

CONE BEAM COMPUTED TOMOGRAPHY

Using the same fixation method and plastic container, but filled with water only, the phantom was scanned using dental tomography (Veraview x800, Morita) under standard clinical settings (FOV 150 × 75 mm; kV 100; mA 6; exposure time 17.86 s; voxel size 0.25 mm). The phantom was imaged three times and the DICOM files were used twice to match the sample size.

SAMPLES

A single investigator obtained the samples using dental implant planning software (coDiagnostiX 10.5.0, Dental Wings, Inc.). DICOM files from MRI and CBCT scans were imported. Bone tissue was segmented using standardized thresholds for each group. STL files of the alveolar ridge and prosthetic planning were imported and registered with the bone segmentations as recommended by the software manufacturer.

All samples were standardized in terms of patient coordinate system, panoramic curve, and the color of segmentation and STL files. In addition, each dataset was codified to blind the examiners to different groups.

MEASUREMENT OF BONE VOLUME

After an initial calibration, two independent implant specialists (with 25 and 8 years of experience in digital implant planning, respectively) assessed the bone volume using dental implant planning software (coDiagnostiX). Linear measurements were performed in the region of canines and first molar of the prosthetic planning as follows (Figure 2):

- Alveolar ridge height: vertical distance between the upper central point of the alveolar ridge crest and the lower central point of the lower border of the mandible.
- Alveolar ridge width: horizontal distance between the buccal cortical bone and the lingual cortical bone at the lower limit of the buccal and lingual flanges of the prosthetic planning.
- Distance ridge to nerve canal: distance between the upper central point of the alveolar bone crest and the upper cortical bone of the mandibular canal.

To standardize the slice selection for the measurements, the software “localizer” tool was used aiming to the centre of the occlusal face of the canine and first molar of the prosthetic planning (Figure 2A,B)

IMAGE QUALITY

The same examiners evaluated the quality of visualization of five anatomical structures (cortical bone, trabecular bone, alveolar ridge, mental foramen, mandibular canal) using a 5-point Likert scale as: 1 = visualization of the anatomical

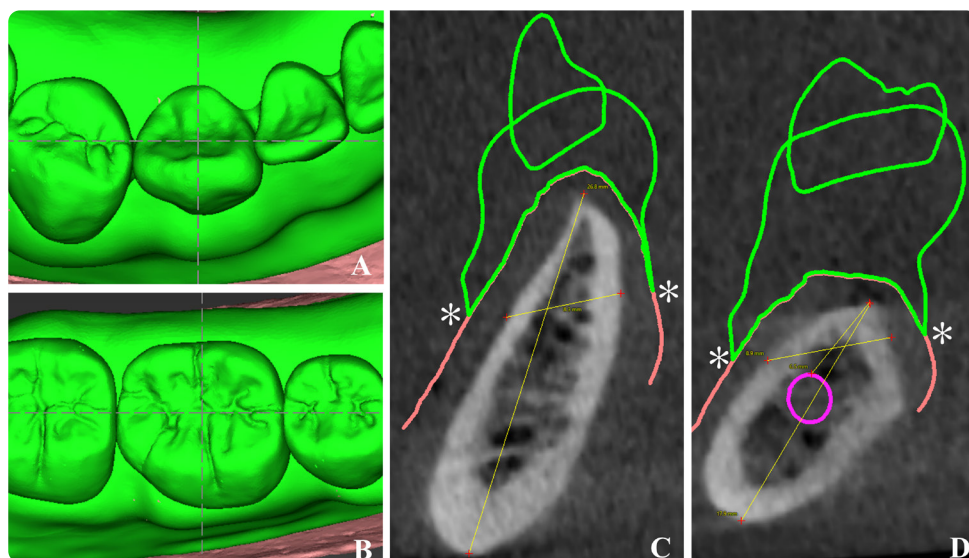


Figure 2: Bone volume measurement. (A, B) Standardized slice determination with “localizer” tool aiming to the centre of the occlusal face of the canine and first molar. (C, D) Canine and first molar linear measurements. The asterisk (*) represents the vertical reference point of the prosthetic planning flanges. The purple circle represents the mandibular canal.

structure is not possible, 2 = only <25% of the anatomical structure is visible, 3 = 25-50% of the anatomical structure is visible, 4 = 50-75% of the anatomical structure is visible, 5 = visualization of the anatomical structure is 100% possible. For clinical validity, measures were then clustered as nonvalid (score ≤ 2) or valid for clinical use (score ≥ 3).¹³ Examiners were allowed to adjust image parameters (e.g., magnification, brightness, and contrast).

STATISTICAL ANALYSIS

The Shapiro-Wilk test was used to assess normality of linear measurements, while differences between groups were analyzed using the Friedman test followed by the Wilcoxon signed-rank test. Inter-examiner reliability for linear measurements was determined using the intraclass correlation coefficient (ICC), further classified according to Altman *et al.*¹⁴ as: poor (≤ 0.20), fair (0.21-0.40), moderate (0.41-0.60), good (0.61-0.80) and very good (0.81-1.00). Inter-examiner reliability for image quality was assessed using the percentage of agreement (%), while significant differences between groups were analyzed using the chi-squared (X^2) test. A significant threshold of $p = 0.05$ was used in all tests (SPSS 26, IBM Corp.).

RESULTS

BONE VOLUME

Inter-examiner reliability for linear measurements was mostly very good for CBCT (ICC = 0.748 to 0.981) and good to very good for T1-weighted (ICC = 0.674 to 0.924). T2-weighted measurements showed a wider range of reliability from poor to very good (ICC = 0.201 to 0.851). (Table 1).

Due to the varying influence of the imaging examination on examiner reliability, descriptive statistics and comparisons were analyzed separately (Table 2). Significant differences in alveolar ridge height were observed in the posterior region for both examiners ($p = 0.032$). T2-weighted differed significantly from CBCT for examiner 1 ($p = 0.046$) and from T1-weighted for examiner 1 ($p = 0.028$) and examiner 2 ($p = 0.027$).

For alveolar ridge width, significant differences were observed in the anterior region for examiner 1 ($p = 0.006$), with all pairwise comparisons also showing significance (CBCT-T1 $p = 0.026$; CBCT-T2 $p = 0.028$; T1-T2 $p = 0.046$). In the posterior region, significant differences were found for examiner 1 ($p = 0.006$) and examiner 2 ($p = 0.009$). T1-weighted was significantly different from CBCT for examiner 2 ($p = 0.028$), whereas T2-weighted was significantly different from CBCT for both examiners ($p = 0.028$). Differences between T1- and T2-weighted were significant for examiner 1 ($p = 0.028$).

For the distance from the alveolar ridge to the mandibular nerve canal, significant differences were found for examiner 1 ($p = 0.006$), with T1-weighted differing from CBCT ($p = 0.027$). Significant difference between T1- and T2-weighted was also observed for examiner 1 ($p = 0.028$).

Table 1. Intraclass correlation coefficient for bone volume measurement.

Measurement	Exam	Inter-examiner reliability (ICC)	
Alveolar ridge height	Anterior region	CBCT	.981
		T1	.924
		T2	.659
	Posterior region	CBCT	.932
		T1	.834
		T2	.851
Alveolar ridge width	Anterior region	CBCT	.892
		T1	.802
		T2	.381
	Posterior region	CBCT	.748
		T1	.752
		T2	.235
Distance ridge-nerve	CBCT	.945	
	T1	.674	
	T2	.201	

IMAGE QUALITY

CBCT yielded perfect inter-examiner agreement and clinical validity (100%) in all cases (Table 3). Reduced agreement was observed for T2- (80%) followed by T1-weighted (75%) when considering all anatomical structures together. In addition, a tendency to reduced clinical validity was observed for T2-weighted (90%) followed by T1- (82.5%), with no significant difference between the three modalities ($p = 0.054$).

When anatomical structures were analyzed individually, inter-examiner agreement for T1- ranged from 25% to 100%, while for T2-weighted ranged from 33% to 100%. Despite no significant difference in image quality between the different groups ($p > 0.052$), a tendency was observed to clinically valid images (Figure 3). T1-weighted images showed to be clinically valid in 75% of mental foramen and 37.5% of mandibular nerve canal. Similarly, for T2-weighted images, 83.3% of alveolar ridge and 66.7% of mandibular nerve canal were considered clinically valid.

DISCUSSION

Accurate imaging of the hard and soft tissues facilitates diagnosis and appropriate treatment planning for rehabilitation with dental implants.¹⁵ MRI can image both, but achieving the

Table 2. Descriptive statistics and comparison between bone volume measurement by each examiner and imaging exam.

Measurement	Examiner	Exam	Median	IQR	Friedman (p value)	Wilcoxon signed ranked test (p value)							
						CBCT-T1	CBCT-T2	T1-T2					
Alveolar ridge height	Anterior region	Examiner 1	CBCT	25.30	1.98	.119							
			T1	25.15	1.90								
			T2	25.65	1.93								
		Examiner 2	CBCT	25.20	1.90								
			T1	25.85	2.05								
			T2	26.30	2.07								
	Posterior region	Examiner 1	CBCT	17.15	1.82	.032*	.686	.046*	.028*				
			T1	17.05	1.98								
			T2	18.55	2.15								
		Examiner 2	CBCT	17.90	1.65								
			T1	17.90	2.10								
			T2	19.25	2.63								
Alveolar ridge width	Anterior region	Examiner 1	CBCT	8.30	0.80	.006*	.026*	.028*	.046*				
			T1	9.35	1.80								
			T2	11.25	1.90								
		Examiner 2	CBCT	13.50	6.80					.311			
			T1	13.75	2.67								
			T2	14.75	3.78								
	Examiner 1	CBCT	9.30	1.50									
		T1	9.50	1.35									
		T2	12.15	2.17									
	Posterior region	Examiner 2	CBCT	11.25	3.45	.009*	.028*	.028*	.400				
			T1	14.35	1.17								
			T2	14.30	1.60								
Distance ridge-nerve	Examiner 1	CBCT	6.25	1.05	.006*					.027*	.173	.028*	
		T1	3.25	1.63									
		T2	7.20	1.20									
	Examiner 2	CBCT	6.55	1.45		.438							
		T1	8.10	2.60									
		T2	7.45	3.27									

*Means statistical significance difference

Table 3. Image quality.

Image exam		Inter-examiner agreement (%)	Nonvalid for clinical use (%)	Valid for clinical use (%)	X ² -Test (p value)
CBCT		100	0	100	
T1		75	17.5	82.5	.054
T2		80	10	90	
Anatomical structure		Inter-examiner agreement (%)	Nonvalid for clinical use (%)	Valid for clinical use (%)	X ² -Test (p-value)
Cortical bone	CBCT	100	0	100	
	T1	100	0	100	1.000
	T2	100	0	100	
Trabecular bone	CBCT	100	0	100	
	T1	100	0	100	1.000
	T2	100	0	100	
Mental foramen	CBCT	100	0	100	
	T1	50	25	75	.189
	T2	100	0	100	
Alveolar ridge	CBCT	100	0	100	
	T1	100	0	100	.293
	T2	66	16.7	83.3	
Nerve canal	CBCT	100	0	100	
	T1	25	62.5	37.5	.052
	T2	33	33.3	66.7	

necessary spatial resolution with clinically acceptable scan times for hard tissues is challenging with traditional MRI protocols. Due to the abundance of electrons in soft tissues, protocols imaging these types of tissues do not face the same difficulties. Conversely, mineralized tissues in MRI yield rapidly decaying signals; therefore, in this study, the parameters used were previously tested in a pilot study.

Significant differences were observed between T1- and T2-weighted images compared to CBCT in most bone volume measurements, whereas no significant differences were found in the image quality. In addition, a tendency was noted towards lower inter-examiner agreement and the overestimation of distances, particularly with T2-weighted images. When compared to CBCT, measurements of alveolar ridge height in the posterior region were overestimated by one examiner. Similarly, measurements of alveolar ridge width were overestimated in both the anterior region by one examiner and the posterior region by both examiners in T2-weighted images.

Conversely, the T1-weighted distance from the alveolar ridge to the mandibular nerve canal was underestimated, with a significant difference for one examiner compared to CBCT. There was also a tendency for T1-weighted images to be less clinically valid for the mental foramen and the mandibular nerve canal.

There is a lack of studies in the literature evaluating MRI protocols for implant planning in edentulous cases. Pompa *et al* conducted a study of implant planning and bone height measurements using proton density, T1- and T2-weighted MRI compared with computed tomography.¹⁶ Planning was considered feasible in 30 patients requiring single tooth replacement or with partial edentulism. The differences in MRI and CT measurements ranged from 0.04 to 1.1, with no significant difference. These findings are partially consistent with the present study, which found significant differences in posterior bone height using a 3T MRI scanner compared with CBCT data.

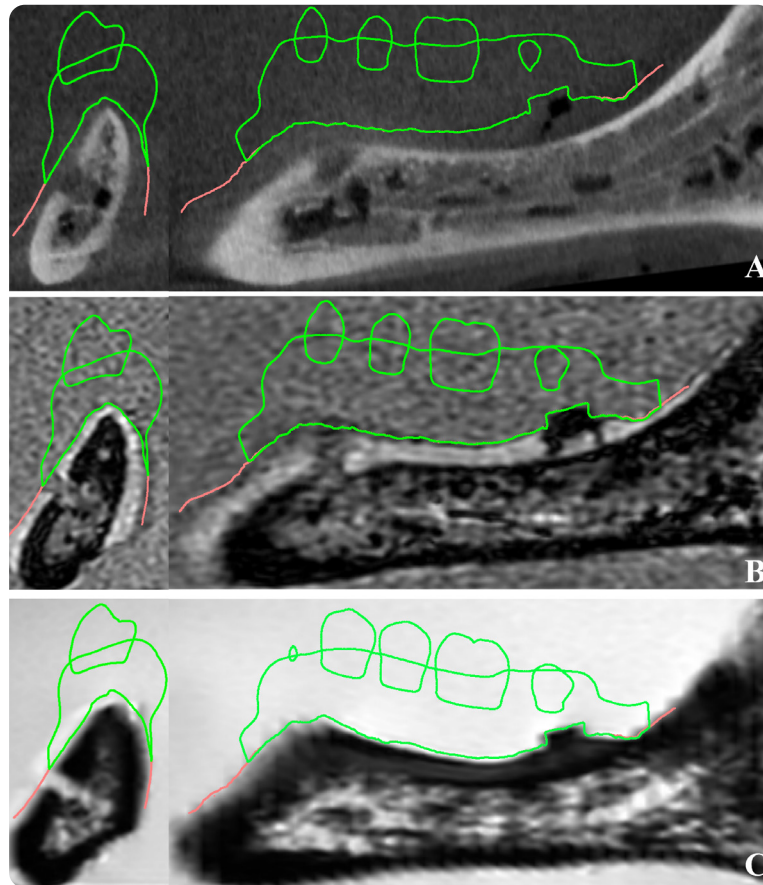


Figure 3: Visualization of anatomical structures. A, CBCT. B, T1-weighted. C, T2-weighted.

However, their study used a 1.5T MRI scanner and compared measurements to CT, which may affect accuracy.

Similarly, Assaf *et al.* evaluated optimized T1- and T2-weighted MRI sequences for maxillofacial structures *in vivo*.¹⁷ They found that surrounding structures were more visible with T2-weighted sequences, whereas cortical and trabecular bone were clearer with T1-weighted images. Other studies have also reported that mandibular canals and alveolar bone are poorly imaged with T2-weighted protocols due to low signal-to-noise ratios.^{18,19} These findings are consistent with the present study, where T1-weighted images tended to provide better visualization of the alveolar ridge compared to T2-weighted images.

Probst *et al.* used 3T MRI for digital implant planning and subsequent prosthetic treatment in 9 patients.²⁰ Only T1-weighted images were imported into the planning software, with T2-weighted images used separately to assess soft tissue, particularly the position of the mandibular nerve relative to the planned implants, which provided excellent visualization. The study reported that the cortical and trabecular bone, teeth and maxillary sinuses were clearly visible on T1-weighted images, whereas the visibility of the mandibular canal was limited. Their findings are consistent with the present study, which also found that the mandibular canal was partially visible, particularly on T1-weighted images, with a trend towards better image quality on T2-weighted images.

To measure distances in an image, the endpoints must be clearly identifiable, with appropriate contrast to ensure visibility. In MRI, bone usually has very low or no signal and appears black, so the signal intensity in the surrounding voxels determines the contrast around the bone. In this study, a contrast agent was added to the water in the phantom to provide signal intensity around the bone. Consequently, the visualization of anatomical structures and accuracy of measurements may have been influenced more by surrounding voxel intensity than by the bone's intrinsic lack of signal. However, this effect varied depending on the imaging sequence used and outcome evaluated. For instance, T2-weighted imaging produced high signal intensity in the voxels surrounding the bone, which enhanced tissue contrast and improved visualization of the mandibular canal lumen but reduced measurement accuracy. In contrast, T1-weighted imaging exhibited lower voxel intensity around the bone, resulting in better measurement accuracy but poorer visualization of the mandibular canal. Additionally, variation in factors such as image resolution, signal-to-noise ratio, and contrast-to-tissue ratio may also have contributed to these observed differences.

MRI technology has its own drawbacks. In dental implantology, there is the possibility of artefacts from implants and restorations, although these can be minimized with dedicated artefact suppression modes.¹² The disadvantage of longer scan times may also increase the risk of motion artefacts, which may require correction or repeat scans.²¹ Fortunately, newly

developed dental-specific MRI systems allow for shorter scan times (≤ 3 minutes).²² High costs, space requirements and the need for specialized personnel have also been addressed.^{22,23} In addition, contraindications such as claustrophobia, pacemakers, defibrillators, metal injuries, large tattoos and nonremovable piercings must be considered.²²

The main advantages of MRI in dental implant planning are the absence of radiation exposure and the ability to image both hard and soft tissues. With direct imaging of nerves and vessels, MRI provides better visualization of the mandibular canal than CBCT²⁴ and orthopantomography.²⁵ It has also shown promise in measuring peri-implant bone defects around zirconia implants^{26,27} and visualizing bone oedema, which could lead to early diagnosis of peri-implant conditions.^{23,28}

This study has limitations, particularly the *in vitro* design, which does not consider the complexities encountered in clinical situations, such as patient movement and the presence of live tissues with dynamic physiological processes. The use of a single defleshed mandible as a phantom, lacking the mandibular nerve and blood vessels, also limits external validity and clinical applicability, despite efforts to artificially reproduce the soft tissues. The phantom also lacked bone marrow tissue, which in the mandible contains adipocytes and hematopoietic cells. These cells would have resulted in a hyperintense signal and potentially a better signal-to-noise ratio.²⁹ The absence of surrounding anatomical structures further limits the signal-to-noise ratio, which potentially affects image quality. Additionally, the phantom does not replicate individual physiological variations, such as those related to age, bone density, inflammatory conditions, or pathology

Air bubbles were observed trapped in the trabecular bone of the phantom despite efforts to remove them after immersion in the solution in the plastic containers. Thus, the presence of air may also have affected the measurements and visibility of anatomical structures due to differential magnetic susceptibility and signal drop-out artefacts.³⁰ Air bubbles produce grey scale intensities comparable to bone, leading to potential pixel misclassification.²⁹ This study also did not quantitatively evaluate the signal-to-noise and contrast-to-tissue ratios within the imaging modalities but rather made observations from visually perceived variations. Finally, the results may have been influenced by the different years of experience of the examiners. Therefore, the results should be interpreted with caution, considering the variability of anatomical structures in the clinical setting and the need for larger and more comprehensive clinical studies.

Despite the widespread use of MRI for the diagnosis of soft tissues, its effectiveness for imaging hard tissues such as bone and teeth are limited due to their low water content and short relaxation times. Therefore, recent advances in techniques such as ultrashort echo time (UTE), zero echo time (ZTE) and sweep imaging with Fourier transformation (SWIFT) show promise for improving the signal-to-noise ratio and image quality of these tissues.^{3,31} In the present study, traditional

sequences were adapted to allow imaging of the phantom, which also demonstrates the potential for further development of such protocols in clinical settings. The continuous development of MRI protocols, software and hardware and their integration into digital prosthetic planning should be addressed in future studies and could enhance the accuracy and reliability of MRI for dental implant procedures.³²

The wide range of examiner variability and deviations, even after calibration, emphasizes the need for comprehensive training that goes beyond understanding the technology to focus on practical clinical application in MRI-based implant planning. Hands-on experience is essential to improve accuracy and consistency, ensuring the effective use of MRI in clinical settings.^{22,33} For example, a recent study that evaluated the temporomandibular joint using a dental-dedicated MRI system reported challenges in the subjective assessment of image quality by professionals with varying levels of experience, including neuroradiologists, oral radiologists, and orofacial pain specialists.³⁴ The authors emphasized that the observed variation in interexaminer agreement suggested that certain groups of professionals might require further training to reach a comparable level of proficiency.³⁴ Additionally, the deviations in linear measurements observed in the present study ranged from a median of 3 mm to 6 mm. These values exceed the acceptable threshold of around 2 mm for the safety zone in mandibular dental implant surgery.³⁵ Therefore, the results of this study should be interpreted with caution, as these differences could lead to tissue injury, including that of the inferior alveolar nerve

Further research exploring advanced MRI techniques (UTE, ZTE, SWIFT) in patients with diverse anatomical variations and different clinical scenarios is also needed to allow the translation of these preliminary findings into treatment workflows. Efforts should also focus on accurately segmenting bone tissue in MRIs to generate the surface models necessary for computer-aided procedures. Reducing scan times and motion artifacts, potentially through dental-dedicated MRI systems²² and artifact suppression techniques would also improve the diagnostic and planning processes in dental implantology

CONCLUSION

Compared to CBCT, both T1- and T2-weighted MRI protocols showed significantly lower reproducibility and accuracy in measuring bone volume. There was a reduced image quality, especially when visualizing the mandibular nerve canal. Further studies assessing improved MRI protocols and clinical data are necessary for planning dental implants with MRI in edentulous cases.

CONFLICT STATEMENT

The authors declare no conflict of interest.

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REFERENCES

- Luangchana, P., Pornprasertsuk-Damrongsri, S., Kiattavorncharoen, S. and Jirajariyavej, B. Accuracy of linear measurements using cone beam computed tomography and panoramic radiography in dental implant treatment planning. *Int J Oral Maxillofac Implants*. 2015; **30**(6):1287-1294.
- Genç, T., Duruel, O., Kutlu, H.B., Dursun, E., Karabulut, E. and Tözüm, T.F. Evaluation of anatomical structures and variations in the maxilla and the mandible before dental implant treatment. *Dent Med Probl*. 2018; **55**(3):233–240.
- Al-Haj Husain, A., Zollinger, M., Stadlinger, B., Özcan, M., Winklhofer, S., Al-Haj Husain, N., et al. Magnetic resonance imaging in dental implant surgery: a systematic review. *Int J Implant Dent* 2024;**10**(1):14.
- Flügge, T, Ludwig, U, Winter, G, Amrein, P, Kernen, F. and Nelson, K. Fully guided implant surgery using Magnetic Resonance Imaging – An *in vitro* study on accuracy in human mandibles. *Clin Oral Implants Res*. 2020; **31**(8):737–746.
- Flügge, T., Hövener, J.B., Ludwig, U., Eisenbeiss, A.K., Spittau, B., Hennig, J., et al. Magnetic resonance imaging of intraoral hard and soft tissues using an intraoral coil and FLASH sequences. *Eur Radiol*. 2016; **26**(12):4616–4623.
- Algarín, J.M., Díaz-Caballero, E., Borreguero, J., Galve, F., Grau-Ruiz, D., Rigla, J.P., et al. Simultaneous imaging of hard and soft biological tissues in a low-field dental MRI scanner. *Sci Rep*. 2020; **10**(1):1–14.
- Hashemi, R.H., Bradley, W.G. and Lisanti, C.J. *MRI: the basics: The Basics*. Lippincott Williams & Wilkins; 2012.
- Florkow, M.C., Willemsen, K., Mascarenhas, V.V., Oei, E.H.G., van Stralen, M. and Seevinck, P.R. Magnetic resonance imaging versus computed tomography for three-dimensional bone imaging of musculoskeletal pathologies: A review. *J Magn Reson Imaging*. 2022; **56**(1):11–34.
- Krithikadatta, J., Datta, M. and Gopikrishna, V. CRIS Guidelines (Checklist for Reporting *In-vitro* Studies): A concept note on the need for standardized guidelines for improving quality and transparency in reporting *in-vitro* studies in experimental dental research. *J Conserv Dent*. 2014; **17**(4):301.
- Parize, H., Meier, N., Kleinheinz, J., Laganá, D.C., Sesma, N. and Bohner, L. Effect of magnetic resonance imaging protocol on decision-making for positioning of dental implants in edentulous cases. *J Prosthodont*. 2024;1–8.
- Harries, J., Jochimsen, T.H., Scholz, T., Schlender, T., Barthel, H., Sabri, O., et al. A realistic phantom of the human head for PET-MRI. *EJNMMI Phys*. 2020;**7**(1).
- Bohner, L., Hanisch, M., Parize, H., Sesma, N., Kleinheinz, J. and Meier, N. SEMAC + VAT for Suppression of artifacts induced by dental-implant-supported restorations in magnetic resonance imaging. *J Clin Med*. 2023; **12**(3).
- Willershausen, I., Evangelidou, S., Fautz, H.P., Amarteifio, P., May, M.S., Stroebel, A., et al. Low-Field MRI for dental imaging in pediatric patients with supernumerary and ectopic teeth: A comparative study of 0.55 T and ultra-low-dose CT. *Invest Radiol*. 2024; **00**(00).
- Altman, D.G. *Practical statistics for medical research*. Chapman and Hall/CRC; 1990.
- Al-Haj Husain, A., Stadlinger, B., Özcan, M., Schöneegg, D., Winklhofer, S., Al-Haj Husain, N., et al. Buccal bone thickness assessment for immediate anterior dental implant planning: A pilot study comparing cone-beam computed tomography and 3D double-echo steady-state MRI. *Clin Implant Dent Relat Res*. 2023; **25**(1):35–45.
- Pompa, V., Galasso, S., Cassetta, M., Pompa, G., De Angelis, F. and Di Carlo, S. A comparative study of Magnetic Resonance (MR) and Computed Tomography (CT) in the pre-implant evaluation. *Ann Stomatol (Roma)*. 2010; **1**(3–4):33–38.
- Assaf, A.T., Zrnc, T.A., Remus, C.C., Schönfeld, M., Habermann, C.R., Riecke, B., et al. Evaluation of four different optimized magnetic-resonance-imaging sequences for visualization of dental and maxillo-mandibular structures at 3 T. *J Cranio-Maxillofacial Surg*. 2014; **42**(7):1356–1363.
- Öçbe, M., Borahan, M.O. and Çimşit, N.Ç. Evaluation of the inferior alveolar nerve with 3 tesla turbo spin echo magnetic resonance imaging. *Eur J Res Dent*. 2022; **6**(2):73–79.
- Imamura, H., Sato, H., Matsuura, T., Ishikawa, M. and Zeze, R. A comparative study of computed tomography and magnetic resonance imaging for the detection of mandibular canals and cross-sectional areas in diagnosis prior to dental implant treatment. *Clin Implant Dent Relat Res*. 2004; **6**(2):75–81.
- Probst, F.A., Schweiger, J., Stumbaum, M.J., Karampinos, D., Burian, E. and Probst, M. Magnetic resonance imaging based computer-guided dental implant surgery—A clinical pilot study. *Clin Implant Dent Relat Res*. 2020; **22**(5):612–621.
- Castella, R., Arn, L., Dupuis, E., Callaghan, M.F., Draganski, B. and Lutti, A. Controlling motion artefact levels in MR images by suspending data acquisition during periods of head motion. *Magn Reson Med*. 2018; **80**(6):2415–2426.
- Greiser, A., Christensen, J., Fuglsig, J.M.C.S., Johannsen, K.M., Nixdorf, D.R., Burzan, K., et al. Dental-dedicated MRI, a novel approach for dentomaxillofacial diagnostic imaging: technical specifications and feasibility. *Dentomaxillofac Radiol*. 2024; **53**(1):74–85.
- Tyndall, D.A., Price, J.B., Gaalaas, L. and Spin-Neto, R. Surveying the landscape of diagnostic imaging in dentistry's future: Four emerging technologies with promise [Internet]. Vol. 155, *Journal of the American Dental Association*. *J Am Dent Assoc*. 2024; **155**:364–378.
- Al-Haj Husain, A., Stadlinger, B., Winklhofer, S., Piccirelli, M. and Valdec, S. Magnetic resonance imaging for preoperative diagnosis in third molar surgery: a systematic review. *Oral Radiol*. 2023; **39**(1):1–17.
- Husain, A.A.H., Oechslin, D.A., Stadlinger, B., Winklhofer, S., Özcan, M., Schöneegg, D., et al. Preoperative imaging in third molar surgery—A prospective comparison of X-ray-based and radiation-free magnetic resonance orthopantomography. *J Cranio-Maxillofacial Surg*. 2024; **52**(1):117–126.
- Miotk, N., Schwindling, F.S., Zidan, M., Juerchott, A., Rammelsberg, P., Hosseini, Z., et al. Reliability and accuracy of intraoral radiography, cone beam CT, and dental MRI for evaluation of peri-implant bone lesions at zirconia implants – an *ex vivo* feasibility study. *J Dent*. 2023; **130**:104422.
- Hilgenfeld, T., Juerchott, A., Deisenhofer, U.K., Krisam, J., Rammelsberg, P., Heiland, S., et al. Accuracy of cone-beam computed tomography, dental magnetic resonance imaging, and intraoral radiography for detecting peri-implant bone defects at single zirconia implants—An *in vitro* study. *Clin Oral Implants Res*. 2018; **29**:922–930.

28. Probst, M., Burian, E., Robl, T., Weidlich, D., Karampinos, D., Brunner, T., et al. Magnetic resonance imaging as a diagnostic tool for periodontal disease: A prospective study with correlation to standard clinical findings—Is there added value? *J Clin Periodontol.* 2021; **48**(7):929–948.
29. Soldati, E., Rossi, F., Vicente, J., Guenoun, D., Pithioux, M., Iotti, S., et al. Survey of MRI usefulness for the clinical assessment of bone microstructure. *Int J Mol Sci.* 2021; **22**(5):1–27.
30. Chung, H., Wehrli, FW, Williams, JL, Wehrli, SL. Three-dimensional nuclear magnetic resonance microimaging of trabecular bone. *J Bone Miner Res.* 1995; **10**(10):1452–1461.
31. Mastrogiacomo, S., Dou, W., Jansen, J.A. and Walboomers, X.F. Magnetic resonance imaging of hard tissues and hard tissue engineered bio-substitutes. *Mol Imaging Biol.* 2019; **21**(6):1003–1019.
32. Kong, X., Zhu, Y., Shen, S., Wu, J., He, Y., Hong, M., et al. A low-cost portable 50 mT MRI scanner for dental imaging. *IEEE Trans Instrum Meas.* 2023; **73**:1–11.
33. Fuglsig, J., Wenzel, A., Hansen, B., Lund, T. and Spin-Neto, R. Magnetic resonance imaging for the planning, execution, and follow-up of implant-based oral rehabilitation: systematic review. *Int J Oral Maxillofac Implants.* 2021; **36**(3):432–441.
34. Nixdorf, D.R., Greiser, A., Hayes, C., Gaalaas, L., Groenke, B.R., e Silva, J.M. de C., et al. Comparison of a 0.55 T dental-dedicated magnetic resonance imaging system with a 1.5 T system in evaluation of the temporomandibular joint regarding subjective image quality assessment and rater agreement. *Oral Surg Oral Med Oral Pathol Oral Radiol.* 2025; **140**(1):113-124
35. Greenstein, G. and Tarnow, D. The mental foramen and nerve: clinical and anatomical factors related to dental implant placement: a literature review. *J Periodontol.* 2006; **77**(12):1933–1943.