

# Changes in ultrasound imaging of joints, entheses, bursae and tendons 24 and 48 h after adjusted weight training

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*Ther Adv Musculoskelet Dis*

2022, Vol. 14: 1–13

DOI: 10.1177/  
1759720X221111610

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## Abstract

**Background:** Joint effusion and enthesitis are common ultrasound findings in rheumatic diseases such as rheumatoid arthritis or spondyloarthritis. However, changes of joints and entheses were not only observed in patients but also in physically active individuals and athletes.

**Objectives:** The purpose of this study was to evaluate joint, enthesal, bursal and tendon musculoskeletal ultrasound (MSUS) findings in large and medium joints of young healthy individuals after completing a standardised weight training.

**Design:** This is a prospective cohort study.

**Methods:** MSUS examinations of large- and medium-sized joints, and related enthesal sites, bursae and tendons were performed on young healthy individuals (ages 18–30 years). Before, 24 and 48 h after completing 1 h of standardised weight exercise, the subjects were evaluated by MSUS. The development of the MSUS findings and associated effects were examined using generalised linear mixed effects models.

**Results:** In total, 51 healthy individuals (52.9% female) with a mean age of 23.7 ( $\pm 2.5$ ) years were enrolled. The results showed an increase in the number of individuals with at least one joint effusion from 37 (72.5%) before the weight training to 48 (94.1%) after 48 h. Enteses with pathologies were observed in 14 participants (27.5%) at baseline, increasing to 29 participants (56.9%) 48 h after the weight training. Biceps tendon sheath effusion was detected in 9 individuals (17.6%) prior to training, rising to 22 individuals (43.1%) after 48 h. A significant increase in the number of joints with effusion and abnormal entheses within 48 h after the weight training was indicated by the generalised linear mixed effects models.

**Conclusion:** Within 48 h after the weight training session, a significant increase in the prevalence of joint effusion in large and medium joints and the prevalence of abnormal entheses was observed. As a result, when performing and interpreting an MSUS examination, the patient's physical activities should be taken into account.

**Keywords:** enthesal hyperperfusion, enthesal pathology, joint effusion, joint hyperperfusion, musculoskeletal ultrasound, physical activity, tendinitis

Received: 5 March 2022; revised manuscript accepted: 18 June 2022.

## Introduction

Physical activity and its effects on joints and entheses have become one of the topics of increasing interest among athletes and sports medicine specialists, and within the area of rheumatology. Rheumatic diseases are known to cause inflammation, damage and abnormalities in musculoskeletal

ultrasound (MSUS) of joints, tendons and entheses, but numerous studies show that sports exercise can cause similar changes. Some MSUS imaging studies observed joint abnormalities in athletes and physically active individuals. One ultrasound study reported an increased intra-tendinous flow in the dominant patellar tendon in elite badminton

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players after repeated matches.<sup>1</sup> Synovitis was identified in asymptomatic professional soccer players by a magnetic resonance imaging (MRI) study in at least one joint in 67.6% of the examined feet.<sup>2</sup> Another study including professional soccer players observed one or more knee joint lesions, such as synovitis, cartilage and meniscal lesions in all examined joints.<sup>3</sup> Polat *et al.*<sup>4</sup> reported a significantly higher prevalence of tendinopathy, meniscal injury and cartilage damage in the knees of kangaroo jumpers compared with the control group by MRI imaging.

Regarding different imaging approaches of the musculoskeletal system, the ultrasound examination has earned substantial popularity due to the flexible handling and low costs of the procedure. In the evaluation of vascular and soft-tissue changes, and structural abnormalities of musculoskeletal conditions, grey-scale (GS) and power Doppler (PD) ultrasound is widely applied in rheumatological practice. To ensure comparable results, the European League Against Rheumatism (EULAR) working group for MSUS published standardised scanning planes for the upper and lower extremity joints.<sup>5</sup> In addition, definitions for elementary lesions, such as synovitis and enthesitis, and their scoring were published by the working group.<sup>6</sup> Reliability was demonstrated for ultrasound examinations carried out by experienced sonographers.<sup>7</sup> Using ultrasound on a regular basis, the conflicting observations of the impact of physical activity on MSUS results may leave the rheumatologist unsure regarding their evaluation. In patients with or without the diagnosis of a rheumatic disease, physical activity may alter the presentation of ultrasound results. Therefore, the purpose of this study was to assess the development of joint, enthesal, bursal and tendon ultrasound findings in large and medium joints of young healthy individuals after 1 h of standardised weight training.

## Methods

This prospective cohort study was approved by the local medical ethics committee of the University Hospital Bonn (Lfd. Nr. 149/19; date: 05/07/19), and written informed consent was obtained from every participant prior to inclusion. The Department of Rheumatology and Clinical Immunology at the University Hospital Bonn, Germany and the University Sports Division of the University of Bonn, Germany recruited 51 healthy individuals [27 female (52.9%) and 24 male (47.1%) individuals] to

participate in the study. Inclusion criteria were age between 18 and 30 years and free consensus to participate. Exclusion criteria included chronic diseases affecting the musculoskeletal system, electronic implants, cardiac arrhythmia and current pregnancy. Individuals were selected randomly for participation. Within 48 h in advance of the study, participants were requested to waive physical exercise and consumption of alcohol. After signing an informed consent form, the individuals answered a questionnaire concerning demographic data (sex, age, ethnicity, handedness, height and weight), medical history including sport injuries, and duration and nature of physical activity per week. The Short-Form International Physical Activity Questionnaire (SF-IPAQ) was used to evaluate the individual participants' fitness level.<sup>8</sup>

MSUS examination was performed before (T<sub>0</sub>), 24 h (T<sub>1</sub>) and 48 h (T<sub>2</sub>) after individuals conducted a supervised weight training. Before starting the weight training, a bioelectrical impedance analysis (BIA) was applied to assess the participant's body composition.

The reporting of this study conforms to the 'EULAR recommendations for the reporting of ultrasound studies in rheumatic and musculoskeletal diseases (RMDs).'<sup>9</sup>

## BIA

BIA was performed using the SECA medical Body Composition Analyzer 515 (SECA GmbH & Co. KG, Hamburg, Germany). Tetrapolar, single-frequency (5 kHz) impedance measurements were taken to acquire fat mass (FM), fat-free mass (FFM) and skeletal muscle mass (SMM). Values were divided by height squared creating the fat mass index (FMI), fat-free mass index (FFMI) and skeletal muscle mass/height<sup>2</sup> (SMM/height<sup>2</sup>) for height adjustment.<sup>10,11</sup>

## Standardised weight training

After the first MSUS examination, the individuals conducted a standardised whole-body weight training under the guidance of board-certified fitness trainers.

The standardised weight training consisted of eight exercises (five upper body and three lower body exercises), three sets per exercise, and a total of 24 sets. Before the workout session, a

3-min whole-body warm-up using a rowing ergometer was mandatory and a specific warm-up set for each exercise with 50% of predetermined training load. Training load for each exercise was determined in a habituation training session, using the OMNI resistance exercise scale (OMNI-RES) to target a scale value of 8 for the first set.<sup>12</sup> Exercises in the workout session were grouped into supersets for a time-efficient training regime (Supplementary Figure 1).<sup>13</sup>

Based on performed repetitions and used weight, two fitness indices were calculated. One representing upper body strength based on the training volume (repetitions  $\times$  weight) of the seated row machine and one representing lower body strength based on the training volume of the leg press. The training volume of the first of three training sets of both exercises was divided by the individuals' BMI to calculate the indices.<sup>14-16</sup> Representing the individual strength, the indices allowed for a precise comparison between the participants. For example, participants lifting heavier weight and thus have a higher training volume reach a higher index than participants with a lower training volume and the same BMI.

#### *Ultrasound examination*

Three high-end ultrasound machines (two GE Logiq S8 machines, manufactured 2018; one Alpinion E-CUBE 8 machine, manufactured 2019) with multifrequency linear probes (8–15 or 6–15 MHz) operating at a frequency of 8–15 MHz (depending on the joint) were used for every MSUS examination. The settings for PD ultrasound were Doppler frequency of 7.7 MHz and pulse repetition frequency of 800 Hz for the GE Logiq S8 machines and Doppler frequency of 6.0 MHz and pulse repetition frequency of 600 Hz for the Alpinion E-CUBE 8 machine. An average GS ultrasound gain of 50% was set. Ultrasound was performed by three board-certified rheumatologists with 13 (P.K.), 14 (V.S.S.) and 16 (D.S.) years of ultrasound experience [German Society for Ultrasound in Medicine (DEGUM)/European Federation of Societies for Ultrasound in Medicine and Biology (EFSUMB) level II and III]. Sonographers used ultrasound presets for each joint, which were set similarly for each device. Ultrasound presets were tested on 10 individuals prior to the begin of the study to standardise image quality. Sonographers were allowed to change image depth and focus point position, if necessary.<sup>8</sup>

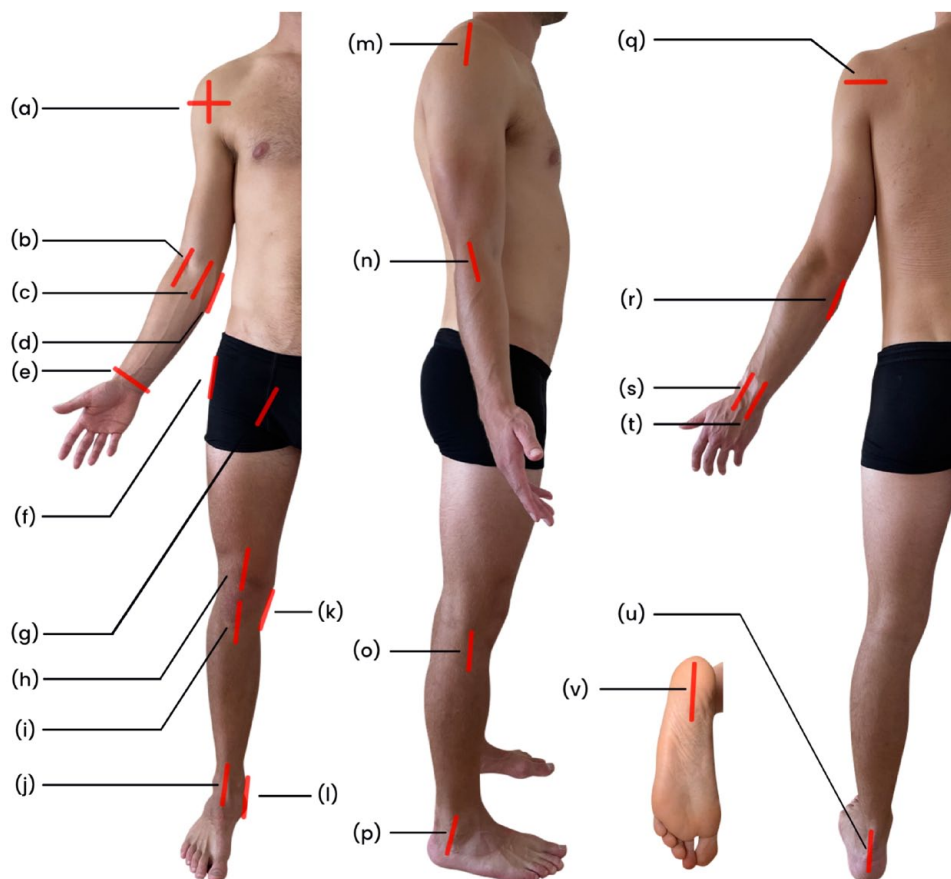
The bilateral and dynamic ultrasound examination included large and medium joints and assessment of specific enthesal sites (Figure 1). The large and medium joints and respective entheses were chosen for examination as they are commonly affected by rheumatological diseases such as rheumatoid arthritis or psoriatic arthritis. In addition, these regions particularly endure mechanical stress due to physical activity.

Applied scanning planes for joint, enthesis, tendon and bursa lesions were selected based on the Sonography of Large Joints in Rheumatology (SOLAR) score and predefined scanning planes for the assessment of wrist and tibiotalar joints, entheses, bursae and tendons as described before.<sup>5,8,17</sup> The individuals were examined in a sitting position when the upper extremities were assessed. Ultrasound examination of the lower extremities was carried out with the participants lying on the examination table. The shoulder was assessed with the elbow 90° flexed and the hand resting on the participant's thigh in supination. For dorsal assessment, an external rotation of the humerus was performed with the elbow 90° flexed. The elbow was assessed in neutral position and in 90° flexion for dorsal scans. The examination of wrist, hip and knee joints was performed with the joints resting in neutral position.<sup>5</sup> Ankle joint assessment was carried out with the knee joint 90° flexed and the foot positioned upright on the examination table in 20° plantar flexion. The proximal plantar fascia entheses and distal Achilles' tendon entheses were assessed with the participant lying prone and the feet hanging over the end of the examination table in active dorsiflexion.<sup>8</sup> The duration of the ultrasound examinations ranged between 30 and 60 min.

Participants were assigned randomly to the sonographers at every visit. The ultrasound images were blinded with regard to patient data and stored for future rating. Image acquisition and rating were performed by different persons. The rating was carried out by one of the authors (J.K.S.) together with each of the experienced sonographers (V.S.S., P.K. and D.S.).

#### *Ultrasound scoring of enthesal sites*

The evaluation of enthesal sites was carried out according to the enthesitis criteria defined by the Outcome Measures in Rheumatology (OMERACT) ultrasound task force for enthesitis.



**Figure 1.** Applied bilateral ultrasound planes of large and medium joints.

The bilateral examination comprised shoulder (q), elbow (b and c), wrist (e, s and t), hip (g), knee (k and o) and ankle (j) joints and deltoid muscle entheses (m), common flexor and extensor tendon entheses (d and n), distal triceps tendon entheses (r), distal quadriceps tendon entheses (h), proximal and distal patellar tendon entheses (i), distal Achilles' tendon entheses (u) and proximal plantar fascia entheses (v). The biceps tendon (a) and the extensor hallucis longus tendon (j), tibialis posterior tendon (l), flexor digitorum longus tendon (l), flexor hallucis longus tendon (l) and peroneus longus and brevis tendon (p) were examined for tenosynovitis assessment. In addition, bursitis evaluation of the trochanteric bursa (f), supra- and infrapatellar bursa (h and i) and retrocalcaneal bursa (u) was conducted.

The presence of enthesiophytes (step-up of the bone outline), calcification (hyperechoic foci), erosion (step-down outline defect), thickened entheses (increased thickness of the insertion) and hypoechogenicity (absence of the homogeneous fibrillar impression) was evaluated binarily (y/n), whereas semiquantitative scoring for Doppler signal at the entheses (< 2 mm from cortical bone) was applied (grades 0–3).<sup>18</sup>

#### *Ultrasound scoring of joints, tendons and bursae*

Joint effusion and synovial hyperperfusion of the joints were evaluated by GS and PD mode using a semiquantitative score (grades 0–3).<sup>19,20</sup> Binary (y/n) evaluation of the presence of bursal or tendon sheath effusion and hyperperfusion was

carried out. Effusion was defined as hypo- to anechoic area within the joint capsule, bursa or tendon sheath. Doppler signals were evaluated for the assessment of hyperperfusion.

#### *Statistical analysis*

For statistical analysis, SPSS statistical software, version 27.00 (IBM, Armonk, NY, USA) and R statistical software (Version 4.0.3; R Foundation for Statistical Computation, Vienna, Austria) were used. Absolute and relative frequencies are presented for describing categorical variables. Mean standard deviation and ranges were calculated for continuous data. The development of ultrasound findings from baseline to follow-up at 24 and 48 h after the weight training and effects on the



development were analysed using generalised linear mixed effects models. As the number of joints with effusion and entheses with pathologies are count measurements, a Poisson distribution with a logarithmic link function was used. To account for repeated measurements within an individual, these were included in the model as a random effect. The time in days was included as a fixed effect. Further independent variables, such as age, sex, hours of physical activity per week, BMI, FMI, FFMI, SMM/height<sup>2</sup>, upper and lower body fitness indices were evaluated in separate models. As it was assumed that the influence of these variables might be time-dependent, a fixed term and a slope term (interaction with time) were included in the model. The analyses were carried out on a patient level and thus findings in all joints were summed. Missing values in the outcome were imputed by last value carried forward. Missing values in risk factors and covariates were not imputed. Significance level of all exploratory analyses was 0.05. Also, *p*-values were not adjusted for multiple testing.

#### *Inter- and intrareader reliability*

For reliability analysis, the three sonographers (P.K., D.S. and V.S.S.) involved in the study rated 100 stored ultrasound images of two participants. The scoring was repeated after 24 h to assess the intrareader reliability. Joint effusion, hyperperfusion and enthesal pathology were evaluated binarily (y/n) in GS and PD images.<sup>8</sup> Inter-reader agreement was determined by calculating Cohen's kappa for each pair, based on their first image evaluation. Kappa values of less than 0.0 were considered poor, 0–0.20 slight, 0.21–0.40 fair, 0.41–0.60 moderate, 0.61–0.80 substantial and 0.81–1.0 almost perfect agreement.<sup>21</sup>

## Results

#### *Population characteristics*

This study comprised the examination of 51 healthy individuals with a mean age of  $23.65 \pm 2.46$  (range: 19–30) years. Most of the participants were Caucasian (94.1%), two individuals were African (3.9%) and one South American (2.0%). The participants had a mean BMI of  $22.54 \pm 3.07$  (range: 18.61–36.55) kg/m<sup>2</sup>. The BIA revealed a mean FMI, mean FFMI and SMM/height<sup>2</sup> of  $4.38 \pm 1.77$ ,  $18.16 \pm 2.51$  and  $8.59 \pm 1.55$  kg/m<sup>2</sup>, respectively. The mean hours of physical activity per week were  $4.78 \pm 3.02$  (range: 1.00–15.00) h. Although the participants were asked not to

perform any physical activity 48 h prior the study, two individuals reported medium level of physical activity. According to the results of the SF-IPAQ, 56.9% of the individuals (*n* = 29) performed high-level, 31.4% (*n* = 16) moderate-level and 11.8% (*n* = 6) low-level physical activity. Visiting a fitness centre on a regular basis was stated by 33 participants (64.7%). The fitness indices of the upper and lower body were calculated with a mean of  $0.88 \pm 0.62$  and  $3.90 \pm 1.12$ , respectively.<sup>8</sup>

Two individuals did not complete the last follow-up examination due to a common cold. Seven values of both fitness indices and one value of physical activity per week were missing.

#### *Development of joint effusion*

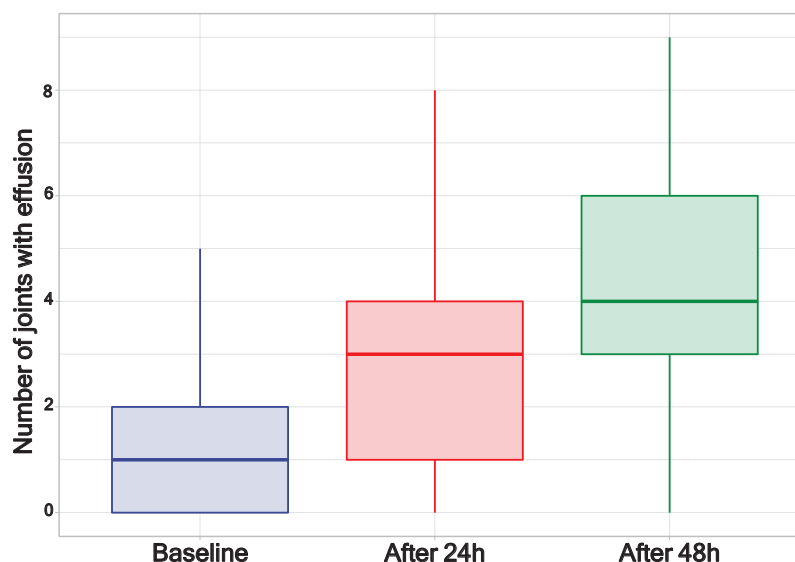
The number of individuals with joint effusion in at least one joint increased from 37 individuals (72.5%) at T0 to 45 individuals (88.2%) at T1 and to 48 individuals (94.1%) at T2 after the weight training. The mean number of joints affected by effusion was 1.49 at T0, 2.82 at T1 and 4.16 at T2.

Predominantly, joint effusion was evaluated grade I. At T1, 12 joints (8.3%) and at T2, 19 joints (8.8%) exhibited grade II effusion. Grade III effusion was detected in only one joint at T2 (0.5%).

At T1, 10 individuals (19.6%) presented with effusion in one joint, whereas in 8 individuals (15.7%), two joints with effusion were observed. In 10 individuals (19.6%), effusion in three joints was detected. The maximum number of joints with effusion was eight and was observed in one case (2.0%). At T2, joint effusion in one and two joints was observed in two (3.9%) and five cases (9.8%), respectively. Overall, 14 individuals (27.5%) presented with effusion in three joints. The highest number of affected joints was nine and was detected in one case (Figure 2).

Synovial hyperperfusion was not detected at T0.<sup>8</sup> At T1, hyperperfusion was observed in four joints with effusion (2.8%) and two joints without effusion (0.4%). Then, 48 h after the weight training, hyperperfusion was detected in a total of two joints, one with simultaneous joint effusion (0.5%) and one without (0.3%). An erosion was observed in the knee of one individual (2.0%) at T0.

The elbow joint showed the highest number of effusions at T1, with a total of 40 joints in 28



**Figure 2.** Number of joints with effusion per individual at baseline, after 24 and 48 h. Development of joint effusion from baseline (T0)<sup>8</sup> to 24 h (T1) and 48 h (T2) following weight training.

individuals (54.9%), which was followed by the wrist joint with 48 joints in 32 individuals (62.7%) at T2. The wrist was also the joint with the highest number of individuals showing bilateral joint effusion (Figures 3 and 4).

The wrist joint showed the greatest increase in the number of affected joints at T2, ranging from 18 joints at T0 to 48 joints at T2. The hip had the lowest number of effusion joints at all time periods (Table 1).

#### *Development of enthesal pathology*

Overall, 14 individuals (27.5%) presented with enthesal pathology in at least one enthesis at T0, 24 individuals (47.1%) at T1 and 29 individuals (56.9%) at T2. The mean number of entheses with abnormal findings per individual increased from 0.37 at T0 to 1.02 at T1 and 1.12 at T2.<sup>8</sup> The only enthesal pathology observed at T1 and T2 was hyperperfusion.

At T1, 10 individuals (19.6%) showed hyperperfusion in one enthesal site. Seven (13.7%) and three cases (5.9%) presented with hyperperfusion in two and three entheses, respectively. In one case (2.0%), the maximum number of enthesal sites with hyperperfusion identified was six.

Hyperperfusion was observed in one and two enthesal sites in 11 individuals (21.6%) and in

three enthesal sites in 6 individuals (11.8%) at T2. There was no hyperperfusion in four or five entheses, although one individual (2.0%) had six enthesal locations with hyperperfusion. Predominantly, grade I hyperperfusion was observed. Grade II hyperperfusion was observed in one enthesal site at T1 (1.9% of enthesal sites with pathologies), whereas four enthesal sites showed grade II hyperperfusion at T2 (7.0% of enthesal sites with pathologies). A grade III hyperperfusion could not be detected at any time point during the study.

The enthesal site most affected by pathologies at T1 was the common flexor tendon enthesis of the forearm regarding 12 enthesal sites in 11 individuals (21.6%). The deltoid muscle insertion showed the highest number of entheses with hyperperfusion overall, with a total number of 13 entheses in 12 individuals (23.5%) at T2 (Figure 5). It was detected on the left side in two cases (3.9%) on the right side in nine cases (17.6%) and on both sides in one case (2.0%). The highest increase in affected entheses was also seen in the deltoid muscle enthesis from three entheses at baseline to six entheses at T1 to 13 entheses at T2.

#### *Factors associated with the number of joints with effusion and entheses with pathologies*

The generalised linear mixed effects models showed a significant increase in the number of



**Figure 3.** Ultrasound images of common joint and tendon effusions.

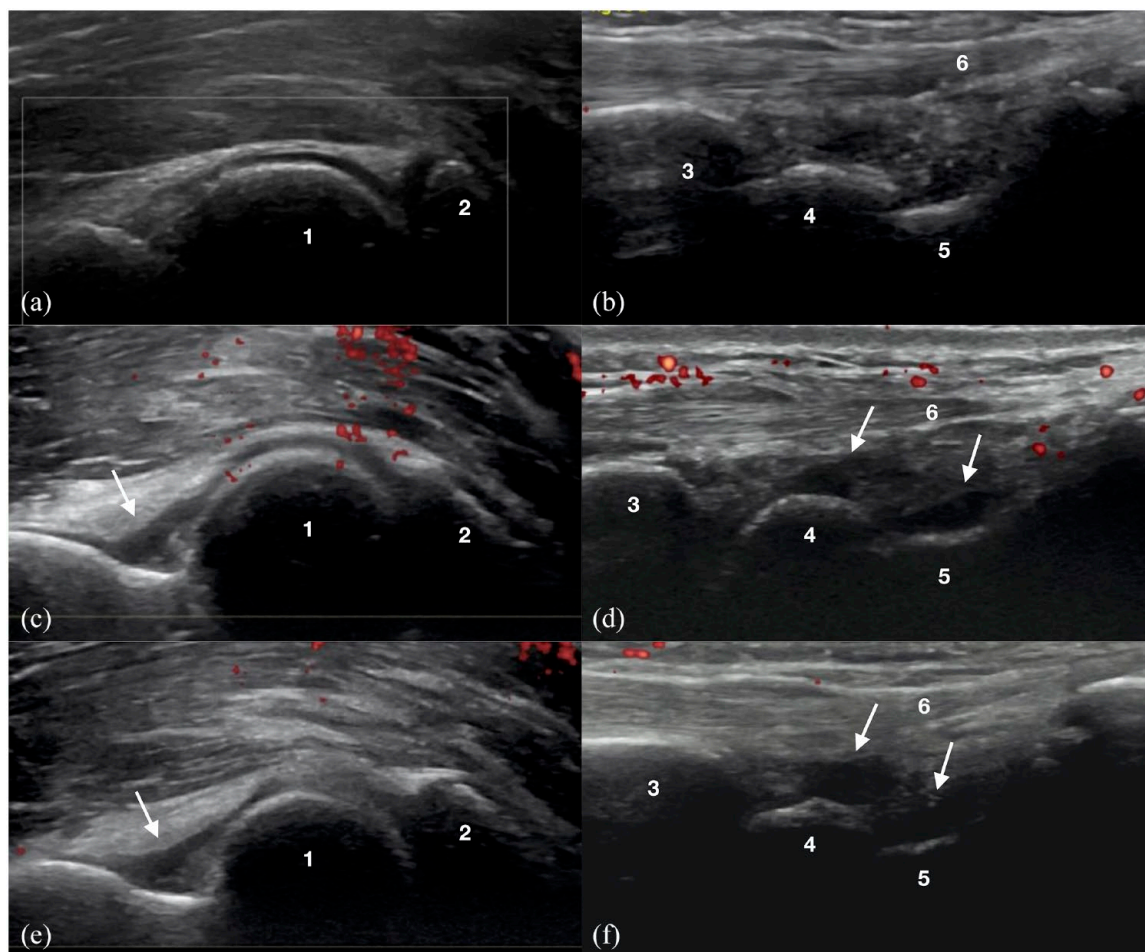
Ultrasound images of the wrist and elbow joint, and the biceps tendon, which were the most commonly affected structures. (a) Longitudinal section of the wrist joint (radio-carpal) displaying grade II effusion – 1: distal radius, 2: lunate bone, 3: capitate bone, 4: fourth extensor compartment; (b) anterior longitudinal humeroulnar scan of the elbow joint with grade I effusion – 5: humerus, 6: coronoid process of the ulna; (c) anterior longitudinal scan of the biceps tendon displaying tendon sheath effusion – 7: humerus, 8: biceps tendon.

joints with effusion and entheses with pathologies per individual with time after the weight training,  $p < 0.001$ ,  $\text{Exp}(b) = 1.63$ , 95% CI [1.45, 1.84] and  $p < 0.001$ ,  $\text{Exp}(b) = 1.58$ , 95% CI [1.27, 1.97].

A significant association between the FMI and the overall number of joints with effusion was detected when including all individuals,  $p = 0.049$ ,  $\text{Exp}(b) = 0.87$ , 95% CI [0.76, 1.00]. In a sensitivity analysis, one outlier with a considerable higher FMI (11.71 kg/m<sup>2</sup>) compared with the mean (4.38 kg/m<sup>2</sup>) was excluded. After exclusion, no significant effect of the FMI was observed

anymore,  $p = 0.211$ ,  $\text{Exp}(b) = 0.91$ , 95% CI [0.79, 1.05]. No significant association between age, sex, hours of physical activity per week, BMI, FFMI, SMM/height<sup>2</sup>, upper or lower body fitness indices and the overall number of joints with effusion was spotted.

Hours of physical activity per week had a significant association with the overall number of entheses with pathologies,  $p = 0.031$ ,  $\text{Exp}(b) = 0.84$ , 95% CI [0.73, 0.98], but when adjusting for this variable, no effect of the time on the number of entheses with pathologies was observed anymore.



**Figure 4.** Development of elbow and wrist joint effusion within 48 h after the weight training. Ultrasound images of the elbow [a, c, e] and wrist joint [b, d, f] before as well as 24 and 48 h after the weight training are displayed. (a) Anterior longitudinal humeroulnar scan of the elbow joint without joint effusion examined before the weight training; (b) longitudinal section of the wrist joint (radio-carpal) without joint effusion before the weight training; (c) anterior longitudinal humeroulnar scan of the elbow joint of the same participant as in A, displaying grade I joint effusion after 24 h; (d) longitudinal section of the wrist joint (radio-carpal) of the same participant as in (b), presenting with grade I joint effusion after 24 h; (e) the same participant as in (a) and (c) examined 48 h after the weight training displaying grade I joint effusion; (f) the same participant as in (b) and (d) examined after 48 h presenting with grade II joint effusion; 1: humerus, 2: coronoid process of the ulna, 3: distal radius, 4: lunate bone, 5: capitate bone, 6: fourth extensor compartment.

No significant association between age, sex, BMI, FMI, FFMI, SMM/height<sup>2</sup>, upper, or lower body fitness indices and the overall number of entheses with pathologies was noticed. None of the interaction terms between time and other independent variables showed a significant association with the number of entheses with pathologies or number of joints with effusion.

No significant association between the development of the numbers of joints with effusion or entheses with pathologies and age, sex, hours of physical activity per week, BMI, FMI, FFMI, SMM/height<sup>2</sup>, upper or lower body fitness indices was noted (Supplementary Table 1).

#### *Development of tendon and bursal ultrasound findings*

The highest number of tendon abnormalities was observed in the biceps tendon. Overall, 9 cases (17.6%) showed tendon sheath effusion at baseline, which increased to 16 cases (31.4%) at T1 and 22 cases (43.1%) at T2. Hyperperfusion of the biceps tendon was noted in one case at T1 (2.0%) without tendon sheath effusion and in six participants (11.8%) at T2, of which four cases (7.8%) presented with simultaneous tendon sheath effusion. The retrocalcaneal bursa showed the highest number of bursal effusions as observed at baseline, at T1 and T2 in 9 (17.6%), 12 (23.5%), and 11 (21.6%) cases, respectively



**Table 1.** Development of joint effusion within 48 h.

Joint	Time	Right side, n (%)	Left side, n (%)	Both sides, n (%)	No effusion, n (%)
Shoulder	T0	4 (7.8)	1 (2.0)	0 (0.0)	46 (90.2)
	T1	3 (5.9)	5 (9.8)	3 (5.9)	40 (78.4)
	T2	9 (17.6)	9 (17.6)	6 (11.8)	27 (52.9)
Elbow	T0	2 (3.9)	7 (13.7)	7 (13.7)	35 (68.6)
	T1	4 (7.8)	12 (23.5)	12 (23.5)	23 (45.1)
	T2	5 (9.8)	12 (23.5)	14 (27.5)	20 (39.2)
Wrist	T0	6 (11.8)	6 (11.8)	3 (5.9)	36 (70.6)
	T1	7 (13.7)	8 (15.7)	11 (21.6)	25 (49.0)
	T2	10 (19.6)	6 (11.8)	16 (31.4)	19 (37.3)
Hip	T0	0 (0.0)	1 (2.0)	0 (0.0)	50 (98.0)
	T1	2 (3.9)	6 (11.8)	2 (3.9)	41 (80.4)
	T2	6 (11.8)	4 (7.8)	4 (7.8)	37 (72.5)
Knee	T0	7 (13.7)	5 (9.8)	1 (2.0)	38 (74.5)
	T1	4 (7.8)	10 (19.6)	2 (3.9)	35 (68.6)
	T2	7 (13.7)	10 (19.6)	12 (23.5)	22 (43.1)
Ankle	T0	2 (3.9)	5 (9.8)	4 (7.8)	40 (78.4)
	T1	7 (13.7)	7 (13.7)	5 (9.8)	32 (62.7)
	T2	9 (17.6)	7 (13.7)	9 (17.6)	26 (51.0)

Number of participants presenting with and without joint effusion in the respective joint detected by ultrasound at baseline (T0),<sup>a</sup> 24 h (T1) and 48 h (T2) after the weight training.

(Supplementary Table 2). Hyperperfusion of the bursae or tendons except for the biceps tendon was not observed in any case.

#### *Inter- and intrareader reliability*

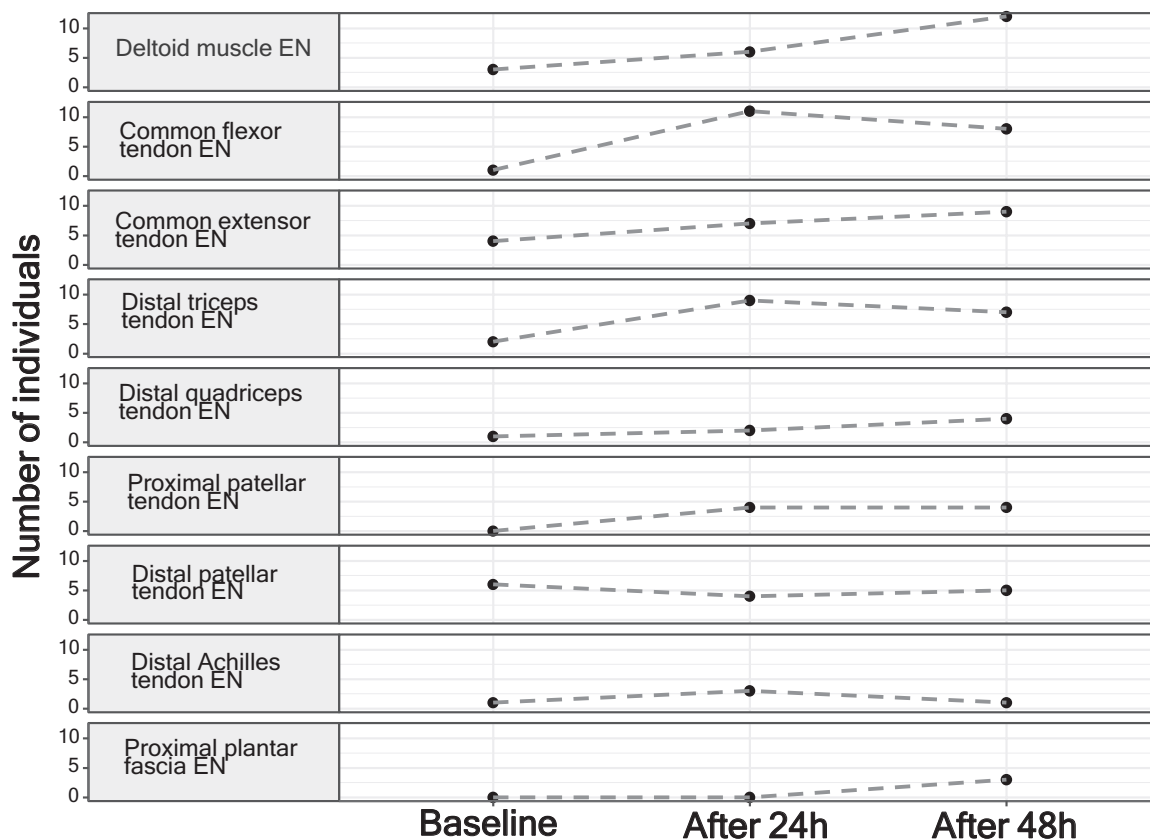
The intrareader reliability analysis showed an excellent agreement for all raters, reaching a mean kappa value of 0.954. Inter-reader reliability results for the pair V.S.S./P.K. demonstrated substantial agreement [ $K=0.745$ , asymptotic standard error ( $se$ )=0.123]. An almost perfect agreement was observed for the pairs V.S.S./D.S. ( $K=0.886$ ,  $se=0.080$ ) and D.S./P.K. ( $K=0.854$ ,  $se=0.102$ ).<sup>8</sup>

#### **Discussion**

The aim of this study was to analyse MSUS findings after 1 h of sex adjusted weight training in

terms of joint effusions, enthesal, tendons and bursal pathology in young healthy individuals. According to our results, enthesal hyperperfusion, observed in 56.86% ( $n=29$ ) after 48 h and joint effusion observed in 94.12% ( $n=48$ ) after 48 h increase significantly after weight training and thus should be interpreted with caution in the respective patient population. In addition, biceps tendon abnormalities and effusion of the retrocalcaneal bursa were observed in 47.1% ( $n=24$ ) and 21.6% ( $n=11$ ) 48 h after the weight training.

The mean number of joints with effusion increased from 1.49 at baseline to 2.82 after 24 h and 4.16 after 48 h. The development of joint effusion in relation to physical activity has been studied before with varying results, largely focusing on professional athletes. Hohmann *et al.*<sup>22</sup> did not detect any changes in MRI images of the hips



**Figure 5.** Development of enthesal hyperperfusion by anatomical localisation. The development of enthesal pathologies by anatomical localisation at T0 (baseline),<sup>8</sup> T1 (after 24 h), and T2 (after 48 h) is displayed. EN = enthesitis.

and knees of eight marathon runners before and after the race. Another study evaluated the knee and ankle joints of 105 marathon runners by ultrasound observing no development or changes in joint effusion of both joints.<sup>23</sup> Yet, in both studies, highly trained athletes were expected to undergo frequent and high-level training in advance of the race. This may also have influenced the results in addition to the marathon. In fact, Major and Helms<sup>24</sup> observed abnormalities in 74% of the knees of professional basketball players by MRI during their preseason physical examination and reported a percentage of knee joint effusion of 35%. Nevertheless, no information was given regarding physical activity right before conducting the MRI examination.

However, an influence of physical activity on joint findings was also observed in normal volunteers. Stehling *et al.*<sup>25</sup> studied knee abnormalities in an asymptomatic, middle-aged population using MRI and their association to physical activity assessed by the Physical Activity Scale for Elderly

(PASE). They described a significantly higher prevalence of knee joint effusion, cartilage, ligament, meniscus abnormalities and bone marrow edema pattern in participants with a higher PASE.

In addition to an increased number of joints with effusion, we also found a significantly increased number of entheses with hyperperfusion per participant after weight training. Our results are supported by a recent study evaluating enthesitis of the Achilles and patellar tendon, and the lateral humeral epicondyles in 32 badminton players before and after an hour of training. The researchers noted a significantly higher PD score following training, indicating that mechanical stress promotes enthesal hyperperfusion. However, the examination was performed directly after the training and thus, no information was obtained on how long this hyperperfusion lasted.<sup>26</sup> According to our results, the number of entheses displaying hyperperfusion increases during the 48-h period. Alternatively, another study comparing the Madrid Sonographic Enthesis Index (MASEI)

scores of athletes and non-athlete controls failed to detect a significant difference between the athletes and non-athletes. However, they did not evaluate the direct effect of a training session but defined ‘athletes’ as individuals performing more than 6 h of physical activity per week and required the non-athlete controls to perform less than an hour of physical activity per week.<sup>27</sup> We observed the highest increase in individuals with enthesal hyperperfusion at the deltoid muscle insertion. Another localisation of entheses that could have been expected to be increasingly affected due to mechanical load is the lower extremity. A significant increase in proximal patellar tendon entheses with hypervascularity was previously observed in runners after performing a marathon.<sup>23</sup> In our study, the number of individuals with pathologies of entheses located at the lower extremities was overall lower than those of the upper extremity. The number of individuals with pathologies of the distal patellar entheses even decreased from 6 (11.8%) to 5 (9.8%) after 48 h. This could be due to the fact that a marathon strains the lower extremity joints more vigorously than does a weight training session. Furthermore, a majority of the participants ( $n=30$ ; 58.8%) stated that they perform endurance training on a regular basis, which strenuously involves the lower extremity and may lead to another conclusion: Wervers *et al.*<sup>28</sup> suggested that entheses adapt to a regular level of physical activity and respond to a change in physical activity. Our data support this hypothesis as we found that individuals performing weekly physical activity to a greater extent had lower numbers of pathological entheses independently of the examination time. This finding indicates a habituation process towards physical activity in highly trained individuals. In patients with axial spondyloarthritis, a randomised controlled trial showed a significant reduction of disease activity (symptoms and inflammation) after 3 months of high-intensity physical training.<sup>29</sup> However, the role of physical activity in pathophysiology and treatment of spondyloarthritis is still not entirely understood.<sup>30</sup> As a result, our findings may not only be applicable in healthy individuals but also in rheumatological patients; however, further studies including patients are required to obtain deeper insights of their ultrasound presentation after physical activity.

Our study has limitations. We only observed a time frame until 48 h after the weight training. Considering the number of entheses with pathologies and joints with effusion still increasing

within 2 days, a longer observation period might be better to fully assess the development of the ultrasound findings. The fact that we did not include a control group also represents a limitation to our study. In addition, we asked the participants not to perform any physical activity within 48 h, and based on our results, this period may not have been long enough. For further investigation, we would recommend a longer renunciation of any physical activity by the participants involved, which would however not be a real-life setting any more.

### Conclusion

According to our results, the prevalence of joint effusion in large and medium joints and the prevalence of abnormal entheses increase significantly within 48 h after a 1-h weight training session. In addition, biceps tendon abnormalities and effusion of the retrocalcaneal bursa were observed in a notable part of the study population after 48 h. As a result, the patient’s physical activities should be considered when performing and interpreting an MSUS examination in clinical practise as they may alter the ultrasound findings.

### Declarations

#### *Ethics approval and consent to participate*

Ethical approval was obtained by the medical ethics committee of the Rheinische Friedrich-Wilhelms-Universität Bonn (Lfd. Nr. 149/19). Written informed consent was obtained from every individual prior to inclusion.

#### *Consent for publication*

Written informed consent for publication was obtained.

#### *Author contributions*

**Julia K. Schreiner:** Data curation; Formal analysis; Investigation; Methodology; Project administration; Visualization; Writing – original draft.

**Florian Recker:** Validation; Visualization; Writing – original draft; Writing – review & editing.

**Dennis Scheicht:** Investigation; Methodology; Writing – review & editing.

**Pantelis Karakostas:** Investigation; Methodology; Writing – review & editing.

**Jana Ziob:** Investigation; Resources; Writing – review & editing.

**Charlotte Behning:** Formal analysis; Writing – review & editing.

**Peter Preuss:** Conceptualization; Data curation; Investigation; Methodology; Resources; Supervision; Writing – review & editing.

**Peter Brossart:** Methodology; Resources; Supervision; Writing – review & editing.

**Valentin S. Schäfer:** Conceptualization; Data curation; Investigation; Methodology; Resources; Supervision; Writing – review & editing.

#### *Acknowledgements*

The authors thank the participants for making this study possible. They also thank Hexal AG for funding this study.

#### *Funding*

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was supported by Hexal AG.

#### *Competing interests*

The authors declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Valentin S. Schäfer has received a research grant from Hexal AG. The other authors declare that they have no competing interests.

#### *Availability of data and material*

Derived data underlying the results of this study are available to researchers who provide a methodologically sound proposal to the corresponding author.

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#### **Supplemental material**

Supplemental material for this article is available online.

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