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Imaging of the Temporomandibular Joint in Juvenile Idiopathic Arthritis

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Objective. **Temporomandibular joint (TMJ) arthritis in children with juvenile idiopathic arthritis (JIA) is extremely common but frequently asymptomatic. Magnetic resonance imaging (MRI) with contrast remains the gold standard for identifying TMJ arthritis in JIA. A reliable scoring system with published MRI examples of typical acute and chronic TMJ arthritis changes will be invaluable for future prospective treatment trials of TMJ arthritis in JIA.**

Methods. **MRIs were collected from routine clinical studies assessing TMJ arthritis in JIA. Representative images were selected for publication to depict acute (synovial fluid, bone marrow edema, and synovial enhancement) and chronic (pannus, disc derangement, and condylar head flattening and erosions) TMJ arthritis findings. A preliminary MRI-based scoring system for assessing degrees of acute and chronic TMJ arthritis was developed and tested for inter- and intrareader reliability.**

Results. **TMJ MRIs representative of acute and chronic TMJ arthritis in JIA were selected from among thousands taken (>500 TMJ MRI studies annually at Children's of Alabama) since September 2007. Moreover, computed tomography scans depicting select bony changes (osteophyte formation, micrognathia) were chosen for publication. A description of the MRI protocol for assessing TMJ arthritis is included. A preliminary scoring system weighted for degree of acute and chronic TMJ arthritis MRI findings was found to have substantial inter- and intrareader reliability.**

Conclusion. **A published set of MRIs depicting representative acute and chronic changes will help establish a standardized scoring system to assess TMJ arthritis in children with JIA. Future validation will aid in assessing improvement during treatment trials of TMJ arthritis.**

INTRODUCTION

Temporomandibular joint (TMJ) arthritis occurs in up to 80% of children with juvenile idiopathic arthritis (JIA) and can result in substantial jaw deformity (1,2). TMJ arthritis is frequently present at disease onset (2) and occurs in all JIA subtypes (3,4). Untreated, TMJ arthritis leads to micrognathia, poor mouth opening, facial dysmorphism, and lifetime disability and pain (5–7). As early disease is typically clinically asymptomatic (2), many patients are diagnosed in advanced stage. However, even at large US medical centers, the TMJ is not routinely imaged in patients with JIA (8) and it has been termed the "forgotten joint" of JIA (5). A number of radiographic approaches have been employed to study TMJ arthritis, including panoramic radiographs, cone-beamed computed tomography (CT), ultrasound, and magnetic resonance imaging (MRI) with contrast. Based on its high sensitivity and specificity, MRI has become the modality of choice for early diagnosis of synovial inflammation of the TMJ in children with JIA (1,2,9,10).

MRI with gadolinium contrast is capable of detecting subtle acute findings of TMJ arthritis. This may prompt specific localized therapy for TMJ arthritis in children with JIA since TMJ arthritis is frequently present despite aggressive systemic therapy with disease-modifying antirheumatic drugs and biologic agents (4). The hope is that early aggressive therapy of TMJ arthritis in children with JIA will help to prevent progressive destructive disease. Several groups have reported benefit of the use of intraarticular (11–13) and transcutaneous (14) long-acting corticosteroids for treating TMJ arthritis in children with JIA, and more recently intraarticular infliximab has been explored in cases of refractory TMJ arthritis (15,16). Measuring the benefit of therapy for TMJ arthritis in children with

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Significance & Innovations

- We have compiled for the first time an atlas of radiographic images of the temporomandibular joint (TMJ) in children with juvenile idiopathic arthritis (JIA). These images portray both acute (synovial fluid, bone marrow edema, synovial enhancement) and chronic (condylar head flattening and erosions, pannus, disc displacement and destruction) TMJ imaging findings frequently present in children with JIA.
- A proposed TMJ magnetic resonance imaging scoring system is presented with reliability testing to allow for monitoring and scoring of TMJ arthritis in children with JIA. This will allow for the ability to quantify changes in TMJ disease over time and facilitate clinical trials involving treatment of TMJ arthritis in children with JIA.

JIA has relied on mouth opening distances, patient-reported pain and function, and MRI findings (11,13, 14,16–19). However, none of these scales have been formally validated.

Although the effectiveness of MRI in demonstrating a variety of both acute and chronic TMJ changes in JIA has been reported (1–3,6,13,16,20–26), no large imaging studies have been published. At our institution, more than 500 TMJ MRI examinations are performed annually to explore TMJ arthritis in children with JIA. Herein, we report a sampling of the variety of the spectrum of MRI findings of the TMJ in children with JIA. Specifically, images are included depicting normal TMJs and TMJs with early changes, such as small effusion, synovial enhancement, and marrow edema, to more advanced changes, including pannus formation, condylar head flattening and erosions, disc deformity, bony destruction, and osteophyte formation. Also included is normal TMJ anatomy on MRI and the utility of CT imaging for bony evaluations. The ability to track progression of disease without treatment and response to therapy over time by MRI is also presented. A proposed scoring system of acute and chronic TMJ arthritis MRI findings was tested for inter- and intrareader reliability. The scoring system is proposed for objectively tracking TMJ arthritis in children with JIA. This scoring system, combined with an atlas of TMJ MRI findings, will help to establish an objective measure of improvement or worsening in order to allow for future prospective clinical trials centered on treating TMJ arthritis in children with JIA.

MATERIALS AND METHODS

TMJ MRI protocol. MRI studies were performed using either a 1.5T (Philips Ingenia or Siemens Avanto) or 3.0T magnet (Philips Ingenia) and using either dedicated surface coils (1.5T) or high-definition Cranio-Spinal coils (3T) for TMJ as previously described (13,16). Precontrast imaging included T1 coronal, T2 fast spin-echo fat-suppressed coronal, sagittal, and proton-density sagittal for anatomic detail. Following intravenous (IV) administration of gadolinium (Magnevist), fat-suppressed coronal and sagittal T1-weighted images were obtained. Only closed-mouth views were obtained. Children younger than age 8 years typically required IV sedation with propofol or general anesthesia.

MRI scoring and testing of reliability. Interrater characteristics of the scoring method (see Supplementary Table 1, available in the online version of this article at http://onlinelibrary.wiley.com/doi/10.1002/acr.22177/abstract) were examined. Twenty MRI examinations were chosen to represent the spectrum of MRI findings and were reviewed by 2 radiologists (YNV and SAR) who were each blinded to other's ratings. The acute and chronic scores for individual joints (40 in total) were compared between the 2 raters using the kappa statistic. In order to account for scores that were similar but not in perfect agreement, we performed a weighted kappa statistic, with weights equal to

$$1 - (\text{[rater 1 score} - \text{rater 2 score]} / \text{[maximum number of possible ratings} - 1]) \quad (27)$$

Intrarater characteristics of the scoring method were also examined. Ten MRI examinations from the interrater evaluation were selected (representing the spectrum of severity from normal to severe) and the same radiologists rescored them several weeks after the initial ratings. The first and second scores from each individual rater were compared using the same method as the interrater analysis. Kappa scores in the range of 0.61–0.80 were considered to represent substantial agreement (27).

RESULTS

Normal anatomy of the TMJ. The TMJ is a ball and socket joint between the mandibular condyle and the articular eminence of the squamous portion of the temporal bone (5). The meniscus or disc is a biconcave structure with a central thin portion and anterior and posterior thicker portions known as anterior and posterior bands. The disc, along with its attachments, divides the joint into superior and inferior spaces. The posterior band is continuous with the bilaminar zone. In a closed-mouth position, the posterior band lies immediately above the condyle. As the condyle translates forward during opening of the jaw, the thinner intermediate zone of the disc becomes the articular surface between the condyle and the articular eminence (Figure 1A). On MRI, the condyle is smooth and rounded in shape. The marrow is fatty and, on fat-suppressed sequences, no edema is seen. No synovial effusion is seen. The normal disc is hypointense on all sequences. Minimal to no synovial enhancement is seen on postcontrast images (Figure 1B–D) (10).

Acute changes of the TMJ as seen by MRI. In children with JIA, MRI features of the TMJ may be divided into acute and chronic changes. Acute changes include syno-

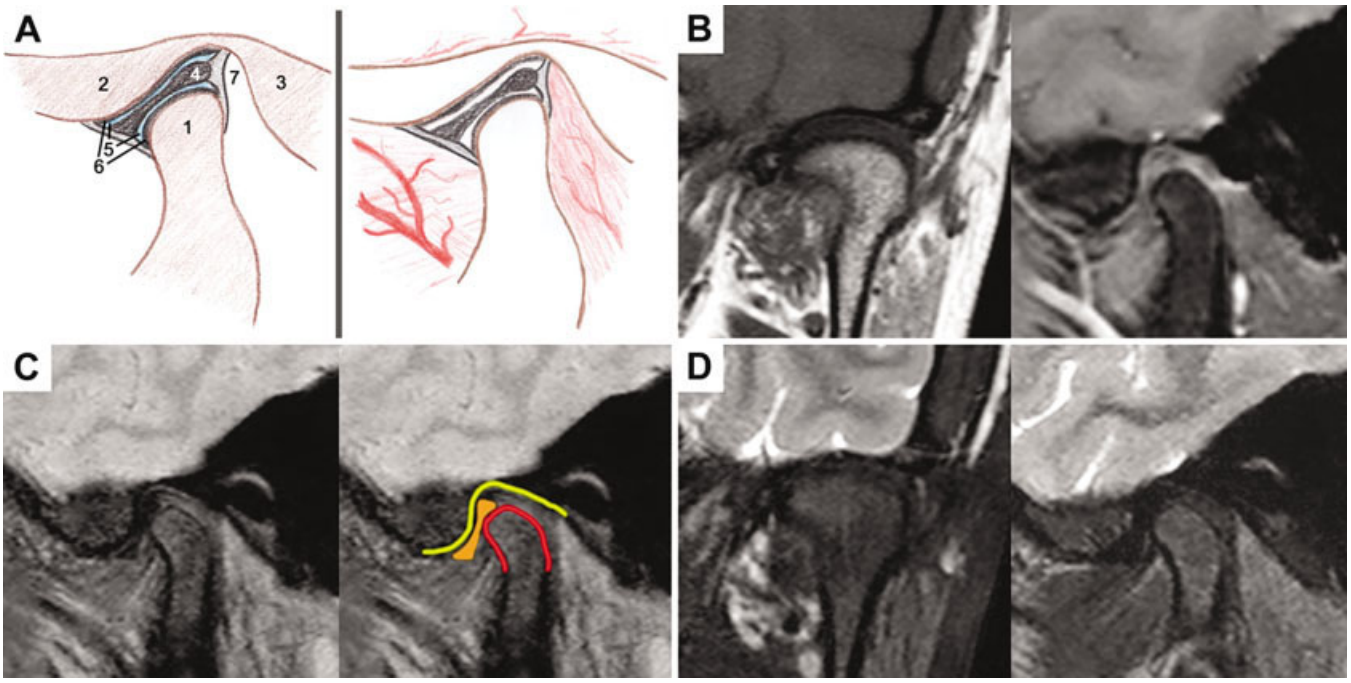

Figure 1. Normal temporomandibular joint (TMJ) anatomy of a single joint. **A**, Diagram (left) of normal TMJ anatomy in sagittal view. 1 = mandibular condyle; 2 = temporal bone articular eminence; 3 = temporal bone mastoid portion; 4 = articular disc; 5 = superior and inferior joint spaces; 6 = superior and inferior articular cartilage; 7 = bilaminar zone. Diagram (right) of normal enhancement (red). Note normal muscular and vascular enhancement anterior to the condyle in the bilaminar zone and intracranially; only faint synovial enhancement is seen along the superior and inferior articular cartilage. **B**, Coronal T1 (left) and sagittal T1 fat-suppressed (FS) (right) images show normal rounded condylar shape, normal joint space, no synovial enhancement, and normal marrow signal and saturation on FS sequence. **C**, Sagittal proton-density FS image (right) demonstrates normal condyle (red outline), disc (orange), and articular eminence (yellow outline). **D**, Coronal (left) and sagittal (right) T2 FS images show no synovial effusion, erosion, marrow edema, or pannus.

vial effusion, synovial enhancement, synovial thickening, and bone marrow edema. Synovial enhancement can be defined as an increase in signal intensity on postcontrast images. It has been reported to be the most common early finding in children with JIA, and this has been our experience as well (1,2,4,21,28). The enhancement may be minimal to mild (<1 mm), moderate (2 mm), or severe (>3 mm), including regions of focal thickening (Figure 2B). It remains unclear at present whether bilateral symmetric enhancement of the TMJ is pathologic or not (1,2,10,29). It may be pathologic for some children with JIA where disease progresses, but not for others where MRI findings remain unchanged over time.

Like synovial enhancement, synovial effusions of the TMJ are frequently noted on MRIs of children with JIA. Synovial effusion can be defined as intraarticular hypointensity on T1 scans and hyperintensity on T2 scans (Figure 2C). It has been reported to be the second most common finding, ranging from 23–65% of patients with JIA (21,28). Synovial effusion of the TMJ may be minimal initially and also may be confined to aspects of the superior or inferior compartments of the joint. Moreover, effusions may be absent in advanced disease with severe destruction. Nevertheless, bone marrow edema may be seen in early as well as in advanced disease (Figure 2D). The subcondylar bone may show edema visualized as low intensity on T1 sequences and hyperintensity on T2-weighted sequences. Gadolinium may also help reveal marrow edema as enhancement on postcontrast images.

Chronic changes of the TMJ as seen by MRI. Chronic changes of TMJ arthritis include pannus formation, condylar flattening, bony erosions, and disc deformity, destruction, and displacement. In addition, bony destruction and hypertrophic bone formation, as well as micrognathia due to growth disturbance, can be the result of chronic TMJ arthritis in children. Condylar head flattening, defined as loss of the normal rounded shape, can be seen prior to erosive changes and more advanced destruction (Figure 3A). Condylar erosions, defined as focal irregularity of the articular surface and subarticular bone (Figure 3B), may be subtle in early stages, involving less than one-third of the surface. Late stages may show completely destroyed articular surfaces (Figure 3D). Like other joints, TMJ arthritis may result in pannus formation, which is seen as an intermediate hyperintense mass within the joint on T1- and T2-weighted sequences (Figure 3C). Pannus may also show robust enhancement following contrast (Figure 3C).

Disc changes can also be seen in the presence of severe chronic arthritis and can be recognized as irregular, thinned, or displaced (Figure 3D). Similarly, micrognathia is often seen in advanced disease, resulting from growth disturbance especially if untreated. This is often best visualized by CT scan (Figure 4B). CT is also useful for detecting bony erosions (Figures 4B and C), whereas MRI better defines synovial thickening, pannus, disc deformity, and marrow enhancement (Figures 4A and C). Finally, osteophyte formation, characterized by hypertrophic bone

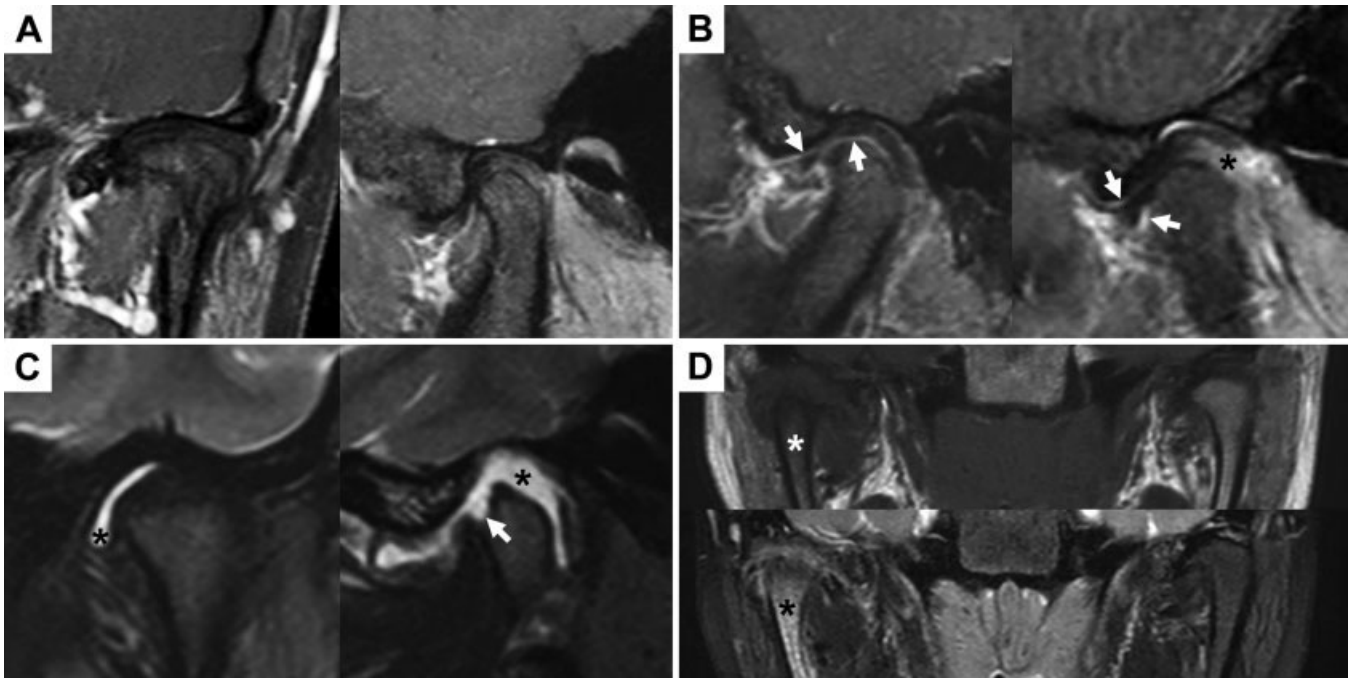

Figure 2. Acute changes of temporomandibular joint (TMJ) arthritis. **A**, Coronal (left) and sagittal (right) T1 fat-suppressed (FS) with-contrast (C+) images of a normal joint show no synovial or osseous enhancement. **B**, In contrast, sagittal T1 FS C+ of 2 patients with active TMJ arthritis show minimal (left) to mild (right) synovial enhancement (**arrows**) and pannus enhancement (*). **C**, Coronal and sagittal T2 FS images of moderate (left) and large (right) synovial effusions (*) in 2 patients with active arthritis. Also, note focal cortical erosion (**arrow**). **D**, Coronal T1 (top) and T2 (bottom) images show marrow edema of the left mandibular condyle, with decreased T1 and increased T2 signal (*).

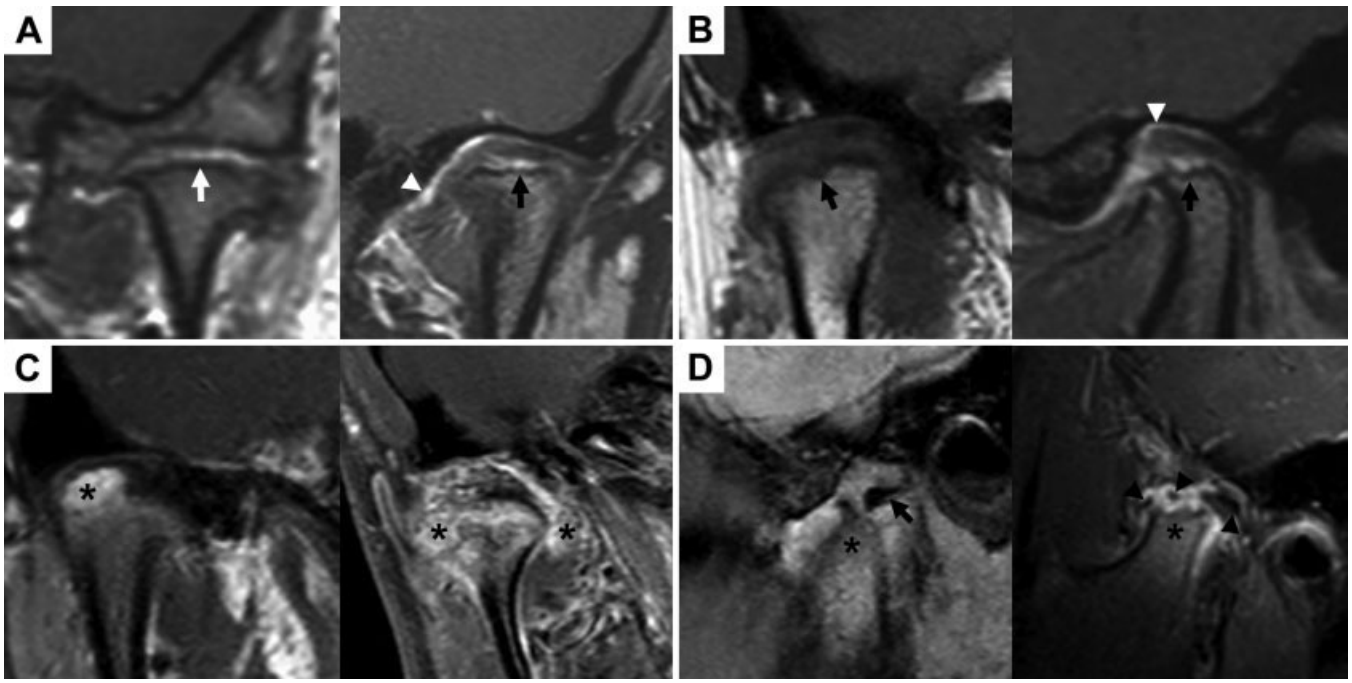

Figure 3. Chronic changes of temporomandibular joint (TMJ) arthritis. **A**, Coronal T1 images of 2 patients with chronic TMJ arthritis show diffuse articular surface flattening and irregularity (**arrows**). Moderate synovial enhancement is also present and more apparent in the second patient (**arrowhead**). **B**, Coronal T1 (left) and sagittal T1 fat-suppressed (FS) with-contrast (C+; right) images of 2 patients with chronic TMJ arthritis show erosions of the articular surface (**arrows**), as well as moderate synovial enhancement (**arrowhead**). **C**, Coronal T1 FS C+ images in 2 separate patients demonstrate moderate and large pannus formation with avid enhancement (*). **D**, Sagittal proton-density (left) and sagittal T1 FS C+ (right) images in 2 patients with chronic TMJ arthritis show disc deformity and clumping (**arrow**), and disc fragmentation and displacement (**arrowheads**). Both patients also show large articular surface erosions (*).

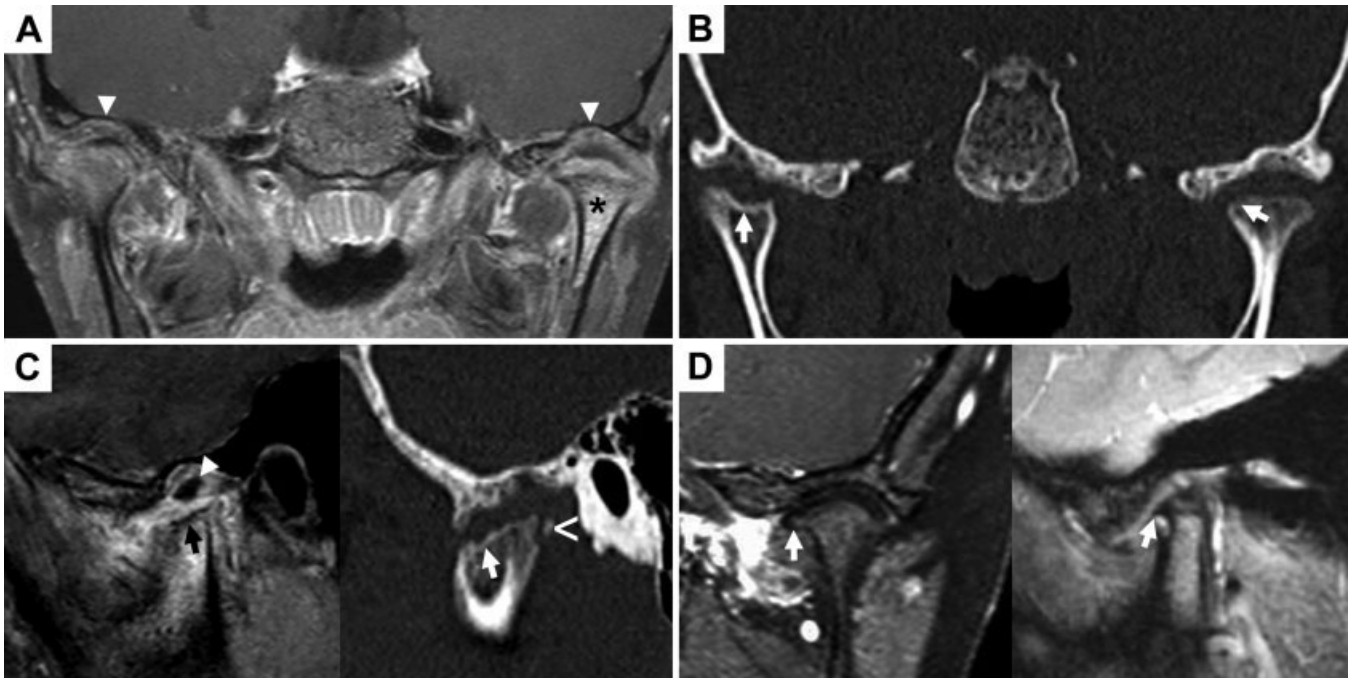

Figure 4. Chronic changes of temporomandibular joint (TMJ) arthritis with computed tomography (CT) correlation. **A**, Coronal T1 with-contrast (C+) image shows synovial thickening and irregularity (**arrowheads**), pannus formation, and marrow enhancement (*). **B**, Corresponding coronal CT image of the same patient demonstrates erosions (**arrows**) and irregular joint space widening. **C**, Sagittal T1 fat-suppressed (FS) C+ (left) and corresponding sagittal CT (right) images from the same patient as in **A** and **B** demonstrate disc deformity (**arrowhead**), erosions (**arrows**), and calcium deposit (<). **D**, Coronal (left) and sagittal T1 FS C+ (right) images in another patient with chronic TMJ arthritis show osteophyte formation (**arrows**) and articular surface flattening.

formation, is best shown by CT in advanced disease but can also be detected by MRI (Figure 4D). It is unclear whether heterotopic bone formation in TMJ arthritis is the result of prolonged inflammation, use of intraarticular steroids, or a combination of the two. Nonetheless, heterotopic ossification does seem to be associated with aggressive TMJ arthritis (30).

Progression of disease as noted by TMJ MRI. MRI evaluations, lacking ionizing radiation as with CT scans, can be used repeatedly to follow disease course in children with chronic TMJ arthritis. Figure 5A (left panel) shows an example of a TMJ MRI of a child with JIA that starts as mild synovial enhancement. A year later MRI reveals decreased enhancement in conjunction with systemic low-dose methotrexate and the tumor necrosis factor inhibitor etanercept (Figure 5A, middle panel). However, a year later, after no local or systemic treatment (lost to followup), the MRI reveals notable acute and chronic TMJ arthritis findings, which include severe synovial enhancement, subarticular erosions, and disc destruction and displacement (Figure 5A, right panel). Similarly, Figure 5B demonstrates progression of TMJ arthritis from mild synovial enhancement (left panel) to severe synovial thickening and pannus (middle panel) to severe destructive changes in the joint (right panel).

Serial MRI evaluations are also effective in demonstrating response to therapy, showing improvement following systemic or intraarticular steroid treatment. Figure 6A reveals moderate synovial thickening and subarticular erosion. Following intraarticular steroids, synovial enhancement has resolved (Figure 6B). There have been several reports demonstrating the benefit of intraarticular steroids in treating TMJ arthritis in children with JIA (2,11,13,17, 31,32) but there have been no randomized controlled trials (33). This highlights the importance of developing a standardized methodology for imaging and scoring TMJ arthritis by MRI to assess therapeutic response.

Reliability testing of the proposed TMJ MRI scoring system. In order to allow for quantification of acute and chronic TMJ changes over time as assessed by MRI, we developed a graded scoring system to assess degrees of TMJ involvement in JIA as assessed by MRI with contrast (see Supplementary Table 1, available in the online version of this article at http://onlinelibrary.wiley.com/doi/10.1002/acr.22177/abstract). To assess the reliability of our proposed graded scoring system, we analyzed both acute and chronic scores of TMJ arthritis from 40 joints (20 selected JIA patients) with a range of TMJ MRI findings (minimal to severe). Of the 40 TMJ joints evaluated, the 2 reviewers scored perfect agreement 25% of the time for the acute score and 38% of the time for the chronic score (kappa statistic of 0.14 and 0.31, respectively) (see Supplementary Tables 2 and 3, available in the online version of this article at http://onlinelibrary.wiley.com/doi/10.1002/acr.22177/abstract).

When the weighted kappa was used, the kappa statistic increased to 0.51 for the acute score and 0.68 for the chronic score. The most frequent discrepancy in the scores between the 2 raters was the amount of joint effusion; there was perfect agreement only 38% of the time for this com-

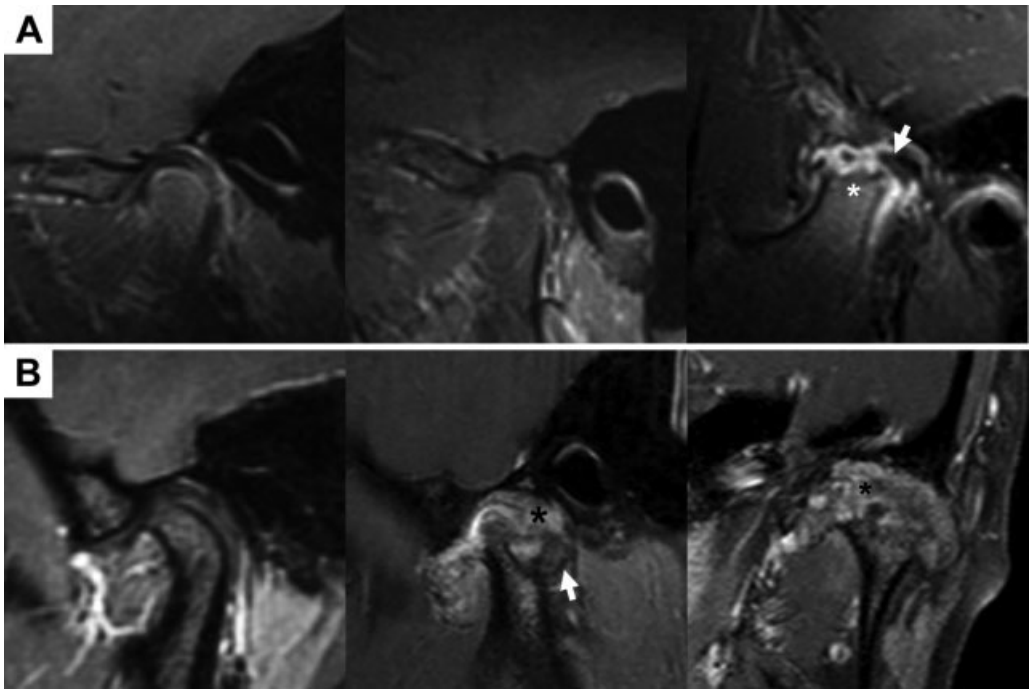

Figure 5. Temporal progression of temporomandibular joint arthritis. **A**, Sagittal T1 fat-suppressed (FS) with-contrast (C+) images of the same patient obtained in 2010 (left), 2011 (middle), and 2012 (right). Only mild synovial enhancement was present in 2010. In 2011, after systemic methotrexate and etanercept therapy, enhancement had decreased. The patient was subsequently lost to followup with no treatment, and in 2012 magnetic resonance imaging showed severe synovial enhancement, cortical irregularity, subarticular erosions (*), and disc destruction with displacement (**arrow**). **B**, Sagittal T1 FS C+ image obtained in 2011 (left) and sagittal (middle) and coronal (right) T1 FS C+ images of the same patient obtained in 2012. Only mild synovial enhancement was present in 2011. By 2012, severe synovial thickening and pannus (*) had developed, along with extensive destructive osseous changes with fragmentation (**arrow**).

ponent of the acute score. The most frequent area of agreement in the scores was the presence of osteophytes; there was perfect agreement 85% of the time. Of the 20 TMJ joints (10 selected from previous 20 JIA patient MRI studies) evaluated twice, the reviewers had perfect agreement with their prior scores 80% of the time for the acute score and 73% of the time for the chronic score (unweighted kappa statistic of 0.76 and 0.67, respectively). Both reviewers individually had similar personal kappa statistics. Thus, there was substantial agreement for both the inter- and intrareader reliability scores over a range of acute and chronic TMJ MRI findings from children with JIA.

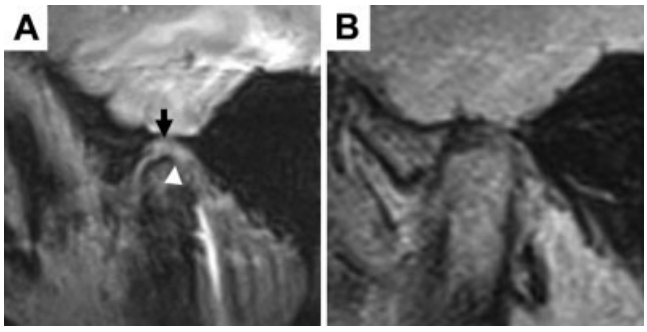

Figure 6. Response to intraarticular triamcinolone hexacetonide therapy. **A**, Sagittal T1 fat-suppressed with-contrast image shows moderate synovial thickening (**arrow**) and subarticular erosion (**arrowhead**). **B**, After intraarticular triamcinolone hexacetonide therapy, no residual enhancement is seen.

DISCUSSION

At present, MRI with contrast appears to be the gold standard (highest sensitivity and specificity) imaging methodology for evaluating acute and chronic changes in the TMJs of children with JIA (1,2). There are multiple protocols available for imaging TMJ arthritis in children with JIA by MRI (1,2,10,21,26,34), and the protocol used for this study is included in the Methods. Herein, we have also compiled representative MRIs of normal anatomy and various acute and chronic TMJ findings commonly noted in children with JIA (Figures 1–6). These images are to be used in conjunction with our proposed scoring system (see Supplementary Table 1, available in the online version of this article at http://onlinelibrary.wiley.com/doi/10.1002/acr.22177/abstract) for evaluating the degrees of acute (synovial fluid, bone marrow edema, and synovial enhancement) and chronic (pannus, disc displacement and destruction, condylar head flattening and erosions, and osteophytes) changes in TMJ disease as detected by MRI in children with JIA.

The scoring system should allow for quantifying changes in TMJ arthritis over time and following interventions (e.g., intraarticular corticosteroid treatment). In test-

ing both the inter- and intrareader reliability of the proposed scoring system, there was minimal variance in scores between readers for the acute and chronic changes (see Supplementary Tables 2 and 3, available in the online version of this article at http://onlinelibrary.wiley.com/doi/10.1002/acr.22177/abstract) and in the individual readers' scoring of the same image over time (data not shown). However, there remains some limitations of our imaging protocol and scoring system. The current imaging protocol lasts approximately 45 minutes, frequently requiring significant sedation for children age 8 years and younger. Because of the sedation, there are also only closed-mouth images. In addition, MRI is costly. Nevertheless, future validation of this scoring system, or others recently proposed (35), will be critically important prior to use in randomized treatment trials of TMJ arthritis in children with JIA. The TMJ remains a joint that is difficult to treat with poor response to systemic treatment (4) and potential side effects from therapy (30). Thus, current and novel (16) treatment approaches need to be tested in a more rigorous prospective fashion (33), and this will depend upon a reliable scoring system to assess both acute and chronic TMJ findings in children with JIA.

AUTHOR CONTRIBUTIONS

All authors were involved in drafting the article or revising it critically for important intellectual content, and all authors approved the final version to be submitted for publication. Dr. Cron had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Study conception and design. Vaid, Dunnavant, Royal, Cron.
Acquisition of data. Vaid, Dunnavant, Royal.
Analysis and interpretation of data. Royal, Beukelman, Stoll, Cron.

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