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Dental MRI versus CBCT for Immediate Implant Planning: A Radiation-Free Approach with Comparable Spatial Accuracy

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ABSTRACT: Background: Three-dimensional imaging is essential for prosthetically driven implant placement. Although cone-beam computed tomography (CBCT) is the gold standard for implant planning, concerns regarding ionizing radiation exposure have encouraged the exploration of non-ionizing alternatives. Recent advances in dental magnetic resonance imaging (MRI) have improved visualization of hard and soft tissues.

Aim: To compare the accuracy of MRI and CBCT in guided immediate implant planning by evaluating three-dimensional implant positioning and deviations at the coronal, apical, and guide tube levels.

Materials and Methods: This comparative clinical study included three subjects requiring immediate implant placement. Nine implants were evaluated using a paired design. Implant planning was performed independently using MRI and CBCT datasets after co-registration with digitized cast data. Three-dimensional implant coordinates were analyzed, and linear and angular deviations between MRI- and CBCT-based plans were measured. Statistical analysis was performed using a paired sample t-test ($p < 0.05$).

Results: The mean coronal discrepancy between MRI and CBCT measurements was 0.05829 ± 0.03777 mm, while the mean apical discrepancy was 0.06903 ± 0.03969 mm. The mean angular discrepancy at the guide tube level was 0.00032 ± 0.00009°. Coronal deviations ranged from 0.01412 to 0.12098 mm, and apical deviations ranged from 0.01882 to 0.13717 mm. No statistically significant differences were observed between

MRI and CBCT measurements ($p > 0.05$), indicating a high degree of agreement.

Conclusion: Dental MRI demonstrated spatial accuracy comparable to CBCT for guided immediate implant planning. Its radiation-free nature and superior soft-tissue visualization support its potential as an alternative imaging modality for implant planning...

INTRODUCTION

Since the advent of osseointegration by Brånemark, dental implants have become one of the most predictable methods for the rehabilitation of missing teeth. Developments in surgical techniques, material science, and digitalization have contributed to improved implant success rates, making implantology increasingly prosthetically driven.[1]

The philosophy of modern implantology is based on backward planning, where implants are positioned according to the planned prosthetic rehabilitation and then accurately transferred to the patient's anatomy with the help of computer-guided surgery. Therefore, an accurate three-dimensional evaluation of the available bone volume and surrounding anatomical structures is essential.[2,3]

CBCT has been recognized as the gold standard imaging modality in implant dentistry because of its ability to produce high-quality three-dimensional images.[4,5] However, CBCT involves the use of ionizing radiation, several studies have suggested a possible association between repeated exposure to dental radiographs and an increased risk of cancer and meningioma.[6] Although the radiation dose is considerably lower than that of conventional medical CT, concerns regarding cumulative radiation exposure still remain.

MRI provides a completely different approach to image acquisition by using magnetic fields and radiofrequency pulses without exposing patients to ionizing radiation.[7] MRI acts on tissues by using a strong magnetic field and radiofrequency pulses to align and excite hydrogen protons present in water and fat. As these protons return to their original state, they emit signals that are detected and converted into detailed images. Differences in proton relaxation properties among tissues produce image contrast, allowing visualization without ionizing radiation. Earlier, the use of MRI in dentistry was limited because of poor visualization of mineralized tissues and susceptibility artifacts. However, recent advances such as dedicated dental coils, ultrashort echo-time (UTE) imaging, MSVAT-SPACE imaging, and advanced reconstruction algorithms have significantly improved the quality of dental MRI images.[8–11]

Several studies have demonstrated that MRI-based implant planning is feasible like Gray et al. reported that MRI can provide an accurate preoperative assessment for implant planning.[12–14] Hilgenfeld et al. demonstrated excellent agreement between MRI- and CBCT-based guided implant planning.[15] Mercado et al. further showed the successful application of fully digital MRI-guided implant surgery.[16] More recently, systematic reviews have suggested that MRI may serve as a promising alternative to CBCT in selected implant patients.[17]

Despite these promising findings, there is still limited evidence regarding the use of MRI for immediate implant planning. Immediate implant placement requires careful evaluation of the extraction socket anatomy, preservation of the alveolar bone, and achievement of adequate primary stability.[18] Therefore, the accuracy of MRI for immediate implant planning remains an important clinical concern.

The present study was conducted to compare implant positions obtained using dental MRI and CBCT during guided immediate implant planning to determine whether MRI can serve as an accurate clinical alternative.

MATERIALS AND METHODS

Study Design

This prospective study was approved by the institutional Ethics committee of Santosh University (approval number SU/2024/1349[1]). Written informed consent was obtained from all participants. The study was done at the Department of Prosthodontics and Crown & Bridge, Santosh Dental College and Hospital, Ghaziabad, Uttar Pradesh, India, spanning two years. The purpose was to compare and contrast the spatial precision of MRI and CBCT for implant positioning.

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Sample size and Patients Selection

Calculation of sample size was done by using OpenEpi Version 3 software. Based on the comparison of two means, nine sites were needed in order to have sufficient statistical power. The nine sites were their own controls due to the fact that their measurement was taken using MRI and CBCT modalities.

Nine sites for immediate implant placement were considered as subjects of this investigation. The assessment was done in both MRI and CBCT modalities.

Inclusion Criteria

- Cases of immediate implant placements with intact anatomy of the extraction socket
- Healthy condition of the gums' architecture
- Sufficient amount of bone for the placement of implants with dimensions of at least 3.5 mm in diameter and 10 mm in length
- No infections or alveolar trauma present.
- Anatomically sound conditions for guided implant placement

Exclusion Criteria

- Patients requiring bone augmentation at the surgical implant placement site.
- Contraindications to MRI examination like Haemodynamic monitoring and temporary pacing devices, Eg. Swan-Ganz catheter, cardiac pacemaker, implanted cardioverter-defibrillator (ICD), retained transvenous pacemaker and defibrillator leads, electronic implant or device, eg, insulin pump or other infusion pump, permanent contraceptive devices, diaphragm, or pessary, cochlear, otologic, or other ear implant, neurostimulation system etc.
- Patients below 18 years of age.
- Pregnant patients.
- Patients with claustrophobia.

Softwares Used

1. 3D Slicer – DICOM visualization and segmentation
2. ITK-SNAP – refinement of anatomical segmentation.
3. Blue Sky Plan (Blue Sky Bio, USA) – implant planning and dataset co-registration
4. Meshmixer (Autodesk, USA) – implant and guide tube isolation
5. CloudCompare – three-dimensional deviation analysis
6. Microsoft Excel – data tabulation and statistical organization
7. Patients were selected according to this criteria and informed consent was taken.

Imaging Workflow

The full arch impressions were made and casts were made from them using the stone. They were digitally scanned to obtain STL data sets.

The MRI and CBCT scans were separately obtained for each patient. The DICOM files of MRI and CBCT were imported in software programs such as 3D slicer and ITK-SNAP for segmentation and visualization purposes. Implant planning was done in Blue Sky Plan software following registration of STL and DICOM data sets using teeth surfaces as reference points.

Implant Planning and Deviation Analysis

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After implant planning:

- Implant and guide tube giving angulation of implant were segmented using Meshmixer.
- STL files for implant entry point, apex and long axis were made.
- MRI and CBCT plans were overlaid using Cloud Compare software.
- 3D deviations were measured.

The following measures were taken:

1. Linear deviation at implant entry point
2. Linear deviation at implant apex
3. Angular deviation

Statistics included descriptive statistics and paired sample t-test with level of significance of $p < 0.05$.

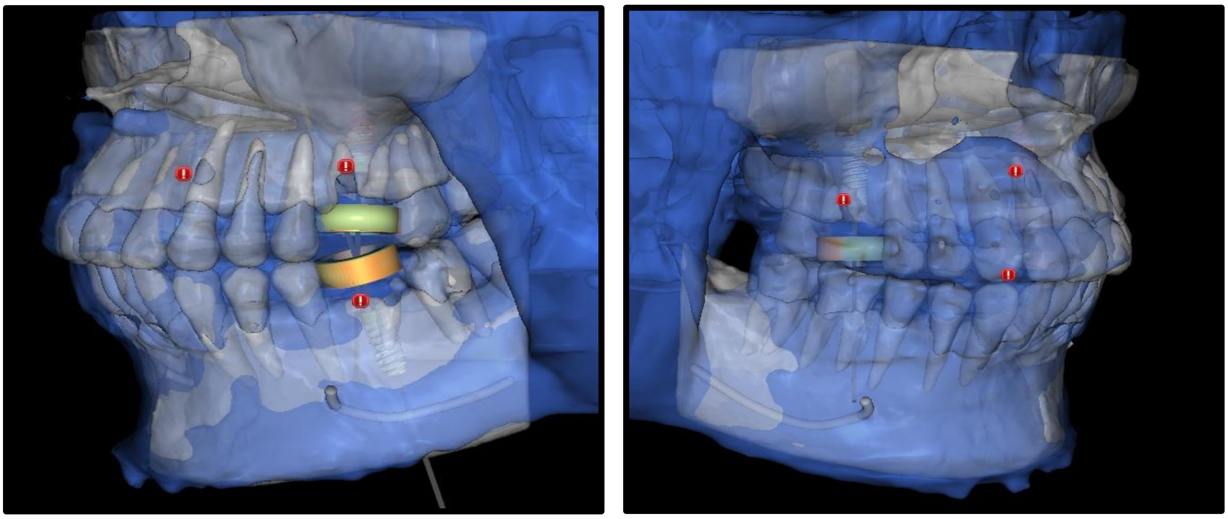

Figure 1. Overlapping of MRI and CBCT implant positioning for Patient 1

RESULTS

Sample Summary

Table I. Sample Summary

Variable	Frequency
Total cases	3
Total implant sites	9
MRI scans	9
CBCT scans	9

The study included three clinical cases comprising nine implant sites. Each site underwent evaluation using both MRI and CBCT, creating a paired comparison design.

Three-Dimensional Implant Position Analysis

The 3D coordinates measured by means of MRI and CBCT scans matched very well when assessed at coronal, apical, and implant angulations levels.

Coronal deviations measured from 0.01412 mm to 0.12098 mm, whereas apical deviations were measured from 0.01882 mm to 0.13717 mm. Deviations of angulations were calculated from 0.00014° to 0.00041°. All these measurements were well below clinically relevant limits.

Table II. Mean Deviation Between MRI and CBCT

Level	Mean Deviation	Standard Deviation
Coronal (Top)	0.05829 mm	0.03777 mm
Apical (Bottom)	0.06903 mm	0.03969 mm
Angulations	0.00032°	0.00009°

The apical deviation showed a slight tendency to be larger than that of the coronal deviation; yet, both were still within a clinically insignificant range. The deviation in the angulation was very low, implying nearly similar implant angulations in both the MRI and the CBCT protocols.

Paired Sample t-Test Analysis

No statistically significant differences were observed between MRI and CBCT at any coordinate level.

For example:

Coronal X-axis: $p = 0.999$

Coronal Y-axis: $p = 0.975$

Coronal Z-axis: $p = 1.000$

Apical coordinates: $p = 0.992–1.000$

Angulation coordinates: $p = 1.000$

All p-values is more than 0.05, indicating statistical equivalence between MRI and CBCT measurements.

Table III. Paired Sample t-Test Comparison of Mean X, Y and Z Coordinates Between Dental MRI and CBCT at top, bottom and Guide Tube Levels

	Axis	Groups	Mean	Std. Deviation	t value	p value
Top	X	MRI	56.60	22.87	.001	.999
		CBCT	56.59	22.88		
	Y	MRI	37.55	1.52	-.032	.975
		CBCT	37.57	1.52		
	Z	MRI	56.88	12.14	.000	1.000
		CBCT	56.88	12.13		
Bottom	X	MRI	56.92	23.03	.000	1.000
		CBCT	56.91	23.02		
	Y	MRI	38.86	2.35	-.010	.992

		CBCT	38.87	2.36		
	Z	MRI	59.68	20.10	.000	1.000
		CBCT	59.68	20.07		
Angulation	X	MRI	56.28	22.81	.000	1.000
		CBCT	56.28	22.81		
	Y	MRI	36.17	1.19	.000	1.000
		CBCT	36.17	1.19		
	Z	MRI	53.90	4.31	.000	1.000
		CBCT	53.90	4.31		

Table IV. Comparison of Mean Three-Dimensional Coordinates and Linear and angular Deviations of Implant Position Between Dental MRI and CBCT at Coronal, Apical levels and Angulations.

	Top			Top linear deviation	Bottom			Bottom linear deviation	Angulation			Angular deviation
	Mean X	Mean Y	Mean Z		Mean X	Mean Y	Mean Z		Mean X	Mean Y	Mean Z	
MRI	26.7937	36.8857	62.7699	0.05369	27.8318	38.835	70.6486	0.04379	25.7065	34.977	54.1015	0.00032
CBCT	26.8267	36.926	62.7829		27.8012	38.8363	70.6173		25.7065	34.9767	54.1016	
MRI	66.7789	37.9433	63.9812	0.05758	65.6513	39.6644	71.901	0.13717	67.9564	36.1634	55.2966	0.0003
CBCT	66.7432	37.9721	63.9464		65.7254	39.7661	71.8464		67.9566	36.1636	55.2965	
MRI	67.5556	36.2026	36.2405	0.01412	69.4192	37.405	28.3092	0.10094	65.5076	34.8567	44.9948	0.00022
CBCT	67.5441	36.2104	36.243		69.3641	37.3209	28.3181		65.5077	34.8569	44.9948	
MRI	27.1164	36.512	61.6701	0.11937	27.5852	37.9064	69.9231	0.06085	26.4666	34.9949	52.8997	0.00037
CBCT	27.0062	36.5571	61.6616		27.6102	37.96	69.9088		26.4668	34.9946	52.8998	
MRI	72.1334	37.4521	65.5249	0.04814	70.9033	38.7977	73.5824	0.07011	73.4283	36.0769	56.9855	0.00014
CBCT	72.0925	37.4284	65.5158		70.8332	38.7965	73.5822		73.4284	36.0768	56.9855	
M	73.9	38.5	41.2	0.120	74.8	40.5	33.0	0.112	73.0	36.3	49.8	0.000

RI	079	111	667	98	974	068	67	06	317	541	563	41
CBCT	74.0223	38.5494	41.2758		74.8583	40.5468	33.1641		73.0313	36.354	49.8563	
MRI	25.1937	35.6921	66.2425	0.02671	24.2366	35.2668	74.7678	0.04289	26.2363	36.2038	57.4945	0.00041
CBCT	25.2111	35.7114	66.2487		24.2656	35.2354	74.7643		26.2359	36.2039	57.4945	
MRI	75.3518	37.9672	68.0193	0.05051	75.2358	37.6237	76.621	0.03468	75.5189	38.3671	59.1366	0.00036
CBCT	75.3273	38.0102	68.0294		75.2574	37.6508	76.6224		75.5192	38.3669	59.1366	
MRI	74.5703	40.7933	46.2006	0.03347	76.4785	43.6927	38.3163	0.01882	72.6947	37.5536	54.2944	0.00037
CBCT	74.5383	40.8016	46.1954		76.4931	43.6818	38.321		72.6949	37.5539	54.2945	

** Linear/angular deviation - SQRT((X1−X2)²+(Y1−Y2)²+(Z1−Z2)²)* $\sqrt{(X1-X2)^2+(Y1-Y2)^2+(Z1-Z2)^2}$

The mean deviation at the coronal level was 0.05829 ± 0.03777 mm, while at the apical level it was slightly higher at 0.06903 ± 0.03969 mm. The guide tube level demonstrated an exceptionally small mean deviation of 0.00032 ± 0.00009 degrees.

In general, the three-dimensional coordinates obtained with the help of MRI were in a very close agreement with those obtained using CBCT. The mean differences in all measurements, except for the angle of the implant, were less than 0.1 mm; angular deviations of the implant were practically equal to zero. No statistically significant differences between MRI and CBCT were detected concerning any measured coordinate. In other words, MRI could accurately reproduce implant placement, its angulation, and position. From a clinical point of view, the differences measured are very small, and they do not have any practical importance when speaking about guided surgical procedure and therefore justify the use of MRI in planning the procedure of immediate implant placement.

DISCUSSION

The success of implant treatment depends largely on accurate implant positioning, as the biomechanics of load distribution, emergence profile of the prosthetic restoration, aesthetics, and long-term health of the peri-implant tissues are all influenced by implant position.[1,19] Errors in implant positioning can result in prosthetic complications, peri-implant bone loss, and injury to adjacent anatomical structures.[10,20]

CBCT continues to be regarded as the gold standard because of its excellent spatial resolution. However, the use of ionizing radiation should always be justified, particularly in younger patients and in patients who may require repeated imaging.[3,6] This supports the ALARA(As Low As Reasonably Achievable) principle, which requires keeping radiation doses to workers and the public as low as social, economic, and practical factors allow.

The findings of the present study are in alignment with those reported by Hilgenfeld et al., who demonstrated excellent correlation between MRI- and CBCT-based implant planning and showed that MRI-generated surgical guides were sufficiently accurate for clinical use.[15] Similarly, Mercado et al. reported the successful application of fully digital MRI-guided implant surgery.[16] Probst et al. also favours the clinical feasibility of MRI-based computer-guided implant surgery with acceptable levels of accuracy.[21]

In the present study, the mean coronal deviation was only 0.05829 mm, while the mean apical deviation was 0.06903 mm and angular deviation was 0.00032°. These values are considerably lower than those commonly reported in the literature on guided implant surgery, indicating an excellent degree of geometric agreement between MRI- and CBCT-based planning.

One of the major advantages of MRI is its ability to visualize both hard and soft tissues without exposing patients to ionizing radiation.[9,17] MRI can accurately depict the alveolar bone, surrounding soft tissues, neurovascular structures, and adjacent anatomical landmarks.[10,19]

Recent studies have further supported the increasing role of MRI in implant dentistry. Grandoch et al. reported that 1.5-T MRI may serve as an alternative to CBCT for implant planning.[22] Zhang et al. concluded that the geometric accuracy of MRI is sufficient for it to be considered an alternative imaging modality in selected clinical situations.[23]

In contrast to the findings of the present study, Fuglsig et al. Concluded that although MRI shows considerable promise for implant planning, the existing evidence remains insufficient to support its routine replacement of CBCT because of heterogeneity in imaging protocols and limited clinical validation. The present study, however, demonstrated no statistically significant differences between MRI- and CBCT-based implant planning, supporting the feasibility of MRI as a radiation-free alternative for immediate implant planning[19]

Despite these advantages, MRI still has certain limitations, including higher cost compared to CBCT, longer scanning time, limited availability, susceptibility to motion artifacts, and image distortion caused by metallic restorations.[11,24] Nevertheless, continued technological advancements are expected to overcome many of these limitations in the future.

Based on the findings of the present study, the null hypothesis was accepted. The absence of any statistically significant difference between MRI and CBCT in evaluating implant position indicates that MRI can accurately reproduce implant position information obtained from CBCT and has the potential to serve as a reliable imaging modality for guided immediate implant planning since there was a very high degree of correlation between the two imaging modalities, with little to no difference in either linear or angular deviations.

CLINICAL SIGNIFICANCE

In conclusion, it appears that the use of dental MRI allows clinicians to perform guided immediate implant planning without the risk of exposing their patients to ionizing radiation while still ensuring clinically sufficient spatial accuracy.

CONCLUSION

The results obtained in this study suggest that dental MRI provides similar levels of implant planning accuracy to CBCT for guided immediate implant placement. Considering the lack of any statistically significant linear or angular deviations between MRI and CBCT, the level of spatial correlation between the two methods regarding implant positioning appears to be very high. Besides the high level of visualization quality concerning implant entry points, apical positions, and implant angulations, MRI provides one additional and important benefit to dentists – radiation-free imaging. With further progress being made in dental MRI technology, it becomes likely that MRI will become an effective alternative imaging method for implant planning and guided implant surgery.

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