Title page

Normal MRI-based appearances of the temporomandibular joints in children aged 2-18 years

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Introduction

Involvement of the temporomandibular joint (TMJ) has been reported in a high percentage of children with juvenile idiopathic arthritis (JIA), ranging from 17 to 93% depending on study design, JIA categories, diagnostic method and criteria used [1-4]. Left untreated, TMJ arthritis may lead to growth disturbances or destruction, which result in orofacial deformity [3, 5]. As clinical and laboratory findings are often insufficient to detect and monitor TMJ disease [1, 6-8], focus has been directed to imaging studies [7-9]. During the past decade, magnetic resonance imaging (MRI) has emerged as the method of choice for evaluating TMJ disease [10-12]. However, knowledge on the normal, MRI-based appearances of the TMJs during childhood is limited. Although the normal anatomy of the TMJs has been addressed by several authors, the studies are heterogeneous with respect to numbers, age, ethnicity, imaging methods, imaging planes and measurements used [13-18]. Some studies are based on computed tomography (CT) [13, 15, 18, 19], some on cadavers including children aged 3-6 years [15] and others have used silicone impressions from cadavers to assess morphology [15, 16]. Important contributions on MRI based appearances of healthy individuals have been published [14, 17], however, morphologic features are only briefly described and in one study individuals with presumed pathological changes such as synovial enhancement and mandibular changes were excluded leading to selection bias [17]. Moreover, recent studies have addressed the ability of MRI to diagnose active TMJ disease in children with JIA, as findings suggestive of inflammation have been reported in healthy children without JIA [14, 17, 20, 21]. Some of the studies evaluate contrast enhancement [14, 21-23] and others bone marrow edema-like changes [14, 17, 20]. In their study on 46 children who had a total of 100 contrast MRIs of the brain, von Kalle and co-workers also discussed the complexity of contrast enhancement, underpinning the importance of correct measurements and timing of the post-contrast images.

The present study aims to evaluate the reliability of established and new measurements for describing the normal MR-based anatomy of the temporomandibular joints in children aged 2-18 years, and, based on the most robust measures, to characterize the normal appearance of the TMJ.

Material and Methods

In this retrospective crossectional study, children aged 2-18 years who had undergone a head MRI during the period 2005 - 2015 at Haukeland University Hospital were included. The examinations had been performed for reasons other than juvenile idiopathic arthritis or diseases known to involve the TMJs. The children were identified by record review, and were included if MRI had been performed on a 1.5 or a 3 Tesla (T) MR machine, using a dedicated head coil and including the following sequences; high-resolution 3D T1-weighted sequence (T1-MPRAGE) with or without intravenous contrast and a fluid-sensitive sequence (T2-weighted sequence with or without fat suppression).

Children were excluded from the study if they had systemic inflammatory diseases including JIA, tumors affecting brain/head, hydrocephalus, syndromes involving cerebral malformations or skeletal dysplasias, suboptimal MRI images and MRI examinations showing other pathologies in, or in close proximity to the TMJs. Benign lesions such as arachnoid cysts and small white matter cysts were not considered as exclusion criteria. Furthermore, indications such as follow-up after treatment of intracranial infection, intracranial hemorrhage and thrombosis were included. To ensure a balanced dataset, the sample was stratified by age and sex.

The study was approved by the regional ethics committee (2016/257/REK vest). No MRI examinations were performed for the purpose of this study alone.

Imaging

96 of 101 MRI examinations were performed on a 1,5T scanner (Siemens Symphony Vision, Siemens healthcare, Erlangen, Germany), using a 64 channels head coil. All 96 had a sagittal high-resolution (3D) T1-weighted sequence with slice thickness 1.1 mm, repetition time (TR) 2110 ms, echo time (TE) 3.93 ms, number of signal averages (NSA) 1, flip angle 15°, matrix 256x240. In 47/96 patients the T1 sequence was performed after injection of intravenous gadolinium (0.2 ml/kg body weight of gadoterate meglumine (Dotarem, Guerbet, France)), of whom 36 also had pre-contrast T1-weighted images. A T2-weighted turbo spin echo sequence in axial and/or coronal plane with slice thickness 5 mm, TR 3240, TE 86, NSA 2 and matrix 256x190 was performed in 87/101 patients.

Five of the MRI examinations were performed using a 3T MRI scanner (Signa HDxt, General Electric Medical Systems, Milwaukee, USA) with a 32-channel head coil. A sagittal high-resolution (3D) T1-weighted sequence with slice thickness 1 mm, TR 7.816 ms, TE 2.952 ms, NSA 1 and matrix 256x192 and a T2-weighted spin echo sequence with slice thickness 3 mm, TR 4700, TE 99, NSA 1.5 and matrix 416x416 were performed. The examinations were performed in a closed mouth position.

Imaging analysis

All 3D MRI scans were exported to a post-processing program (SyngoVia, Siemens Healthcare GmbH) to ensure identical imaging planes. Based on the high-resolution T1-weighted images, a new stack of T1-weighted images was reconstructed in the sagittal/oblique plane, aligned along the mandible (1 mm slice thickness, 1 mm increment) for assessment of the following features; a) condylar shape (0 =rounded, 1 =mildly flattened, 2 =moderately flattened or 3 =severely flattened), b) presence of an anterior, condylar beak [13] (no/yes), c) anterior condylar inclination (0 =no inclination, 1 =mild, 2 =moderate), d) shape of glenoid fossa eminence (0 = normal, S-shaped, 1 =slightly flattened or widened fossa eminence, 2 =clear widening of the fossa or flattening of the eminence, 3 =extensive abnormality) [24], e) measurements of the joint space, temporal fossa angle and condylar inclination (Figures 1-2).

From the T1-weighted coronal plane, the following features were registered; a) shape of the condyle (0 =rounded, 1 =mildly flattened, 2 =moderate to severely flattened), b) presence of condylar surface irregularities (no/yes) (Figures 3-4). The following features were assessed based on T2-weighted images; a) amount of joint fluid at a 0-2 scale (0 =none, 1 =a mild amount, defined as a fine, hyperintense line in the upper or lower joint compartment or as small dots in an articular recess, 2=a moderate amount, defined as >2mm fluid in one or more of the of abovementioned locations), and b) presence of bone marrow edema (BME) (no/yes). BME was defined as a lesion within the trabecular bone with ill-defined margins and signal characteristics consistent with increased water content, returning high signal on T2-weighted and low signal on T1-weighted images. T1-weighted sequences with intravenous gadolinium in the transverse plane were used to score the degree of enhancement on a 0-2 scale (0 =none, 1 =mild, 2 =moderate), as compared to pre-contrast images. The degree of contrast enhancement was scored as mild when seen immediately around the condyle, or as moderate when seen exceeding the joint tissue [21].

On axial T1-weighted images without intravenous gadolinium the joint tissue was scrutinized for hyperintense areas which could possibly confound the assessment of post-contrast enhancement (yes/no).

The examinations were read twice, using high resolution, diagnostic screens (Agfa PACS for the first reading and Sectra PACS for the 2nd reading). In the first session, all images were read by three radiologists in consensus (O.A, T.A, and K.R.) with 9, 10 and 25 years of experience. During this first session, all findings were thoroughly discussed for calibration issues. After an interval of 3 months, all examinations were re-read by two of the radiologists (O.A. and T.A. in consensus) for assessment of intraobserver agreement. Anatomical features that could not be precisely assessed were not used in the description of normal anatomy.

Statistics

Continuous data are presented as means (± SD), ordinal data as medians (ranges) and dichotomous data as proportions. Intraobserver consensus agreement for the assessment of condylar and fossa eminence shape was performed using a simple Cohen's Kappa coefficient [25]. A kappa score of <0.2 is considered poor, 0.21-0.40 fair, 0.41-0.60 moderate, 0.61-0.80 good and 0.81-1.00 very good. Differences in measurements were analyzed by establishing 95% limits of agreement (termed repeatability coefficient, when used for repeat measurements) as per Bland and Altman [26]. Bland-Altman plots are generally interpreted informally, and a clinically acceptable agreement was set at 15%. The children were grouped into six age groups (2-5, 6-9, 10-13, 14-16 and 17-18 years of age). Chi squared tests were used to examine possible associations between age and anterior condylar inclination in the sagittal/oblique plane and condylar flattening in the coronal plane. Moreover, hierarchical multiple regression was used to assess the ability of age to predict the anterior condylar inclination, after controlling for the influence of sex. A significance level of 0.05 was decided a priori and all the reported p values are two-tailed. Statistical analyses were performed using IBM SPSS Statistics, version 23.

Results

The TMJs in 101 children between 2 and 18 years (45 girls) with a mean age of 10.7 (SD =5.3) years were evaluated. Indications for the examinations are presented in table 1. There were no differences according to sex or side for any of the variables, thus, the results for both sexes merged, right side, are reported.

Intraobserver agreement

The mean right joint space height was 3.8mm, with a mean difference of 0.2mm between the first and second readings (95% limits of agreement -1.5 to 1.1mm). The mean right condylar angle was 20.4°, with a mean difference of 5.5° between the first and second readings (95% limits of agreement -17.4 to 23.2°). The mean right fossa angle was 101.3°, with a mean difference of 0.7° between the first and second readings (95% limits of agreement -21.8 to 19.9°).

A scoring system consisting of three different categories resulted in moderate to good intraobserver consensus agreement for the assessment of anterior condylar inclination in the sagittal/oblique plane, with a Kappa value of 0.7 (95% CI = ±0.1) for the right side. The intraobserver consensus agreement for condylar shape in the coronal plane on a 0-2 scale was 0.4 (95% CI = ±0.2) for the right side, and 0.6 (95% CI = ±0.2) for the left side. The assessment of condylar flattening and shape of the glenoid fossa-eminence in the sagittal/oblique plane, right side, showed fair levels of consensus agreement on a 0-3 scale, with Kappa values of 0.3 (95%CI=±0.1) and 0.2 (95%C I=±0.1), respectively. Dichotomizing the variables did not improve the results.

The agreement for assessment of an anterior condylar beak, condylar surface irregularities, bone marrow edema or joint fluid could not be adequately tested due to a severely skewed distribution of the findings (Figure 7).

Normal anatomy

On a 0-2 scale, assessed in the sagittal/oblique plane, 34 (34%) of 101 right condyles were straight, while 47 (47%) showed mild anterior inclination and 20 (20%) showed moderate anterior inclination (Table 2). There was a statistically significant increase in inclination by age ($p<0.0001$), with 78% of the condyles in the 2-5 years age group showing straight condyles and none of the condyles in the group aged 17-18. None of the condyles in the 2-5 years group showed moderate anterior inclination in comparison to 45% and 40% of the condyles in the 14-16 and 17-18 years age groups, respectively. Hierarchical multiple regression did not add to the results.

Subjective classification of the shape of the mandibular condyle in the coronal plane showed that 81 (80%) of the condyles were rounded, 20 (20%) were slightly flattened and none were clearly flattened (Table 2). The presence and degree of flattening was not associated with age (p =0.94).

35 out of 36 right TMJs showed contrast enhancement, of which 32 were judged to be mild and 3 were moderate (Table 3). There was no association between the presence and degree of enhancement and age (p =0.44). Bilateral, mild enhancement was shown in 29 of the 36 children (81%) and bilateral, moderate enhancement in 2 children. In 2 children there was moderate synovial enhancement in one TMJ and mild enhancement in the other TMJ while in two children only a mild, unilateral enhancement was seen. The indications for MR imaging in the children with moderate enhancement did not differ from the other children (headache, white-matter cyst, epilepsy and follow-up after thrombosis or intracranial hemorrhage).

Discussion

In a cohort of children examined for reasons other than TMJ-disease, we have identified two imaging features of sufficient precision to describe parts of the anatomy, namely ordinal classification of anterior, condylar inclination in the sagittal/oblique plane and flattening of the condyle in the coronal plane. Several other features and measures commonly used to describe TMJ anatomy, such as the condylar and glenoid fossa eminence shapes in the sagittal/oblique plane, performed poorly. One might argue that 0-3 scale scoring systems, ranging from a rounded to a severely flattened condyle or from a normal S-shaped to an extensively abnormal glenoid fossa eminence, can be applied on pathological joints only (Figure 6 a,b). However, collapsing score categories 1-3 into one category did not change the results although one third was categorized as flattened by at least one of the two observers.

The same was true for the glenoid fossa eminence, suggesting that a subjective assessment is hampered with difficulties.

Continuous measurements of the joint space height, fossa eminence and anterior condylar inclination angles also performed poorly, with values unacceptable for clinical purposes. The latter findings are disappointing, given the thorough standardisation work performed prior to the first reading session. Similar results have, however, been reported by others [27]. In a CT based study of 420 TMJs in 210 children without JIA, Karlo and co-workers [13] found a relatively poor inter observer agreement for measurements of condylar size, with 95% limits of agreement (LOA) lying around 30 - 50% of the mean condylar width and length, respectively. As for condylar anteversion, the mean angle was 27° with a 95% LOA being 60-100% of the mean anteversion angle, indicating methodological difficulties with measuring small structures and angles. Opposite, they found a very good agreement for the assessment of anterior condylar inclination on a 0-2 scale, with a kappa value of 0.67, which is similar to the intraobserver consensus agreement found in our MR-based study. Unfortunately, the authors did not examine interobserver variability of condylar flattening.

In a study by Weiss [7] including 32 patients with JIA, interobserver agreement was assessed in 8 out of 32 patients. For any findings of disease, the kappa coefficient was 1.0 but for specific findings the kappa was lower; effusion (κ=0.38) and synovial thickening (κ=0.33). In sum, although studies addressing the repeatability of features and measurements used for describing normal TMJ anatomy are sparse, assessment of anterior condylar inclination in the sagittal/oblique plane on a 0-2 scale seems to be sufficiently precise. Based on our results, we would add a second feature, namely condylar flattening on a 0-2 scale on coronal images.

In the present study, all except for 2 of 36 examinations showed bilateral contrast enhancement of the TMJs. The precision of assessing contrast enhancement of the TMJs in healthy children has been addressed in a few studies [21, 22]. In a study of 100 contrast enhanced MRIs in 46 children without JIA, von Kalle and co-workers reported relative poor inter-observer agreement for the assessment of dynamic enhancement. Two experienced radiologists independently drew region of interests (ROIs) for analysis of signal-intensity curves. Similar results were obtained when the same observer did repeat measurements of 20 cases. Due to their wide limits of agreement (LOAs), they combined the findings of both observers for description of TMJ enhancement in children without JIA [21]. In another paper, Ma and co-workers reported on 67 children with JIA and 24 children without JIA focusing on contrast enhancement in both synovial tissue and in the mandibular condyle. Subjective assessment of the degree of enhancement was performed, but the authors did not report on the precision of their findings. Quantitative assessment was also performed by two radiologists independently drawing ROIs for calculation of two different types of signal intensity ratios. Repeatability of these ratios was assessed with intraclass correlation in the JIA cohort, showing interobserver values from 0.93-0.98 and intraobserver values from 0.97-0.98. They did not report separately on repeatability on the healthy cohort.

We found that the condylar inclination in the sagittal/oblique plane increased by age, and that 60% of children under the age of ten had straight condyles while the majority of those aged 17-18 years had marked anterior inclination. In the CT-based study by Karlo et al including 210 children without JIA[13], the authors described three different condylar shapes based on a sagittal view; a smooth, round shape most frequently seen in children aged 0-5 years, an intermediate type with development of an anterior beak, which, together with an anterior flattening of the condyle primarily was observed in children older than ten years of age. Our findings support those of Karlo and colleagues, demonstrating an association between age and increasing anterior inclination. Although the assessment of condylar flattening on sagittal view performed poorly in our study, some condyles were definitely judged to be flattened on both assessments, and as such also support the findings by Karlo et al.

In our study, one out of five condyles was slightly flattened in the coronal plane. In contrast, Tzaribachev and colleagues found none with condylar flattening in 96 children aged 3-13 years without JIA [17]. This discrepancy may in part be explained by the fact that we used a high-resolution T1 sequence reconstructed along the mandible while Tzaribachev and colleagues used a 3 mm coronal T2-weighted sequence.

Some condyles were judged to have an irregular surface when based on the sagittal/oblique view; however, the finding could not be confirmed on the coronal view. Moreover, the repeatability was poor, leaving the credibility of this finding in question. In their study of children with no evidence of JIA, Tzaribachev and colleagues did not observe any condylar erosions, defined as abnormal irregularity of the osseous cortex and/or loss of normal mushroom-like shape of the mandibular condyle[17].

We found that some condyles had features suggestive of bone marrow-edema, but again, the precision of this finding was poor for estimation of rates. Other authors show similar results; Kottke et al reported mild edema-like bone marrow in 10% of TMJs [14] while Tzaribachev and co-workers found no TMJs with bone marrow-edema in a study on 96 non-rheumatic children[17].

Joint fluid, as assessed on axial and/or coronal images, was seen in 6 and 10 out of 202 TMjs based on the first and second reading, however, similar to bone marrow edema-like change, the precision of this finding was poor. Kottke, in his study of 27 children without JIA[14], reported on small amounts of intraarticular fluid in 31% when based on axial T2-weighted images without fat saturation and in 83% on sagittal-oblique T2-weighted images with fat saturation as fine lines in the upper or lower joint compartment or as small dots in an articular recess. Taken together, the results are diverging, probably reflecting the increased conspicuity of joint fluid in TMJ in the sagittal-oblique plane, which probably would be the preferred plane for joint fluid assessment in the TMJ. Tzaribachev [17], also using axial and coronal images, found small amounts of joint fluid in 3 out of 96 children and as such the results are consistent with our study.

In a few previous studies (1, 8, 12), any degree of contrast enhancement of the joint tissue has been considered suggestive of active inflammatory disease. In the present study, mild or even moderate enhancement of the joint tissue was seen in all but one of the patients who had contrast intravenously. Although the majority of postcontrast images were performed immediately after contrast injection, one might speculate that the more pronounced enhancement was due to delayed images, with diffusion of contrast into the joint space.

Our findings are in accordance with the study of Kottke and co-workers [14], showing that 79% of the TMJs enhanced. Their findings were based on subjective and objective assessment of T1-weighted fat saturated images taken immediately after contrast, as compared to T1-weighted images pre-contrast in 27 children, 1-16 years of age, without any known TMJ disease.

Our results are also supported by two other recent publications; in 46 children without TMJ disease von Kalle and colleagues [21]showed 73% (23, 123) mean increase in signal intensity in synovial tissue while Ma and co-workers [22] showed 66% (40, 92) mean increase in 24 children without rheumatologic disease.

Limitations

The retrospective nature of the study might have influenced the results. However, the referrals and the reports of the included children were scrutinized for information that might be associated with TMJ pathology. Further, exact details on the timing of post-contrast images were unavailable although the most post-contrast series were performed immediately after contrast injection. According to a recent study, timing of imaging post-contrast images has a significant impact on the degree of enhancement [21]. Although we cannot entirely rule out that contrast enhancement of joint tissue is related to the underlying disease or treatment of the children, the wide spectrum of indications for MRI in the included cohort makes this somewhat unlikely. Mild contrast enhancement of joint tissue should therefore be considered a normal finding. All of the examinations were performed with a 32- or 64-channel head coil. One might argue that a dedicated surface coil would have added to image quality regarding both spatial resolution and signal-to-noise ratio. Finally, most of the T2-weighted sequences were performed with 5 mm slice thickness, which could lead to an underestimation of the amount of bone marrow edema and joint fluid due to volume averaging.

Conclusions:

We have identified two robust features to describe parts of the TMJ anatomy as assessed on MRI in children without evidence of TMJ disease, namely a subjective assessment of anterior inclination in the sagittal/oblique plane and condylar flatting in the coronal plane. The shape of the mandibular condyle is straight in the younger age group, with an increasing anterior inclination by age. Mild flattening of the condyle, shown in the coronal plane is a common finding and not necessarily indicative of chronic inflammatory disease. Mild contrast enhancement of the TMJs should be considered a normal finding.

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Table 1. Clinical indications for performing head MRI in 101 children (45 girls) included in the study, aged 2-18 years

Clinical indication for head MRI	**Number of children (girls in parenthesis)**
Epilepsy	49 (21)
Benign brain tumour	12 (5)
Headache	11 (11)
Intracranial infection, follow-up	7 (1)
Intracranial hemorrhage or thrombosis, follow-up	6 (3)
Psychiatric work-up	3 (0)
Brain work-up due to disease in other part of the body	3 (1)
Nausea	2 (1)
Others	8 (2)

Table 2. MR-based TMJ anatomy in 101 children aged 2-18 years (45 girls) with no evidence of TMJ disease. Right TMJs, based on the first reading. Only robust measures have been included.

	Age groups (years)					
MRI characteristics	2-5 (n=23)	6-9 (n=20)	10-13 (n=16)	14-16 (n=29)	17-18 (n=13)	p-value†
Anterior condylar inclination*						<0.0001
Straight	18	8	4	4	0	
Mild	5	12	9	16	5	
Moderate	0	0	3	9	8	
Condylar flattening, coronal plane						0.94
Rounded	19	17	13	22	10	
Slightly flattened	4	3	3	7	3	
Clearly flattened	0	0	0	0	0	

*Based on subjective assessment

† Pearson chi-square test

Table 3. Enhancement of the right TMJs in 36 children* with no evidence of TMJ disease by age group, based on immediate post-contrast T1-weighted images as compared to pre-contrast T1-weighted images, first reading.

	Age groups (years)					
	2-5 (n=3)	6-9 (n=4)	10-13 (n=5)	14-16 (n=17)	17-18 (n=7)	p-value†
Contrast enhancement						0.44
No enhancement	0	0	0	1	0	
Mild enhancement	2	3	4	16	7	
Moderate enhancement	1	1	1	0	0	

*one MR examination was excluded due to artefacts
† Pearson chi-square test

Legends

Fig 1 Sagittal/oblique reconstruction of high-resolution T1-weighted images in a 16 year old girl with no evidence of JIA disease, undergoing follow-up after sinus venous thrombosis, demonstrating a straight condyle and measurement of the joint space height (white line). The joint space was measured between the top of the condyle and the deepest part of the glenoid fossa.

Fig 2 Sagittal/oblique reconstruction of high-resolution T1-weighted images in a 17 year old girl with no evidence of JIA disease, undergoing neurologic work-up, showing the temporal fossa angle (straight arrow) as defined by a line between the deepest point of the fossa and the top of the articular eminence and a line from the deepest part of the fossa parallel to the tympanic part of the temporal bone. The inclination angle (curved arrow) is defined by a line parallel to the anterior part of the mandibular condyle and a line parallel to the posterior cortex of the mandibular ramus.

Fig 3 Coronal reconstruction of high-resolution T1-weighted, postcontrast images in a 18 year old boy with no evidence of JIA disease, demonstrating rounded, smooth condyles bilaterally (straight arrows). The condyles were scored as rounded, given an upward convex contour.

Fig 4 Coronal reconstruction of high-resolution T1-weighted, postcontrast images in a 8 year old girl, undergoing MRI due to head ache with no evidence of JIA disease, showing mildly flattened, smooth condyles (straight arrows). The condyles were scored to be mildly flattened when the upward convexity was in between rounded and entirely flat.

Fig 5 Coronal T2-weighted turbo spin echo images of a 17 year old boy undergoing brain work-up due to disease in other parts of the body, with no evidence of JIA disease, showing mild amounts of joint fluid (straight arrows) defined by fine hyperintense lines within the joint compartment.

Fig 6a Sagittal/oblique reconstruction of high-resolution T1-weighted postcontrast images in a 2 year old boy, undergoing follow-up after sinus venous thrombosis, with no evidence of JIA disease, showing clear flattening of the eminence (straight arrow) as proposed by Arvidsson (24).

Fig 6b Sagittal/oblique reconstruction of high-resolution T1-weighted postcontrast images in a 8 year old boy, undergoing MRI due to head ache, with no evidence of JIA disease, showing a S-shaped fossa/eminence (straight arrow) as proposed by Arvidsson (24)

Fig 7 The distribution of findings for a set of variables as judged by the 3 observers (consensus) during the first reading session. Due to skewed datasets, kappa statistics could not be applied.

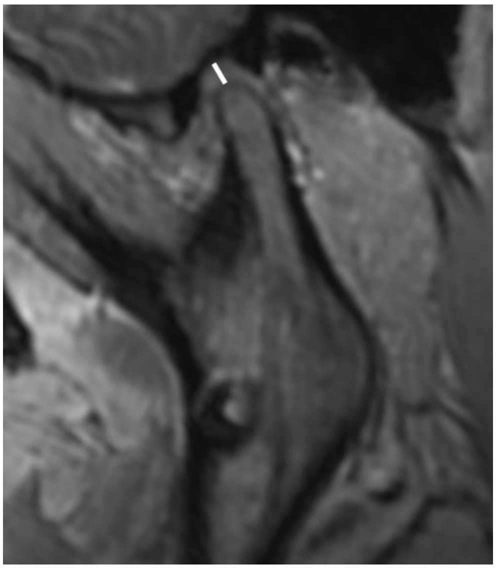

Fig 1

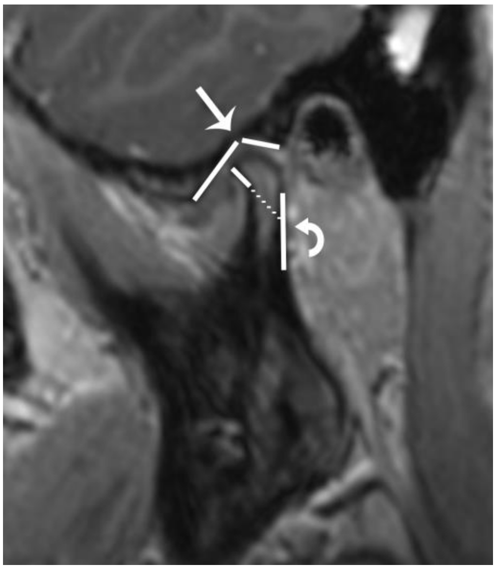

Fig 2

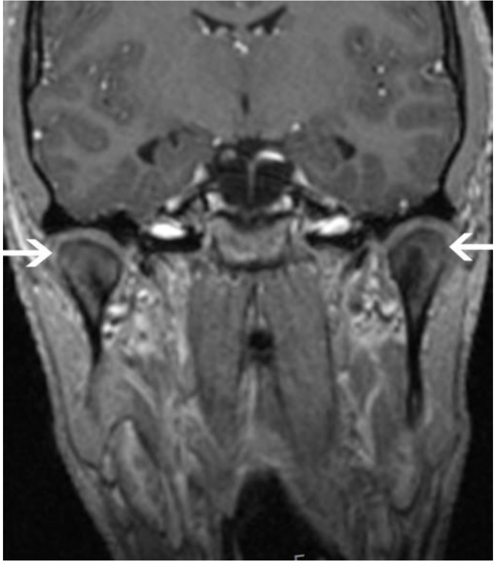

Fig 3

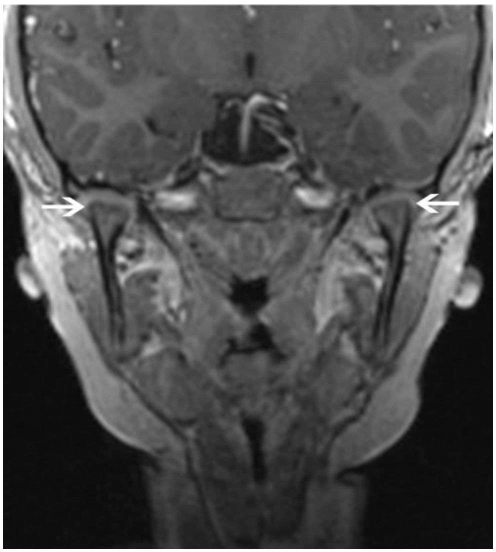

Fig 4

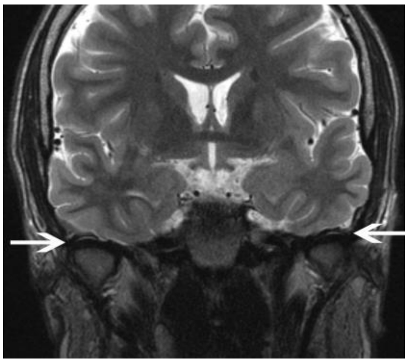

Fig 5

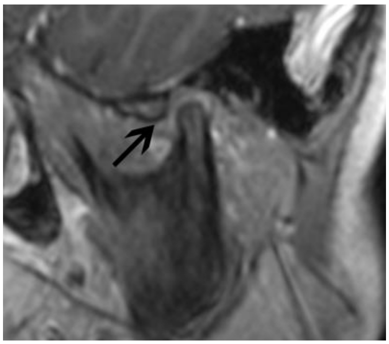

Fig 6a

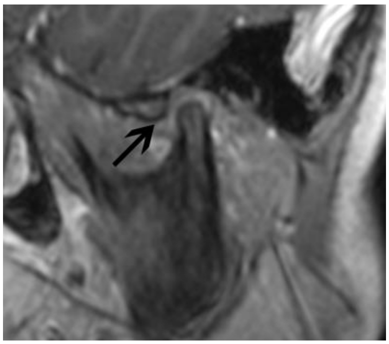

Fig 6b

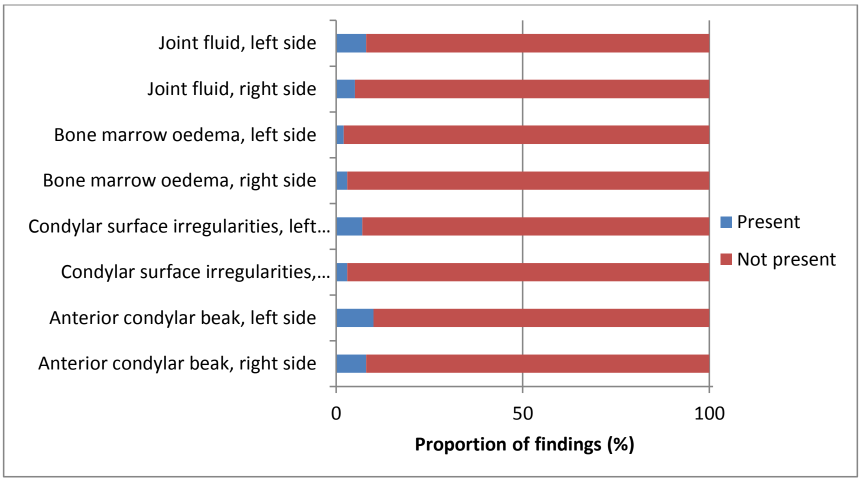

Fig 7