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Comparison of MRI with dedicated head and neck signal amplification coil and cone beam computed tomography: MRI is a useful tool in diagnostics of cranio-facial growth disorders

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ABSTRACT

Objective: Magnetic resonance imaging (MRI) shows excellent image quality for the depiction of soft tissues and is therefore an important imaging technique in medical diagnostics. However, the practical simultaneous presentation of hard and soft tissue structures of the mouth, jaw and facial area is not fully satisfactory at this time. We investigated the image quality of 1.5 T MRI using a dedicated signal amplifying coil for the application in the oral and maxillofacial field of and compared it with cone beam computed tomography (CBCT). We hypothesized that imaging quality for growth disorders of the facial skull does not differ significantly between the two imaging techniques.

Materials and methods: 12 patients were consecutively enrolled into this study between 01/2016 and 12/2017. Patients received diagnostic imaging for clinical indications using 1,5 T MRI using a dedicated head and neck coil for signal amplification as well as an CBCT. For each patient 5 different MRI sequences and one CBCT protocol were assessed. Images were evaluated by a radiologist and a dentist in consensus. On the basis of 51 anatomical structures and orthodontic, cephalometric reference points, the five datasets were subjectively rated and compared to the CBCT dataset.

Results: Patient age was in the range of 19–78 years. 2614 (69.8%) out of 3744 possible valuations were assessable. Compared to CBCT, MRI images were rated to have a superior image quality of presentation for 42 out of 51 anatomic structures ($p < 0.05$). Notably, 5 out of 51 structures were not assessable due to missing values. T1-weighted MRI images were rated superiorly to T2-weighted images in displaying anatomically relevant landmarks in the oral and maxillofacial field. MRI datasets were inferior in imaging cephalometric and orthodontic reference points in comparison to CBCT images.

Conclusion: In conclusion, this pilot study demonstrates that radiation-free dental MRI enables a reliable detection of important anatomical structures. Thus, the signal amplified MRI presents a radiation-free imaging alternative to established CBCT in craniofacial growth disorders protocols. However, imaging quality in MRI datasets remains inferior to CBCT images for cephalometric and orthodontic reference points.

1. Introduction

Magnetic resonance imaging (MRI) is a radiation-free imaging modality providing outstanding soft tissue contrasts for clinical diagnostics (Dammann et al., 2014; Detterbeck et al., 2016). However, the simultaneous presentation of hard and soft tissue structures of the jaw and mouth region using MRI is not satisfactory in the clinical routine. The problems of MRI in this region are

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associated with a lack of contrast in hard tissues containing smaller amounts of protons, the long duration of MRI recording and susceptibility artifacts by dental implants (Weiger et al., 2010; Idiyatullin et al., 2011; Weiger and Pruessmann, 2011) (Klocke et al., 2006; Starcukova et al., 2008; Boujraf et al., 2009a, b, c; Du et al., 2010; Tymofiyeva et al., 2010).

Current technical advances however are targeted to improve the usefulness of MRI for imaging craniomaxillofacial diseases using higher field strengths (Weiger et al., 2010; Idiyatullin et al., 2011; Weiger and Pruessmann, 2011; Weiger et al., 2011), dedicated coil systems (Boujraf et al., 2009a, b, c; Boujraf et al., 2009a, b, c; Bracher et al., 2011; Bracher et al., 2013), and optimized sequence techniques like SWeep Imaging with Fourier Transformation (SWIFT) (Idiyatullin et al., 2011) or ultrashort echo time (Bracher et al., 2013) have led to an improved image quality followed by an increased interest in dental MRI.

As a result of recent technical developments, MRI has become a promising method for characterizing anatomical structures and pathologies in the fields of implantology (Aguiar et al., 2008; Ritter et al., 2009), orthodontics (Tymofiyeva et al., 2010; Detterbeck et al., 2016; Heil et al., 2017), periodontology (Geibel et al., 2015) and endodontics (Weglarz et al., 2004). Nevertheless, there may be some anatomical structures that cannot be completely displayed using MRI and there are still particular advantages for the depiction of dental and bone structures using CBCT images. For this reason, we aimed to investigate whether dental MRI can produce a reliable differentiation in special anatomical structures in the head and neck.

To our knowledge, no study in the given literature has investigated if MRI with a dedicated dental signal amplification coil can provide an adequate anatomical depiction of maxillofacial structures and how its subjective qualitative performance is rated in view with CBCT.

Therefore, we compared MRI and CBCT in order to evaluate the clinical potential and quality of magnetic resonance imaging for dental use. We aimed to clarify if signal amplified MRI presents a useful tool in diagnosis and treatment of growth disorders of the facial skull. Further, we tested its limits and benefits in comparison to CBCT.

2. Materials and methods

In this prospective study we consecutively enrolled 12 European patients in the time between 2016 and 2017. Inclusion criteria was that age>18 years and had received both CBCT and dental MRI for clinical indications. None of the scans were conducted for study purposes only. The study was conducted in accordance with the principles of the Declaration of Helsinki (2002) and was approved by the Ethics Committee of the University Clinic of Cologne (No. 14-413). All patients' data were anonymized when extracted from the clinic's database for this research. Informed consent of all patients was obtained.

Exclusion criteria were defined as: patients with ferromagnetic implants (e.g. retainer, unremovable piercings, prosthetic crowns, osteosynthesis), cardiac stimulators, tattoos, pregnancy or claustrophobia, patients without informed consent, patients under 18 years and patients with ASA score higher than 3 were not included in this study.

X-Rays were performed with a cone beam CT (Galileos, Sirona, Bensheim, Germany), 90 kV, 7 mA and with radiation dose of 28 mAs. Effective time of exposure was 10–40 s, volume of $512 \times 512 \times 512$ pixel with 0,3 mm voxel. A complete surrounding scan took 14 s.

MRI datasets were obtained by a 1.5 T MRI unit (Achieva, Philips, Healthcare, Best, NL). The detailed scan parameters are listed in Table 3. During MRI protocols all patients were equipped with special modified version of an orbit-4-chanel head and neck coil (Version 2, Noras, Höchberg, Germany). All protocols were examined by a trained radiologist and an experienced maxillofacial surgeon in the University hospital's department for clinical radiology by viewing the data in the local PACS System (Impax, Agfa Healthcare, Mortsel, Belgium).

In our study, CBCT and MRI diagnostics were obtained for each patient within a time frame of 24 h to 4 months. For each of the acquisition protocols a total of 51 anatomical and cephalometric points were rated using a 5 point Likert scale. The possible values ranged from 0 points (Grade 5: not useful) to 4 points (Grad 1: very good) (Table 1). 31 anatomical structures from 5 different regions and 20 reference points (anatomical, anthropological, radiological, constructed points and soft tissue points) were evaluated depending on the FRS-analysis modified by Bhatia und Leighton (Bhatia and Leighton, 1993). Every single structure was valued in axial, sagittal and coronal slights as well as in every different spin echo resonance and compared to the other slights. Additionally, all MRI protocols were viewed in direct comparison with the respective CBCT images (Fig. 4).

If precise marking of anatomical, anthropological and radiological points was not obtainable by the applied program, the respective corresponding areas were marked instead (Table 2).

For categorical variables and statistical analysis, the Shapiro-Wilk-Test, t-test and Mann-Whitney-U-Tests were used as appropriate. P-values were considered significant at the level of significance <0.05. Descriptive analysis was performed as well. Mean average and 95% confidence interval were done for each dataset. We assumed an abnormal distributed patient group for a value of significance less than 0.05.

The result of the Shapiro-Wilk-Test was the premise for further proceedings. In case of normal distribution, we chose the t-test for independent patient groups. In case of abnormal distribution, we chose the Mann-Whitney U -Test.

The effective power was detected with the Pearson correlation coefficient and rated with the relation of Cohen. Weak correlation was defined as ($r \geq 0{,}1$), middle effect as ($r \geq 0{,}3$) and strong effect as ($r \geq 0{,}5$). All statistical analysis was performed in appliance of IBM SPSS Statistics v24.0 (IBM, Armonk, USA).

If an anatomical structure was merely partly examinable and not completely displayed, the structure was not statistically evaluated. However, all structures were included in narrative analysis.

Protocols with a detection rate lower than 2/3 were excluded from the study.

3. Results

Patient age was between 19 and 78 years with a normal distribution of age groups in the population. The mean average age was 44 (SD ± 16,2) years. Five of these patients were female and seven were male.

Only 2614 (69.8%) of 3744 possible valuations were assessable. Out of 51 assessable structures, 46 (86.3%) were rated and 8 of those 46 structures were rated significantly superior in MRI (Fig. 1). In 4 out of 46 assessable structures, all MRI datasets were evaluated as significantly worse in comparison to CBCT (Figs. 2 and 3). In comparison of the average evaluations, almost similar results were observed for T2 protocols (Fig. 4). In total, almost 2/3 of the cases that were evaluated as significantly worse were volumetric protocols. Only datasets of 3D-T1-FFE were evaluated as significantly better in some cases (Fig. 1).

In direct comparison of MRI and CBCT datasets, the acquisition datasets 3D-T1-FFE and T1W_2stacksCLEAR should be noted (Fig. 1). For 5 out of 27 cases, the anatomical structures were

Table 1
Grading, Scoring system and criteria measurement issues in detail.

Grade	Points
Very good to Fail (Grade 1 to 5), X	4 Points to ≤ 0 Points, Structure/point of reference not depicted in field of vision of image
Criteria	**Points and Valuation**
Image sharpness & resolution	2 points (Good), 1 point (moderate), 0 points (poor/bad)
Image contrast, overview & Distinction	2 points (good), 1 point (moderate), 0 points (poor/bad)
Artifacts	0 points (no limitations), (−1) point (region limited assessable), (−2) points (region partially not assessable), (−4) points (region not assessable)
Criteria	**Details**
Image sharpness & resolution	Structure/point of reference identifiable, image sharpness/ resolution sufficient, fluid, continuous boundary lines
Image contrast, overview & distinction	Structure/point of reference identifiable, neighboring structures definable, border distinct and continuous, consistent brightness of same tissues, inner structures of tissues identifiable
Artifacts	Artifacts present, distortion/obstruction of depiction due to artifacts

Table 2
Anatomical structures and cephalometric reference points, *anterior and posterior nasal spine are counted for cephalometric points and anatomical structures, but solely in total.

Region	Anatomical Structures
Frontonasoethmoidal region	Frontal sinus, sphenoidal sinus, ethmoid cells, nasal septum, nasal bone, superior nasal concha, middle nasal concha, inferior nasal concha, piriform aperture, anterior nasal spine, posterior nasal spine
Orbital region	Supraorbital margin, lateral orbital margin, medial orbital rim, orbital floor, optic canal, inferior orbital fissure, supraorbital foramen, infraorbital foramen
Zygomatic complex	Maxillary sinus, zygomatic arch, zygomatic alveolar crest, incisive foramen
Mandible	Articular condyle, coronoid process, mandibular foramen, mandibular canal, mental foramen
Temporomandibular Joint	Condylar fossa, articular tubercle, distance between condyloid fossa and condyle
Type	**Cephalometric reference points**
Anatomic points	Nasion, apical maxillary incisor, incisal maxillary incisor, incisal mandibular incisor, apical mandibular incisor, cusp of first maxillary molars, oblique fissure of first mandibular molar
Anthropological points	(Anterior nasal spine, posterior nasal spine)*, A-point, B-point, Menton
Radiological point	Articulare (dorsal margin of the upper collum)
Constructed points	Sella turcica, anterior tangent point, Posterior tangent point, Gonion
Soft tissue points	Nasion', pogonion', upper lip point, lower lip point, subnasal point

evaluated as significantly better in MRI than CBCT (articular condyle, mandibular canal, condylar fossa, articular tubercle and the distance between condylar fossa and condyle/articular disc). In all five cases this included the datasets of T1W_2stacks CLEAR and in 4 cases it included the datasets of 3D-T1-FFE. The effective power according to the classification of Cohen correlated to a strong effect in almost all significant evaluations. Only in one case was a medium effect size calculated. For the cephalometric and orthodontic points, in 3 out of 17 assessable cases at least one MRI dataset was evaluated as superior to the CBCT dataset (Fig. 1; articular, upper lip point and lower lip point). In all cases the dataset of T1W_2stacks CLEAR was represented. In 2 cases the dataset of T1W_2stacks CLEAR and 3D-T1-FFE were assessed as superior. The effective power according to Cohen correlated a strong effect.

The anatomic points in 8 (+2*) out of 27 cases and the cephalometric and orthodontic points in 8 (+2*) out of 18 (+2*) cases of MRI imaging were evaluated as significantly inferior to CBCT in at least one MRI acquisition protocol. Especially affected regions included orbital and frontal nasal ethmoidal regions and the differentiated depiction of mandibular hard tissue. With only a few exceptions, the volume acquisition protocols were inferior to the CBCT due to the easily distinguishable hard tissues. MRI datasets that were rated significantly inferior affected the following points: sphenoidal sinus, ethmoidal cells, medial nasal concha, apertura piriformis, anterior nasal spine, posterior nasal spine, infraorbital fissure, coronoid process, mental foramen, A-point, B-point, anterior tangent point, posterior tangent point, maxillary incisal incisor, mandibular incisal incisor UK, maxillary first molar cusps, and oblique fissure of mandibular first molars.

In 4 cases all MRI acquisition protocols were rated significantly inferior to CBCT (sphenoidal sinus, ethmoidal cells, infraorbital fissure, and the coronoid process).

4. Discussion

In our study, we evaluated the image quality of MRIs in clinically relevant, high field intensity of 1,5 T images using an innovative head and neck coil and providing a direct comparison to CBCT imaging. Our aim was to optimize the performance of this MRI imaging dataset with regard to special anatomic regions in the head and neck as well as to dental imaging. Our focus was on the applicability to the technically challenging simultaneous presentation of hard and soft tissue structures of the mouth, jaw and facial area. We documented that the MRI protocols in 42 out of 46 cases presented significantly equivalent or better imaging results than CBCT. In the literature, to our knowledge, there are no similar studies in living human patients with 1,5 T MRI and a signal amplification coil, indicating the growing investigative potential relating to different imaging modalities of CBCT and 1.5 T MRI on their anatomical reliability.

The anatomic landmarks were chosen in accordance to prior research works in the cranio-and maxillofacial lareas (Bhatia and Leighton, 1993; Mischkowski, 2007). Thus, our assessment included relevant landmarks and observational protocols of the whole craniofacial skull with orthodontic marking points.

In total, 2614 out of 3744 possible evaluations (69.8%) were taken into consideration. For four anatomical points and one cephalometric point, no significantly usable result could be obtained due to few MRI datasets. Two cephalometric points, the menton and pogonion, could only be evaluated in 2 patients in the CBCT datasets because they were located on the outermost margin of the field of view (FOV). The MRI was evaluated as equivalent or better in the process of elimination when compared to CBCT. As a result, these mentioned points are included in the overall statistic.

Table 3
Detailed MRI scan parameters.

	Philips Achieva 1.5 T		Range of scanner parameters of referring institutions (Siemens, Toshiba, Philips [1.5–3.0 T])	
Parameter	Axial FLAIR[a]	Sagittal FLAIR[a]	Sagittal FLAIR[a]	Axial FLAIR[a]
Field of view (mm)	256 × 256	320 × 320	256 × 256–488 × 512	256 × 256–568 × 640
Matrix	256 × 172	300 × 150	256 × 184–320 × 192	256 × 172–320 × 192
Slice thickness (mm)	6.0	6.0	4.0–6.0	4.0–6.0
Repetition time (msec)	6000	6000	5307–9000	6000–12000
Echo time (msec)	120	120	83–120	100–140
Inversion time (msec)	2000	2000	2000–2500	2000–2850

[a] FLAIR - Fluid attenuated inversion recovery.

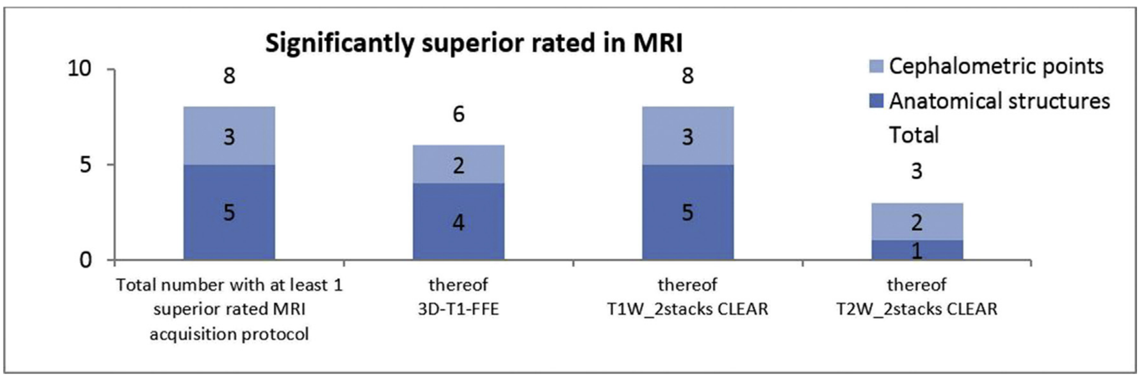

Fig. 1. Total number of anatomical structures/cephalometric points significantly superior rated in MRI.

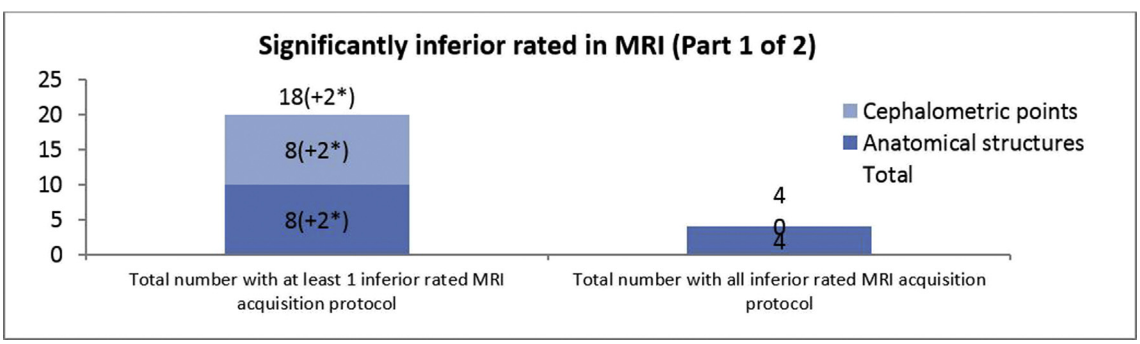

Fig. 2. Total number of anatomical structures/cephalometric points significantly inferior rated in MRI (Part 1 of 2); *anterior and posterior nasal spine are counted for cephalometric points and anatomical structures, but solely in total.

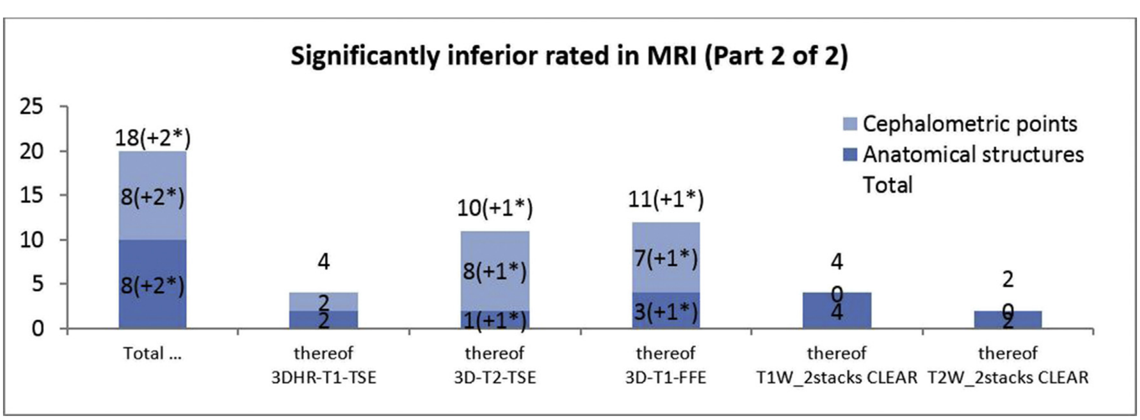

Fig. 3. Total number of anatomical structures/cephalometric points significantly inferior rated in MRI (Part 2 of 2); *anterior and posterior nasal spine are counted for cephalometric points and anatomical structures, but solely in total.

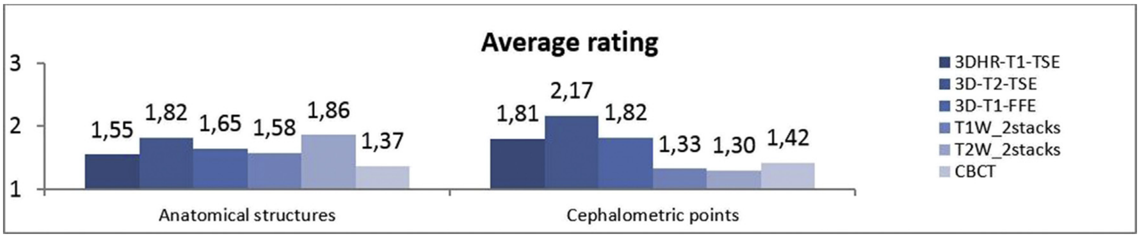

Fig. 4. Average rating for all acquisition protocols in grades 1-5.

In 8 out of 46 assessable anatomic/cephalometric, orthodontic points evaluation of MRI datasets was found to be significantly better than the corresponding depiction with CBCT datasets. Especially the mandibular and temporomandibular joint regions were affected with the following points: articular condyle, mandibular canal, condylar fossa, articular tubercle and the distance between condylar fossa and condyle (articular disc). In addition, the cephalometric points articular, upper lip point and lower lip point were evaluated significantly better. The superior evaluation can be attributed to the high-quality depiction of osseous outline and cortex, the clear distinction of nerve tissue and cortex, cartilage and cortex, and the significant differentiation of soft tissue. The significantly superior depiction of the temporomandibular joint region stood out and confirms a meta-analysis from 2016, which states that MRI is the gold standard and is predominantly used in visualizing soft tissues in diagnosis of pathologies of the discus, the ligamentous apparatus and the capsule (Pupo et al., 2016).

5 acquisition protocols were tested against a CBCT dataset. As a result, the large sample size of significantly inferior MRI datasets was reduced to 4 cases. Affected points include the sphenoidal sinus, ethmoidal cells, infraorbital fissure, and coronoid process. The CBCT datasets were evaluated as significantly superior to MRI datasets for these points (high effect size according to Cohen) or there were too few datasets present. However, dedicated adaption of MRI image sequences using spin echo sequences could show a comparable performance to CBCT in these areas. Due to the broad distance of the orbital and frontal nasal ethmoidal region to the head and neck coil, the SNR for this region turned out rather poor in the image sequences chosen. Especially the sphenoidal sinus and the infraorbital fissure were affected. Due to missing assessable MRI datasets the 3D-T1-FFE protocol was comparable to the CBCT datasets. This has a negative consequence for the evaluation, because the thin osseous walls and cortex cannot be depicted as well differentiated compared to other MRI protocols. The depiction of ethmoidal cells was problematic because thin osseous walls had to be shown differentiated from mucous membrane and air. As already reported in the literature (Bracher et al., 2013), we confirm that air content especially in areas where fine and slight structures are to be analyzed decrease the validity of MRI-images. For the coronoid process the differentiation of cartilage and muscle insertion was not possible. However, with CBCT the coronoid process could be depicted completely and could be analyzed (Fig. 5).

As reported in literature (Bracher et al., 2013), we confirm further limitations of MRI technology as the susceptibility of artifacts in patients with fixed metal prosthetics. Depending on the alloy and size of the prosthetics, small artifacts (Fig. 6, T1W_2stacks CLEAR) and larger artifacts were depicted, so that entire areas of the image could not be assessed (Fig. 6, 3DHR-T1-TSE). In previous studies less sensible protocols were used and it was shown that protocols using ultrashort echo times could reduce artifacts in titanium and cobalt-chrome alloys (Du et al., 2010).

In contrast to earlier investigations of CBCT images, our study did not solely focus on the osseous structures and the comparison of radiological procedures but additionally includes the depiction and comparison of soft tissues in a subsequent step. Different studies exist to make a simultaneous statement on osseous structures and soft tissues. In a systematic review from 2016, the

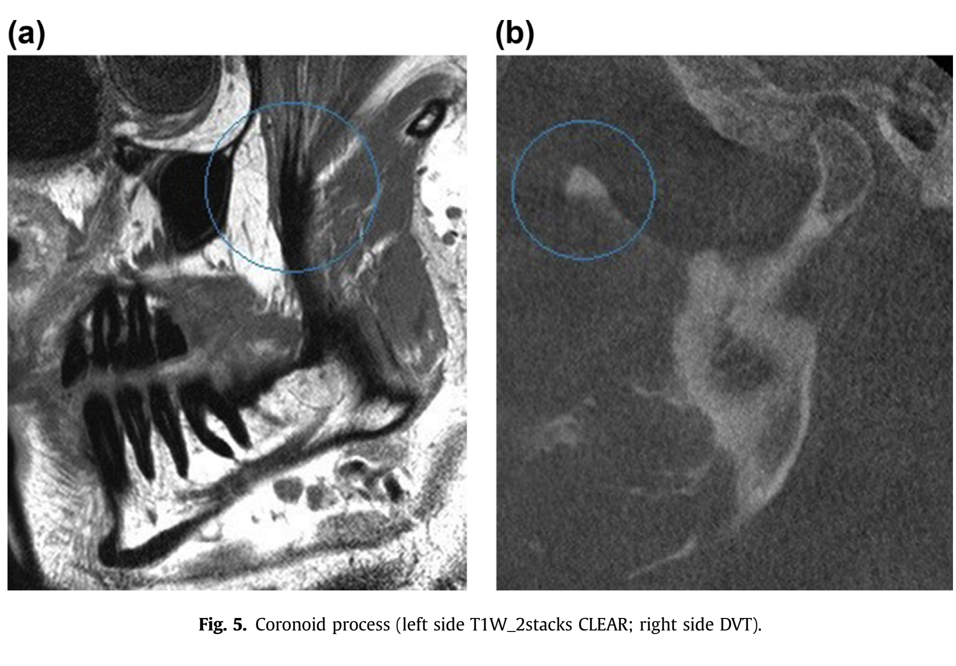

Fig. 5. Coronoid process (left side T1W_2stacks CLEAR; right side DVT).

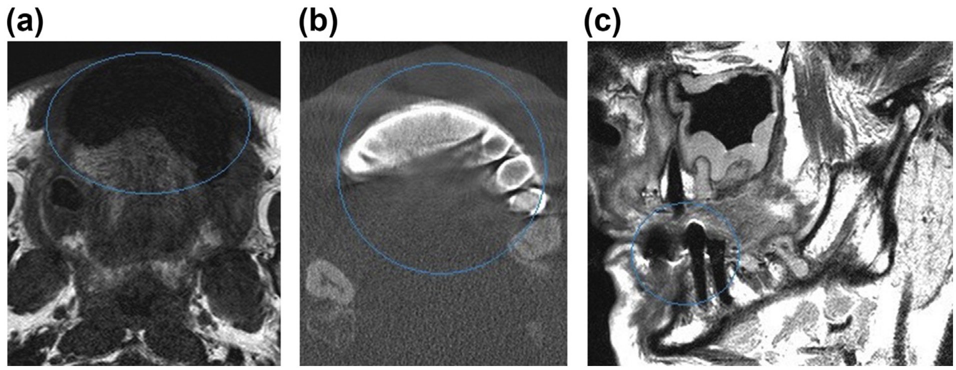

Fig. 6. Artifacts (from the left to the right side: 3DHR-T1-TSE, DVT, T1W_2stacks CLEAR).

combination of MRI and CT was evaluated in assessing osseous structures and soft tissues of the temporomandibular joint (Al-Saleh et al., 2016). An advantage of the favorable benefit-risk-profile solely using MRI is not given because the mentioned study also used CT imaging.

In appliance of innovative coils that were close fitting to the skin/the area to be depicted, the signal-noise ratio was improved considerably. Therefore, in 42 out of 46 cases the MRI protocols were evaluated as significantly equivalent or better, and validated previous studies (Boujraf et al., 2009a, b, c; Bracher et al. 2011, 2013).

A comparison to the prevailing gold standard, 2D lateral x-ray imaging, was not conducted. However, a different study from the University of Heidelberg in 2017 showed that lateral x-rays that were converted from MRI datasets enabled measurements with a high reliability in correspondence to lateral x-ray evaluations (Heil et al., 2017).

Certain advantages and disadvantages can be expressed about each of the 5 acquisition protocols and applicable range of indications. For the assessed points and the criteria described in this study, the T2-weighed protocols show no advantage in comparison with the T1-weighed protocols. In comparison of the average evaluations, the T2-weighed protocols were assessed as lower quality (Fig. 4) or negligibly equivalent. This finding is in line with our results which show that solely T1-weighed protocols were significantly better than CBCT (Fig. 1). The scan mode (3D vs. Multislice) is chosen based on the indication. The 2stacks CLEAR protocols stand out in comparison to volumetric protocols in that it allows for a quick overview of the situation of the jaws, similar to a panoramic tomographic image. The datasets provide high-quality high-resolution images with clear lines, so that tissues can be differentiated easily. Compared to CBCT datasets, the images were evaluated as equivalent or better (Fig. 7). The protocol T1W_2stacks CLEAR displayed the temporomandibular region better than the partner protocol T2W_2stacks CLEAR. The 2stacks CLEAR protocols link up with the indication for panoramic x-ray, which constitutes primary imaging for diagnostic purposes in the dental and maxillofacial region along with intraoral dental radiography (Dammann et al., 2014). The application scope is in line with the indications included in the S2k guidelines for dental volume tomography (Schulze et al., 2013) which are mentioned in the introduction. In total, almost 2/3 of the cases rated significantly inferior to volumetric protocols. Only 3D-T1-FFE datasets were evaluated as significantly better in some cases (Fig. 1). Hard tissues, such as the maxillary cortex wall, were depicted as more differentiated in general, especially in the high-resolution protocol 3DHR-T2-TSE. Soft tissue, such as the inferior alveolar nerve, is depicted really well in the FFE-protocol. We claim that signal amplified 1,5 T MRI presents a useful tool in diagnosis and treatment of growth disorders of the facial skull. This study shows proof in ability to visualize osseous and dental structures as well as anatomical structures or anatomical-structural changes in living human patients. Our study

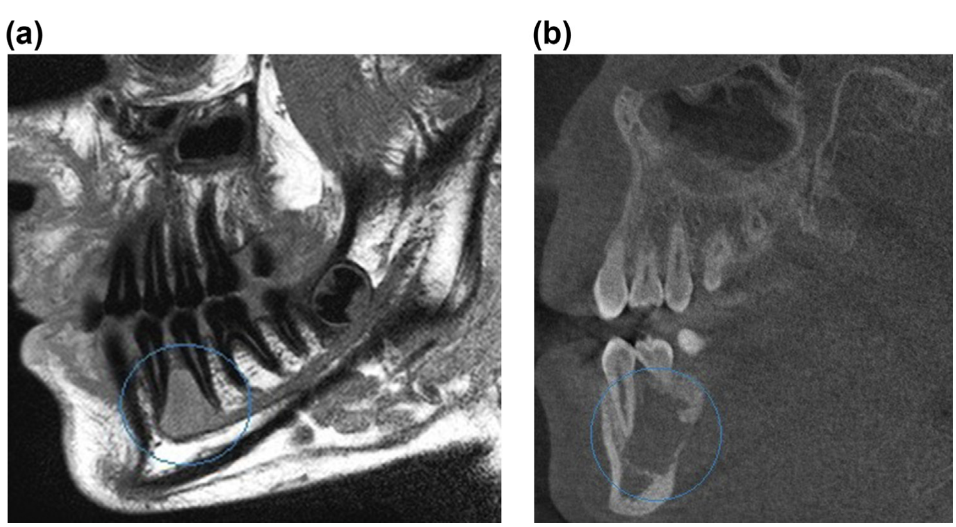

Fig. 7. Cyst in the lower jaw (left side T1W_2stacks CLEAR; right side DVT).

also shows proof in principle of in vivo MRI-based diagnosis using a signal amplified 1,5 T MRI under research conditions.

Besides the retrospective nature of the study, there are several limitations to be discussed. The study does not provide data in regard to intra- and interobserver variance of observations which would serve as an indicator of reproducibility. Despite the technical advancements of MRI and the advantages shown in comparison to CBCT, the study was not designed to suggest replacement of CBCT. We believe that CBCT still has dedicated and clinically relevant advantages in comparison to MRI in regard to the depiction of osseous fine structures.

5. Conclusion

In terms of clinical relevance of this study, it can be concluded that signal amplified 1,5 T MRI in the present setting and special indication constitutes a suitable, clinically relevant alternative to CBCT for osseous structures and soft tissues in dental and head and neck regions at the same time. For patients, it provides added value in imaging without radiation exposure. This can lead to new indications in craniofacial growth disorders. Of note, this is a feasibility study and further investigations of lager cohorts are needed.

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