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Original article

Effect of mechanical stress on magnetic resonance imaging of the sacroiliac joints: assessment of military recruits by magnetic resonance imaging study

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Abstract

Objective. To assess the baseline condition of the SI joints (SIJs) in healthy individuals without symptoms of back pain and to study the effect of mechanical stress caused by intense physical training on MRI of the SIJs.

Methods. Twenty-two military recruits underwent an MRI of the SIJs before and after 6 weeks of intense standardized physical training. Bone marrow oedema and structural lesions were scored based on the Spondyloarthritis Research Consortium of Canada (SPARCC) method, by three trained readers blinded for time sequence and clinical findings. Additionally, fulfilment of the Assessment of SpondyloArthritis international Society (ASAS) definition of a positive MRI was evaluated.

Results. At baseline, 9/22 recruits (40.9%) already presented a SPARCC score $\geqslant 1$; this number increased to 11/22 (50.0%) at week 6 ($P = 0.625$). In these patients, the mean (SD) SPARCC score was 2.4 (0.4) at baseline, compared to 3.7 (1.3) at week 6. Overall, the mean (SD) change in SPARCC score over time in all 22 patients was 0.9 (0.6) ($P = 0.109$). A positive MRI according to the ASAS definition was present in 5/22 recruits (22.7%) at baseline, which increased to 8/22 (36.4%) at follow-up ($P = 0.375$). Structural lesions were present in 6/22 subjects (27.3%), both at baseline and after 6 weeks of training.

Conclusion. A substantial proportion of healthy active individuals without any symptoms of back pain displayed bone marrow oedema lesions on MRI at baseline. However, MRI lesions did not increase significantly after 6 weeks of intensive physical training. Our study underscores the necessity to interpret MRI findings of the SIJs in the appropriate clinical context, even in a young active population.

CLINICAL SCIENCE

Rheumatology key messages

- Healthy active individuals can also display bone marrow oedema of the sacroiliac joints on MRI.
- Mechanical stress does not seem to increase bone marrow oedema on MRI after several weeks of physical training.
- MRI should only be requested in the appropriate clinical context.

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Introduction

In the past decade, considerable efforts have been made to shorten the diagnostic delay in axial spondyloarthritis (axSpA), with MRI becoming the preferred method to detect sacroiliitis in an early disease stage [1–3]. While MRI is a sensitive method for detection of bone marrow oedema (BME) and structural lesions, there are only limited data regarding the specificity of MRI lesions in a non-SpA population. Nevertheless, some data have been published regarding mechanical low back pain patients [4, 5]. Physical activity might influence the interpretation of MRI lesions. Previously, McGonagle *et al.* [6] have hypothesized that mechanical stress plays an important role in the pathophysiology of SpA. In a proof of concept study in mice, the unloading of hind legs resulted in less entheseal inflammation compared with weight bearing [7]. In humans, Ward *et al.* [8] have shown that mechanical stress in the form of vibration, bending, twisting and stretching is detrimental regarding functionality and structural progression in AS. Similarly, AS patients exerting manual labour developed more syndesmophytes, compared with their non-manual labour counterparts [9]. In humans performing a variety of sport activities, the presence of BME on MRI has been described for several joints [10–17]. However, currently, information on the impact of mechanical stress on MRI findings of the SI joint (SIJ) is lacking. Therefore, we studied the effect of mechanical stress caused by intense physical training on the SIJs in healthy individuals.

Methods

This pilot study was a 6-week observational study in young military recruits, selected for initiation of basic military training after thorough physical and psychological examination. These subjects participated on a voluntary basis and provided informed consent. This study was authorized by the local ethics committee of the University Hospital of Ghent and the Jessa Hospital of Hasselt.

Subjects

Twenty-five recruits without history of back pain were randomly selected out of the pool of 341 recruits from the ‘Koninklijke School voor Onderofficieren Campus Saffraanberg’. The inclusion criteria for participation in the study consisted of inclusion before initiation of physical training, 18–45 years of age and completion of a 6-week standardized training schedule. The exclusion criteria were contraindication for MRI, pelvis or back injury in the past year prior to inclusion, scoliosis, prior exposure to anti-TNF therapy and prior diagnosis of a chronic inflammatory condition.

Physical activity

The training consisted of daily exercise including marching with backpacks, military tactical exercises, drills, running, shooting exercises and some theoretical classes. All recruits followed a daily training programme with identical equipment and were living in the same housing and environmental conditions. Therefore, the extrinsic contributing factors that could affect the incidence of BME or structural lesions of the SIJs were standardized.

Imaging

Prior to the initiation of training, an MRI of the SIJs (MRI-SIJ) was performed and repeated after completion of the 6-week training programme. Eventually, 22 recruits completed the training and had an MRI-SIJ at both time points. MRI-SIJ was performed employing identical technical properties as in daily clinical practice. MRI was obtained on a 1.5 T MRI unit (Avanto/Symphony, Siemens Medical, Erlangen, Germany). The SIJs were imaged in a body flexed array coil (Siemens Medical). The sequence protocol included the following: semicoronal (along long axis of the sacral bone) T1-weighted turbo spin echo (tse) [slice thickness (ST): 3 mm; repetition time/echo time (TR/TE): 679/20 ms]; semicoronal short tau inversion recovery (STIR) (ST: 3 mm; TR/TE/TI: 5030/70/150 ms); and axial STIR (ST: 5 mm; TR/TE/TI: 7540/70/150 ms).

Scoring method

The presence of lesions on MRI-SIJ was scored independently by three well-trained readers (Md.H., G.V. and T.R.), blinded for time sequence. Both T1 and STIR sequences were read simultaneously. The images were read in blinded pairs, including both time points. BME, sclerosis, erosions, fatty lesions and (partial) ankylosis, as defined by the Assessment of SpondyloArthritis international Society (ASAS) MRI working group, were scored [2]. Therefore, the reported lesions displayed characteristics of lesions seen in SpA patients. Based on the Spondyloarthritis Research Consortium of Canada (SPARCC) scoring system for inflammation in the SIJs, six slices were scored per patient, representing the cartilaginous part of the joint. Per slice, each SIJ was divided into four quadrants [18]. The first slice was selected based on the visibility of at least two quadrants per SIJ, with the remaining five slices subsequent to the first selected slice [4]. Per slice, each quadrant was scored for the presence of BME. Additionally, per slice each SIJ was scored for intensity and/or depth of the BME. Also, the fulfilment of the definition of a positive MRI as defined by ASAS was evaluated, which entails the presence of one BME lesion on two or more consecutive slices or more than one BME lesion on a single slice. The structural lesions were scored using the same method. Erosions were reported when present on two or more consecutive slices, increasing sensitivity. Furthermore, the presence of five or more fatty lesions and/or erosions, three or more erosions or three or more fatty lesions was evaluated, as these cut-off values have been shown to yield a specificity of $>95\%$ for SpA [5]. The total number of lesions was recorded as the highest number of lesions scored by at least two readers. For example, if reader 1 scored six BME lesions, while reader 2 scored eight and reader 3 scored five lesions, the highest number of lesions scored by at least two readers is six BME lesions. The fulfilment of the ASAS definition and of different cut-off values regarding structural lesions was estimated by consensus of two out of three readers.

Statistical analys

SPSS Statistics v. 4 (IBM Corp., Armonk, NY, USA) was used to perform the statistical analysis. Alpha was set at

0.05. The non-parametric Wilcoxon matched-pairs signed-rank test was used to evaluate the evolution of both BME and structural lesions over time. The fulfilment of the ASAS criteria of a positive MRI at different time points was analysed using the paired McNemar test.

Results

Recruits and MRI lesions

Nineteen out of the 22 asymptomatic recruits were male, with mean age of 25 (0.8) years. At baseline, 9/22 recruits (40.9%) presented with a SPARCC score of ⩾ 1, which increased to 11/22 (50%) at week 6 ($P = 0.625$); three recruits developed new BME over time, whereas in one recruit the BME lesions disappeared. In patients displaying BME, the mean SPARCC score was 2.4 (0.4) at baseline, compared with 3.7 (1.3) at week 6. Percentiles (p0, p25, p75, p100) of SPARCC score were 1, 1, 3, 5 and 1, 1, 4, 16 at baseline and week 6, respectively. Overall, the mean change in SPARCC score over time in all 22 patients was 0.9 (0.6) ($P = 0.109$). BME lesions with fulfilment of the ASAS definition of a positive MRI were present in 5/22 recruits (22.7%) at baseline, increasing to 8/22 (36.4%) after 6 weeks of physical activity ($P = 0.375$): four recruits were positive at both time points, four initially MRI negative recruits became MRI positive and one recruit became MRI negative.

At baseline, structural lesions were present in 6/22 subjects (27.3%) with one, three and three subjects presenting with a score of ⩾ 1 for sclerosis, fatty lesions and erosions, respectively. This number did not increase after 6 weeks of mechanical stress (Table 1). The evolution over time of a BME lesion on MRI-SIJ in a 31-year-old recruit is visualized in Fig. 1.

None of the subjects displayed (partial) ankylosis. The descriptive statistics regarding the structural lesion distribution are visualized in Table 2.

When applying the cut-off values for structural lesions with specificity of > 95% in SpA defined by de Hooge *et al.*, only one subject had five or more fatty lesions and/or erosions at baseline and after 6 weeks of mechanical stress. None of the recruits had three or more erosions at any time point, whereas 4.5% (1/22) displayed three or more fatty lesions at baseline. After 6 weeks of training, one additional recruit displayed three or more fatty lesions. Both BME and structural lesions were present in 3/22 (13.6%) at baseline. After 6 weeks of physical training, 4/22 (18.2%) displayed both BME and structural lesions (not significant).

Agreement

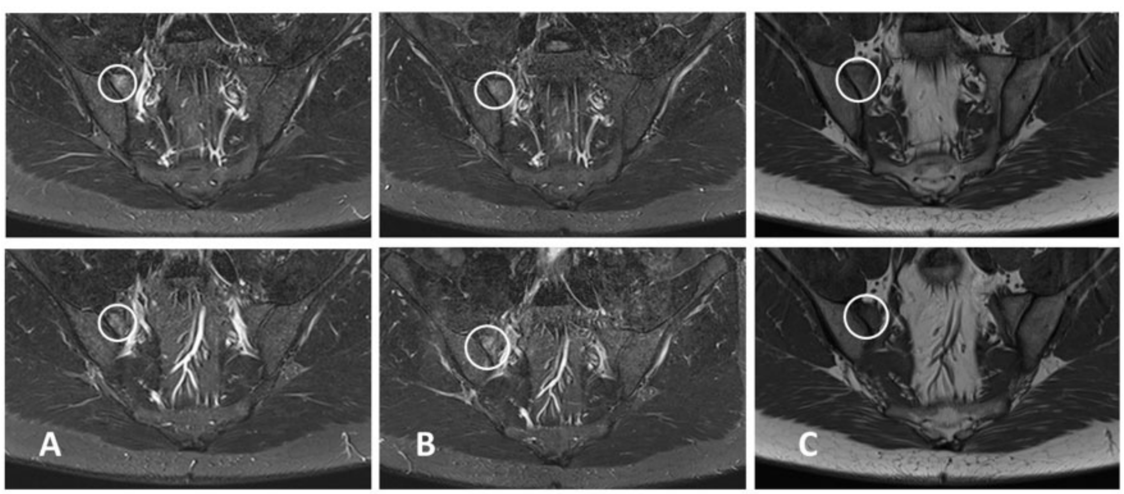
The agreement of MRI scoring was substantial with an intraclass correlation coefficient of 0.75 for BME lesions. Kappa agreement for the ASAS definition was good (0.65). Regarding the structural lesions, kappa agreement for

Table 1 MRI-SIJ lesions in military recruits before and after training

MRI lesions	Baseline $n = 22$	Week 6 $n = 22$
BME lesions	9 (40.9)	11 (50.0)
Structural lesions	6 (27.3)	6 (27.3)
Sclerosis	1 (4.5)	1 (4.5)
Erosions	3 (13.6)	3 (13.6)
Fatty lesions	3 (13.6)	3 (13.6)
(Partial) ankylosis	0	0

All values given as *n* (%).

Fig. 1 MRI-SIJ in a military recruit before and after training



(**A**) Baseline MRI-SIJ in a 31-year old male military recruit. (**B**) BME of the right SI joint after 6 weeks of training, present on 2 consecutive slides. (**C**) T1 sequences of the SI joints after 6 weeks of training.

TABLE 2 Descriptive statistics of MRI-SIJ lesions in young military recruits

MRI lesions	Baseline	Week 6
Inflammatory lesions	$n = 9$	$n = 11$
Mean (S.D.)	2.4 (0.4)	3.7 (1.3)
Median (p0, p25, p75, p100)	3.0 (1.0, 1.0, 3.0, 5.0)	3.0 (1.0, 1.0, 4.0, 16.0)
Sclerosis	$n = 1$	$n = 1$
Mean (S.D.)	NA[a]	NA[a]
Median (p0, p25, p75, p100)	NA[a]	NA[a]
Erosions	$n = 3$	$n = 3$
Mean (S.D.)	1.0 (0.0)	1.0 (0.0)
Median (p0, p25, p75, p100)	1.0 (1.0, 1.0, 1.0, 1.0)	1.0 (1.0, 1.0, 1.0, 1.0)
Fatty lesions	$n = 3$	$n = 3$
Mean (S.D.)	7.3 (5.8)	9.3 (6.4)
Median (p0, p25, p75, p100)	2.0 (1.0, 1.0, 2.0, 19.0)	4.0 (2.0, 2.0, 4.0, 22.0)

[a]Only one patient displayed sclerosis at baseline and week 6. No percentiles could be computed. p0, p25, p75, p100: percentiles.

erosions and fatty lesions was good (0.64) and fair (0.54), respectively. The assessment of kappa agreement for sclerosis and (partial) ankylosis was not possible as only one subject displayed sclerosis and none of the subjects displayed ankylosis.

Discussion

To our knowledge, this is the first study to evaluate the effect of mechanical stress on MRI-SIJ. Overall, there was a high prevalence of MRI lesions in healthy active individuals without any symptoms of back pain, both at baseline and after 6 weeks of follow-up. However, MRI lesions do not seem to increase significantly after 6 weeks of intensive physical training.

In this study BME lesions on MRI were commonly reported. Notwithstanding the definition of a positive MRI-SIJ according to the ASAS criteria should only be used in patients with SpA, real-life experience indicates that rheumatologists might use the definition as a benchmark in their diagnostic process of patients with aspecific back pain. Therefore, we challenged whether this definition would lead to false-positive results in a cohort of young, healthy soldiers. In concordance with our results in healthy recruits, Arnbak *et al.* [19] have shown that if only MRI positivity by ASAS is taken into account in the evaluation of chronic low back pain in young individuals, up to 20% would meet this criterion, whereas only 5% of patients with chronic low back pain are expected to have axSpA [20]. A similar prevalence to our results of ASAS positive MRIs was reported by Weber *et al.* [4] in a non-specific back pain (NSBP) cohort, while only 7% of healthy controls displayed a ‘positive MRI’. Taking this into account, the imprudent interpretation of MRI-SIJ, combined with the high diagnostic value attributed to a positive MRI, may lead to NSBP patients being wrongly diagnosed as SpA [21]. These findings emphasize the importance of the recently published cautionary guidelines for the application of the ASAS definition of a positive MRI [22]. Nevertheless, the median SPARCC score of 3 in these asymptomatic recruits displaying BME is low compared with the SPARCC scores of $\geqslant 5$ in AxSpA cohorts and randomized clinical trials [23–27].

Of the structural lesions, erosions and fatty lesions were the most prevalent. Most studies evaluating MRI lesions in non-SpA subjects, have focused on the NSBP population, which is the clinical context wherein MRI-SIJ requests are most frequent. Similar to our findings in healthy recruits, erosions were frequently seen in NSBP patients [4, 5, 19]. Notably, in our study population, erosions were present in ~14%, which may be in line with the suggestion that in young athletes ~18% display erosions of the SIJ related to symphysis pubis stress injury [28]. Therefore, active individuals may display more structural lesions than non-active individuals. Moreover, erosions of the SIJ were significantly more prevalent in younger age groups [19]. Anyhow, the evaluation of structural lesions on MRI remains challenging, with lower agreement scores regarding erosions compared with the interpretation of BME lesions [4, 5].

In the present study we could not demonstrate a significant effect of mechanical stress on MRI-SIJ over time. Although there were two additional recruits with BME after 6 weeks of physical activity, this was not statistically significant. These findings are consistent with literature, showing that in 16 asymptomatic professional runners and 26 asymptomatic professional basketball players, no difference was seen in the presence of BME lesions before and after the training season [14]. In accordance with our results, 14/16 (88%) runners already presented BME of the pubic bones, hips, knees and/or ankles at the start of the season, with more than half of BME lesions fluctuating over time [10]. In recreational runners before and after a marathon and in contact sports after a 2-h training session, similar findings were reported at the level of the knees and symphysis, respectively [11–13]. Nevertheless, other authors did find a modest significant increase of BME in young asymptomatic male soccer players, in addition to already exhibiting BME in 11/18

(61%) at baseline. Moreover, the severity of this BME was mildly positively correlated with the training history, with less prior training resulting in more development of BME [15]. Interestingly, in 12 healthy controls, alteration of weight bearing by overpronation of the foot resulted in appearance of BME in hips, knees, ankles or feet of 11/12 (91.7%) after 2 weeks [29].

Subjects aspiring to join the army might be more likely to practice sports and train for the selection procedure. Moreover, athletes have been shown to exhibit more BME of the joints compared with healthy controls [16, 17]. Therefore, the additional 6-week physical training might not hold up to the overall mechanical stress the body had already endured by previous training. This might not only explain the overall lack of (additional) effect of the mechanical stress after 6 weeks, but also the high number of MRI lesions at baseline in these trained individuals. Thus, evaluating mechanical stress in an untrained population may lead to different conclusions.

The main limitation of our study is the small study population. Since this is the first study looking at mechanical stress on the axial skeleton and the presence of MRI-SIJ lesions, it is unknown whether a statistically significant difference in the presence of MRI lesions after mechanical stress would have been found in a larger study population. Moreover, as these were healthy controls, some clinical aspects, such as HLA-B27 status and CRP values, were not available. Nevertheless, the strength of our study comprises the inclusion of a well-defined and—most importantly—homogeneously trained study population, permitting us to investigate the impact of mechanical stress, shielded from various confounders, such as living and sleeping conditions, hobbies, heterogeneity in mechanical stress and daily routine among others, during the observation time. Moreover, MRI images were standardized and scored independently by three trained readers according to definitions provided by ASAS. Additionally, the inclusion of erosions only when seen on two consecutive slices increased the sensitivity.

Future research may focus on confirming these results in a larger sample size and in a broader and general population, in whom the effect of mechanical stress might be more pronounced. Also, the mapping of weight bearing of the sacroiliac joint across different sport activities should be considered. Several features of mechanical stress could influence the outcome of such a study. Critical intensity, frequency and/or duration of the physical activity—or combinations thereof—could be explored in order to determine its possible effect on the presence of MRI lesions in the SIJ.

In conclusion, MRI lesions did not significantly increase upon mechanical stress. However, there was a high prevalence of BME lesions in healthy active individuals without symptoms of back pain. Strikingly, half of the patients displaying BME could even be categorized as having a positive MRI as defined by ASAS. Our data highlight the importance of interpreting imaging in the appropriate clinical context.

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