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Age dependent ultrasound B-mode findings of the elbow joint in healthy children and adolescents

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Abstract
Due to maturation of joints, various changes take place, not only in the field of paediatric rheumatology but also in paediatric orthopaedics musculoskeletal ultrasound plays an important role in both the diagnosis and the follow-up of diseases in this field. To differentiate between physiological and pathological findings, the knowledge of reference values of joint structures is indispensable. The objective was to define B-mode ultrasound age- and sex-related reference values for the elbow joint in healthy children and adolescents during maturation. In a cross-sectional, multicentre ultrasound study we examined both sides of the elbow joints of 437 healthy children and adolescents (194 boys/243 girls) being between one and less than 18 years old. The children were classified into six equal age groups and divided according to their gender. We measured the distance between the outer margin of the joint capsule and the bone surface to define the bone-capsule distance (BCD), the thickness of the joint cartilage as well as the thickness of the joint capsule. The bone–capsule junction zone and the shape of the joint capsule were analysed qualitatively. The bone capsule distance and the capsule thickness increased with age. In contrast, the joint cartilage thickness decreased. In most cases the junction zone was peaked. The joint capsule showed mostly a concave shape. Intra- and interobserver reliabilities were good. We propose B-mode ultrasound age- and sex-related reference values for the elbow joint in a large number of healthy children and adolescents for the first time. By applying these standard values to the ultrasound examination of the elbow joint, it may be possible to achieve greater certainty in the diagnosis of pathological processes.

Keywords Musculoskeletal ultrasound · Elbow joint · Healthy children · Reference values · Paediatric rheumatology · Paediatric orthopaedics

Introductory letter

In the field of paediatric rheumatology and also in paediatric orthopaedics musculoskeletal ultrasound (MSUS) plays an important role in both the diagnosis and the follow-up of diseases in this field. Due to maturation of the skeletal system various changes of the joints take place. To differentiate between physiological and pathological findings, the knowledge of reference values of joint structures is indispensable. Therefore, we evaluated in a cross-sectional multicentre study B-mode ultrasound reference values for both sides of the elbow joint in 437 healthy children and adolescents (194 boys/234 girls) aged between one year and less than 18 years. The children were classified into six equal age groups and divided according to their gender. We measured the distance between the bone surface and the outer margin of the joint capsule to define the bone–capsule distance (BCD), the thickness of the joint cartilage as well as the thickness of the joint capsule. The bone–capsule junction zone and the shape of the joint capsule were analyzed qualitatively. For the examined parameters we found that the bone–capsule distance increases while the thickness of the joint cartilage decreases with age. The capsule thickness remains constant regardless of age. The joint capsule shape is predominantly concave in children older than 10 years. The bone–capsule junction zone was peaked in the majority of the study population. For the first time B-mode ultrasound

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age and sex-related reference values for the elbow joints in healthy children and adolescents are available.

Introduction

Sonography plays an important role as an imaging method in rheumatic diseases of the musculoskeletal system in adults, adolescents and children. Typical ultrasound signs of joint inflammation are effusion, hyperplasia of the synovia, joint capsule distension and, in Doppler sonography, hyperaemia of the synovia. In addition to erosions sonographic signs of joint destruction may be cartilage loss. Several studies showed the superiority of the ultrasound diagnosis compared to the clinical examination in detecting subclinical disease activity in rheumatic diseases [1, 2]. In order to recognize pathological processes, knowledge of normal findings is required. Until today, in contrast to arthrosonography in adulthood, there is a lack of standard reference values in healthy children and adolescents. There is no publication available for the elbow joint and there are only a few for other joints [3–7].

In contrast to adulthood there are different maturation degrees of unossified hyaline cartilages with secondary ossification centres depending on age in childhood [8]. This maturation process is also characterized by a reduction of the epiphyseal hyaline cartilage while the bone formation is increasing. At the end of this process, only a small stripe of joint cartilage remains (Fig. 1).

The aim of this study was, therefore, to describe intra-articular parameters that are crucial in the sonographic assessment of joint inflammation.

For this purpose we examined 874 elbow joints from children between the ages of 1 and 18 years. To cover the age-related articular changes, six equally distributed age groups were formed. We determined the bone–capsule distance (BCD), the cartilage and capsule thicknesses. To determine standard reference values for these parameters, we have decided to calculate the 95% reference interval; therefore, we calculated the 2.5 and 97.5 centiles.

The insertion of the capsule to the bone surface was as well as the shape of the capsule in relation to the dorsal bone surface qualitatively evaluated.

Materials and methods

This study was performed by members of the Imaging Working Group of the German Society of Rheumatology in Childhood and Adolescence (GKJR). It was a cross-sectional multicentre study on the elbow joint in healthy children. The study was approved by the ethical committee of the Justus Liebig University Giessen (file number AZ 114/12; 15. Feb. 2013). All study participants as well as their legal guardians gave their written informed consent before entering the study. Two paediatric rheumatologists with more than 10 years experience in musculoskeletal ultrasound reviewed all US pictures and measurements. The pictures were evaluated for compliance with the standard ultrasound scans and the correct measurements. Furthermore, the correctness of the transfer of the measurement results to the spreadsheet was checked. Only pictures and measurements that achieved a consensus concerning good technical quality were considered for the final analysis.

Fig. 1 Changes of the humero-radial joint through the maturation process during childhood (B-mode sonography), upward filled triangle radial head

Study sample

The recruited study participants were children of our own families and friends, children from hospitals and children who visited outpatient clinics for vaccinations or medical school check-ups. All these children did not have any signs or symptoms of arthritis or arthralgia in their clinical history. Children who took nonsteroidal drugs (e.g. Naproxen, Ibuprofen, Indomethacin) or prednisolone within 6 months before the examination were excluded from the survey. A paediatric rheumatologist with at least 10 years' experience performed a joint evaluation to exclude any joint pathology. This examination took place the same day as the ultrasound

examination. The study participants were aged between one and less than 18 years. In total 437 healthy patients (194 boys/243 girls) were included. The study population was divided into six age groups with each group comprising 3 years of age to consider musculoskeletal maturation. Depending on age groups and gender we could include between 23 and 54 children into the age groups 1–5. The lowest number of participants with 15 adolescents was in the male group aged 16–18 years.

Arthrosonography examination

In most cases the same paediatric rheumatologist performed both the clinical examination and the arthrosonography. Before the study began, a training took place in order to standardize the settings and procedures of the clinical as well as the ultrasound examinations. All investigators of the study centres were paediatric rheumatologists with long time experience in arthrosonography and they took part together in this training to exclude any bias.

We used standard ultrasound scans as described in the literature [8]. The measurements were performed in real time and the pictures were stored in a Picture Archiving Communication System (PACS) at each study centre. All pictures and measurements were reviewed by two paediatric rheumatologists. If pictures or measurements did not achieve a consent, the study centres were invited to repeat the measurements on the original, digitally stored pictures. Only measurements that achieved a consensus were included into the final analysis.

The following ultrasound systems were used: GE Logiq S8 (L6-15), Siemens Sonoline G40 (L9-5), Philips HD 11 (L12-5), Toshiba Xario XG (PLT-1204AX), Siemens Acuson S2000 (L9-4, 18 L6) and Esaote My Lab 60 (LA52E). The frequencies of the linear probes were 9–12 MHz. Due to non-compliance not all measurements could be taken from all participants.

Standard scans

The elbow joint was scanned in supine position with the elbow joint being extended (Fig. 2a).

A ventral longitudinal scan of the humeroradial joint was performed in order to measure the distance perpendicular between the bone surface and the outer border of the joint capsule (BCD). We described the capsule shape in relation to the corresponding bone surface as convex, concave or straight. The insertion of the joint capsule to the bone was described as peaked or round. The ventral transversal scan of the humeroradial and humeroulnar joint was performed in order to measure the joint cartilage and capsule thickness on the lateral and medial side (Fig. 2b).

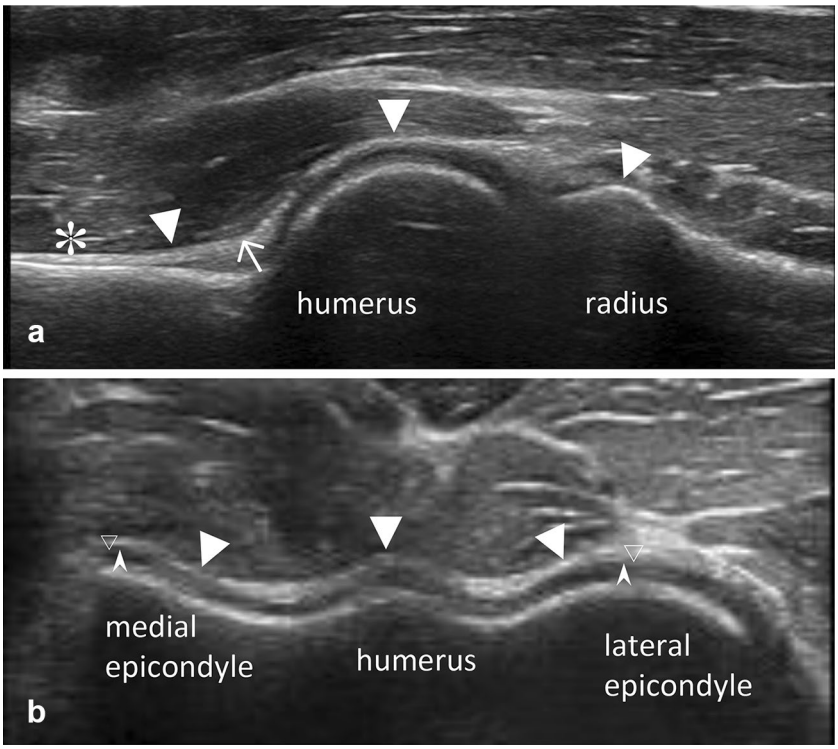


Fig. 2 **a** longitudinal humero-radial scan (upward arrow) bone–capsule distance, (asterisk) joint–capsule junction zone, (downward triangle) joint capsule. **b** Humero-radial transversal scan (upward filled triangle) cartilage thickness, (downward open triangle) joint capsule thickness, (downward filled triangle) joint capsule

Interobserver analysis

Ten children were examined by two rheumatologists independently on two consecutive days. Both investigators did not know the measurements of each other.

Statistical analysis

SPSS version 22 (IBM Armonk, US) and MedCalc Statistical Software version 14.12.0 (MedCalc Software bvba, Ostend, Belgium) were used for statistical analysis. Categorical data were expressed as the means, nominal and ordinal data as absolute values and percentages. Data were reviewed for outliers. Any outliers were excluded from further analysis. To calculate age-related reference intervals, we applied a weighted polynomial regression model. For the polynomial model we selected a power of 1 for the mean and standard deviation. We plotted the graphs using the mean and the 2.5th and 97.5th centiles (95% reference interval). To compare the joints on both sides, we used the Wilcoxon test with non-parametric datasets and a paired samples *t* test in parametric data sets. To compare the joints between both genders, we used a Mann–Whitney *U* test in non-parametric data sets and an independent samples *t* test in parametric data sets. The interobserver analyses of categorical data were calculated using average measurements in a two-way mixed model with absolute agreement, nominal and ordinal data using the kappa method. A correlation analysis was performed using Spearman's correlations. A p value < 0.05 was considered statistically significant.

Results

We analysed the ultrasound measurements of both sides of the elbow joint from 437 healthy children and adolescents (194 boys, 243 girls). The measurements are listed in the Tables 1 and 2. Figure 3a, b shows the minimum and maximum values as well as the calculated median of the 874 joints. The calculated 95% confidence interval is shown in Fig. 4a, b.

The BCD increased for both genders with raising age. For the boys the distance inclined from the youngest to the oldest children on the right side from 3 to 4.7 mm and on the

Table 1 Measurement values of elbow joint right side, minimum–maximum distance and median (mm)

Right side	Bone–capsule distance		Capsule thickness medial		Capsule thickness lateral		Cartilage thickness medial		Cartilage thickness lateral	
Age group (years)	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
1 (1.–3.)										
n	24	30	24	28	22	28	24	28	23	28
Min–max	1.6–4.4	1.7–3.7	0.4–1.6	0.1–1.7	0.6–1.6	0.4–2.0	0.4–4.7	0.4–7.6	0.3–4.5	0.4–3.8
Median	3.0	2.7	1.0	0.9	1.1	1.0	1.6	1.8	2.4	2.1
2 (4.–6.)										
n	30	41	29	40	29	40	30	40	31	40
Min–max	2.2–4.1	1.8–4.1	0.3–2.0	0.4–1.9	0.4–1.7	0.4–1.9	0.1–3.8	0.1–4.0	1.1–3.4	1.1–2.8
Median	3.2	3.0	1.1	0.9	1.1	1.1	2.0	2.2	2.2	2.0
3 (7.–9.)										
n	49	43	47	44	48	44	48	44	49	44
Min–max	2.5–4.9	2.2–4.9	0.3–2.2	0.1–1.7	0.3–1.7	0.4–2.7	0.6–5.5	0.8–6.2	1.2–2.9	1.1–2.9
Median	3.7	3.6	0.8	0.9	1.1	1.1	3.1	2.2	2.1	1.8
4 (10.–12.)										
n	37	54	37	53	37	54	37	53	36	54
Min–max	1.9–5.6	2.2–6.1	0.1–1.6	0.4–1.8	0.4–2.5	0.4–1.7	0.4–5.1	0.7–4.6	0.7–2.8	0.6–2.2
Median	3.7	3.6	0.9	0.8	1.1	1.0	2.9	1.8	1.9	1.4
5 (13.–15.)										
n	38	45	38	46	37	45	39	46	39	45
Min–max	2.5–6.2	1.5–6.3	0.3–1.9	0.1–1.3	0.4–1.8	0.3–1.8	0.7–3.6	0.4–1.6	0.7–2.2	0.5–1.8
Median	4.4	4.0	0.8	0.8	1.1	1.0	1.7	1.0	1.5	1.2
6 (16.–18.)										
n	16	30	16	30	16	30	15	29	16	30
Min–max	2.5–6.8	1.2–6.6	0.1–1.5	0.1–1.5	0.7–1.9	0.1–1.8	0.5–1.9	0.3–1.3	0.3–2.2	0.5–1.3
Median	4.7	3.9	0.9	0.8	1.2	1.0	1.2	0.8	1.3	0.9

Table 2 Measurement values of elbow joint left side, minimum–maximum distance and median (mm)

Left side	Bone–capsule distance		Capsule thickness medial		Capsule thickness lateral		Cartilage thickness medial		Cartilage thickness lateral	
Age group (years)	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
1 (1.–3.)										
n	25	30	24	27	23	27	25	26	24	27
Min–max	1.8–3.5	1.7–3.3	0.2–1.6	0.3–1.5	0.5–1.7	0.3–1.5	0.3–5.5	0.4–7.2	0.1–4.5	0.4–3.8
Median	2.8	2.5	1.0	0.9	1.1	1.0	1.4	1.7	2.3	2.1
2 (4.–6.)										
n	30	41	28	39	29	40	30	39	30	40
Min–max	2.1–4.1	1.8–4.0	0.4–1.7	0.2–1.8	0.5–2.2	0.5–1.7	0.3–4.2	0.7–5.3	0.8–4.0	0.9–3.6
Median	3.0	3.0	1.0	1.0	1.1	1.1	2.4	2.0	2.5	1.8
3 (7.–9.)										
n	50	42	48	41	49	41	49	41	49	40
Min–max	2.0–5.0	2.2–4.8	0.4–2.2	0.2–1.5	0.3–1.7	0.5–1.9	0.4–5.8	0.4–4.4	1.3–2.8	0.9–2.7
Median	3.6	3.5	0.8	0.9	1.0	0.9	3.2	2.6	1.9	1.8
4 (10.–12.)										
n	37	53	36	51	36	53	37	52	37	53
Min–max	2.3–5.4	1.7–5.8	0.3–1.9	0.2–1.4	0.3–1.9	0.5–2.1	0.4–5.7	0.6–5.3	0.9–2.9	0.7–2.2
Median	3.8	3.8	0.8	0.8	1.1	1.0	3.0	1.8	1.9	1.4
5 (13.–15.)										
n	38	43	39	44	39	44	39	43	39	44
Min–max	2.8–6.0	1.6–5.9	0.1–1.6	0.1–1.4	0.5–2.6	0.4–1.7	0.6–3.9	0.3–1.6	0.5–2.4	0.7–1.8
Median	4.4	3.8	0.8	0.7	1.2	1.1	1.6	1.0	1.5	1.1
6 (16.–18.)										
n	15	30	16	30	15	31	15	31	16	31
Min–max	2.4–5.6	1.6–6.4	0.2–1.4	0.1–1.3	0.7–1.9	0.4–1.9	0.5–1.9	0.3–1.4	0.7–1.9	0.4–1.6
Median	4.0	4.0	0.8	0.7	1.2	0.9	1.2	0.9	1.3	1.0

left side from 2.8 to 4.7 mm. For the girls the distance grew from 2.7 mm (2.5 mm left) to 3.9 mm (4 mm left). The cartilage thickness in both genders decreased by 1 mm. There were no changes in capsule thickness observed. Results are shown in Fig. 5.

In the younger population both straight and concave capsule shapes were observed, whereas the capsules in the older children were mostly concave shaped. In more than 50% of the children in age group 1 we found a straight capsule formation, while in age group 6 the capsule formation was straight in only 20%.

In the majority the capsule bone junction zone was sharp.

Differences between both sides

The boys in the age groups 1, 3 and 6 showed statistically significant differences in cartilage thickness between both joint sides in favour of the right side. The differences were <0.3 mm. For the girls only in age group 3 there was a significant difference of 0.4 mm ($p=0.02$) in favour of the left side.

Differences between genders

Only in some age groups there were significant differences between boys and girls. All these differences favoured the boys. For the left elbow joint there was a difference in age group 5 regarding the BCD of 0.6 mm. For the cartilage thickness we found for this joint a difference of 0.3–1.2 mm regarding the medial elbow side in age groups 3–6. In age groups 2 as well as 4–6 there were a difference on the lateral side (0.3–0.7 mm) regarding the cartilage thickness. For the right elbow joint there were significant differences regarding the BCD in the age groups 1 and 6 (0.3–0.8 mm). For the capsule thickness we found a difference of 0.4 mm regarding the lateral side in age group 6 and regarding the cartilage thickness on the medial as well as on the lateral side in the age groups 3–6 (0.3–1.1 mm).

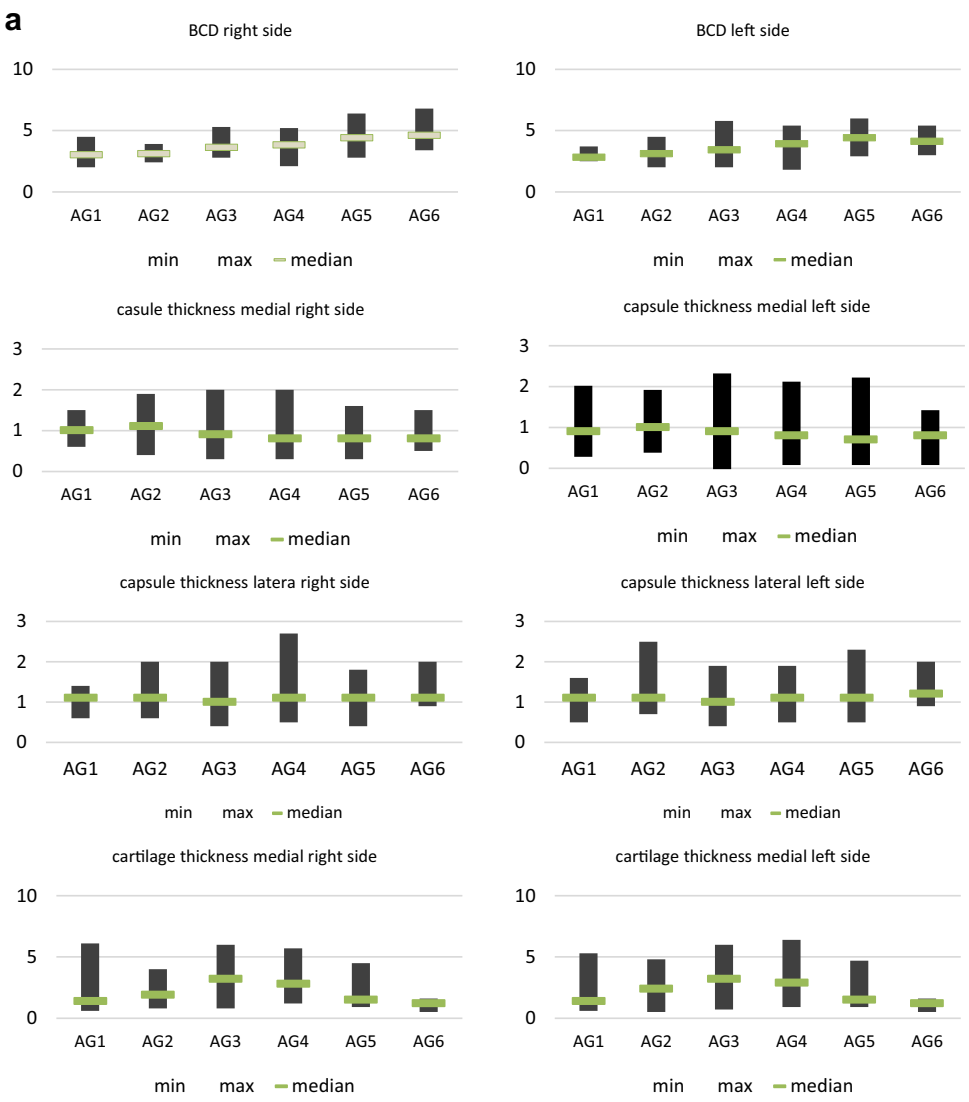


Fig. 3 **a** Measurement values for boys, minimum, maximum and median (mm); *AG* age group. **b** Measurement values for girls, minimum, maximum and median (mm); *AG* age group

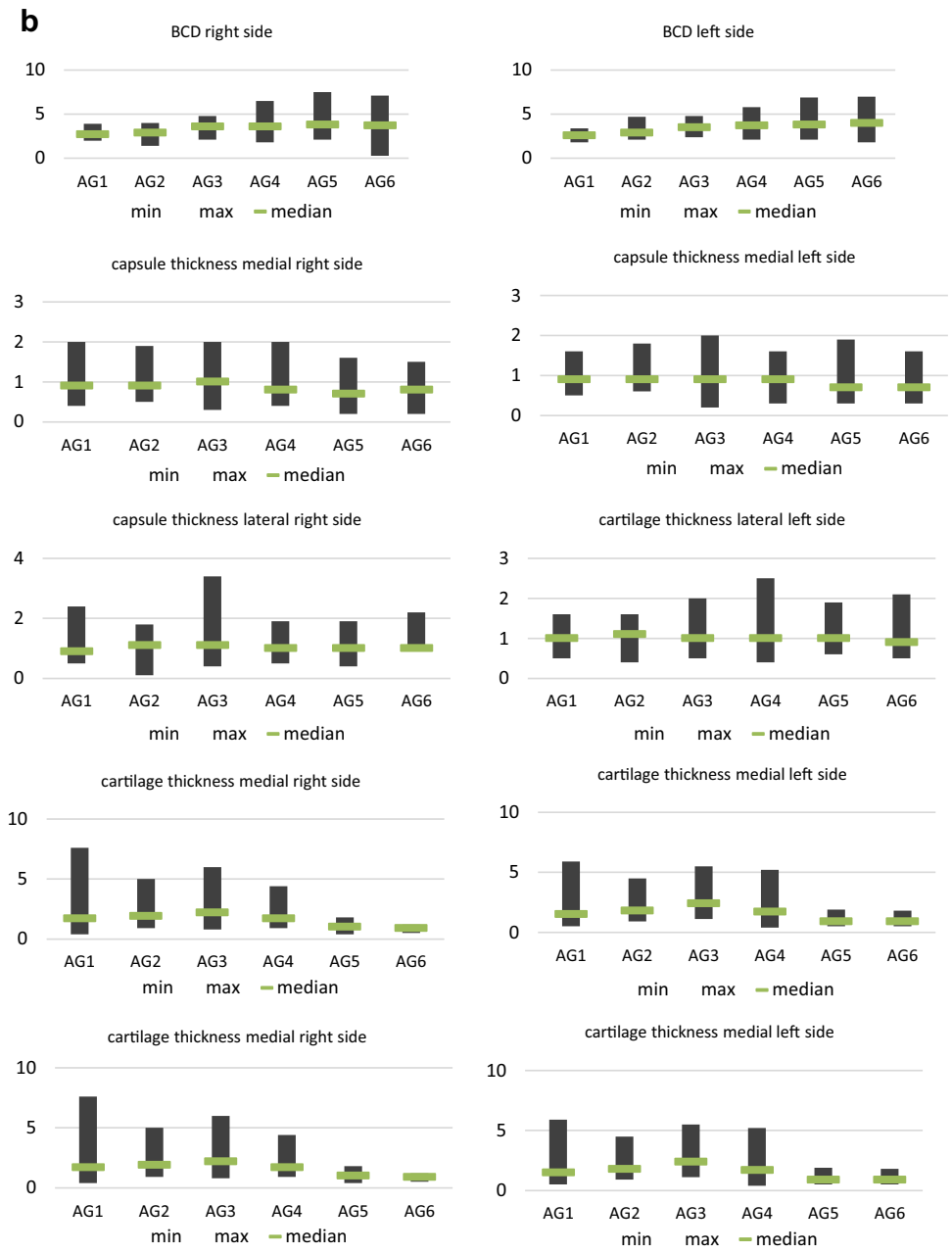
Discussion

For rheumatic diseases in childhood arthrosonography has shown great potential in early diagnosis as well as in monitoring of the inflammation [9]. For Juvenile Idiopathic Arthritis (JIA) Collado elaborated the PedSynS already in 2013, a scoring system of paediatric synovitis, to monitor joint activity changes [10]. A definition of joint parameters addressing the bone, cartilage, joint capsule, epiphyseal centre and synovial membrane for knees and ankles was published by the OMERACT group in 2015 [11].The same group proposed definitions for sonographic features of synovitis in childhood for B-mode sonography, added to Doppler findings recently [12, 13]. Several authors described the ultrasound examination technique of the elbow joint [14] and specified sonographic changes due to the maturation process [14–16]. However, up to now there are no reference values for healthy children. This lack of standardized normal findings resulted in difficulties to differentiate between physiological and pathological findings [17]. To define age-related changes for the elbow joint, our working group examined the elbow joints of 437 healthy children and adolescents (874 joints).

Joint effusions distend the joint capsule. Therefore, recognizing a deviation from normal BCD is one of the most important signs to detect a joint inflammation [17, 18]. In accordance with previous studies on other joints we found a BCD increasing with age also for the elbow joint [4, 5, 19]. By possessing the knowledge of physiological distances between bone and capsule it will be easier to decide whether intraarticular fluid is of normal range or a sign of joint inflammation.

Long-lasting inflammation processes may result in reduction of joint cartilage. For this reason we determined the cartilage thickness. Our results showed a decreasing thickness with rising age and were, therefore, in accordance with

Fig. 3 (continued)



similar ultrasound studies of other joints [5, 6, 20]. Corresponding to a study by Spannow for other joints we also found statistically significant differences for the joint cartilage thickness between both genders [20]. Boys had a thicker cartilage than girls in the higher age groups (age group 4–6). In contrast, there were no significant differences for children between 1 and 6 years for this parameter.

The measured parameters showed statistically significant differences between the two body sides in different age groups. However, these differences of less than 0.4 mm should not be clinically significant. Since we did not collect information on the handedness of the study population, we were not able to analyse the influence of this item.

The capsule thickness did not show age-dependent changes.

Using a qualitative grading of the joint capsule shape we found a concave form from the age of 10 years in 2/3 of the children. A convex shape as a possible sign of joint effusion we found in up to 7% of our healthy study population. This result is important because a convex capsule morphology is often considered as an indirect radiological sign of increased intraarticular fluid due to the inflammation process.

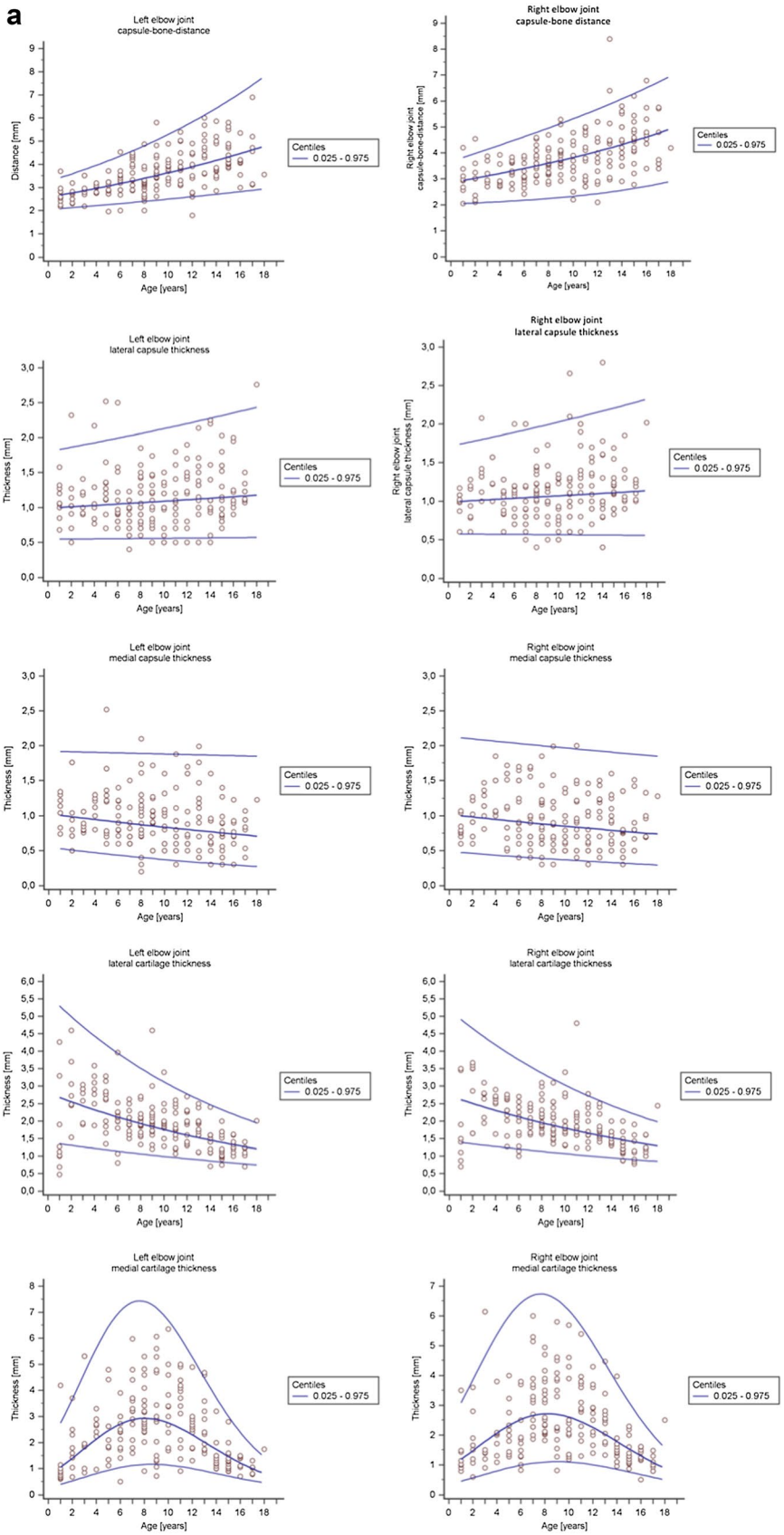
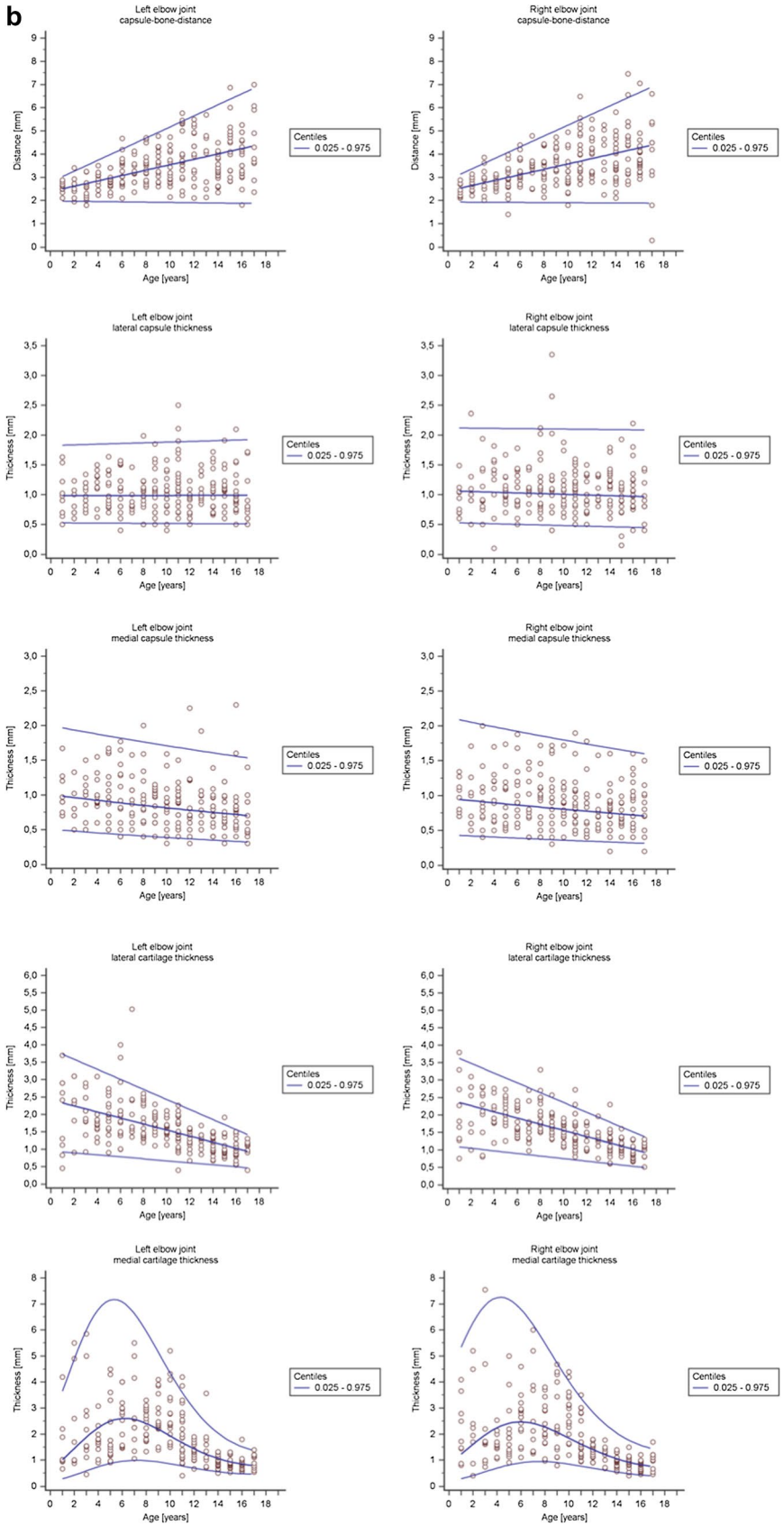


Fig. 4 **a** Age-related reference values (boys), Upper and lower lines indicate the 5th/95th centiles, the middle line the median. **b** Age-related reference values (girls), Upper and lower lines indicate the 5th/95th centiles, the middle line the median

Fig. 4 (continued)



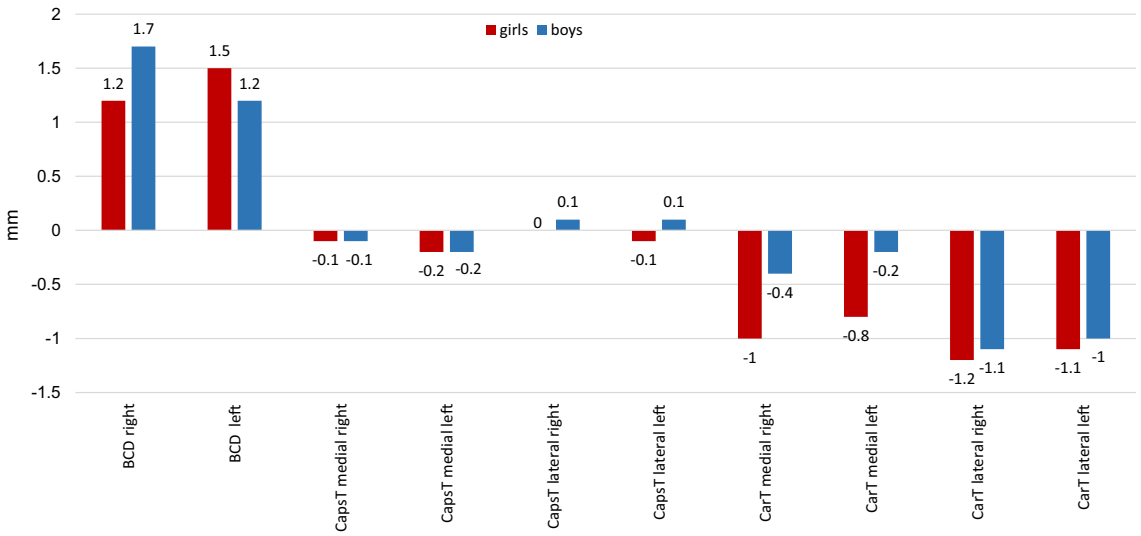


Fig. 5 Age dependend differences between age group 1 and 6. *BCD* bone–capsule distance, *CapsT* joint capsule thickness, *CarT* cartilage thickness

Limitations

Due to the various ultrasound systems used different image qualities resulted. To minimize this shortcoming, we conducted an extensive review process described in the "Materials and methods" section. Another limitation was the missing comparison of our measurements with the gold standard MRI as a second imaging method.

Conclusion

Musculoskeletal ultrasound is an important tool in the diagnosis and observation of joint structures. Especially in inflammatory processes, such as rheumatic diseases, the ultrasound assessment of joint structures is helpful in the diagnosis and follow-up of the disease. We were able to show that during the maturation the bone–capsule distance increases while the thickness of the joint cartilage decreases with age. The capsule thickness remains constant regardless of age. The elbow joint capsule shape is predominantly concave in children older than 10 years. To the best of our knowledge this is the largest B-mode ultrasound study that analysed several characteristics of the elbow joint in healthy children and adolescents. Our findings might be helpful to distinguish between normal physiological findings and pathological abnormalities caused by chronic arthritis.

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Author contributions RT, HL, RFT, MH, KP-B, GG, RB, CN, AN-T, MK-L, PS, DW: patient examination, ultrasound examination, cooperation and supplementation of the article. RFT: patient examination, ultrasound examination, cooperation and supplementation of the article and statistics.

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Compliance with ethical standards

Conflict of interest All authors declares that he has no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with ethical standards of the institutional and/or national committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants/parents included in the study.

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