A Comparative Analysis of Magnetic Resonance Imaging and Radiographic Examinations of Patients with Atypical Odontalgia

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Aims: To examine *(1)* the occurrence of magnetic resonance imaging (MRI) signal changes in the painful regions of patients with atypical odontalgia (AO) and *(2)* the correlation of such findings to periapical bone defects detected with a comprehensive radiographic examination including cone beam computed tomography (CBCT). **Methods:** A total of 20 patients (mean age 52 years, range 34 to 65) diagnosed with AO participated. Mean pain intensity (± standard deviation) was 5.6 ± 1.8 on a 0–10 numerical rating scale, and mean pain duration was 4.3 ± 5.2 years. The inclusion criterion was chronic pain (> 6 months) located in a region with no clear pathologic cause identified clinically or in periapical radiographs. In addition to a clinical examination and a self-report questionnaire, the assessments included radiographic examinations (panoramic, periapical, and CBCT images), and an MRI examination. Changes in MRI signal in the painful region were recorded. Spearman's rank correlation between radiographic and MRI findings was calculated. **Results:** Eight of the patients (40%) had MRI signal changes in the pain region. The correlation to radiographic periapical radiolucencies was 0.526 (P = .003). Of the eight teeth displaying changes in MRI signal, six showed periapical radiolucency in the radiographs. **Conclusion:** MRI examination revealed no changes in the painful region in a majority of patients with AO, suggesting that inflammation was not present. MRI findings were significantly correlated to radiographic findings. *J Oral Facial Pain Headache 2014;28:233–242. doi: 10.11607/ofph.1230*

Key words: *cone beam computed tomography, magnetic resonance imaging, orofacial pain, persistent dentoalveolar pain disorder, trigeminal pain*

Atypical odontalgia (AO) is a severe orofacial pain condition, also known as persistent dentoalveolar pain disorder[1] and classified by the International Headache Society (IHS) as "persistent idiopathic facial pain of intraoral dentoalveolar subset."[2] AO has traditionally been rather unsatisfactorily defined as tooth-related pain, or pain at a site where a tooth was extracted, in the absence of clinical and radiographic evidence of tooth pathology or other relevant orofacial hard or soft tissue pathology.[3,4]

The mechanisms responsible for the development of this pain condition are largely unknown but are hypothesized to involve deafferentation of peripheral sensory neurons in the trigeminal system occurring in predisposed patients.[5,6] The origin of AO is suggested to be neuropathic.[4–6] Clinically, patients often report pain onset to have occurred after dental treatment[7] usually involving an endodontic or surgical procedure. In a systematic review, the frequency of persistent non-odontogenic pain after endodontic treatment was estimated to 3.4%.[8]

The diagnosis of AO is based on case history and comprehensive clinical and radiographic examinations. As the current definition of AO indicates, diagnosis rests heavily on the absence of unequivocal radiographic evidence of pathology. Patients with AO often have had multiple endodontic treatments in the painful area and/or other invasive dental treatments such as explorative surgery, apicectomies, and extractions.[9,10] Diagnosis may therefore be more difficult because consequences such as scar tissue formation and permanent loss of labial cortical bone plate may present as periapical radiolucency in radiographs.

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The most common radiographic examinations used clinically to detect periapical bone changes are intraoral periapical and panoramic radiography. A systematic review concluded that these techniques have a limited capacity to show small bone lesions but a high capacity to identify normal periapical conditions.[11] Cone beam computed tomography (CBCT) is a technique that has the capacity to visualize more periapical bone defects than periapical radiography.[12,13] A recent study on AO patients confirmed that more periapical bone defects were identified using CBCT compared to periapical and panoramic radiography.[14]

Periapical radiolucency associated with root-filled teeth can be related to inflammatory changes, cyst formation, or healing with scar tissue after apical surgery.[15–19] This makes it difficult to draw conclusions from radiographic appearances regarding the diagnosis of various forms of periapical bone tissue changes,[11] especially when a radiolucency has remained unchanged over time. Magnetic resonance imaging (MRI) has been suggested to be used to show dental pathology.[20–23] An experimental study demonstrated the feasibility of MRI in imaging of dental and periodontal structures, and it suggested that MRI (showing edema) seems to be more a more sensitive instrument to detect early inflammation in bone tissue than radiography (showing the loss of mineral that is the consequence of inflammation).[24]

In periapical bone tissue, signal changes in various MRI sequences around teeth with apical radiolucencies have been described.[20] An increase in signal in specific sequences, indicating the presence of unbound protons in the tissue, was interpreted as high water content and suggested to indicate edema. An observed decrease in signal in other sequences is consistent with the loss of marrow and sclerosis of the bone tissue found in chronic inflammation.[20] Although these findings have not been correlated to histologic features, it seems plausible that MRI may be able to detect inflammatory changes in periapical bone tissue. Conversely, the absence of such signal changes in comparison to surrounding bone tissue may suggest the absence of inflammatory changes. The underlying concept is that if MRI is able to determine whether inflammation is absent or present in the painful regions of patients suspected of suffering from neuropathic tooth pain, it may be an important tool for use in this challenging diagnostic situation.

Therefore, the primary aim of the study was to examine *(1)* the occurrence MRI signal changes in the painful regions of patients with AO and *(2)* the correlation of such findings to periapical bone defects detected with a comprehensive radiographic examination including CBCT. It was hypothesized that there would be no changes in MRI signal in the painful region of the majority of patients diagnosed with AO. An additional but subordinate aim was to describe patients' MRI findings around the apex of teeth diagnosed with symptomatic apical periodontitis (SAP), with the hypothesis that these patients would exhibit changes in MRI signal consistent with the presence of inflammatory infiltrates in bone tissue and loss of marrow.

Materials and Methods

Participants and Study Design

Twenty consecutive patients (18 females, 2 males, mean age 52 years, range 34 to 65) diagnosed with AO were recruited from the Department of Orofacial Pain and Jaw Function (Faculty of Odontology, Malmö University, Malmö, Sweden) between December 2005 and June 2007. The study was performed according to the 1964 Declaration of Helsinki (2008 revision)[25] and approved by the Regional Ethics Review Board at Lund University (Daybook No. 168/2006, Lund, Sweden). The patients were asked to sign an informed-consent form; they received no monetary compensation for their participation.

A previous study examined the diagnostic value of CBCT examination in chronic tooth pain investigations in the same sample.[14] The inclusion criterion was continuous or recurrent pain persisting for more than 6 months that *(1)* was located in a region where a tooth had been endodontically or surgically treated or extracted and *(2)* had no pathologic cause clearly detectable in clinical examination or in panoramic or intraoral periapical radiographs. To ensure eligibility, an experienced orofacial pain specialist (TL) examined all patients prior to study participation to rule out other pain causes with reasonable certainty. This included an examination of the masticatory system according to the Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD),[26] neck examination, transillumination of natural teeth with an optical fiber, vitality testing of non–root-filled teeth, assessment of periodontal pocket depth, and selective loading of cusps. Any invasive treatment (orthograde endodontic treatment/retreatment, apical surgery, and tooth extractions) in the painful region during the previous 60 months was recorded. In endodontically treated teeth, the radiographs (panoramic and intraoral periapical images) were interpreted in relation to previous images and to previous interventions, in accordance with standard clinical practice. Thus, any periapical bone destruction associated with a root-filled tooth included in this study either showed clear radiographic signs of ongoing healing or was interpreted as a residual defect after surgery, and therefore considered unlikely to represent periapical disease and to cause ongoing pain. The pre-imaging clinical

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examination also comprised testing for pain on percussion and on apical palpation, as well as a qualitative somatosensory examination assessing sensory function (hypo- or hypersensitivity or -algesia to touch, cold, and/or pinprick pain in the pain area compared to the contralateral pain-free side). In addition, all patients completed a questionnaire with self-report pain measures including average pain intensity (graded on a 0–10 numerical rating scale, NRS), pain duration (years), and frequency of pain (continuous, recurrent, or occasional); these data are shown in Table 1.

In accordance with the inclusion criterion (and the definition of AO that it was based on), all patients had at least one root-filled tooth in the pain region. However, because the condition is not tooth-specific, more than one tooth per patient could be assessed. Each patient with AO had only one painful region, and in total, 30 teeth (1 to 3 teeth per patient) were present in the 20 painful regions and assessed. Twenty-one of these teeth had been endodontically treated, and the remaining 9 teeth were considered vital and healthy after clinical and radiographic assessment.

In addition, five patients (three females, two males, mean age 62 years), each with one painful tooth diagnosed with SAP, were recruited from the Department of Endodontics and the emergency clinic (Faculty of Odontology, Malmö University, Malmö, Sweden). These patients were examined for exploratory purposes, and thus the findings were not compared to any findings made in patients with AO. All patients with SAP reported continuous or recurrent pain from a tooth that had a periapical bone defect clearly visible radiographically.

Exclusion criteria for both groups were trigeminal neuralgia, herpes zoster, maxillary sinusitis, cluster headache, and paroxysmal hemicrania.

Table 1 Description of the 20 Patients with Atypical Odontalgia

	No. of patients (%)	Mean	SD	Range
Age (y)		52		34–65
Sex				
Female	18 (90)			
Male	2 (10)			
Pain intensity on 0–10 NRS		5.6	1.8	
Pain duration (y)		4.3	5.2	
Pain frequency				
Continuous	19 (95)			
Recurrent	1 (5)			
Orthograde endodontic treatment	20 (100)*			
Apical surgery	10 (50)*			
Tooth extraction	4 (20)*			
Pain on percussion (≥ 1 tooth)	8 (40)			
Pain on apical palpation (≥ 1 tooth)	8 (40)			
Pain on percussion and on apical palpation (≥ 1 tooth)	6 (30)			
Somatosensory changes (QualST)	19 (95)			
Radiolucency detected	9 (45)			
Changes in MRI signal	8 (40)			

*Time between the last previous endodontic treatment in the painful region and the MRI ranged from 5 to 60+ months. For apical surgery, the range was 11 to 60+ months, and for tooth extraction 11 to 48 months.
NRS = numerical rating scale; QualST = qualitative sensory examination; MRI = magnetic resonance imaging.

Radiographic Examination

The conventional radiographic examination of the painful area comprised intraoral periapical and panoramic radiographs; the full details were described in an earlier publication.[14] All patients were examined with CBCT at the Department of Diagnostic Radiology (Diagnostic Centre, Skåne University Hospital, Malmö, Sweden). The CBCT machine was a 3D Accuitomo (J Morita). The image area was 3 × 4 cm, and contiguous sections with a thickness of 1 mm were reformatted in three perpendicular planes (axial, coronal, and sagittal).

The radiographic findings reported here were derived from the assessment of periapical and panoramic images in combination with CBCT, and are thus not to be confused with findings from CBCT only. This approach followed the strategy of normal clinical procedure, where information from all available images is combined into a final record.

Periapical bone defect was the outcome measure, defined as a radiolucent area associated with the root tip and rated as 0 = not detectable, 1 = uncertain, or 2 = detectable. Two experienced specialists in oral and maxillofacial radiology (author AP and observer CL) interpreted the radiographs in a blinded procedure. In cases of disagreement between the observers, the examinations were reassessed and a mutual decision was made. The procedures for image assessment and for determination of interobserver and intraobserver agreements between the radiographic assessments have been described in detail in a previous study.[14]

MRI Examination

All patients underwent an MRI examination with and without contrast enhancement (Sonata Vision 1.5 T system, Siemens). Contrast was enhanced by injections of Magnevist (469 mg/mL, Schering Nordiska). The examinations were performed in the Department of Diagnostic Radiology, Diagnostic Centre, Skåne University Hospital, Malmö, Sweden, and comprised the following five sequences: *(1)* axial T1-weighted images (T1), *(2)* axial T2 Short Tau Inversion Recovery (T2 STIR), *(3)* axial three-dimensional constructive

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Table 2 Correlation Between Radiographic and MRI Findings in the 20 Patients

	Radiographic bone defect n (%)		
	Present	Absent	Total
MRI changes in signal n (%)			
Present	6 (30)	2 (10)	8 (40)
Absent	3 (15)	9 (45)	12 (60)
Total	9 (45)	11 (55)	20 (100)

Uncertain findings were considered nonexistent. For each painful region, the following findings were recorded. In the radiographs: periapical bone defect associated with the apex of any tooth. In the MRIs: changes in signal compared to surrounding tissues interpreted as abnormal. Shaded boxes reflect findings that were in agreement between the methods (15 patients or 75%). All teeth showing radiographic bone defects were root-filled, and in 5 of the 9 patients, the bone defect was only detectable by using CBCT.

interference in steady state (3D CISS), *(4)* axial T1-weighted images following gadolinium contrast administration (T1 gd), and *(5)* axial T1-weighted images with fat suppression following gadolinium contrast administration (T1 fs gd). The nominal resolutions for all sequences were as follows: T1 axial, T1 axial gd, T1 axial fs gd, 3 mm (0.9 × 0.8 × 3.0); T2 STIR, 3 mm (0.9 × 0.8 × 3.0); and 3D CISS, 0.6 mm (0.6 × 0.6 × 0.6).

Two experienced specialists in neuroradiology (authors PM and KA-K) interpreted the MRI examinations independently of each other. The interpretation was done on PACS (Picture Archiving and Communication System). The outcome measure was changes in MRI signal in the alveolar bone. Findings were recorded for each of the five sequences and rated as 0 = not detectable, 1 = uncertain, or 2 = detectable. An overall judgment of whether the observer considered the painful region to appear abnormal or normal according to the MRI examination as a whole was also presented, and in the overall assessment no "uncertain" ratings were allowed. The following findings were considered as abnormal and recorded: *(1)* regions of increased signal intensity on T2 STIR and/or decreased signal intensity on T1-weighted images, and *(2)* contrast enhancement on T1-weighted images and T1-weighted images with fat suppression. The observers were given information on the painful region, but not the results from the radiographic examination or information on previous treatment (such as recent surgery) or the tentative diagnosis (AO or SAP). Observer disagreement was resolved by reassessing and then discussing the images in a joint session until consensus was reached. The consensus opinion was then used in all comparisons between imaging methods.

Comparison Between Radiographic and MRI Findings

Comparisons between radiographic and MRI findings were made at the patient level; the information to the MRI observers was restricted to painful region, and no specific tooth was indicated. The main outcome for MRI was changes in MRI signal compared to surrounding tissues; for radiography the main outcome was presence of a periapical bone defect at one or more teeth in the painful region.

Diagnostic Efficacy

To estimate the diagnostic efficacy of MRI examination to identify AO, sensitivity and specificity were calculated using the comprehensive pre-imaging clinical assessment as the reference standard, combining the 20 patients with AO and the 5 patients with SAP into one sample (thus an 80% prevalence of AO).

Statistical Analyses

Mean values and standard deviations were calculated for all continuous variables. The correlation between radiography and MRI was analyzed using Spearman's rank correlation. Cohen's kappa assessed interobserver agreement and for the radiographs also intraobserver agreement.[27] For MRI, agreement was analyzed both for each sequence separately and for the observers' overall judgment (normal/abnormal MRI). For radiography, the analysis was based on the overall judgment. Kappa values < 0.2 were considered poor agreement, 0.21 to 0.40 fair, 0.41 to 0.60 moderate, 0.61 to 0.80 good, and 0.81 to 1.00 very good.[28] The percentage of total agreement was also calculated. Statistical tests were performed two-tailed and at the 5% significance level. All calculations were made using Predictive Analytics Software (PASW Statistics Version 18.0 for Windows; SPSS Inc).

Results

Radiographic and MRI Findings

Table 1 shows the frequency of abnormal findings in the radiographic and MRI examinations, together with clinical findings and patient and pain characteristics. The correlation between radiographic and MRI findings (Table 2) was 0.526 (P = .003). In 75% of the patients (15/20), the radiographic findings agreed with the findings of the MRI images; in the majority of these (9/15 patients), no abnormal findings occurred (Fig 1). In the remaining 5 patients, 3 patients displayed a radiographic bone defect when MRI was normal (Fig 2) and 2 patients had normal radiography but MRI showed changes in the region (Fig 3); in 1 of these patients, the finding was made in the area where a tooth was extracted 18 months earlier. Six

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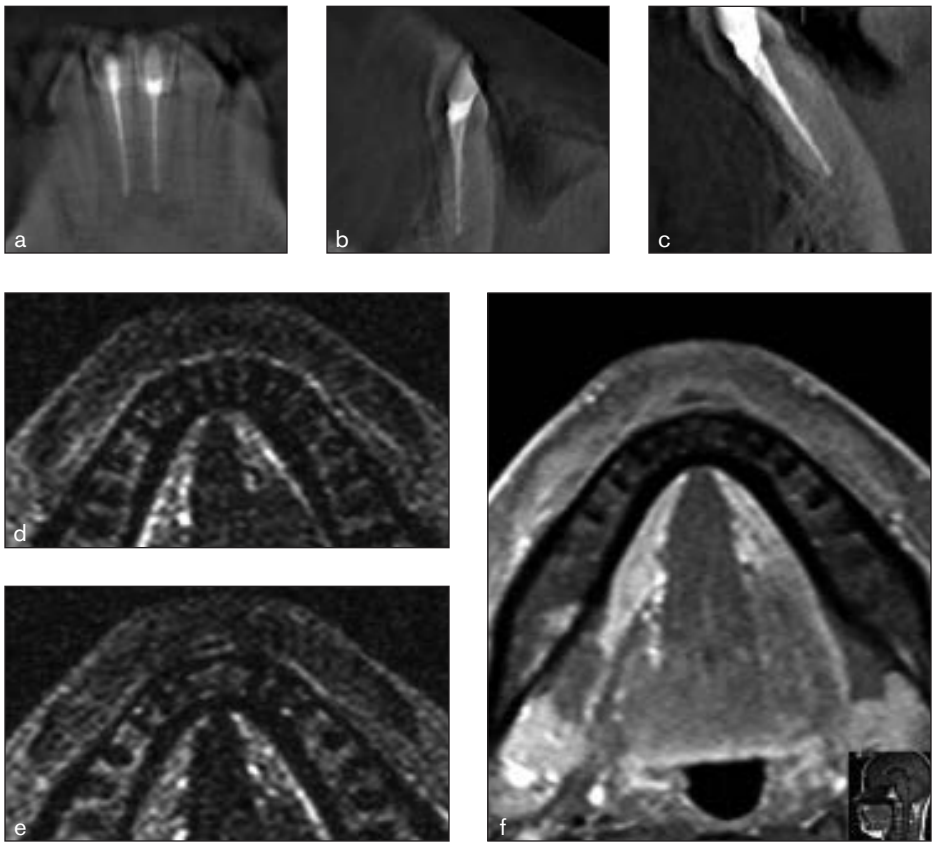

Fig 1 Negative CBCT and MRI findings in one patient diagnosed with AO. **(a)** CBCT coronal view of mandibular left central incisor (tooth 31) and lateral incisor (tooth 32) as well as CBCT sagittal views of **(b)** tooth 31 and **(c)** tooth 32 displayed no periapical or other radiolucency in the region. MRI findings were also normal. MRI T2 STIR at **(d)** apical and **(e)** immediately inferior levels, and **(f)** MRI T1 fs gd at immediately inferior level. (T2 STIR = axial T2-weighted image with Short Tau Inversion Recovery; T1 fs gd = axial T1-weighted fat suppressed image with gadolinium contrast enhancement.)

patients displayed both a CBCT radiolucency and changes in MRI signal (Fig 4).

Five patients had undergone invasive dental treatment in the painful region during the 12 months preceding imaging. Three patients had received only orthograde endodontic treatment (5, 11, and 12 months previously, respectively), one had received orthograde endodontic treatment and subsequent apical surgery of the same tooth (11 months previously), and one patient had had a tooth in the region extracted (11 months previously).

Both patients recently undergoing surgery or extraction had changes in MRI signal in the painful region, while neither of the patients who had only received orthograde endodontic treatment displayed such changes.

In all eight patients with abnormal MRI findings, abnormal signal and contrast enhancement were found on T2 STIR and T1-weighted images before and following contrast administration, whereas on 3D CISS, positive findings were recorded only in two patients and in both of them the findings were classified as uncertain.

In the patients with SAP, changes in MRI signal were observed in four patients and no such change was found in one patient. All patients with SAP had normal 3D CISS appearance.

Observer Agreement in Image Assessment

The interobserver agreement was found to be moderate to good for all MRI sequences, very good for the overall judgment (whether the overall MRI was considered normal or abnormal), and fair for radiographic images (Table 3).

Sensitivity and Specificity of MRI Examination

The sensitivity of abnormal MRI to identify AO—or exclude periapical inflammation—was 0.6, and the specificity was 0.8.

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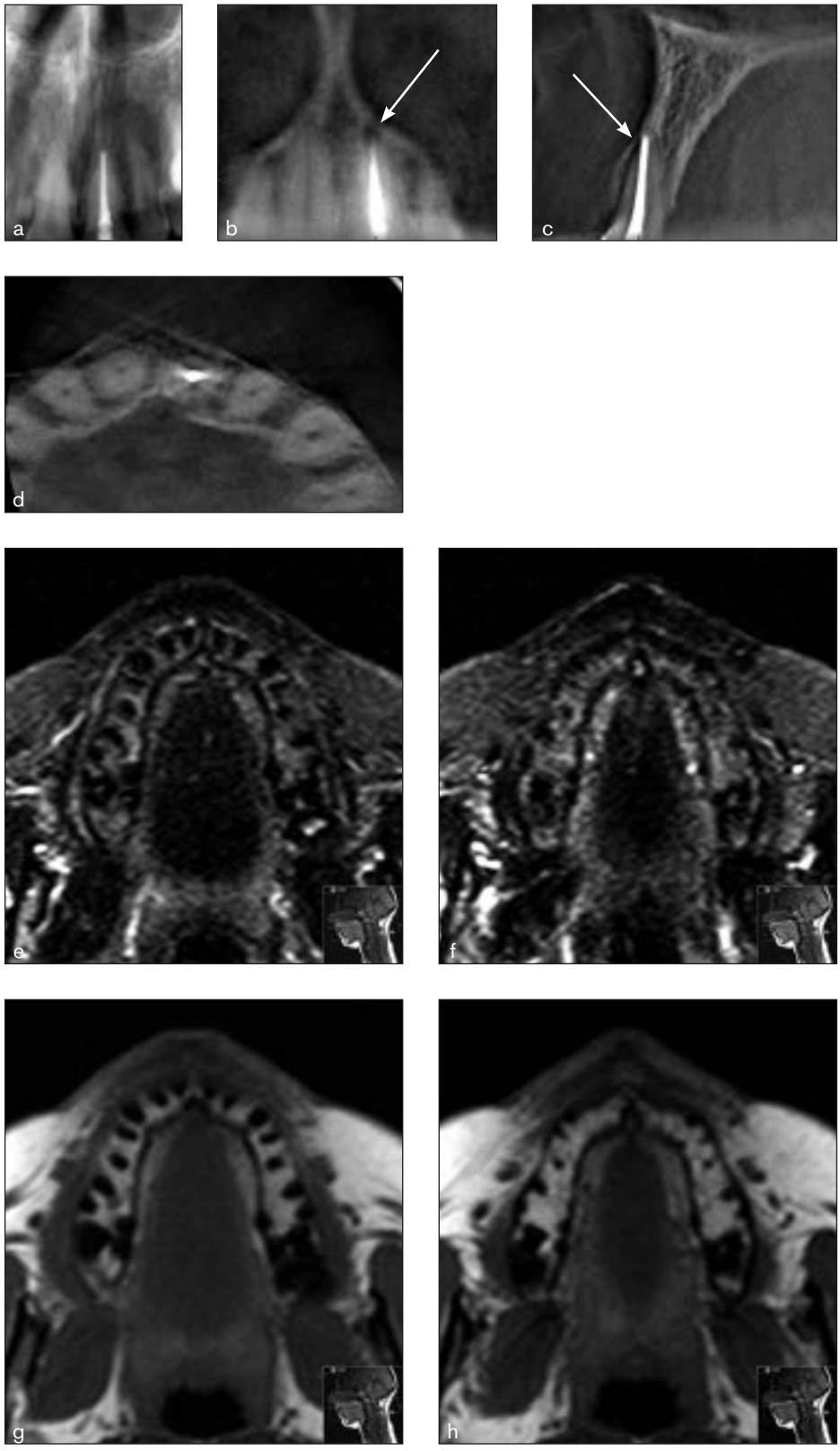

Fig 2 Positive CBCT and negative MRI findings for the maxillary left central incisor of one patient diagnosed with AO. **(a)** Normal periapical radiograph. CBCT **(b)** coronal and **(c)** sagittal views displayed a buccal periapical bone defect *(arrows),* but **(d)** axial view did not. MRI findings were normal. **(e,f)** MRI T2 STIR and **(g,h)** MRI T1 fs gd at apical and immediately superior levels. (T2 STIR = axial T2-weighted image with Short Tau Inversion Recovery; T1 fs gd = axial T1-weighted fat suppressed image with gadolinium contrast enhancement.)

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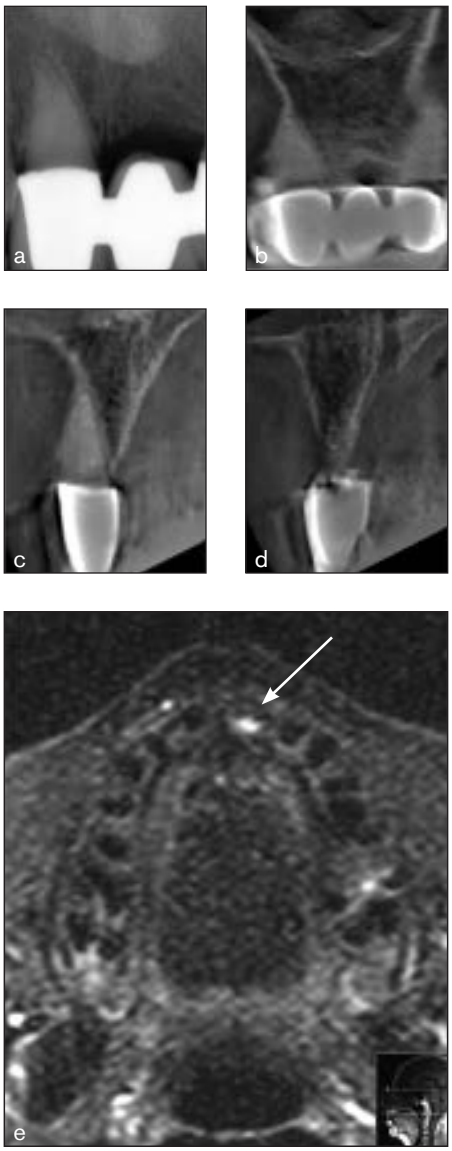

Fig 3 Negative CBCT and positive MRI findings in the maxillary incisor region (11-21) of one patient diagnosed with AO. The maxillary left central (tooth 21) was extracted 22 months prior to imaging. **(a)** Normal periapical radiograph. CBCT **(b)** coronal view, **(c)** sagittal view of tooth 11, and **(d)** sagittal view of extraction area 21 displayed no periapical or other radiolucency in the region. **(e)** MRI (T2 STIR) displayed contrast enhancement in the extraction area *(arrow)*. (T2 STIR = axial T2-weighted image with Short Tau Inversion Recovery.)

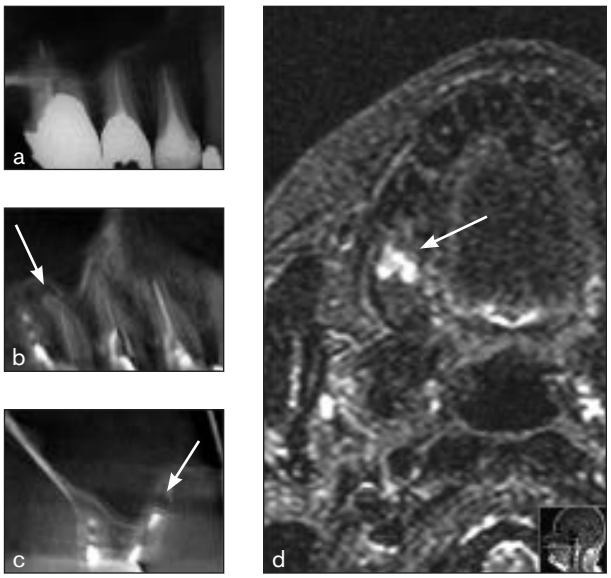

Fig 4 Positive CBCT and MRI findings of maxillary right first molar in one patient diagnosed with AO. **(a)** Normal periapical radiograph. CBCT **(b)** sagittal view of buccal roots and **(c)** coronal view of palatal and distobuccal roots displayed periapical radiolucencies at the mesiobuccal and palatal roots *(arrows)*. **(d)** MRI (T2 STIR) displayed an increase in signal *(arrow)*. (T2 STIR = axial T2-weighted image with Short Tau Inversion Recovery.)

Table 3 Interobserver Agreement in the 20 Patients with Atypical Odontalgia (30 Teeth) Assessed

	Kappa value	% agreement
MRI sequences		
T1	0.60	86
T1 gd*	0.63	90
T1 fs gd*	0.66	90
T2 STIR	0.66	86
3D CISS	0.77	95
MRI overall†	0.89	95
Radiography‡	0.40	66

* One patient did not receive contrast enhancement.
† Agreement on patient level (was abnormality present or absent).
‡ From Pigg et al[14] (panoramic + periapical + CBCT assessed in combination). Intraobserver agreement for radiographic images was Kappa 0.52 (74%).
T1 = axial T1-weighted images; T1 gd = axial T1-weighted images following gadolinium contrast administration; T1 fs gd = axial T1-weighted images with fat suppression following gadolinium contrast administration; T2 STIR = axial T2-Short Tau Inversion Recovery; 3D CISS = axial three-dimensional constructive interference in steady state.

Discussion

MRI Findings in Patients with AO

The main finding of this study was that the results of the radiographic and MRI examinations coincided in 75% of the patients with AO. A plausible interpretation is that MRI changes in signal when a periapical bone defect was visible could mean that inflammatory changes are present; in contrast, when no signal change was seen in MRI despite the presence of a periapical bone defect, bony healing may be in progress. However, because a reference standard was lacking (histology was not performed in this study), the true significance of the findings is not known. Twenty-one of the 30 teeth in the painful regions were endodontically treated, which makes clinical vitality testing impossible and the presence of a periapical bone defect difficult to interpret. The radiographic examination included panoramic and intraoral periapical radiographs and CBCT. A former study examining the same individuals showed that

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CBCT added information to the conventional radiographs,[14] and CBCT is probably the best radiographic technique available today to assess periapical bone tissue. There is presently no information on sensitivity and specificity of CBCT, as clinical studies with a true reference method are lacking.[11]

The findings on MRI were classified as abnormal in eight patients with AO. Although 3D CISS provides thin slices (0.7 mm thickness), which allows multiplanar reconstruction in three different planes, this sequence did not contribute with any added diagnostic utility and thus was redundant. In addition, no 3D CISS changes were recorded for any patient with SAP, which supports this observation. The other four sequences were shown to provide equally useful diagnostic information with moderate to good interobserver agreement (kappa 0.6 to 0.66). The agreement was highest for interpreting 3D CISS, since the findings on this sequence were recorded as definitely negative in 18 out of the 20 AO patients.

In two patients, positive MRI findings were made in regions where surgery had been performed (one case of apical surgery and one case of tooth extraction), in both cases 11 months before imaging. However, in the case where apical surgery (maxillary right first premolar) had occurred, a change in MRI signal was recorded in the pain region (as defined by the referral) but around another tooth (maxillary right first molar), and was therefore unlikely to be related to postsurgical healing. In the other case, it cannot be excluded that the change in MRI signal seen 11 months after tooth extraction did represent healing, since bone tissue healing after surgery is associated with an increase in vascular density, and thereby increased fluid content in the tissue.

In one patient, the change in MRI signal correlated with radiographic findings of a periapical bone defect and the absence of buccal bone plate. The patient and tooth had undergone apical surgery 14 months before, and thus the change in MRI signal in the periapical area may be related to soft tissue or "scar" healing. Scar tissue healing was not suspected in any other of the nine remaining apical surgery cases. To the authors' knowledge, no studies have described the appearance of soft tissue healing in jawbone or investigated the time span for normalization of MRI bone appearance after surgical interventions.

In dentistry, the utility of MRI techniques has been demonstrated for examination of the temporomandibular joint[29,30] and for visualization of dental hard and soft tissues,[23] but MRI application is still limited by high cost compared to radiographic imaging methods and by limited access to MRI equipment. With time, progress in technical development is anticipated to reduce this impediment, and for the investigation of selected tooth pain cases in tertiary care clinics, MRI may already be used. MRI has the advantage of not exposing the patients to ionizing radiation, as CT does, and is less sensitive to artifacts from dental fillings. One source of artifact in MRI of the oral cavity is the occasional presence of some fluid accumulation in the gingival folds that might be misinterpreted as gingival edema.

Diagnostic Efficacy of MRI in Chronic Tooth Pain

The clinical findings in AO patients are often inconclusive and closely resemble those made in patients with inflammatory pain. In this study, 50% of the patients reported pain on either tooth percussion or apical palpation, and 30% reported both, which indicates low validity of these commonly applied tests to differentiate between conditions. There is at present no widespread consensus among clinicians or researchers on diagnostic criteria for AO. The most frequently used definition of the condition itself (from which this study's inclusion criterion was derived) is unsatisfactory, mainly because it is too nonspecific and does not indicate any cause for or mechanism behind the condition. While it is not within the scope of the present study to determine which criteria should be applied, an improvement is called for. Recently, operationalized criteria were suggested,[1] and the authors indicated that the degree of certainty to which other conditions can be ruled out may depend on the extent of evaluation, ie, the amount of diagnostic testing applied. Imaging methods, such as CT or MRI, were mentioned as examples of tests that have the potential to increase the specificity but also decrease the sensitivity of the diagnostic work-up. In other words, individuals who do not have AO will be easier to identify, but a number of individuals who truly have this likely neuropathic condition may not fulfill all possible criteria, and therefore remain undiagnosed and untreated/mistreated. The results of the present study, indicating relatively low sensitivity, support the observation. Applying the absence of changes in MRI signal as an absolute diagnostic criterion of AO may thus favor underdiagnosis.

Study Sample

The age and sex distributions of the AO patients in this study agree well with previous reports. List et al described 46 patients, of which 85% were female with a mean age of 56 years; others have reported similar distributions.[7,31–33] Average pain intensity in the study by List et al was similar to the present findings, although mean pain duration was longer (7.7 years). In the present study, 95% of the AO patients reported continuous pain, which compares well with the 87% in the List et al study[7] who experienced pain daily or several times a week. The patients were therefore considered to be representative of a clinical AO population. In the

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present study, 95% had somatosensory abnormalities in the painful area, which is considered an indication of neuropathic involvement. The finding is consistent with earlier observations.[34] A recent study using a similar technique to that in the present study found sensory abnormalities in 96.8% of the AO patients,[35] which supports the view that AO was the correct diagnosis in the subjects included in the present study.

Clinical Utility

An important clinical aspect of applying any diagnostic test is that of benefit for the patient, eg, by improving the certainty of the diagnosis and thus affecting treatment decision or prognosis. In AO, the prevailing recommendation is to avoid further invasive dental treatment; the literature reports that endodontic treatment or various surgical interventions are ineffective in resolving the pain and may even result in increased pain.[6] In the present study, 20 well-examined patients considered to suffer from AO, were examined with CBCT in addition to conventional radiography and MRI. In a few cases, findings were made with these additional diagnostic tests that indicated an alternative, or additional, diagnosis. Evidence of a periapical bone defect clearly detected with CBCT and coinciding with changes in MRI signal may suggest the presence of an inflammatory process that may or may not be the actual cause of the pain problem. Although AO pain has been suggested to involve a clear component of central sensitization,[36] continuous peripheral input such as the activation of primary sensory afferent fibers during ongoing inflammation may conceivably perpetuate the pain; therefore, local inflammation in the painful region should be avoided. Thus, two patients in this study were offered the option of further dental treatment as a direct result of the combined CBCT and MRI findings. One individual, a 53-year-old man, declined treatment since he was not convinced that treating the tooth would help. The second patient, a 64-year-old woman, had the painful root-filled maxillary first molar extracted, and she experienced a short period of pain relief (weeks) after surgery followed by recurring pain with increased intensity and frequency that persisted for at least 5 years. In the remaining 4 patients with concomitant periapical bone defects and abnormal MRI, the changes were tentatively attributed to ongoing healing or scar tissue formation at the tooth apex and did not result in further dental treatment. Thus, the single patient in this study for whom the additional diagnostic tests led to any actual change in treatment, patient follow-up strongly suggests that the initial diagnosis of AO was correct, ie, that the main cause of pain was non-odontogenic and not related to peripheral inflammation. Although this is just one case, it stresses the fact that multiple diagnoses can coincide and may indicate that MRI could decrease sensitivity in diagnosis, which is in agreement with what has been previously suggested.[1] The clinical implication may be that in patients suspected of having AO, MRI is useful mainly to exclude, with higher certainty, pain due to an inflammatory process, thereby strengthening the argument that further dental treatment should be avoided. In contrast, in the cases where MRI signs indicate possible presence of pathology, such as the one described above, these findings must be carefully considered together with all other signs and test results in a comprehensive examination in order to make a correct diagnosis.

MRI Findings in Patients with SAP

The purpose of including a small group of patients with "odontogenic" tooth pain in this study was exploratory, as the authors found no previous reports of MRI findings in this group. The study did not explicitly aim to compare the two conditions, but nevertheless the findings are of interest. In the SAP patients, periapical radiolucency was apparent in all the examined teeth. None had undergone apical surgery. In a study by Tutton and Goddard, teeth with periapical inflammation displayed reduced medullary bone signal in T1 images, interpreted as lower fatty marrow content and sclerosis, and in T2 images, high signal was detected in the same area that was interpreted as indicating high water content and edema.[20] It was therefore anticipated that MRI would show similar changes in signal in all these patients, because clear radiographic signs of inflammation were considered to be present and all patients had pain from the teeth in question. However, one of the SAP patients displayed no such changes in MRI signal compared to surrounding bone tissue. When this patient was followed up with exploratory/apical surgery under the tentative diagnosis of root fracture, no pathologic findings were made that could explain the persistent pain. On later follow-up, 5 years after the initial examination, the patient still had pain, and intraoral radiographs then showed no periapical radiolucency. Thus, the initial diagnosis of SAP was probably incorrect.

Conclusions and Recommendations

MRI examination in patients with suspected noninflammatory tooth pain may add to the diagnostic approaches by excluding inflammatory processes in the jawbone of the painful region with higher certainty. When radiographic findings are uncertain, especially in teeth previously exposed to multiple treatments, MRI assessment may strengthen the argument to avoid further dental treatment and consider noninvasive treatment alternatives. MRI may thereby guide the

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clinician's decision and also provide a helpful argument to persuade the patient that surgical interventions and tooth extractions best be avoided. Further studies are needed to determine the best clinical work-up to diagnose AO with high sensitivity and specificity; it is anticipated that several factors, such as patient-reported pain characteristics, clinical signs and symptoms, imaging, pharmacologic tests, and assessment of sensory function, will all play a role in such an approach.

Acknowledgments

The authors want to thank Professor Christina Lindh, Malmö University, for her kind help in assessing all radiographs (observer CL). The authors report no conflicts of interest related to this study.

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