

EXTENDED REPORT

Standard reference values for musculoskeletal ultrasonography

W A Schmidt, H Schmidt, B Schicke, E Gromnica-Ihle

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See end of article for authors' affiliations

Correspondence to:
Dr W A Schmidt, Medical
Centre for Rheumatology
Berlin-Buch, Karower
Strasse 11, 13125 Berlin;
schmidt.wa@t-online.deAccepted
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Objectives: To determine standard reference values for musculoskeletal ultrasonography in healthy adults. **Methods:** Ultrasonography was performed on 204 shoulders, elbows, hands, hips, knees, and feet of 102 healthy volunteers (mean age 38.4 years; range 20–60; 54 women) with a linear probe (10–5 MHz; Esaote Technos MP). Diameters of tendons, bursae, cartilage, erosions, hypoechoic rims around tendons and at joints were measured with regard to established standard scans. Mean, minimum, and maximum values, as well as two standard deviations (2 SD) were determined. Mean values \pm 2 SD were defined as standard reference values.

Results: Hypoechoic rims were normally present in joints and tendon sheaths owing to physiological synovial fluid and/or cartilage. Similarly, fluid was found in the subdeltoid bursa in 173/204 (85%), at the long biceps tendon in 56 (27%), in the suprapatellar recess in 158 (77%), in the popliteal bursae in 32 (16%), and in the retrocalcaneal bursa in 49 (24%). Erosions of $>$ 1 mm were seen at the humeral head in 47 (23%). Values for important intervals were determined. The correlation between two investigators was 0.96 (0.78–0.99). The reliability of follow up investigations was 0.83 (0.52–0.99).

Conclusions: Fluid in bursae as well as hypoechoic rims within joints and around tendons are common findings in healthy people. This study defines standard reference values for musculoskeletal ultrasonography to prevent misinterpretation of normal fluid as an anatomical abnormality.

Musculoskeletal ultrasonography is a diagnostic method which has been in use for decades.¹ Improvements in technology have led to its increasingly widespread use in rheumatology,^{2–6} orthopaedic surgery,^{7–8} sports medicine,^{9–10} physical therapy,¹¹ and radiology.¹² One of its main indications is the need to distinguish between normal and pathological anatomical structures if clinical findings are ambivalent. Nevertheless, standard reference values have not yet been established for this important diagnostic method. Technological advances have enhanced the resolution of ultrasound images, leading to the ability to detect synovial fluid and cartilage in healthy subjects. Definition of standard reference values is therefore necessary to increase the diagnostic accuracy of ultrasonography.

SUBJECTS AND METHODS

Test subjects

We performed bilateral investigation of 102 white volunteers recruited from among our staff, students, and friends of the authors. We excluded subjects aged $<$ 20 or $>$ 60 years, or with a history of inflammatory rheumatic disease, osteoarthritis, or surgery of any of the investigated joints. None of the subjects developed an inflammatory rheumatic disease 9–11 months after measurement. Table 1 shows the demographic data of subjects.

Ultrasonography

An experienced physician sonographer (HS) performed the investigations and measurements based on standard scans.¹³ We chose the anatomical structures for measurement that we considered most relevant for daily practice. Tables 2–5 show the anatomical structures, the ultrasound planes, and the exact localisation of measurement. Figure 1 delineates the measurement of the finger flexor tendons. Figure 2 shows the measurement at the ankle joint. We saved all images on the hard disk of the ultrasound equipment. In 20 subjects,

another trained physician sonographer (WAS) repeated measurement of the saved images. In two people the same investigator repeated the complete investigation after 1 and 9 months: for one person by HS, and for one by WAS.

We employed a linear probe for all investigations (LA 523, 10–5 MHz; length of the probe, 45 mm; weight of probe 100 g; year of construction 2002; Esaote Technos MP; Esaote SpA; Genua, Italy). Scanner settings were uniform for all measurements: frequency setting, 10 MHz; B mode gain 110%; one focus point position in the region of measurement; procession parameter, PB 5; scan correlation parameter, SCC 7; and enhancing parameter, ENH 5. Bilateral measurement for one test subject took 2 hours. The axial spatial resolution for this probe is 0.154 mm; the lateral spatial resolution is 0.260 mm. The pressure on the probe was below the occurrence of visible deformation of the anatomical structures.

We additionally measured all distances in two subjects to compare the data with technology which had less resolution: ATL (Philips) HDI 3500 (12–5 MHz, length of probe, 38 mm; year of construction 1998; Advanced Technology Laboratories, Bothell, WA, USA). Both the axial and the lateral spatial resolution of this probe are 0.7 mm.

For the investigation of the shoulders the sonographer sat behind the subject. The subject sat with 90° flexion of the elbow. We investigated the biceps tendon in neutral position; the subscapularis tendon in maximum external rotation; and the supraspinatus and infraspinatus tendons, the acromioclavicular and sternoclavicular joint, the subdeltoid bursa, and the acromiohumeral distance in 60° internal rotation. We measured the largest erosion detected at the humeral head. We defined an "erosion" as a pit in the bone surface of $>$ 1 mm diameter in all three diameters (longitudinal, transverse, sagittal).

Abbreviations: MCP, metacarpophalangeal; MRI, magnetic resonance imaging; PIP, proximal interphalangeal

Table 1 Demographic data of the subjects investigated in this study

	Women	Men	All subjects
Number	54	48	102
Age (years)	37.8	39.0	38.4
Right handed	50	44	94
Mean body weight (kg), range	62 (38–94)	80 (62–103)	70 (38–103)
Mean height (cm), range	166 (156–180)	179 (167–198)	172 (156–198)
Good working activity (n)	18	16	34

Occupations: physician (13); salesperson (14); administrative assistant (7); skilled worker (6); student or engineer (5 each); lawyer or teacher (4 each); manager, nurse, physiotherapist, car mechanic, or construction worker (3 each); photographer, advertising assistant, kindergarten teacher, policeman or woman (2 each); secretary, psychologist, speech therapist, bank employee, television producer, programmer, doctor's assistant, pharmacist, dentist, beautician, stewardess, florist, roofer, cook, painter, varnisher, tiler, machine operator, cleaner, truck driver (1 each).

The investigator sat in front of the subject for investigation of the elbows. The subject sat with full extension of the elbow and supination of the lower arm for the anterior scans, and with maximum flexion for the posterior scan.

The investigator sat in front of the subject for investigation of hands and fingers. The subject sat with the hand on top of the thigh, with supination for the volar scans, and with pronation for the dorsal scans in neutral position of the wrist.

For investigation of hips, knees, and feet, the subject was placed prone or supine, with the investigator sitting next to him or her.

For hips, the subject was placed supine with the hip joint in neutral position.

Knees were investigated with the subject placed supine for the anterior scans and prone for the posterior scans, with the knee joint in neutral position. We measured only the intercondylar cartilage with maximum flexion of the knee. Subjects contracted the quadriceps muscle for evaluation of the suprapatellar and lateral recess, the patellar tendon, and the deep infrapatellar bursa.

The examiner investigated feet with the subject placed supine for the anterior scans and prone for the posterior and plantar scans. Anterior scans took place with 90° flexion of the knee, with the sole of the foot resting on the examination

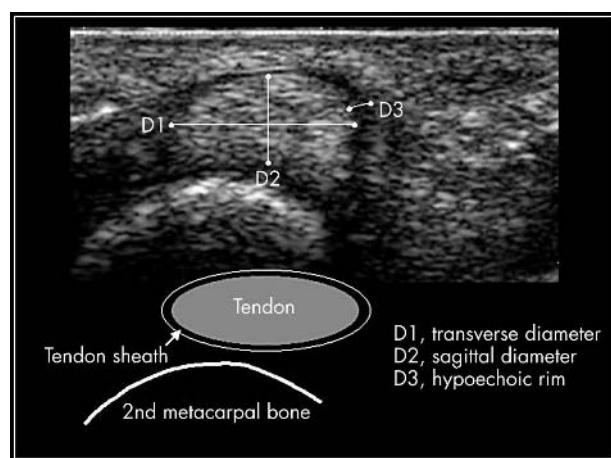


Figure 1 Ultrasound image with measurement of the flexor tendons of the right index finger 1 cm proximal to the metacarpophalangeal (MCP) joint (transverse volar scan). The hypoechoic rim of all tendons was measured at the point of the largest diameter in the images.



Figure 2 Ultrasound image with measurement of the anterior bone-capsule distance of the tibiotalar joint (anterior longitudinal scan).

table. We performed posterior and plantar scans with the foot relaxed and hanging off the edge of the examination table.

We measured all bone-capsule distances perpendicular to the bone.

Statistical analysis

We saved data in a structured query language database and employed SPSS (version 11.0) for processing. Our work produced mean, minimum, and maximum values, as well as two standard deviations (2 SD). We used an analysis of variance to compare the mean values. We evaluated qualitative features by contingency table analysis and the non-parametric χ^2 test. We correlated measured values with age, sex, body weight, and height, sport activities, and hand dominance. We used the paired *t* test for correlated samples to compare the observers.

RESULTS

Tables 2–5 show mean, minimum, and maximum values, as well as 2 SD of the measurements. We have defined standard reference values as those values included in 2 SD.

Shoulders

We detected fluid around 56/204 (27%) long biceps tendons. The diameter of the supraspinatus tendon was larger than those of the subscapularis and the infraspinatus tendons. We found erosions of >1 mm at the humeral head in 47 (23%) shoulders. We determined fluid in 173 (85%) subdeltoid bursae. For the capsular distension of the axillary recess, 2 SD includes diameters ≤ 3.8 mm. The mean transverse diameter of the long biceps tendon was 4.6 mm (2.1–7.2; 2 SD, 2.0) in women and 5.5 mm (3.3–8.8; 2 SD, 2.0) in men. The mean sagittal diameter was 2.5 mm (1.5–6.0; 2 SD, 1.4) in women, and 2.8 mm (1.7–5.2; 2 SD, 1.4) in men. In 11 acromioclavicular joints of nine patients we detected small osteophytes that indicate preclinical osteoarthritis.

Elbows

We made images of capsular distension in all coronoid and olecranon fossae. The anterior ulnar distance between bone and capsule primarily represents cartilage thickness.

Hands, wrists, and fingers

The 2 SD include distances ≤ 2.9 mm and ≤ 3.4 mm for the dorsal and volar capsular distension at the scaphoid bone, respectively; ≤ 1.6 mm and ≤ 2.1 mm at the dorsal and volar aspect of the ulna, respectively; and ≤ 1.9 mm and ≤ 1.6 mm

Table 2 Anatomical structure with ultrasound plane; localisation of measurement; mean, maximum, and minimum value; and two standard deviations at the shoulders and the sternoclavicular joints

Anatomical structure	Ultrasound plane	Exact localisation	Mean value (mm)	Minimum (mm)	Maximum (mm)	2 SD (mm)
Biceps tendon (long head): transverse diameter	Biceps tendon: transverse	Distal end of rotator cuff	5.0	2.1	8.8	2.1
Biceps tendon (long head): sagittal diameter	Biceps tendon: longitudinal	Distal end of rotator cuff	2.6	1.5	6.0	1.4
Biceps tendon (long head): hypoechoic rim	Biceps tendon: longitudinal	Localisation of maximum diameter	1.4	0.5	5.3	1.4
Subscapularis tendon: sagittal diameter	Shoulder: anterior transverse, max. external rotation	2 cm medial of biceps tendon	4.2	2.4	6.5	1.6
Supraspinatus tendon: sagittal diameter	Shoulder: anterior transverse, 60° internal rotation	2 cm lateral of biceps tendon	4.6	1.6	8.0	1.9
Humeral head: cartilage below the supraspinatus tendon	Shoulder: anterior transverse, 60° internal rotation	2 cm lateral of biceps tendon	0.8	0.2	3.0	0.6
Infraspinatus tendon: sagittal diameter	Shoulder: posterior transverse, 60° internal rotation	Maximum posterior point	3.8	1.9	6.9	1.8
Distance between humeral head and acromion	Shoulder: lateral longitudinal, 60° internal rotation	Strictly lateral (cranial side of acromion)	10.9	5.9	19.6	4.2
Humeral head: erosion longitudinal	Shoulder: anterior, lateral or posterior longitudinal	On site of greatest erosion	3.9	1.1	11.4	4.8
Humeral head: erosion transverse	Shoulder: anterior, lateral or posterior transverse	On site of greatest erosion	3.7	1.0	9.4	3.7
Humeral head: erosion sagittal	Shoulder: anterior, lateral or posterior transverse	On site of greatest erosion	2.3	0.8	5.1	1.8
Subdeltoid bursa: sagittal	Shoulder: lateral longitudinal	Maximum diameter	0.5	0.1	2.7	0.6
Axillary recess: sagittal	Axillary recess: longitudinal	Middle of concavity of humeral neck	2.2	0.4	6.2	1.6
Acromioclavicular joint, bone-capsule distance: medial	Acromioclavicular joint: transverse	Lateral end of clavicle	1.7	0.4	4.3	1.4
Acromioclavicular joint bone-capsule distance: lateral	Acromioclavicular joint: transverse	Medial end of acromion	2.5	0.4	5.0	1.7
Acromioclavicular joint space	Acromioclavicular joint: transverse	Cranial aspect: clavicle/acromion	5.2	1.8	11.3	3.3
Sternoclavicular joint, bone-capsule distance: medial	Sternoclavicular joint: oblique	Cranial lateral end of sternum	0.9	0.1	3.8	1.3
Sternoclavicular joint bone-capsule distance: lateral	Sternoclavicular joint: oblique	Medial end of clavicle	1.5	0.1	4.3	1.6
Sternoclavicular joint, joint space	Sternoclavicular joint: oblique	Anterior aspect: sternum/clavicle	8.2	1.5	15.6	5.3

at the volar proximal aspects of the MCP and proximal interphalangeal (PIP) II joints, respectively. We found no erosions at the MCP II and PIP II joints when examining the joints circumferentially with a longitudinal scan. We detected a hypoechoic rim around 198 (97%) of the extensor carpi ulnaris tendons, and around 199 (97%) of the index finger flexor tendons, with 2 SD including ≤ 2.2 mm and ≤ 1.7 mm, respectively.

Hips

The 2 SD of the capsular distension in the anterior recess include distances ≤ 8.0 mm. We found a hypoechoic rim in 176 (86%) of the trochanteric bursae.

Knees

We detected fluid in 158 (77%) of the suprapatellar recessi, in 96 (47%) of the suprapatellar lateral recessi, in 12 (6%) of the deep infrapatellar bursae, and in 32 (16%) of the popliteal bursae. The mean thickness of the intercondylar cartilage was 2.7 mm (1.5–4.1; 2 SD, 1.3) in women and 3.5 mm (2.0–4.9; 2 SD 1.4) in men. The sagittal diameter of the patellar tendon was 2.9 mm (1.6–4.3; 2 SD, 1.0 mm) in women and 3.5 mm (1.2–5.5; 2 SD, 1.6) in men.

Ankles, feet, and toes

The 2 SD of the capsular distension include distances ≤ 2.1 mm in the anterior region and ≤ 2.3 mm in the posterior region of the ankle joint, ≤ 2.6 mm at the talonavicular joint, ≤ 3.5 mm in the first metatarsophalangeal joint, and ≤ 3.1 mm in the second metatarsophalangeal

joint. We found a hypoechoic rim around the following: 138 (68%) of the peroneus longus tendons, 156 (76%) of the peroneus brevis tendons, 93 (46%) of the tibialis anterior tendons, 91 (45%) of the tibialis posterior tendons, and 26 (13%) of the Achilles tendons. The mean sagittal diameter of the Achilles tendon was 4.1 mm (2.6–6.7; 2 SD, 1.4) in women and 4.6 mm (3.0–6.4; 2 SD, 1.6) in men. The mean transverse diameter was 13.3 mm (8.2–17.3; 2 SD, 3.4) in women and 15.4 mm (9.4–20.6; 2 SD, 3.9) in men. We detected fluid in 49 (24%) retrocalcaneal bursae. The 2 SD of the sagittal diameter of the plantar fascia include distances ≤ 4.7 mm.

Correlation with age, sex, body weight, and height, sport activities, and hand dominance

Owing to the large number of correlations investigated, several values reached significant levels ($p < 0.05$) as a result of an α fault. Only six of the correlations for differences between the sexes mentioned above were apparently relevant. There was no statistical significance adjusted to Holm between the dominant and non-dominant side, age < 40 years and age ≥ 40 years, and low and high working activity.

Objectivity and reliability

The rate of agreement between the two investigators (objectivity) was 0.96 (0.78–0.99). It was 0.96 (0.78–0.99) for tendon diameters; 0.95 (0.83–0.99) for capsular distensions at the joints; 0.97 (0.94–0.99) for hypoechoic rims around tendons; 0.95 (0.87–0.99) for joint spaces, erosions, and cartilage thickness; and 0.97 (0.94–0.99) for bursae and

Table 3 Anatomical structure with ultrasound plane; localisation of measurement; mean, maximum, and minimum value; and two standard deviations at the elbows, wrists, hands, and fingers

Anatomical structure	Ultrasound plane	Exact localisation	Mean value (mm)	Minimum (mm)	Maximum (mm)	2 SD (mm)
Elbow: coronoid fossa, bone-capsule distance	Elbow: anterior longitudinal	Bottom of coronoid fossa	1.8	0.3	5.9	1.9
Elbow: anterior ulnar, bone-capsule distance	Elbow: anterior transverse	Most anterior ulnar point	1.0	0.6	2.5	0.5
Elbow: olecranon fossa, bone-capsule distance	Elbow: posterior longitudinal, maximum flexion	Bottom of olecranon fossa, midline	1.9	0.2	4.8	2.0
Wrist: radiocarpal joint, volar bone-capsule distance	Wrist: volar longitudinal radial	Scaphoid bone 1 cm distal of joint	1.7	0.2	4.9	1.7
Wrist: radiocarpal joint, dorsal bone-capsule distance	Wrist: dorsal longitudinal radial	Scaphoid bone 1 cm distal of joint	1.5	0.2	3.7	1.4
Wrist: head of the ulna, volar bone-capsule distance	Wrist: volar longitudinal ulnar	Ulna 1 cm proximal of joint	1.1	0.2	3.4	1.0
Wrist: head of the ulna, dorsal bone-capsule distance	Wrist: dorsal longitudinal ulnar	Maximum dorsal point of ulna	0.8	0.1	2.5	0.8
Wrist: extensor carpi ulnaris tendon transverse diameter	Wrist: dorsal transverse ulnar	Directly distal of the head of the ulna	5.4	1.8	9.0	2.6
Wrist: extensor carpi ulnaris tendon sagittal diameter	Wrist: dorsal transverse ulnar	Directly distal of the head of the ulna	2.7	1.2	7.0	2.1
Wrist: extensor carpi ulnaris tendon hypoechoic rim	Wrist: dorsal transverse ulnar	Directly distal of the head of the ulna	1.2	0.2	3.8	1.0
Hand: index finger flexor tendons transverse diameter	Hand: volar transverse	1 cm proximal of MCP II joint	6.4	2.4	13.6	2.7
Hand: index finger flexor tendons sagittal diameter	Hand: volar transverse	1 cm proximal of MCP II joint	3.6	0.6	9.3	2.2
Hand: index finger flexor tendons hypoechoic rim	Hand: volar transverse	1 cm proximal of MCP II joint	0.9	0.2	3.9	0.8
MCP II joint: maximum bone-capsule distance	MCP II: joint volar longitudinal	Region proximal of MCP II	0.9	0.3	2.7	1.0
PIP II joint: maximum bone-capsule distance	PIP II: joint volar longitudinal	Region proximal of PIP II	0.8	0.1	2.3	0.8

Table 4 Anatomical structure with ultrasound plane; localisation of measurement; mean, maximum, and minimum value; and two standard deviations at the hips and knees

Anatomical structure	Ultrasound plane	Exact localisation	Mean value (mm)	Minimum (mm)	Maximum (mm)	2 SD (mm)
Hip joint: bone-capsule distance	Hip joint: anterior longitudinal parallel to femoral neck	Middle of anterior concavity of femoral neck	5.2	1.1	9.0	2.8
Trochanteric bursa: bone-capsule distance	Major trochanter: transverse	Most lateral aspect of major trochanter	1.1	0.2	5.0	1.1
Knee: suprapatellar recess midline, longitudinal diameter	Knee: anterior suprapatellar mid-line longitudinal	Midline aspect suprapatellar	22.2	4.4	51.2	20.1
Knee: suprapatellar recess midline, transverse diameter	Knee: anterior suprapatellar mid-line transverse	At maximum transverse diameter	13.8	1.3	37.6	14.4
Knee: suprapatellar recess midline, sagittal diameter	Knee: anterior suprapatellar mid-line longitudinal	At maximum longitudinal diameter	2.4	0.5	7.1	2.4
Knee: suprapatellar recess, lateral longitudinal diameter	Knee: anterior suprapatellar lateral longitudinal	At lateral femoral epicondylus	22.8	4.4	52.8	23.0
Knee: suprapatellar recess, lateral transverse diameter	Knee: anterior suprapatellar lateral transverse	At lateral femoral epicondylus	10.8	1.7	37.7	13.5
Knee: suprapatellar recess, lateral sagittal diameter	Knee: anterior suprapatellar lateral longitudinal	At lateral femoral epicondylus	2.4	0.6	6.8	2.5
Knee: cartilage sagittal diameter	Knee: anterior suprapatellar transverse, 90° flexion	Directly proximal of patella	3.1	1.5	4.9	1.4
Knee: patellar tendon sagittal diameter	Knee: anterior infrapatellar longitudinal	2 cm distal of distal end of patella	3.2	1.2	5.5	1.3
Knee: deep infrapatellar bursa longitudinal diameter	Knee: anterior infrapatellar longitudinal	Maximum longitudinal diameter	6.1	2.4	10.4	4.4
Knee: deep infrapatellar bursa transverse diameter	Knee: anterior infrapatellar transverse	Maximum transverse diameter	6.2	2.5	14.5	6.2
Knee: deep infrapatellar bursa sagittal diameter	Knee: anterior infrapatellar longitudinal	Maximum sagittal diameter	2.7	0.7	12.0	6.1
Knee: popliteal bursa longitudinal diameter	Knee: posterior longitudinal	Maximum longitudinal diameter	22.2	5.6	52.7	21.0
Knee: popliteal bursa transverse diameter	Knee: posterior transverse	Maximum transverse diameter	10.1	1.6	29.5	14.6
Knee: popliteal bursa sagittal diameter	Knee: posterior transverse	Maximum sagittal diameter	5.2	1.2	23.6	8.6

Table 5 Anatomical structure with ultrasound plane; localisation of measurement; mean, maximum, and minimum value; and two standard deviations at the ankles, feet, and toes

Anatomical structure	Ultrasound plane	Exact localisation	Mean value (mm)	Minimum (mm)	Maximum (mm)	2 SD (mm)
Tibiotalar joint: anterior bone-capsule distance	Ankle: anterior longitudinal midline	1 cm distal of tibiotalar joint	1.1	0.4	3.8	1.0
Tibiotalar joint: posterior bone-capsule distance	Ankle: posterior longitudinal midline	Directly distal of tibiotalar joint	1.2	0.3	3.7	1.1
Talonavicular joint: anterior bone-capsule distance	Ankle: anterior longitudinal midline	Maximum diameter	1.4	0.4	4.2	1.2
Tibialis anterior tendon: transverse diameter	Ankle: anterior transverse	At tibiotalar joint	8.2	5.0	14.2	3.5
Tibialis anterior tendon: sagittal diameter	Ankle: anterior transverse	At tibiotalar joint	2.5	1.1	4.5	1.3
Tibialis anterior tendon: hypoechoic rim	Ankle: anterior transverse	At tibiotalar joint	0.8	0.1	2.8	0.9
Tibialis posterior tendon: transverse diameter	Ankle: medial transverse	Directly below level of medial malleolus	8.4	3.1	14.1	4.2
Tibialis posterior tendon: sagittal diameter	Ankle: medial transverse	Directly below level of medial malleolus	2.8	1.3	6.0	1.8
Tibialis posterior tendon: hypoechoic rim	Ankle: medial transverse	Directly below level of medial malleolus	1.2	0.2	3.8	1.6
Peroneus longus tendon: transverse diameter	Ankle: lateral transverse	Directly below level of lateral malleolus	6.0	2.5	12.3	3.7
Peroneus longus tendon: sagittal diameter	Ankle: lateral transverse	Directly below level of lateral malleolus	3.0	0.8	6.1	1.6
Peroneus longus tendon: hypoechoic rim	Ankle: lateral transverse	Directly below level of lateral malleolus	1.1	0.2	4.1	1.2
Peroneus brevis tendon: transverse diameter	Ankle: lateral transverse	Directly below level of lateral malleolus	4.3	1.8	13.0	3.0
Peroneus brevis tendon: sagittal diameter	Ankle: lateral transverse	Directly below level of lateral malleolus	2.5	0.5	4.2	1.3
Peroneus brevis tendon: hypoechoic rim	Ankle: lateral transverse	Directly below level of lateral malleolus	0.9	0.2	2.2	0.8
Achilles tendon: transverse diameter	Ankle: posterior transverse	2 cm proximal of calcaneus	14.3	8.2	20.6	4.1
Achilles tendon: sagittal diameter	Ankle: posterior longitudinal	2 cm proximal of calcaneus	4.3	2.6	6.7	1.6
Achilles tendon: hypoechoic rim	Ankle: posterior transverse	2 cm proximal of calcaneus	1.0	0.2	4.4	2.3
Retrocalcaneal bursa: longitudinal diameter	Ankle: posterior longitudinal	Maximum longitudinal diameter	5.5	1.1	13.9	5.0
Retrocalcaneal bursa: transverse diameter	Ankle: posterior transverse	Maximum transverse diameter	5.5	0.9	13.4	5.4
Retrocalcaneal bursa: sagittal diameter	Ankle: posterior longitudinal	Maximum sagittal diameter	1.3	0.3	3.4	1.4
Plantar fascia: sagittal diameter	Plantar: longitudinal	At distal plantar end of calcaneus	3.4	1.8	5.3	1.3
MTP I joint: maximum bone-capsule distance	MTP I joint: anterior longitudinal	Region proximal of MTP I	1.7	0.2	4.8	1.8
MTP II joint: maximum bone-capsule distance	MTP II joint: anterior longitudinal	Region proximal of MTP II	1.6	0.4	3.9	1.5

recesses. It was 0.96 (0.87–0.99) for shoulders, 0.92 (0.83–0.99) for elbows, 0.96 (0.89–0.99) for hands and fingers, 0.96 (0.94–0.99) for hips, 0.98 (0.98–0.99) for knees, and 0.96 (0.78–0.99) for feet and toes.

The rate of agreement between follow up investigations of the same test subject (reliability) was 0.83 (0.52–0.99). It was 0.87 (0.74–0.99) for tendon diameters; 0.84 (0.72–0.97) for capsular distensions at the joints; 0.86 (0.78–0.96) for hypoechoic rims around tendons; 0.84 (0.70–0.99) for joint spaces, erosions, and cartilage thickness; and 0.70 (0.52–0.85) for bursae and recesses. It was 0.86 (0.70–0.97) for shoulders, 0.64 (0.52–0.78) for elbows, 0.84 (0.72–0.96) for hands and fingers, 0.82 (0.70–0.93) for hips, 0.72 (0.57–0.99) for knees, and 0.86 (0.78–0.97) for feet and toes.

When the investigations were compared using different ultrasound equipment with less resolution the reliability was lower: 0.60 (0.04–0.99). Distances generated with the second piece of equipment were greater and lower in half of the measurements, respectively. Thus we did not find a systematic fault with older equipment, but measurement was less exact.

DISCUSSION

Ultrasonography has been extensively considered as a primarily qualitative diagnostic tool.¹⁴ Qualitative measures of course remain important—for example, echogenicity, appearance of neighbouring structures, as well as comparison with the contralateral side and with clinical findings. Only a few small studies have published definitions of standard

reference values in selected anatomical regions. The percentage of detected structures that contain a small amount of fluid is consequently much lower in most publications than in our study. The space between articular surfaces is relatively small in most joints. Most articular fluid is usually distributed throughout joint recesses, where it can be assessed by ultrasonography. A small amount of fluid is also usually detectable in tendon sheaths, where it appears as a thin hypoechoic rim. Advanced high resolution scanners are, in contrast with older equipment, capable of detecting fine details in anatomical structures that demonstrate only very slight deviation from the normal.¹⁵

In asymptomatic shoulders, Arslan *et al* detected biceps tendon fluid in only 8% of cases, and subdeltoid bursal fluid in only 3%.¹⁶ A magnetic resonance imaging (MRI) study found fluid in 20% of subdeltoid bursae.¹⁷ Cartilage thickness at the humeral head was slightly higher in cadavers (1.2 mm) than in our subjects (0.8 mm).¹⁸ Wallny *et al* found a similar mean sagittal diameter of the biceps tendon (2.8 mm *v* 2.6 mm in our study), and a larger diameter of the supraspinatus tendon (6.25 mm) in 50 healthy volunteers.¹⁹ Koski described the axillar scan of the glenohumeral joint and arrived at similar diameters for capsular distension (2.4 mm *v* 2.2 mm in our study).²⁰ Alasaarela *et al* likewise obtained similar diameters for capsular distension (2.2 mm *v* 1.7/2.5 mm in our study) and for joint space (4.1 mm *v* 5.2 mm in our study) for the acromioclavicular joint.²¹

In studies of elbows in healthy subjects, Koski described anterior capsular-distension distances up to 2 mm.²² These

findings are comparable to our data at the ulna (2 SD ≤ 1.5 mm).

Hands, wrists, and fingers are frequently the subjects of investigation, particularly in rheumatology. To our knowledge, however, no studies have published measured distances in a healthy population. In concurrence with other studies, we detected no erosions at the MCP and PIP joints in healthy subjects.^{5, 23} This finding is very important as ultrasonography is a new method used specifically to detect erosions in early rheumatoid arthritis that may not be seen by conventional radiography. In contrast, we found erosions of the humeral head in many healthy adults. Therefore it is not possible to draw any clinical conclusion if ultrasonography detects smaller erosions of the humeral head.

An MRI study of asymptomatic hip joints has described distances ≤ 5 mm between femur and joint capsule.²⁴ In the recess anterior to the femoral neck, Koski *et al* suggested a larger upper limit of 7 mm,²⁵ which is slightly lower than our findings (2 SD includes diameters ≤ 8.0 mm). Sada suggested an upper limit of 9 mm.²⁶ In knee studies, Mielke *et al* found a smaller diameter of the intercondylar cartilage (mean 2.4 mm *v* 3.1 mm). This study did not detect popliteal cysts in a normal population owing to lower resolution with older equipment.²⁷

MRI studies have described fluid in normal ankle joints and in tendon sheaths around the ankles.²⁸ Nazarian *et al* disclosed fluid in the anterior recess of the ankle joint in 33% of subjects examined.²⁹ In addition to our findings and those of two other studies,^{28, 30} Nazarian could not detect fluid in the posterior recess. In contrast, their study found retrocalcaneal bursal fluid in 50% of subjects, compared with 24% in our findings. Their study also found tibialis posterior tendon sheath fluid in 77% of tendons. Another study revealed fluid in 85% of tendons³¹—compared with 45% in our study. The smaller number of tendons with tendon sheath fluid in our study can be explained by the fact that we only used one fixed localisation to evaluate the tendon. Seybold and Hamel found fluid in the peroneal tendon sheaths in only 7% of subjects, compared with 68 and 76% in our study.³¹ The sagittal diameter of the Achilles tendon was 4.9 mm for women and 5.3 mm for men in a Spanish study,³² compared with 4.1 mm and 4.6 mm, respectively, in our study.

Another small study from 1988 described even larger diameters—namely, 6.2 mm (4–9).³³ We have not encountered such large diameters in our studies. For the plantar fascia, our diameters (3.4 mm) are comparable to those described in other studies: 2.9 mm,³⁴ 3.2 mm,³⁵ and 3.3 mm.³⁶ Kamel and Kotob described only a mean diameter of 2.3 mm in 20 healthy Egyptian subjects.³⁷ The diameters for capsular distension at the toes are comparable to those found in another study. The authors suggested that distances >3 mm are pathological.³⁸

In our study we always carried out measurements at the same defined location; distances may therefore be larger in other areas of anatomical structures. In addition, we investigated only 20–60 year old subjects. Distances in younger subjects are different before epiphyseal closure and because of a thicker layer of cartilage. In older people, distances may differ as a result of an increasing prevalence of osteoarthritis and a reduction of cartilage thickness. Our test subjects, furthermore, had obtained a higher education level and practised more sedentary professions than the general population. Nevertheless, we found no correlation of our data with the sports activities of our subjects. Selected distances are different for athletes.³⁹ Body weight and height of our subjects are comparable to data for the American population aged ≥ 20 years, according to findings for population prevalence estimates published by the Third National Health and Nutrition Examination Survey.⁴⁰ The weight of

our subjects was 62 kg for women and 80 kg for men, compared with 66 kg and 80 kg in the American population. Height was 166 cm for women and 179 cm for men compared with 162 cm and 176 cm in the American population.

Although this is the first study which systematically measures distances of healthy adults in all anatomical regions that are important for musculoskeletal ultrasound, further structures remain to be evaluated. We chose those distances that appeared to be most relevant for clinical practice according to our experience. We did not investigate the median and the ulnar nerves because sufficient data have already been published by other authors.^{41–43} We cannot exclude the possibility that the values for the MCP, PIP, and metatarsophalangeal joints that we did not investigate may slightly differ from those of the joints that we chose for this study.

Our study aims at defining a normal population. In accordance with most other studies that have described normal values of musculoskeletal ultrasonography we determined mean values and standard deviations. Analysis of receiver operating characteristic curves can be performed to define more exact standard values that distinguish a well defined disease from a normal population in a selected anatomical structure. This has been investigated in the comparison of Achilles tendon diameters of patients with familial hypercholesterolaemia with diameters of subjects with other lipid profiles.⁴⁴

Studies that investigated distances with MRI arrived at similar results to those obtained with ultrasonography.^{17, 18, 24, 28, 35} Comparison with necropsy studies is difficult because of reduced synovial and interstitial fluid.²⁷

In conclusion, hypoechoic rims within joints and around tendons, fluid in bursae, and erosions at the humeral head are common findings in healthy subjects. It is important to define standard reference values for musculoskeletal ultrasonography to prevent misinterpretation of normal fluid as articular or tendon abnormality.

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Authors' affiliations

W A Schmidt, H Schmidt, E Gromnica-Ihle, Medical Centre for Rheumatology Berlin-Buch, Karower Strasse 11, 13125 Berlin, Germany
B Schicke, Department of Biostatistics, HELIOS Klinikum Berlin, Klinikum Buch, Wiltbergstr 50, 13125 Berlin, Germany

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