Title: **A simple, clinically usable whole-body MRI system of joint assessment in adolescents and young people with juvenile idiopathic arthritis**

Authors: Varvara Choida[1,2,3], Timothy J.P. Bray[1,4], Niels van Vucht[4], Maaz Ali Abbasi[4], Alan P. Bainbridge[1,5], Thomas Parry[1], Debajit Sen[2,3], Sue Mallett[1], Coziana Ciurtin[2,3], Margaret A. Hall-Craggs[1,4]

Affiliations

1. Centre for Medical Imaging, University College London, University College London, London, UK.
2. Centre for Adolescent Rheumatology, Division of Medicine, University College London, UK
3. Department of Rheumatology, University College London Hospitals NHS Foundation Trust, London, UK
4. Department of Imaging, University College London Hospitals NHS Foundation Trust, London, UK
5. Department of Medical Physics, University College Hospitals Trust, London, UK

Correspondence to: Professor Margaret Hall-Craggs, Centre for Medical Imaging, University College London, 2nd Floor Charles Bell House, 43-45 Foley Street, W1W 7TS London, UK. Email: m.hall-craggs@ucl.ac.uk

Abstract

Objectives

To introduce and evaluate a simple method for assessing joint inflammation and structural damage on whole-body MRI (WBMRI) in juvenile idiopathic arthritis (JIA), which is usable in clinical practice.

Methods

The proposed system utilises post-contrast Dixon WBMRI scans. Joints are assessed for synovitis (grade 0-2) and structural damage (present/absent) at 81 sites. The synovitis grading is based on features including above-normal intensity synovial enhancement, synovial hypertrophy, joint effusion, subarticular bone marrow oedema and peri-articular soft tissue oedema.

This system was evaluated in a prospective study of 60 young people (47 patients with JIA and 13 controls with non-inflammatory musculoskeletal pain) who underwent a WBMRI. Three readers (blinded to diagnosis) independently reviewed all images and re-reviewed 20 individual scans. The intra- and inter-reader overall agreement (OA) and the intra- and inter-reader Gwet's agreement coefficients 2 (GAC2) were measured for the detection of a) participants with ≥1 joint with inflammation or structural damage and b) joint inflammation or structural damage for each joint.

Results

The inter-reader OA for detecting patients with ≥1 joint with inflammation, defined as grade 2 synovitis (G2), and ≥1 joint with structural damage were 80% and 73%, respectively. The intra-reader OA for readers 1-3 were 80-90% and 75-90% respectively. The inter-reader OA and GAC2 for joint inflammation (G2) at each joint were both ≥85% for all joints but were lower if grade 1 synovitis was included as positive.

Conclusion

The intra- and inter-reader agreements of this WBMRI assessment system are adequate for assessing objective joint inflammation and damage in JIA.

Rheumatology key messages

- A clinically usable WBMRI-based assessment for joint inflammation and structural damage was developed for JIA
- Joint inflammation on WBMRI was detected with reliable intra- and inter-reader agreement
- WBMRI reporting times were conforming to clinical radiological practice for standard MRI scans

Keywords: whole-body, MRI, JIA, synovitis, activity, joint, Dixon, agreement, reliability, scoring

Introduction

Whole-body MRI (WBMRI) enables the assessment of multiple joints, the entheses and axial skeleton for inflammation in one examination. This technique is promising for the monitoring of conditions like non-systemic juvenile idiopathic arthritis (JIA), which is heterogeneous and causes various patterns of joint inflammation, along with entheseal and axial inflammation in some JIA subtypes (1).

WBMRI has demonstrated its ability to detect joint inflammation in previous research studies (2). However, there are several issues that need to be considered if WBMRI is to be a clinically useful tool. A WBMRI examination that is fit for purpose in JIA should image all the clinically important joints, be acceptable to patients, and be available and at reasonable cost. A framework for assessing and measuring joint inflammation and structural damage on whole-body scans is also required. This framework should provide a holistic objective assessment of musculoskeletal inflammation, be simple and reproducible between scan readers, and provide useful information for clinical decision-making.

Although there are a number of semi-quantitative MRI scoring systems for assessing disease activity in rheumatoid arthritis (3), psoriatic arthritis (4), spondyloarthritis (5, 6), and JIA (7-10), as well as proposed scoring systems for WBMRI (11, 12), these detailed systems are primarily designed for use in the research setting but are not practical for clinical care.

Therefore, our objectives were to develop a simple WBMRI-based joint assessment system that could be used in standard clinical care for patients with JIA, and to evaluate its intra- and inter- reader agreement.

Methods

Subjects

This was a prospective study, approved by London Queen Square Research Ethics Committee (15/LO/1475) and all participants provided informed written consent. The study complied with the ethical principles of the Declaration of Helsinki. We included 60 adolescent and young adult patients, under the care of the adolescent and young adult rheumatology team of University College London Hospital, with either JIA (n=47) according to the International

League of Associations for Rheumatology classification or musculoskeletal pain without inflammatory arthritis (controls, n=13) according to the opinion of their treating rheumatologist. The exclusion criteria for both groups were any contraindications to undergo MRI scan or to receive gadolinium contrast. All participants underwent clinical examination before undergoing a WBMRI scan.

Imaging acquisition

All MRI scans were performed on a 3-Tesla MRI system (Ingenia, Philips Healthcare). 3-D spoiled dual gradient echo Dixon sequences were obtained after administering 10 ml gadoteric acid meglumine (or 0.2 ml/kg if weight ≤50 kg). Coronal acquisitions of the whole body were divided in 6-8 anatomical stations, depending on the patient's height. Fat-water separation was performed in-line using vendor software, and four sets of images were produced: water-only, fat-only, in-phase and opposed-phase. The post-contrast stations 1-7 were 'stitched' into a whole-body image. The MRI parameters included TE: 1.31 & 1.9 ms, TR: 3.5 ms, flip angle: 10 degrees, acquisition matrix: 68-172 x 235-320 x 120 (depending on the station), voxel size 1.59-1.6 x 1.59-1.75 x 5 mm^3, interslice gap: -2.5. The scan duration including the patient positioning, contrast administration and acquisition time of the post-contrast Dixon images was about 30 minutes.

Patients were positioned supine with their hands flat over the front of their thighs and the elbows close to their body. Two anterior phased array coils were placed over the trunk and lower limbs. A posterior coil was integrated in the scanner.

Joint assessment on WBMRI

The peripheral joints, sacroiliac joints (SIJ) and cervical spine (CS) were assessed for inflammation and structural damage on WBMRI, according to the definitions described in Table 1. The joints assessed on WBMRI are listed in Table 2. Synovitis was graded as 0-2 whilst the SIJ and CS were assessed for inflammation dichotomously (Table 1). Grade 1 synovitis (G1S) was defined as above-normal intensity post-contrast synovial enhancement, whereas additional features were required for grade 2 synovitis (G2S). WBMRI images of joints with G2S and structural damage are shown in Figure 1. The readers were instructed to use the multiplanar reconstruction facility on the Picture Archiving and Communication

System (PACS) workstation as they would with normal scan reading practice. The readers had access to the full four sets of Dixon images and reviewed these in combination (Table 1).

Combining joints post-image review according to clinical assessment

After the image review, we combined the joints assessed on WBMRI into 81 joints to harmonise with the clinical assessment of patients with JIA (Table 2). We grouped the small joints of the wrist and foot (which were graded for synovitis individually) onto the wrist, hindfoot and midfoot joints and assigned the highest synovitis grading of the small joints to these complex joints.

Reading sessions

Three musculoskeletal radiologists (MAA, NvV and MHC) with 9, 5, over 25 years of experience respectively reviewed the post-contrast WBMRI images of 60 patients independently, blinded to the diagnosis (JIA or controls) and clinical information in random order. The second round of reading sessions started five weeks after the completion of the first round of WBMRI assessments. All radiologists re-reviewed a subset of 20 WBMRI scans; 17 and 3 scans of JIA patients and controls respectively were selected randomly. During each reading session, an observer (VC) documented the reader's findings in a schematic scoring form (Supplemental Figure 1) and recorded the reporting time. Joints that could not be assessed were crossed on the form.

Training before the reading sessions

Two training sessions were organised for the musculoskeletal radiologists, including hands-on training on WBMRI assessment, using a training set of images. The senior radiologist MHC (experienced in reading JIA whole-body scans) was the trainer at both sessions. The radiologists were given a handbook with the scoring methodology.

Statistical analysis

We measured the intra- and inter--reader agreement and reliability in three levels on the following outcomes.

1. The detection of ≥ 1 joint per participant with a) joint inflammation (without including G1S), b) joint inflammation (including G1S), c) structural damage.
2. The total inflammation score (sum of joint inflammation/patient, with and without G1S; 0-162) and total structural damage score/patient (0-81).

3. The detection of a) joint inflammation (without including G1S), b) joint inflammation (including G1S) and c) structural damage at the same joint. The agreement was calculated per joint, e.g., wrist based on the assessment of all wrist joints on WBMRI. The metacarpophalangeal joints and finger interphalangeal joints (IPJ) were grouped together as hand joints and the agreement was measured collectively for all hand joints. The same approach was applied to the metatarsophalangeal joints and foot IPJ which were grouped as forefoot joints.

At levels 1 and 3, we measured the overall agreement (OA), positive specific agreement (PA), and negative specific agreement (NA) between the readers, as described previously (13) (Supplementary Table S1). In addition, we measured the intra- and inter-reader reliability by Gwet's agreement coefficient 2 [GAC2, (2014)]. The GAC2 was interpreted as: poor (below 0), slight (0-0.20), fair (0.21-0.40), moderate (0.41-0.60), substantial (0.61-0.80), or almost perfect (0.81-1.00) (14). At level 2, the inter-reader /intra-reader reliability were estimated by the two-way random/ mixed effects (respectively), single rater, absolute agreement form of intraclass correlation coefficient (ICC). According to ICC, the reliability was graded as poor (<0.5), moderate (0.5-0.75), good (0.75-0.9), and excellent (>0.90) (15).

Joints that could not be assessed by all radiologists were excluded. The statistical analysis was performed using STATA/MP2 version 16.

Results

Participants

Forty-seven (29 female, 18 male) patients with JIA and 13 (11 female, 2 male) controls underwent a WBMRI scan. The median age was 18 years (range 14-24) for people with JIA and 16 years (range 15-19) for controls. On examination, 25/47 (53%) patients with JIA had either ≥1 active joint and/or clinical sacroiliitis and the remaining patients had neither. All differentiated JIA subtypes were represented; the frequency of each subtype, patients' treatments and disease activity measures are summarised in Supplementary Table S2.

Assessable joints and reporting time

237/4860 (4.9%) joints could not be assessed by all readers. The reasons by decreasing frequency were: 1) joints not included fully in the field of view due to patient's positioning and dimensions [11 (9%) elbow joints, 211 (13%) forefoot joints] or omitted by error (SIJs in one patient), 2) metal artefacts due to dental braces (six TMJs) or orthopaedic surgery (two wrists,

one ankle) 3) joint replacement (three hip joints) and 4) bright artefact (one knee). At the second scoring, no additional joints were identified as not assessable.

The median reporting time (interquartile range) in minutes at the first round was 14 (10.5-19.5) for reader 1; 9.5 (8-14) for reader 2; and 7 (5.5-8.5) for reader 3, who was most experienced in reading WBMRI scans of patients with JIA.

Frequency of synovitis and structural damage detection by readers and participant group

Joint inflammation (defined as G2S in peripheral joints) was detected in 244 (6.8%), 211 (5.9%) and 277 (7.7%) joints of participants with JIA and in 6 (0.6%), 0 and 3 (0.3%) joints of controls, by reader 1, 2 and 3 respectively. Joint inflammation (including G1S) was detected in 429 (11.9%), 361 (10%), and 333 (9.2%) joints in participants with JIA and in 33 (3.2%), 17 (1.7%), and 7 (0.7%) joints in controls, by reader 1, 2 and 3 respectively.

Structural damage was detected in 61 (1.7%), 53 (1.5%) and 82 (2.3%) joints in participants with JIA and in 3 (0.3%), 4 (0.4%), and 3 (0.3%) joints in controls, by reader 1, 2 and 3 respectively.

Inter-reader agreement for the detection of participants with at least one joint with inflammation/structural damage on WBMRI

If we defined peripheral joint inflammation as G2S, the inter-reader OA for the detection of a participant with ≥1 joint with inflammation was 80% (95% CI 74, 85) between the readers. The PA was 82% (95% CI 77, 87), which means that if a reader scores ≥1 joint with inflammation in a patient, there is an 82% probability that another reader will score ≥1 joint with inflammation in the same patient. The NA was 77% (95% CI 70, 83), which indicates that if a reader does not identify any joints with inflammation in a patient, there is a 77% probability that another reader will not identify any. The inter-reader reliability for detecting a participant with joint inflammation was substantial [GAC2 = 61% (95% CI 44, 77)]. If we defined peripheral joint inflammation as G1S or G2S , the inter-reader OA for detecting a participant with ≥1 joint with inflammation was 78% (95% CI 71, 83), PA was 86% (95% CI 82, 90), NA was 44% (95% CI 34, 56) and GAC2 was consistent with substantial reliability [69% (95% CI 54, 84)].

In terms of structural damage, the OA for detecting a participant with ≥1 joint with structural damage was 73% (95% CI 66, 79), PA was 72% (95% CI 65, 78), NA was 75% (95% CI 68, 80) and GAC2 was consistent with moderate reliability [47% (95% CI 30, 64)].

Inter-reader agreement for the detection of the same joint with inflammation or structural damage

The inter-reader OA, PA, NA and GAC2 for joint inflammation (without including G1S) are presented in Figure 2A and Supplementary Table S3. The number of joints with inflammation (not including G1S) according to one, two or all readers per joint is displayed in Figure 2B. The inter-reader PA for joint inflammation was 0 for the CS as only two patients with JIA were identified with CS inflammation by reader 1 and 3 respectively.

Overall, the OA, PA and NA were lower if G1S was included in the definition of peripheral joint inflammation (Supplementary Table S4). The number of joints detected with inflammation (including G1S) by one, two or all readers per joint are shown in Supplementary Figure S2.

The OA, NA and GAC2 on structural damage were above 90% except for the SIJ (OA:84%, GAC2:78%, Supplementary Table S5). The PA for structural damage was low (0-31%) in the small joints of the wrist, hand, forefoot, midfoot, hindfoot and higher in the larger joints [glenohumeral (76%), knee (75%), sacroiliac (51%), elbow (50%), ankle (50%)], except for the hip joint (31%).

Intra-reader agreement and reliability for the detection of participants with at least one joint with inflammation or structural damage on WBMRI

The intra-reader agreement and reliability for readers 1, 2 and 3 for the above are displayed in Table 3.

Intra-reader agreement for joint inflammation and structural damage at the same joint

The number of joints detected with inflammation (without including G1S) in one and both reading sessions by readers 1-3 are displayed in Figure 3. The number of joints detected with inflammation (including G1S), or structural damage, in one and both reading sessions by the readers are displayed in Supplementary Figure S3. The respective intra-reader OA, PA, NA

and GAC2 are not shown as the number of positive joints with joint inflammation or structural damage in this subset of patients was low for many of the joints.

Intra- and inter-reader reliability on total inflammation and structural damage scores per patient

The intra- and inter-reader reliability for total inflammation scores (with and without G1S) were excellent. The intra- and inter-reader reliability for total structural damage scores were moderate to good. The ICCs are summarised in Supplementary Table S6 and Supplementary Table S7.

Discussion

In this study, we introduced and evaluated a simple joint assessment system for patients with JIA based on post-contrast WBMRI Dixon images. The joint assessment on WBMRI covered all the joints that are assessed in patients with JIA in standard clinical care, including the SIJ, providing a comprehensive assessment of disease activity and structural damage. The detection of a patient with joint inflammation by one reader was associated with a high probability that another reader, or the same reader at a second reading, will identify the same patient as having joint inflammation on WBMRI. We selected a cut-off of one joint with inflammation to assess the intra- and inter-reader agreement at the patient level as the detection of one active joint on clinical assessment is likely to influence the treatment plan.

At the joint level, the inter-reader reliability for joint inflammation, defined as G2S, was almost perfect for all joints. The positive agreement was high for many of the frequently involved joints in JIA, such as the knee and ankle joints. This suggests that WBMRI-detected joint inflammation is a potential imaging biomarker of JIA inflammation as it can be measured reliably at multiple joints.

Defining joint inflammation in peripheral joints as G2S, without including G1S, was associated with a higher inter-reader agreement. Our description of G1S is not classified as synovitis based on the OMERACT definitions because of the absence of synovial hypertrophy (3, 4, 16). However, given the qualitative assessment of synovial hypertrophyon WBMRI, G1S could be used to identify the intermediate cases between definite synovitis and normal synovium, despite its uncertain clinical significance. In the clinical setting, G1S should not be treated as definite synovitis.

Structural damage was detected rarely on WBMRI. The inter- reader agreement was higher for the detection of structural damage in large joints compared to small joints (except for hip joints) as the more limited spatial resolution of WBMRI interferes with the assessment for erosions in small joints. Hip structural damage is more complex to define on MRI due to the various structural changes reported in JIA (17), including growth disturbances (18). Cartilage loss cannot be appreciated adequately on WBMRI.

The TMJ was characterised by low inter-reader agreement on joint inflammation and structural damage. To improve the reliability of the TMJ assessment, a higher spatial resolution scan is likely required. We chose not to apply a head coil to patients to make the examination more comfortable. In addition, training for musculoskeletal radiologists in the assessment of TMJ mightbe needed due to their relatively limited experience with TMJ imaging and the multiple components of structural damage in this joint (19).

The SIJ was the most frequently detected joint with structural damage. However, the inter-reader PA was modest for structural damage and inflammation. Dedicated images of the SIJs, in addition to the WBMRI protocol, may be needed to improve the inter-reader agreement and offer a more detailed evaluation of these joints which is useful for detecting disease progression in patients with juvenile spondyloarthritis. Our protocol is based on Dixon imaging, which is a reliable sequence to detect bone marrow oedema and fat metaplasia in the SIJ of patients with spondyloarthritis (20, 21).

Post-contrast Dixon sequences have many additional benefits over the other sequences proposed for the use of WBMRI in inflammatory arthritis (11, 12). Firstly, the water-only Dixon images display a better signal-to-noise ratio and a more uniform fat suppression than short-tau inversion recovery (STIR)(22, 23). Secondly, compared to STIR, the Dixon technique can be combined with contrast administration. Contrast-enhanced MRI improves the assessment for synovitis (24, 25) and is recommended for the joint assessment in JIA (26). The development of more sensitive non-contrast MRI imaging techniques for synovitis is desirable as these would be more ‘patient-friendly’. Thirdly, the T1-weighted in-phase post-contrast images can substitute the need for pre-contrast T1-weighted images, which means inflammation and structural damage can be assessed with one sequence as previously shown (27). The use of Dixon gradient echo sequences makes this WBMRI protocol faster than other

described protocols (12, 28, 29). Although prolonged post-contrast imaging acquisition can potentially lead to false-positive synovitis detection (30), this pattern was not observed in the control group (G2S not seen specifically in joints imaged late vs early).

Moreover, the simpler methodology of the proposed joint assessment system and the schematic reporting of joint pathology in a scoring form resulted in very modest reading times (median reporting time per scan: 7-14 minutes) comparable with the reporting times of MRI scans in clinical practice (31). However, readers were not asked to report incidental findings which can prolong reporting times.

Other strengths of our study were the recruitment of a relatively large number of patients, given that the prevalence of JIA in the UK is 1 in 1000 (32) (10 times less frequent than rheumatoid arthritis (33)), and the inclusion of all JIA subtypes with different patterns of joint inflammation. Moreover, we included a control group and blinded the reading process to decrease bias. In addition, the low detection rate of G2S in this group supports the validity of the WBMRI-detected joint inflammation.

On the other hand, a limitation of our study is that it involved patients and readers from one tertiary centre. We did not include younger children, therefore we did not assess our methodology in patients at earlier stages of their skeletal development and disease. As non-specific bone marrow changes and joint effusions are described in healthy children (34), it would be important to assess the specificity of WBMRI assessment in younger ages. In addition, we devised new criteria for the definition of joint inflammation by encompassing additional components, namely osteitis, joint effusion, and peri-articular soft tissue inflammation. This definition was not developed after consultation with other experts (consensus). However, these features are already included in other joint assessment systems, albeit reported individually (8, 35-38). Finally, a limitation was that joint inflammation and structural damage were encountered in a small proportion of joints. This is expected given the large number of joints assessed on WBMRI compared to the much lower frequency of inflamed joints in patients with active disease, but also due to the inclusion of inactive patients in our study. We addressed this by measuring the PA as well as the OA and NA. The GAC2 was selected over Cohen's kappa statistic, as the former is less affected by the Cohen's kappa paradox (39). Correlation with clinical findings and patients' acceptability of WBMRI have not been assessed here as they will be reported separately.

The role of WBMRI in monitoring joint inflammation and supporting treatment decisions for patients with JIA should be investigated in future research studies. Our proposed WBMRI protocol and joint assessment methodology provide a framework to measure joint inflammation and structural damage. Its ability to detect disease progression or change in disease activity requires further assessment in a longitudinal study. We anticipate that this joint assessment system would be easy to understand by rheumatologists as it mirrors their clinical assessment. With the development of the relevant software, the disease activity on WBMRI could be presented to rheumatologists and patients in one image, for example by using a colour-coded whole-body image, which would enhance their understanding of the findings. Finally, this WBMRI assessment system has real potential for clinical translation as the scanning and reporting times, which could be reduced more in the future with the application of deep learning tools, are in line with other protocols used in clinical practice.

Conclusion

We developed a joint assessment system for evaluating joint inflammation and structural damage in patients with JIA based on a Dixon-based WBMRI after contrast administration. In a prospective study, we demonstrated that the assessment of multiple sites was feasible and time-efficient in terms of scanning and reporting times. The intra- and inter-reader agreements were satisfactory for joint inflammation but more uncertain for structural damage as it was detected rarely. Overall, this system provides a sufficient agreement between readers for its use in the assessment of patients with JIA. Future research studies can refine and use this system to investigate the potential clinical benefits of measuring the disease activity by WBMRI.

Funding

This work was funded by a grant from the Action Medical Research and Humanimal Trust and The Albert Gubay Foundation (GN 2697) to MAHC; by the British Society of Rheumatology to VC (3220566) and the author would like to thank the Society for its help and support; and supported by the Centre of Excellence (Centre for Adolescent Rheumatology Versus Arthritis) grant (21593) and a grant from National Institute for Health Research (NIHR) University College London Hospitals (UCLH) Biomedical Research Centre (BRC) (BRC 525 III/CC 101350) to CC. MAHC and DS are supported by the NIHR UCLH BRC. The views expressed are those of the authors and not necessarily those of the (UK) National Health Service (NHS), the NIHR, or the (UK) Department of Health.
Disclosure statement: The authors have declared no conflicts of interest.

Acknowledgements

The authors thank Lucy Caselton, research radiographer at University College London (UCL), for her input on setting up the whole-body MRI protocol.

Data availability statement

The data underlying this article will be shared on reasonable request to the corresponding author.

References

1. Ording Muller LS, Humphries P, Rosendahl K. The joints in juvenile idiopathic arthritis. Insights Imaging. 2015;6(3):275-84.
2. Choida V, Madenidou AV, Sen D, Hall-Craggs MA, Ciurtin C. The role of whole-body MRI in musculoskeletal inflammation detection and treatment response evaluation in inflammatory arthritis across age: A systematic review. Semin Arthritis Rheum. 2022;52:151953.
3. Ostergaard M, Peterfy C, Conaghan P, McQueen F, Bird P, Ejbjerg B, et al. OMERACT Rheumatoid Arthritis Magnetic Resonance Imaging Studies. Core set of MRI acquisitions, joint pathology definitions, and the OMERACT RA-MRI scoring system. J Rheumatol. 2003;30(6):1385-6.
4. Ostergaard M, McQueen F, Wiell C, Bird P, Boyesen P, Ejbjerg B, et al. The OMERACT psoriatic arthritis magnetic resonance imaging scoring system (PsAMRIS): definitions of key pathologies, suggested MRI sequences, and preliminary scoring system for PsA Hands. J Rheumatol. 2009;36(8):1816-24.
5. Landewe RB, Hermann KG, van der Heijde DM, Baraliakos X, Jurik AG, Lambert RG, et al. Scoring sacroiliac joints by magnetic resonance imaging. A multiple-reader reliability experiment. J Rheumatol. 2005;32(10):2050-5.
6. Krabbe S, Ostergaard M, Pedersen SJ, Weber U, Krober G, Makysmowych W, et al. Canada-Denmark MRI scoring system of the spine in patients with axial spondyloarthritis: updated definitions, scoring rules and inter-reader reliability in a multiple reader setting. RMD Open. 2019;5(2):e001057.
7. Malattia C, Damasio MB, Pistorio A, Ioseliani M, Vilca I, Valle M, et al. Development and preliminary validation of a paediatric-targeted MRI scoring system for the assessment of disease activity and damage in juvenile idiopathic arthritis. Ann Rheum Dis. 2011;70(3):440-6.
8. Hemke R, van Rossum MA, van Veenendaal M, Terra MP, Deurloo EE, de Jonge MC, et al. Reliability and responsiveness of the Juvenile Arthritis MRI Scoring (JAMRIS) system for the knee. Eur Radiol. 2013;23(4):1075-83.
9. Tolend M, Doria AS, Meyers AB, Larheim TA, Abramowicz S, Aguet J, et al. Assessing the Reliability of the OMERACT Juvenile Idiopathic Arthritis Magnetic Resonance Scoring System for Temporomandibular Joints (JAMRIS-TMJ). J Clin Med. 2021;10(18).
10. Otobo TM, Herregods N, Jaremko JL, Sudol-Szopinska I, Maksymowych WP, Meyers AB, et al. Reliability of the Preliminary OMERACT Juvenile Idiopathic Arthritis MRI Score (OMERACT JAMRIS-SIJ). J Clin Med. 2021;10(19).

11. Krabbe S, Eshed I, Gandjbakhch F, Pedersen SJ, Bird P, Mathew AJ, et al. Development and Validation of an OMERACT MRI Whole-Body Score for Inflammation in Peripheral Joints and Entheses in Inflammatory Arthritis (MRI-WIPE). J Rheumatol. 2019;46(9):1215-21.
12. Panwar J, Tolend M, Redd B, Srinivasalu H, Colbert RA, Akikusa J, et al. Consensus-driven conceptual development of a standardized whole body-MRI scoring system for assessment of disease activity in juvenile idiopathic arthritis: MRI in JIA OMERACT working group. Semin Arthritis Rheum. 2021;51(6):1350-9.
13. Nijpels G, van der Heijden A, Elders P, Beulens JWJ, de Vet HCW. The interobserver agreement of ECG abnormalities using Minnesota codes in people with type 2 diabetes. PLoS One. 2021;16(8):e0255466.
14. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics. 1977;33(1):159-74.
15. Koo TK, Li MY. A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. J Chiropr Med. 2016;15(2):155-63.
16. Ostergaard M, Eshed I, Althoff CE, Poggenborg RP, Diekhoff T, Krabbe S, et al. Whole-body Magnetic Resonance Imaging in Inflammatory Arthritis: Systematic Literature Review and First Steps Toward Standardization and an OMERACT Scoring System. J Rheumatol. 2017;44(11):1699-705.
17. Ostrowska M, Gietka P, Manczak M, Michalski E, Sudol-Szopinska I. MRI Findings in Hip in Juvenile Idiopathic Arthritis. J Clin Med. 2021;10(22).
18. Shelmerdine SC, Di Paolo PL, Tanturri de Horatio L, Malattia C, Magni-Manzoni S, Rosendahl K. Imaging of the hip in juvenile idiopathic arthritis. Pediatr Radiol. 2018;48(6):811-7.
19. Angenete OW, Augdal TA, Rygg M, Rosendahl K. MRI in the Assessment of TMJ-Arthritis in Children with JIA; Repeatability of a Newly Devised Scoring System. Acad Radiol. 2022;29(9):1362-77.
20. Bray TJP, Bainbridge A, Punwani S, Ioannou Y, Hall-Craggs MA. Simultaneous Quantification of Bone Edema/Adiposity and Structure in Inflamed Bone Using Chemical Shift-Encoded MRI in Spondyloarthritis. Magn Reson Med. 2018;79(2):1031-42.
21. Allam MFA-B, Isaac KRE-KG, Ismail AH, Ragaee SM. The value of chemical shift imaging and T1-Dixon MRI in evaluation of structural changes in sacroiliac joint in ankylosing spondylitis. Egyptian Journal of Radiology and Nuclear Medicine. 2022;53(1):127.
22. Kirchgesner T, Perlepe V, Michoux N, Larbi A, Vande Berg B. Fat suppression at 2D MR imaging of the hands: Dixon method versus CHESS technique and STIR sequence. Eur J Radiol. 2017;89:40-6.
23. Park HJ, Lee SY, Rho MH, Chung EC, Ahn JH, Park JH, et al. Usefulness of the fast spin-echo three-point Dixon (mDixon) image of the knee joint on 3.0-T MRI: comparison with conventional fast spin-echo T2 weighted image. Br J Radiol. 2016;89(1062):20151074.
24. Lins CF, Salmon CEG, Nogueira-Barbosa MH. Applications of the Dixon technique in the evaluation of the musculoskeletal system. Radiol Bras. 2021;54(1):33-42.
25. Hemke R, Kuijpers TW, van den Berg JM, van Veenendaal M, Dolman KM, van Rossum MA, et al. The diagnostic accuracy of unenhanced MRI in the assessment of joint abnormalities in juvenile idiopathic arthritis. Eur Radiol. 2013;23(7):1998-2004.
26. Hemke R, Herregods N, Jaremko JL, Astrom G, Avenarius D, Becce F, et al. Imaging assessment of children presenting with suspected or known juvenile idiopathic arthritis: ESSR-ESPR points to consider. Eur Radiol. 2020;30(10):5237-49.
27. Kirchgesner T, Stoenoiu M, Michoux N, Durez P, Vande Berg B. Contrast-enhanced T1-weighted Dixon water- and fat-only images to assess osteitis and erosions according to

RAMRIS in hands of patients with early rheumatoid arthritis. Diagn Interv Imaging. 2021;102(7-8):439-45.
28. Poggenborg RP, Pedersen SJ, Eshed I, Sorensen IJ, Moller JM, Madsen OR, et al. Head-to-toe whole-body MRI in psoriatic arthritis, axial spondyloarthritis and healthy subjects: first steps towards global inflammation and damage scores of peripheral and axial joints. Rheumatology (Oxford). 2015;54(6):1039-49.
29. Axelsen MB, Eshed I, Duer-Jensen A, Moller JM, Pedersen SJ, Ostergaard M. Whole-body MRI assessment of disease activity and structural damage in rheumatoid arthritis: first step towards an MRI joint count. Rheumatology (Oxford). 2014;53(5):845-53.
30. Ostergaard M, Klarlund M. Importance of timing of post-contrast MRI in rheumatoid arthritis: what happens during the first 60 minutes after IV gadolinium-DTPA? Ann Rheum Dis. 2001;60(11):1050-4.
31. Radiologists BotFoCRTRCo. The Royal College of Radiologists. Clinical radiology workload: guidance on radiologists' reporting figures. London: The Royal College of Radiologists, 20122012. Available from: https://www.rcr.ac.uk/system/files/publication/field_publication_files/BFCR%2812%2912_workload_0.pdf.
32. EXCELLENCE NIFHAC. Final scope for the appraisal of canakinumab for treating systemic juvenile idiopathic arthritis. Issue Date: October 2013
33. Rheumatoid arthritis: How common is it? Last revised in April 2020.
34. Muller LS, Avenarius D, Damasio B, Eldevik OP, Malattia C, Lambot-Juhan K, et al. The paediatric wrist revisited: redefining MR findings in healthy children. Ann Rheum Dis. 2011;70(4):605-10.
35. Ostrowska M, Michalski E, Gietka P, Manczak M, Posadzy M, Sudol-Szopinska I. Ankle Magnetic Resonance Imaging in Juvenile Idiopathic Arthritis Versus Non-Juvenile Idiopathic Arthritis Patients with Arthralgia. J Clin Med. 2022;11(3).
36. Damasio MB, Malattia C, Tanturri de Horatio L, Mattiuz C, Pistorio A, Bracaglia C, et al. MRI of the wrist in juvenile idiopathic arthritis: proposal of a paediatric synovitis score by a consensus of an international working group. Results of a multicentre reliability study. Pediatr Radiol. 2012;42(9):1047-55.
37. Tanturri de Horatio L, Shelmerdine SC, d'Angelo P, Di Paolo PL, Magni-Manzoni S, Malattia C, et al. A novel magnetic resonance imaging scoring system for active and chronic changes in children and adolescents with juvenile idiopathic arthritis of the hip. Pediatr Radiol. 2022.
38. Tolend MA, Twilt M, Cron RQ, Tzaribachev N, Guleria S, von Kalle T, et al. Toward Establishing a Standardized Magnetic Resonance Imaging Scoring System for Temporomandibular Joints in Juvenile Idiopathic Arthritis. Arthritis Care Res (Hoboken). 2018;70(5):758-67.
39. Wongpakaran N, Wongpakaran T, Wedding D, Gwet KL. A comparison of Cohen's Kappa and Gwet's AC1 when calculating inter-rater reliability coefficients: a study conducted with personality disorder samples. BMC Med Res Methodol. 2013;13:61.