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ORIGINAL ARTICLE

Study of inferior dental canal and its contents using high-resolution magnetic resonance imaging

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Abstract The aim of this study was to evaluate the visualizability, topography, and course of the mandibular canal with particular attention to the incisive canal on 3-T MRI. Particular attention was paid to the incisive canal anastomosis at the symphysis. A total of 64 dentate patients were examined using a modified T2 space sequence using 3-T MRI. The scans were analyzed with respect to the topography of the entire course of the mandibular canal, mental canal, incisive canal, and nutrient canals. The high-field MRI of the lower jaw allowed detailed visualization of the mandibular canal, the incisive canal, and the surrounding connective tissue structures. In the context of the present study, 3-T MRI was found to be a potentially useful imaging method for displaying the course of the entire inferior dental canal for pre-implantation planning, surgical planning, and diagnosis.

Keywords Mandible · Inferior alveolar nerve · Inferior dental canal · Incisive canal · Nutrient canals

Introduction

The inferior alveolar nerve (IAN) runs together with the inferior alveolar artery through the infratemporal fossa and the mandible. On their course, they are surrounded by a bony tube, the mandibular canal (MC). Within the anterior mandible, the MC usually divides into the mental canal (MEC) and the incisive canal (IC) [21]. While the mental canal ends in the mental foramen, the IC courses further on to the anterior chin region. To supply the teeth and the interdental space and gums, the mandibular canal and incisive canal further divide into fine canals within bone named as nutrient canals which contain the terminal fine branches of nerves and blood vessels [15]. Olivier states that beyond this division of the mental canal, there are no further surrounding branching structures arising from this canal [21]. Wadu [24] reported an anastomosis of the ICs in the chin region, where the incisive nerve of the mandible crosses the midline and contributes to the innervation of the opposite side.

Exact knowledge of the precise anatomic topography, and especially of fine anatomical structures, in the mandible is very important for planning dental implants and other surgical procedures of the mandible, and it is an essential foundation to detect pathological processes in diagnosis and surgical planning. In dental practice, several conventional radiographic techniques can be used for imaging the jaw. Today, conventional X-ray imaging or orthopantomography is used routinely. In addition, digital volume tomography (DVT) and, especially, dental CT have been established in dental practice. These modern techniques provide excellent resolution and good contrast between soft tissues and bones, but their utility for the diagnosis of soft tissue structures is limited. More recently, another imaging method, magnetic resonance imaging (MRI), has been studied and recommended by many authors as an effective assessment tool for planning dental implants and other surgical interventions [11, 12]. MRI has been established in many areas, including diagnosis of the head and, particularly, for assessing various peripheral nerve disorders; it is also valuable for visualization and detection of dental diseases [4].

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To the best of our knowledge, the literature contains mostly studies using low-field MRI with only a few studies that have investigated the potential of high-field MRI for better delineation of the canal structures in the mandible [8]. However, high-field MRI techniques promise improved image resolution and better contrast for preoperative diagnostic imaging.

The purpose of the present study was to investigate the potential of 3-T, high-resolution in vivo imaging of the entire inferior dental channel structures, including the mandibular canal, the IC, the MEC, and the nutrient canals of the mandible, and to discuss the possible topographic anatomy and its clinical impact for better preoperative diagnosis.

Materials and methods

Selection of patients in the study group

A total of 64 patients (39 women, 25 men; ø 43.7 years, range 15–76 years) were evaluated. These patients were selected from a group of patients who underwent MRI neck for various reasons during period of 9 months. MRI images of patients with metal artifacts caused by dental materials, as well as not fully dentate patients in the anterior portion of the mandible or with more than 1 or 2 missing teeth, were excluded. Informed consent was obtained from all patients included in this study.

MRI examination

Imaging of the mandible was performed on a 3-T Magnetom Verio MRI (Siemens, Erlangen, Germany) with a standard Siemens head and neck coil. No surface coils were used. The scans were planned in axial orientation parallel to the occlusal plane. For optimal visualization of the channel structures, an optimized 3-D T2 SPACE sequence was used with the following parameters: t2_spc_tra_iso sequence (TR 1000, TE 132, ST 0.64, FOV 184 × 205, Flip Angle 105, Acquisitions 1.5, Matrix 288 × 320, slice oversampling 14.3%). To maximize patient comfort and thus reduce motion artifacts, the scan time for each sequence was limited to 6 min and 24 s. During the investigation, the patients were told to not move the lower jaw and not bite too tightly, to avoid relaxation of the muscles of mastication. Due to the use of isovoxels, it was possible to reconstruct the images in all planes.

Image reconstruction and analysis

After examination, the data were transferred to a workstation and reconstructed as panorama, coronal, and cross-sectional slices using the Osirix software package (Version 3.8.1 32-bit). To create the panorama and cross-sectional images, a cut line following the middle of the mandible was drawn, and cuts parallel to this line and cross-sectional cuts (slice thickness, 0.64 mm) through the whole mandible were reconstructed (Fig. 1). The consecutive cross-sectional images were orthogonal to the outer cortical bone of the mandible (Fig. 1a).

Image evaluation was performed dynamically and using minimum intensity projection (MinIP). The images were analyzed descriptively by two radiologists with respect to the structures and the five criteria described below. The delineation of the proposed structures was graded as: 0, not differentiable; 1, good; and 2, moderately differentiable. For the visual analysis of a good delineation a clear signal-/contrast ratio of the channel structures to the surrounding structures and sharp contours of the canal was characterized. A moderate delineation was described if poor contrast ratio and/or unsharp margins were given.

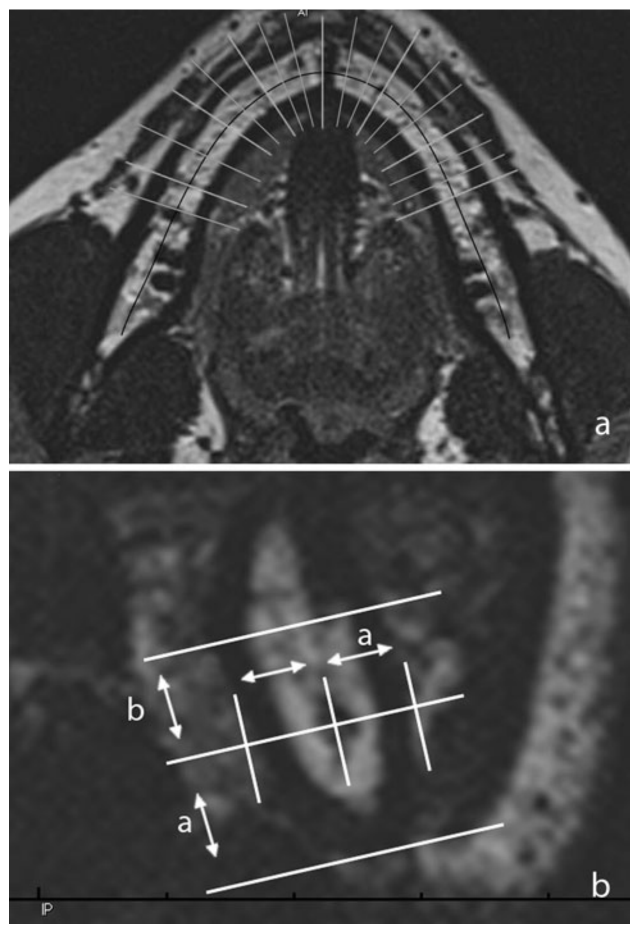

Fig. 1 **a** Axial T2-weighted dental MR SPACE image of the mandible. Planning cross-sectional and panorama view images. **b** Cross-sectional reconstructed image demonstrating the neurovascular bundle, the cortical bone, and the tooth root. Distance determination of the mandibular canal to the root tip, lingual/buccal/basal cortical plate

The evaluation criteria included: (1) differentiability of the mandibular, mental, and incisive canals in the axial and coronal plane and visualization of the nutrient canals to the canine tooth and the medial and lateral incisors; (2) visualization of the IC anastomosis at the symphysis; (3) determination of the length of the IC in the axial projection using MinIP; (4) determination of the topographic location of the IC with respect to the lateral cortical plate (distance a in Fig. 1b) and the root tip (distance b in Fig. 1b) of the first premolar, canine, and incisor teeth in cross-sectional images; and (5) whether the IC always lies below the teeth.

Results

The T2-weighted SPACE sequence showed the anatomical structures in great detail. The contents of the channel structures were hypointense to the surrounding cancellous bone and could be delineated in most cases. Separation of the nerve structures and vessels was not possible.

The MC in its whole course, from the mandibular foramen to the mental foramen, was well or moderately delineated in over 95% of cases. Good delineation was achieved in the axial plane on the right side in 72% and on the left side in 69%. The course of the canal and its bucco-lingual position were seen particularly well in the axial plane. Delineation was not possible in 5% on the right side and in 1% on the left side.

In the coronal plane, good delineation was achieved in 69%, with moderate delineation in 23% of the cases on the right and left sides. In 5% of cases, delineation was not possible. Figure 2 shows an example of a well-circumscribed, hypodense, mandibular canal in the axial (a) and coronal (b) planes.

Delineation of the MEC was possible, but there were problems due to its close location to the bifurcation to the lateral cortical plate. Thus, the canal had to be assessed as a mental foramen in some cases. The right MEC could be demarcated well in 61% and moderately in 23% in the axial plane. The results of the left side were comparable 61% well and 25% moderate delineation.

In comparison, the delineation of the subtle IC was less than that of the mandibular canal. In some cases, the image quality was not sufficient to ensure reliable determination of the IC. The right IC could be demarcated well in 74% (Fig. 3a) and moderately in 23% in the axial plane. The results of the left side were comparable 70% well and 24% moderate delineation. On the other hand, it was more difficult to define the IC in the coronal plane. Good

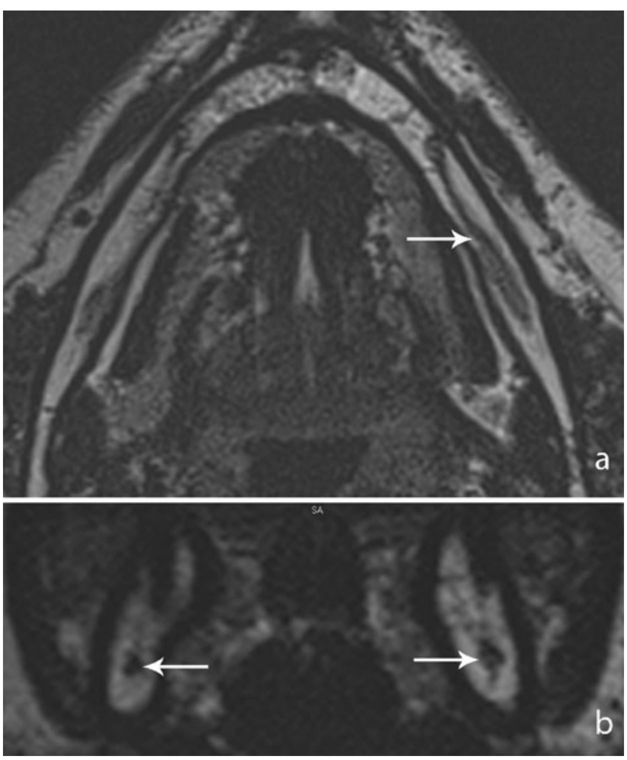

Fig. 2 Axial (**a**) and coronal (**b**) T2-weighted image of the mandible. *Arrows* clearly demarcated mandibular canal

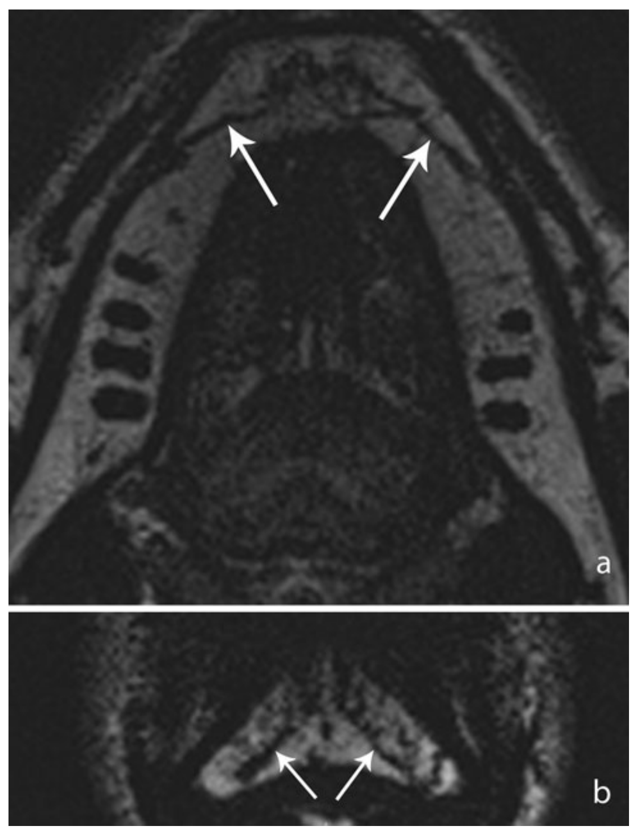

Fig. 3 Axial (**a**) and coronal (**b**) T2-weighted MRI scans of the lower mandible. Clearly delineated incisive canal (*straight arrow*). Nutrient canals (*angular arrow*)

delineation of the right IC was achieved in 59% of cases (Fig. 3b), and moderate delineation was achieved in 28%. The left IC could be delineated well in 58% and moderately in 25%. Figure 1 summarizes the results found on high-field MRI (Table 1).

It was possible to detect the nutrient canals of the canine tooth and the medial/lateral incisor in the T2-weighted SPACE sequence in most cases. Separation of the nerve structures and vessels was not possible. Table 2 summarizes the results found on the MRI.

The majority of the 64 patients, 70%, showed an IC anastomosis (Fig. 4) at the mental symphysis, which was plexus-like in 26% of cases, as already described by Starkie and Stewart [23]. No anastomosis could be detected in 16%. In 14%, no assessment was possible.

The average length of the right and left ICs measured in the axial plane was 2.07 cm (±0.36 cm, $n = 58$) and 2.10 cm (±0.33 cm, $n = 57$), respectively, in the axial projection.

Table 1 Delineation of the dental canal structures

	Right		Left	
	Axial (%)	Coronal (%)	Axial (%)	Coronal (%)
Dental canal				
Good	72	69	69	69
Moderately	23	23	30	23
Not definable	5	8	1	8
Incisive canal				
Good	74	59	70	58
Moderately	23	28	24	25
Not definable	3	13	6	17
Mental canal				
Good	61		61	
Moderately	23		25	
Not definable	16		14	

Table 2 Delineation of the nutrient canals

	Right (%)	Left (%)
Canine tooth		
Good	81	72
Moderately	10	17
Not definable	9	11
Lateral incisor		
Good	70	70
Moderately	13	16
Not definable	17	14
Medial incisor		
Good	69	70
Moderately	15	10
Not definable	16	20

The measured vertical and horizontal distances between the IC and the outer sides of the mandible among the first premolar, canine, and incisor teeth, as well as the standard deviation and the number n of the determined values, are presented in Table 3.

The observation that the IC is always below the anterior teeth was confirmed [17]. In no case was it seen beside the teeth.

Discussion

Planning dental implants and curative interventions of the jaw require detailed anatomical knowledge of the exact position of the regional channel structures.

The correct position of the MC in relation to the cortical bone or tooth is of great interest for surgeons as it helps to avoid complications such as injury to the neurovascular bundle.

Conventional X-ray imaging and orthopantomography are routinely used in dental practice. Orthopantomography has the disadvantage of distortion, [16] and it detects the IC in 15% of cases, with only 1% of cases showing good delineation of the IC [13]. Furthermore, both methods give information in two dimensions, while the visualization of the mandibular structures in the bucco-lingual direction is missing. Thus, both techniques can only be considered for

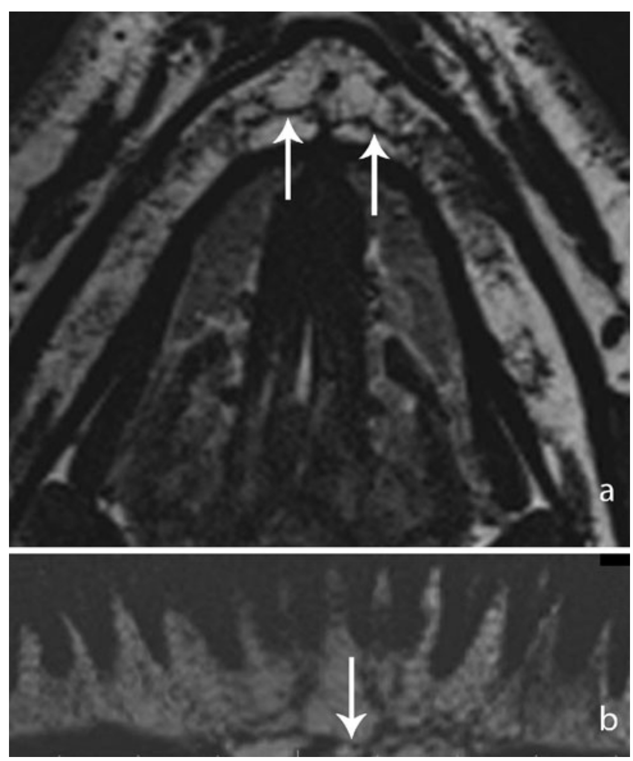

Fig. 4 Axial (**a**) and panorama-reconstructed (**b**) T2-weighted images of the anterior chin region. Anastomosis of the incisive canal (*arrows*)

Table 3 Distances of the incisive canal

	Premolar	Canine	Lateral incisor	Medial incisor
Right (cm)				
Root tip	0.80 (±0.34)	0.75 (±0.30)	0.79 (±0.28)	0.61 (±0.31)
	$n = 54$	$n = 60$	$n = 54$	$n = 39$
Lingual cortical plate	0.55 (±0.14)	0.55 (±0.15)	0.61 (±0.14)	0.68 (±0.16)
	$n = 54$	$n = 60$	$n = 54$	$n = 40$
Basal cortical plate	0.89 (±0.21)	0.89 (±0.25)	1.08 (±0.35)	1.30 (±0.31)
	$n = 54$	$n = 59$	$n = 53$	$n = 39$
Buccal cortical plate	0.40 (±0.12)	0.48 (±0.11)	0.48 (±0.15)	0.45 (±0.15)
	$n = 54$	$n = 60$	$n = 54$	$n = 40$
Left (cm)				
Root tip	0.95 (±1.25)	0.74 (±0.32)	0.83 (±0.32)	0.66 (±0.33)
	$n = 52$	$n = 56$	$n = 49$	$n = 36$
Lingual cortical plate	0.55 (±0.12)	0.56 (±0.13)	0.62 (±0.17)	0.66 (±0.15)
	$n = 52$	$n = 56$	$n = 50$	$n = 36$
Basal cortical plate	0.90 (±0.20)	0.87 (±0.21)	1.07 (±0.32)	1.34 (±0.32)
	$n = 51$	$n = 55$	$n = 50$	$n = 36$
Buccal cortical plate	0.42 (±0.12)	0.47 (±0.12)	0.47 (±0.18)	0.48 (±0.11)
	$n = 52$	$n = 56$	$n = 50$	$n = 36$

preoperative evaluation in order to obtain information about the available bone height. Other techniques are required when additional information in the bucco-lingual plane and the exact location of the channel structures are needed. Hence, in the investigative work up for more extensive dental interventions like split osteotomy, CT has established itself. However, CT scan has the disadvantage that it exposes patient to high dose of radiation [25]. It also has a few limitations with respect to differentiation of tissues for example in cases where bony element of MC is not sclerosed, the delineation by CT is inadequate. The examination of the mandible with MRI has not yet become routine, although the physical principle of MRI requires no ionizing radiation and allows the direct acquisition of information in any plane [9]. Hence, studies can be carried out safely for the patient. In addition to the valuable information about important soft tissue structures provided by this modality, pathological lesions of the lower jaw may be shown with dental MRI [5]. Also in the presence of pathological processes, such as cysts, the neurovascular bundle can be certainly visualized in MRI [14].

In the literature, several authors have already described good visualization of the mandibular canal and the bone dimensions of the mandible and stated that low-field MRI techniques have definite potential for preoperative assessment for dental interventions, e.g., preoperative imaging for implant dentistry [6, 7, 10, 18, 19]. Especially in cases with imprecise delineation of the mandibular canal MRI can be used [22].

Also, dental MRI was directly compared with CT by Haßfeld [10]. He showed within anatomic preparation that was equipped with dental planning template, that the dental MRI is an alternative to CT in diagnostic and planning of dental implants and provide comparable information.

Good contrast of the neurovascular bundle is achieved using T2-weighted sequences [3], as already shown with low-field strength scanners. Reports of high-field MRI are very rare. The present report describes the successful application of 3-T MRI for topographic evaluation to detect the entire course of the canal structures and the outlets in the dentate mandible, as well as to study the practical value of dental high-field MRI.

A high-resolution 3-D T2-weighted SPACE sequence was used to provide good delineation of the canal structures. The good spatial resolution and the thin slice thickness allowed the opportunity for multiplanar reconstruction, which set the foundation for accurate determination of anatomical topography.

The hypodense mandibular canal and MEC structures could be distinguished well from the hyperdense cancellous bone of the lower jaw in the axial and coronal planes (Fig. 2). Consideration of the coronal section images provides additional information on the cranio-caudal position and allows more precise clarification of the localization of the MC (Fig. 2b). The results of good delineation of the MC confirm the information already reported with low-field MRI scanners (1–1.5 T) in the literature [12, 18]. Due to its size, the MC is easy to display, and the benefits of high-field MRI mainly include its high resolution, lower layer thickness (0.64 mm), and a 3-D data set. Differentiation of the nerve and the vessels within the MC was not possible, but this does not significantly limit the diagnostic value of this method.

The present study also demonstrated that even the very subtle mandibular structures, such as the nutrient canals and the IC, could be seen with high-field MRI. It is known that the geometric accuracy of measurements of length and breadth is comparable to that of dental CTs and shows no significant differences in the radiological image [1, 2, 20].

High-resolution MRI brings about a new advanced diagnostic method for investigative work up of patients prior to dental implant procedures; however, evaluation of the data in the present study showed some limitations regarding the position of the IC. Often, no distance measurement could be made below the medial incisor, caused by the anatomical location of the IC, making differentiation between IC and nutrient canal impossible. In some cases, the plexus-like course in the front section also made the analysis more difficult. We have tried to classify these into different types of courses, but this turned out to be difficult due to the 2-D view.

Occasionally, some basic features, like a pyramidal course of the IC (Fig. 3b), a caudal course, a center course, and a high course, were observed in coronal plane. However, it cannot be ruled out that these impressions arise from the slices and the projections. To allow assessment of an accurate representation of the canal in the lower jaw, 3-D visualization of the IC should be performed in future studies with dental MRI.

The majority of the studied patients showed an IC anastomosis (Fig. 4) at the mental symphysis. In some cases, no anastomosis could be found, although the possibility that it existed could not be ruled out. Evidence of links between the two canals was not always clearly displayed due to the complexity, the relatively thick layer thickness for this region, and the extremely subtle neurovascular structures.

Similar to the results of the present study, Wadu [24] described that, in 5 of 6 cases, the incisive nerve crossed the midline and contributed to the innervation of the opposite side. This is supported by practical experience in anesthesia, as two-sided anesthesia is sometimes necessary to numb the area of the incisors.

In conclusion, high-resolution MRI performed using a 3.0-T system can effectively visualize anatomic topography, especially the more subtle structures in the dentate mandible of patients. The current study clearly demonstrated that the application of MRI technologies in dentistry and oral surgery can improve patient care, bring new horizons for the treating specialists, and allow new approaches for implant/dental research.

Ethical standards The study comply with the current laws of the country in which they were performed. Informed consent has been obtained.

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Conflict of interest The authors declare that they do not have any conflict of interest.

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