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Ultrasound of the joints in children; how far have we come in establishing normal standards?

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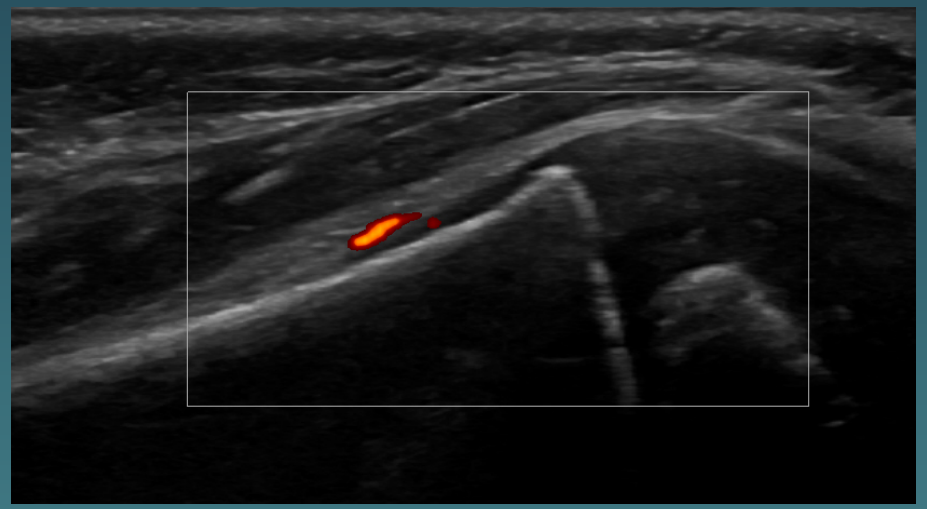

- No conflict of interest

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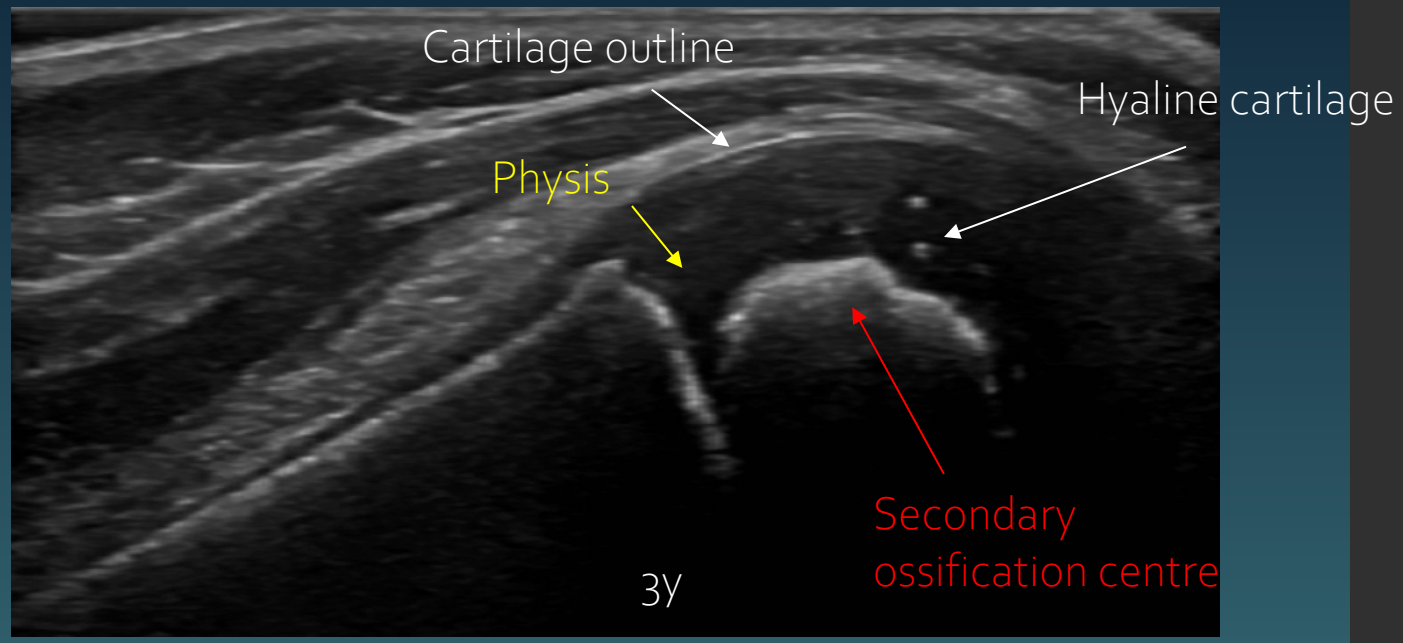
PURPOSE

To summarize recent international efforts on standardization and validation of normal pediatric joint ultrasonography

- Definitions for US findings in joints of healthy children
- Standardization in the sonographic assessment of the pediatric joint
- Dedicated validation for individual joints

DEFINITIONS

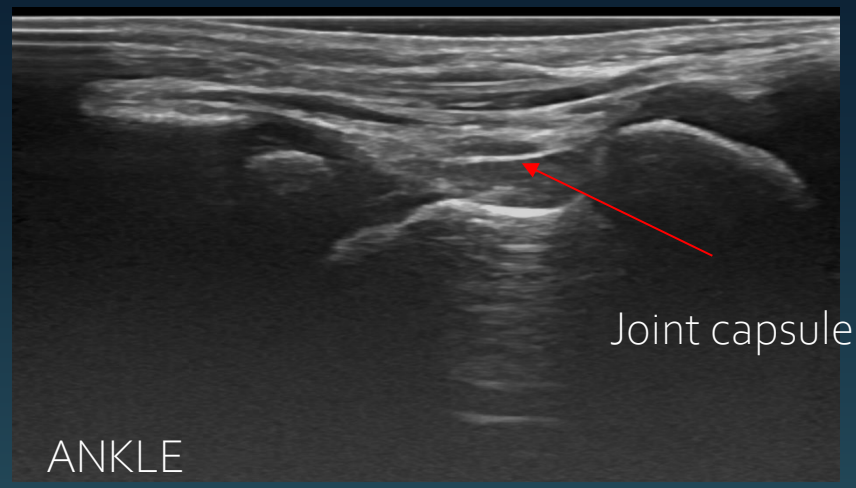
- HYALINE CARTILAGE
- EPIPHYSEAL SECONDARY OSSIFICATION CENTRE
- OSSIFIED PORTION OF ARTICULAR BONE - PHYSIS

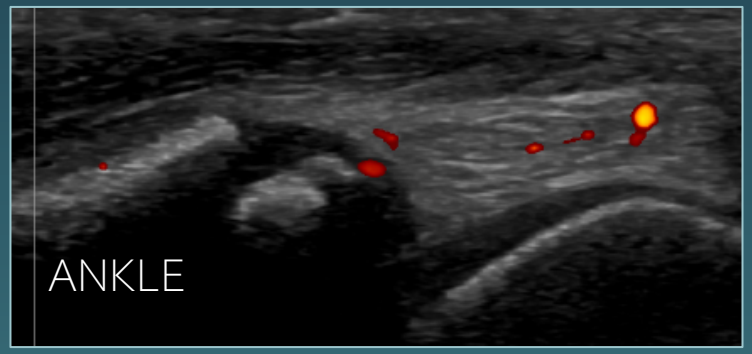


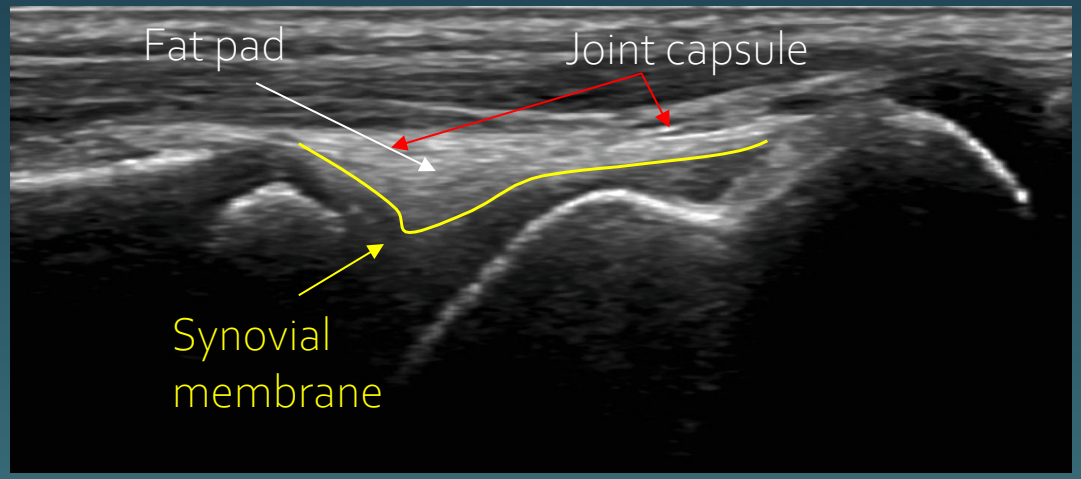
- *Roth et al.* Definitions for the sonographic features of joints in healthy children. **Arthritis Care & Research (2015)** , 67:136-142
- *Collado et al.* Amendment of the OMERACT ultrasound definitions of joints' features in healthy children when using the Doppler technique. **Pediatric Rheumatology (2018)** , 16:23

DEFINITIONS

- JOINT CAPSULE
- NORMAL SYNOVIAL MEMBRANE
- FAT PAD (intra-articular but extrasynovial)







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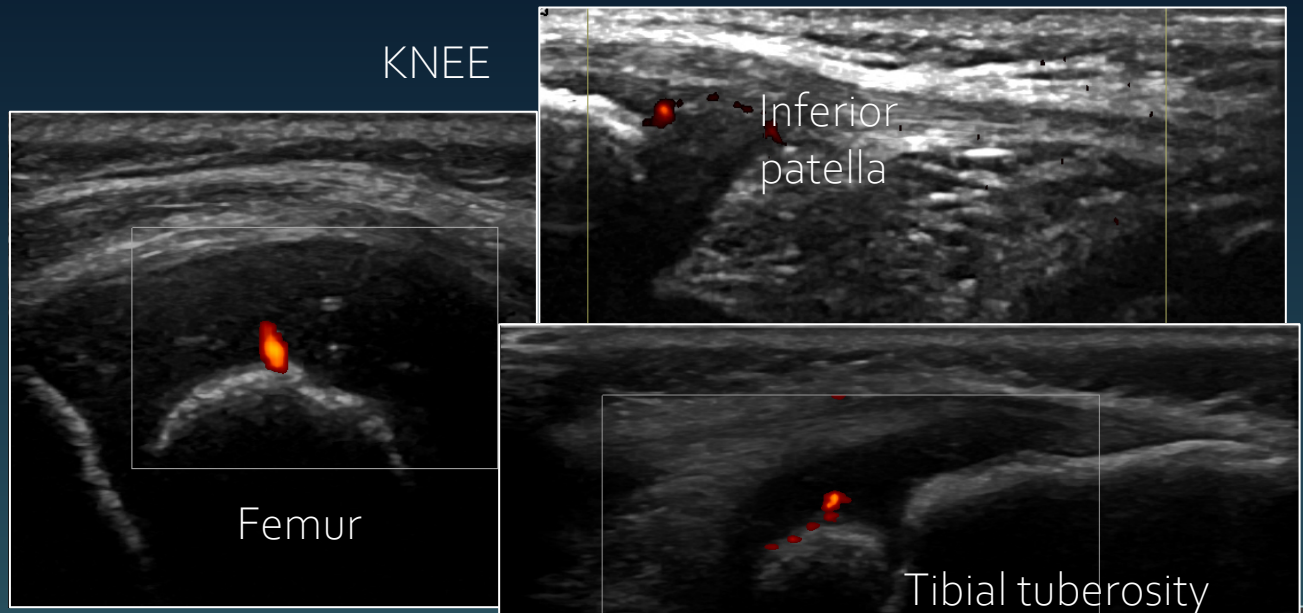
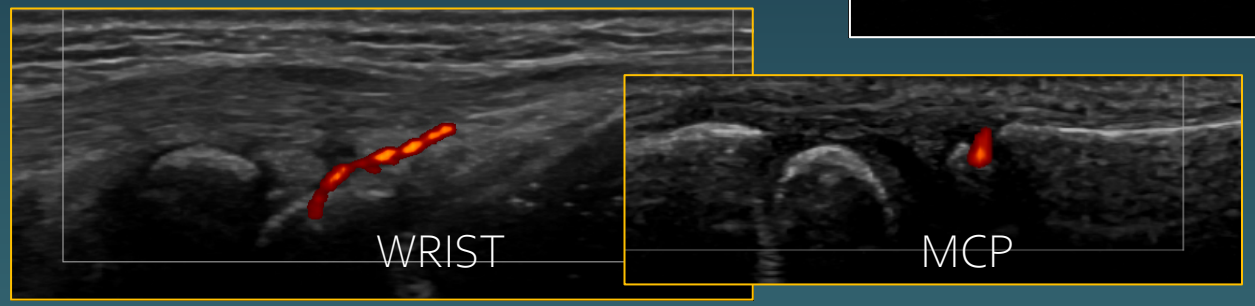
- *Collado et al.* Assessment of the joint recesses and tendon sheaths in healthy children by high resolution B-mode and power doppler sonography. **Clinical and Experimental Rheumatology (2007);**25:915-921

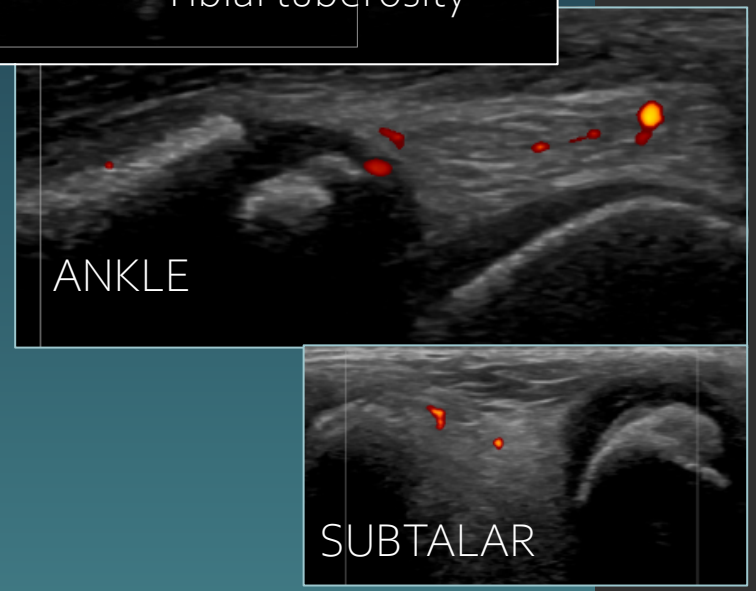
DEFINITIONS

- PHYSIOLOGICAL VASCULARITY doppler signals within the cartilage of the epiphysis, the physis and the short bone, and the fat pads

- The blood flow is easier to detect in younger children than preteens and teenagers.







- Amendment of the OMERACT ultrasound definitions of joints' features in healthy children when using the Doppler technique. **Pediatric Rheumatology (2018)** , 16:23

- *Windschall et al*. Age-related vascularization and ossification of joints in children: an international pilot study to test multi-observer ultrasound reliability. **Arthritis Care & Research (2017)** , 72(4):498-506

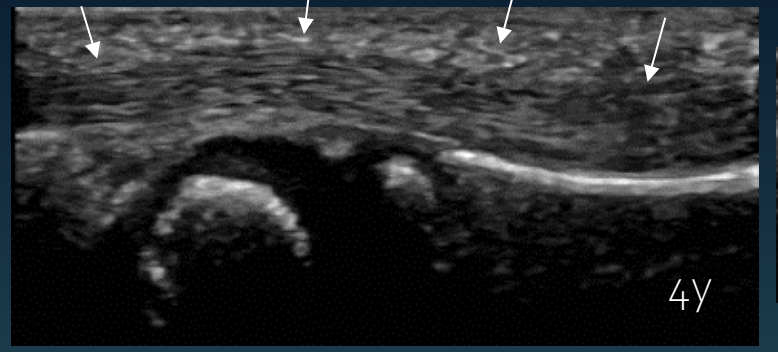
TENDON – TENDON SHEATH-PARATENON

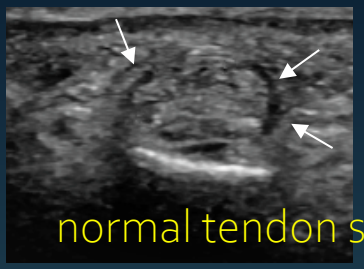
- **Tendons** are hyperechoic fibrillar structures. The fine hyperechoic bands represent the tendon fascicles

- **Tendon sheath** presents as a thin hypoechoic halo in transverse and consists of a parietal and visceral layer

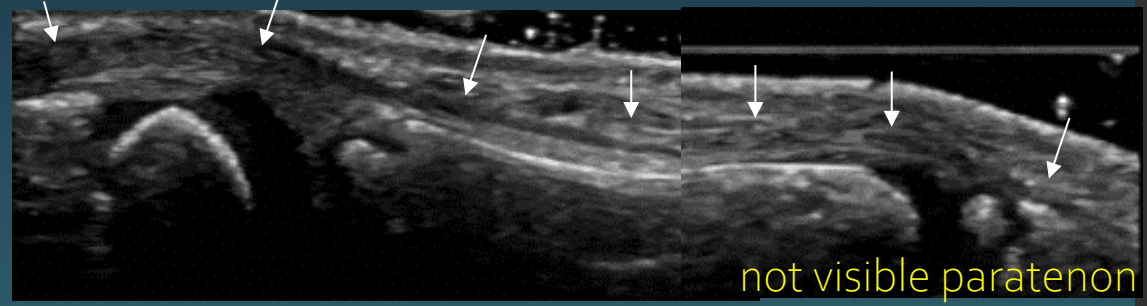
- Many tendons, like quadriceps & Achilles, do not have a tendon sheath but a **paratenon** instead. It's an elastic cover surrounding the tendon that is connective tissue lined by a single layer of synovium, normally not visible

Flexor digitorum tendon MCP2





extensor digitorum tendon

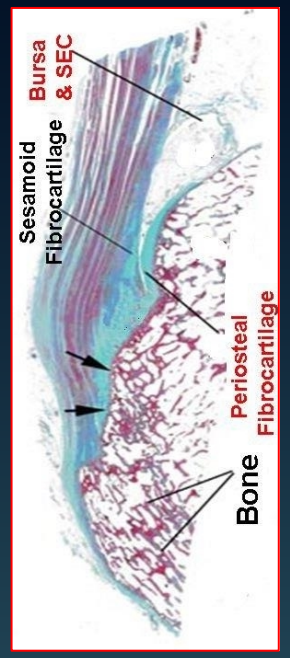


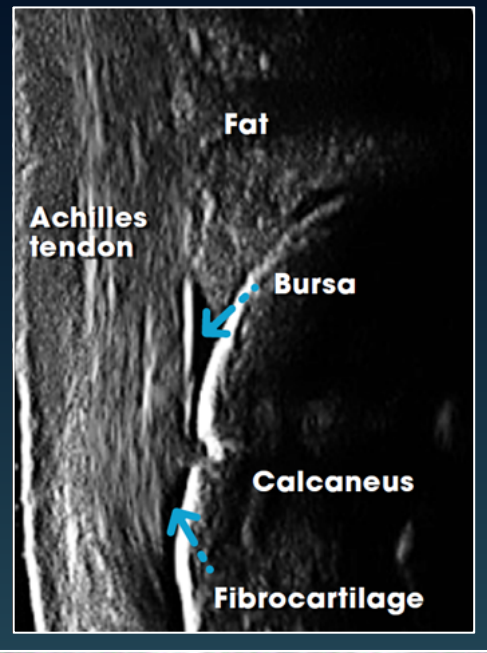
- *Weiss et al*. Imaging in Juvenile Spondyloarthritis. **Curr Rheumatol Rep (2016);18**:75

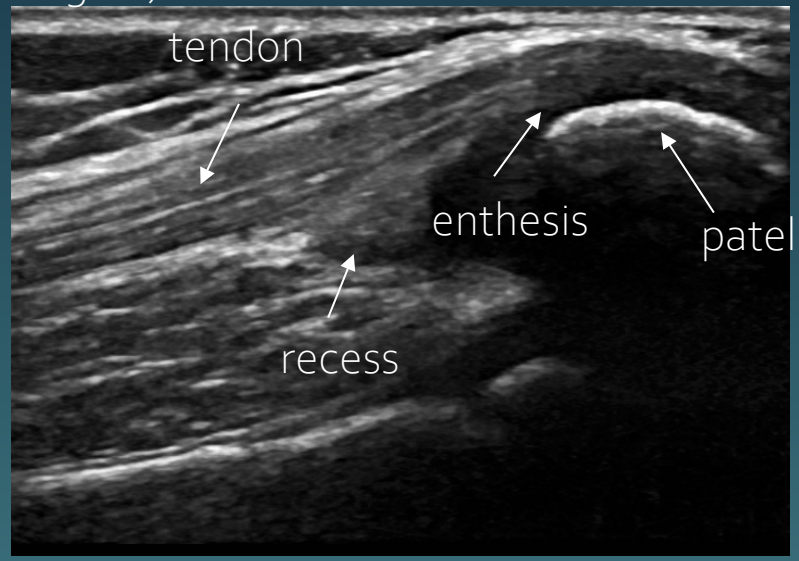
- *Collado et al*. Assessment of the joint recesses and tendon sheaths in healthy children by high resolution B-mode and power doppler sonography. **Clinical and Experimental Rheumatology (2007);**25:915-921

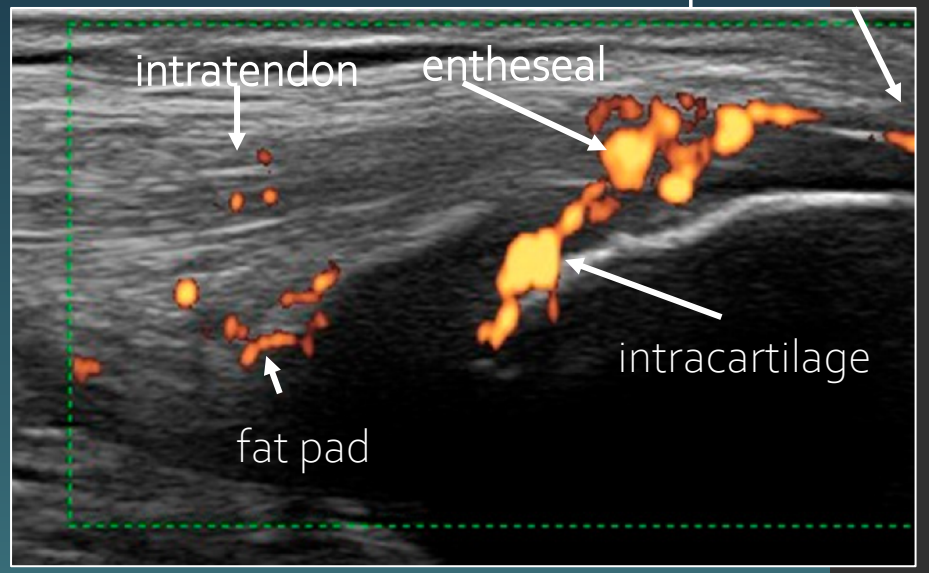
ENTHESIS ORGAN

- The ***enthesis organ*** includes the tendon with the insertion into the bone through fibrocartilage (enthesis), the fat pad and the bursa
- Doppler signals can be found close to the enthesis ,within and along the tendon, fat pad and cartilage, more prevalent in the quadriceps and distal patella tendon entheses. Varies with age. Not prevalent in Achilles.
- There are more data for quadriceps, patella and Achilles tendon. Less data for upper limb entheses and other individual entheses (hip area, fingers)









- *Weiss et al*. Imaging in Juvenile Spondyloarthritis. **Curr Rheumatol Rep (2016);18**:75

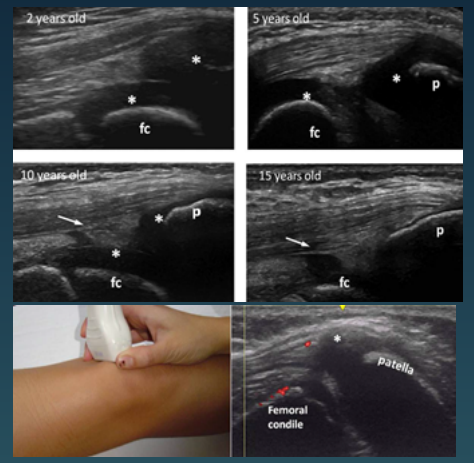
- *Roth et al*. Differential pattern of Doppler signals at lower-extremity entheses of healthy children. **Pediatric Radiology (2019);49**:1335-1343

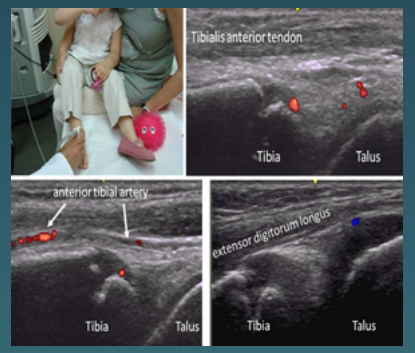
STANDARDISED SCANNING PROTOCOL

It is crucial to develop an examination protocol and standardize a scanning method

- A multicenter study, 64healthy children , 4 groups 3y to 16y
- KNEE, ANKLE, WRIST, MCP 2 (most involved in JIA) with predefined scanning positions and definite reference points
- Highly comparable images among the examiners. Image atlas and age-specific findings developed, providing a framework for ongoing MSUS studies

- Synovial recesses of the 4 joints do not show any doppler signal
- Blood flow of the epiphyseal cartilage, fat pad





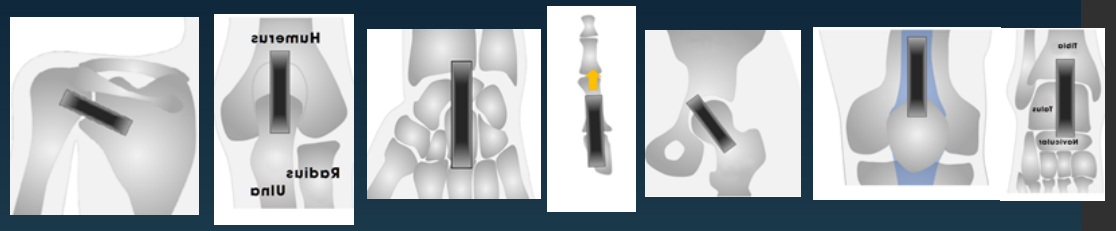
- *Collado et al*. Toward standardized musculoskeletal ultrasound in pediatric rheumatology: normal age-related ultrasound findings. **Arthritis Care & Research (2016)** , 68:348-356
- OMERACT ULTRASOUND PEDIATRIC GROUP

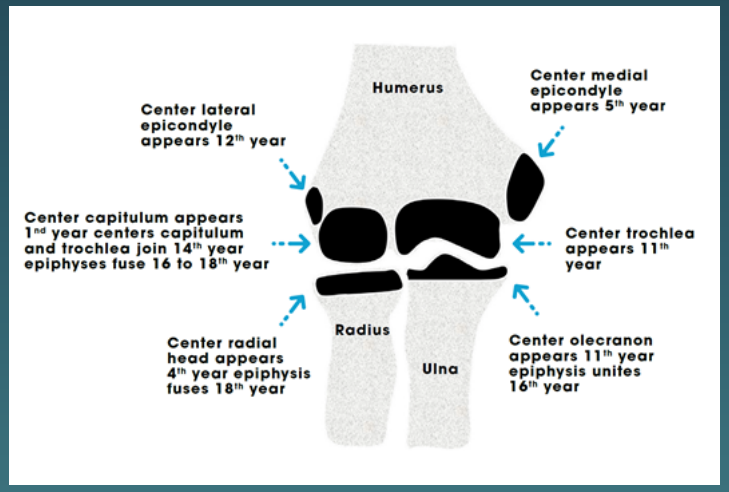
STANDARDISED SCANNING PROTOCOL

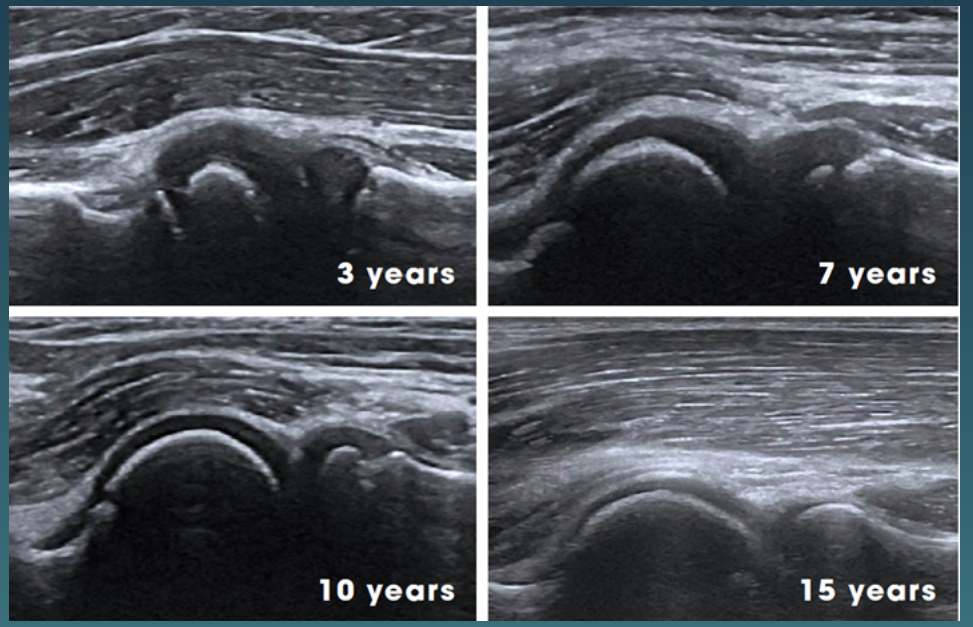
Ped-MUS

- ped-mus.com

Educational initiative led by an independent steering Committee of experts

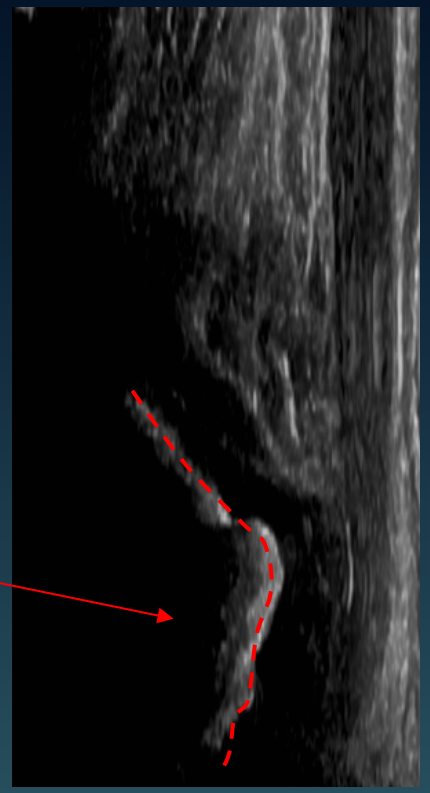






ASSESSMENT OF CARTILAGE

- *Cartilage thickness* changes with age and sex but also with maturity
- Importance for reproducible US measurements beyond observer variability
- The irregularity of ossification centers will affect the ability to obtain precise measurements, especially in younger children



- *Cartilage surface* as an alternative (presence of the cartilage interface sign) might be an important indicator of healthy cartilage

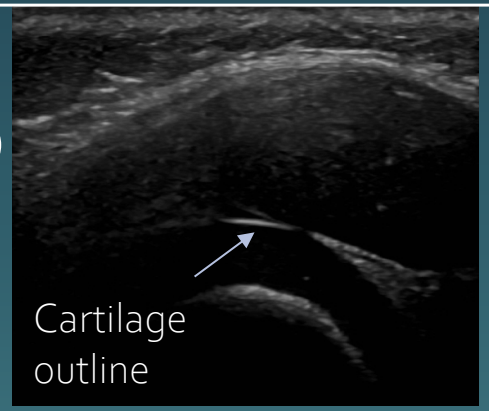


Table 1. Cartilage thickness in 8- and 15-year-old boys and girls, shown as mean (mm), 95% confidence interval (CI) and 95% predicted interval (PI).

Joint, Age Group, 8- and 15-yr-old	Mean, mm	95% CI	95% PI
		Boys	
Knee			
8	3.96	3.86 to 4.06	3.14 to 4.78
15	3.47	3.38 to 3.56	2.65 to 4.28
Ankle			
8	1.14	1.09 to 1.18	1.10 to 1.18
15	0.88	0.83 to 0.92	0.84 to 0.92
Wrist			
8	2.00	1.91 to 2.09	1.95 to 2.04
15	1.18	1.10 to 1.26	1.14 to 1.23
MCP			
8	1.45	1.40 to 1.49	1.41 to 1.48
15	0.71	0.67 to 0.75	0.67 to 0.74
PIP			
8	0.89	0.86 to 0.92	0.85 to 0.93
15	0.59	0.56 to 0.62	0.55 to 0.63
		Girls	
Knee			
8	3.60	3.50 to 3.71	2.71 to 4.50
15	2.87	2.74 to 3.00	1.98 to 3.77
Ankle			
8	0.99	0.96 to 1.03	0.67 to 1.32
15	0.78	0.73 to 0.83	0.46 to 1.10
Wrist			
8	1.71	1.63 to 1.79	1.05 to 2.37
15	0.96	0.86 to 1.05	0.30 to 1.62
MCP			
8	112	1.09 to 1.16	0.83 to 1.42
15	0.53	0.48 to 0.57	0.23 to 0.82
PIP			
8	0.80	0.77 to 0.82	0.58 to 1.01
15	0.44	0.40 to 0.47	0.22 to 0.65

- 394 healthy, 7 to 16y ,children - 3940 joints (KNEE, ANKLE, WRIST, MCP, PIP)
- Cartilage thickness clearly decreases with age
- Boys have thicker cartilage
- No difference between RT and LT

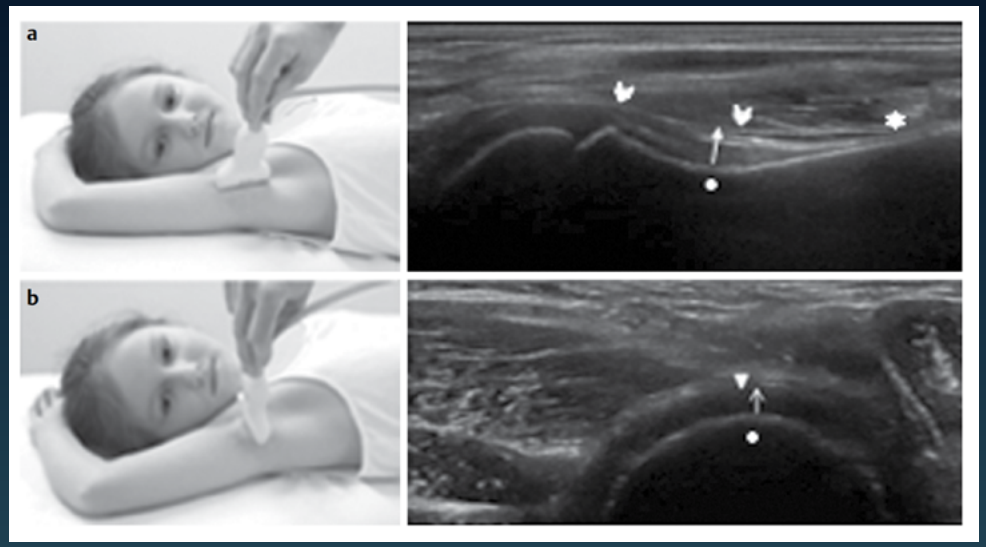
- *Spannow et al.* Ultrasonographic measurements of joint cartilage thickness in healthy children: Age and sex-related standard reference values. **J Rheumtol (2015);37**:2595-2601

IDIVIDUAL JOINT ASSESSMENT

SHOULDER

445 children 1-18y both sides
Axillary longitudinal and transversal scan – B mode

- Measure the capsule-bone distance (BCD)
- Thickness of joint capsule
- Shape of joint capsule (qualitive parameter)
- Thickness of cartilage



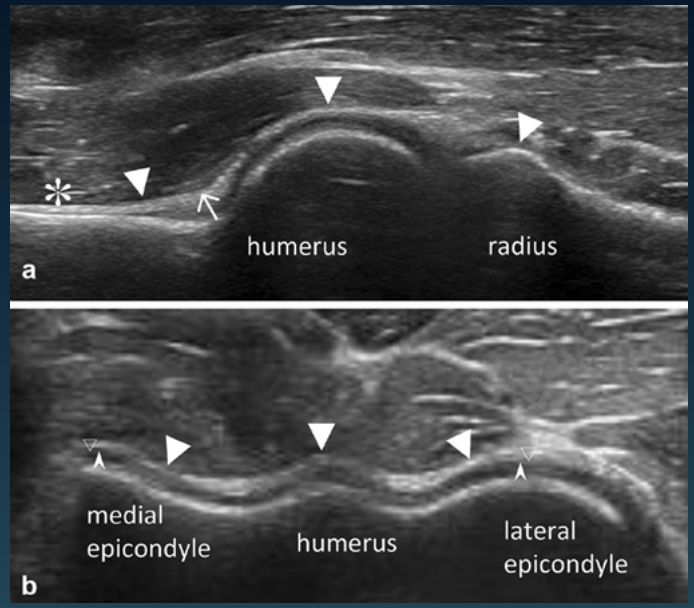
- BCD increasing with age (range in M 2.7-4.2mm / F 2.7-4.1mm)
- Capsule thickness increasing with age 20%
- Capsule shape mostly concave , 12,5% straight or convex (important anatomical variance). NO FLUID
- Cartilage thickness is decreasing with age by 70% (M thicker than F).

- *Trauzeddel et al*. Arthrosonographic reference values of the shoulder joint in healthy children and adolescents: a cross-sectional multicentre ultrasound study. Dorsal soft tissues. **Klin Padiatr (2017);229:293-301**

ELBOW

437 children-adolescents 1-18y (6 age groups)/ 874joints
Humeroradial longitudinal and transversal scan – B mode

- Measure the capsule-bone distance (BCD)
- Thickness of joint capsule
- Shape of joint capsule
- Thickness of cartilage



- BCD increasing with age (median M 2.8-4.7mm / F 2.5-4mm)
- Capsule thickness age-independent (median 0.8-1,2mm)
- Capsule shape mostly concave , 7% convex (important anatomical variance)
- Cartilage thickness decreasing with age (M thicker than F)

- *Trauzeddel et al.* Age dependent ultrasound B-mode findings of the elbow joint in healthy children and adolescents. **Rheumatol Int (2019) June**;39(6):1007-1018

WRIST

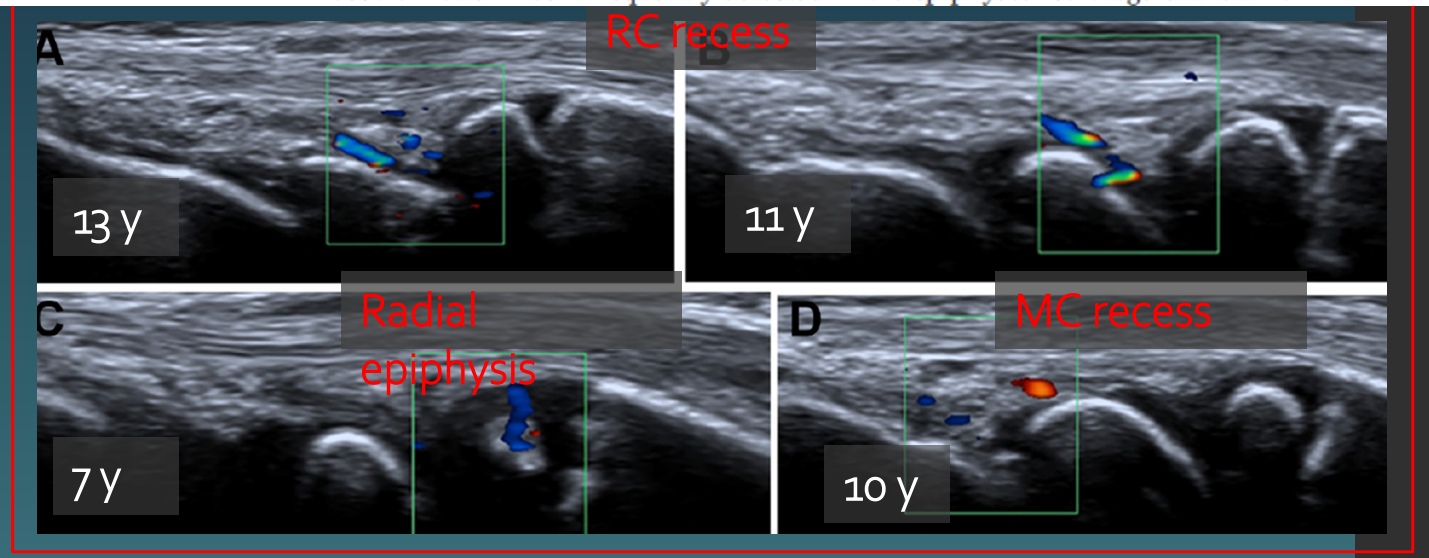
116 children 6-16y
US of the RT wrist with a ***dorsal mid-sagittal image*** *of RC and MC joints in* ***neutral and flexed position***

- The RC and MC recess can be visible (0-3mm), 60% of the RC recess, bulging in the minority. Be careful of the variability of measurements for so small distances!
- Flexion reduces it (84,5%), suggesting fluid
- Doppler signal can be found in the radial epiphysis (17,2%), in the fat pad (6%), close or in the recesses (RC 9,5%(7,8), MC 10,3% (3,5))

- *Collado et al.* Toward standardized musculoskeletal ultrasound in pediatric rheumatology: normal age-related ultrasound findings. **Arthritis Care & Research (2016)** , 68:348-356 (OMERACT)

Table 2. Vascularization findings detected in B-mode combined with Doppler ultrasound (US) examination in healthy pediatric joints*

US examination	Vascularization findings
Longitudinal wrist dorsal lateral	Vessels within or surrounding the synovial recess (when the recess was visualized) were not found in any age groups. There were 1 or 2 vessels located in the intraarticular connective tissue on some carpal bones. Vascularization detectable at 3 different levels of the joint: 1) Vessels in the epiphyseal cartilage of the radius. However, they were not detected in images from the oldest age group. 2) Vessel in the epiphyseal cartilage of the scaphoid, mainly in group 1.
Longitudinal wrist dorsal midline	Vessels surrounding the synovial recess (when it was visualized) were not found in any age groups. There were 1 or 2 vessels located within the intraarticular connective tissue on some carpal bones (deep dorsal carpi branches of the radial artery). Vascularization was infrequently detected in the epiphyseal cartilage of the lunate.
Longitudinal wrist dorsal medial	Vascularization was rare in this area of the joint. It was found mainly in the intraarticular connective tissue on the epiphyseal cartilage of the triquetrum. Vascularization was infrequently detected in the epiphyseal cartilage of the ulna.

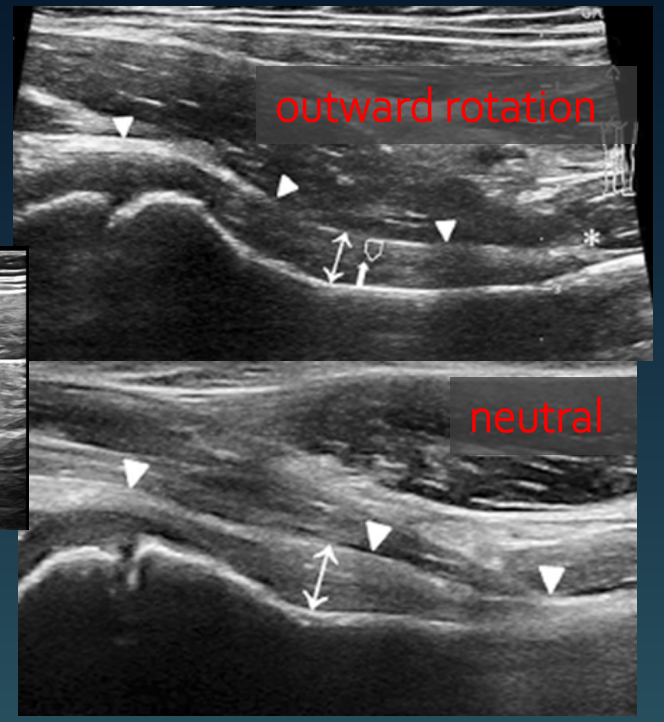


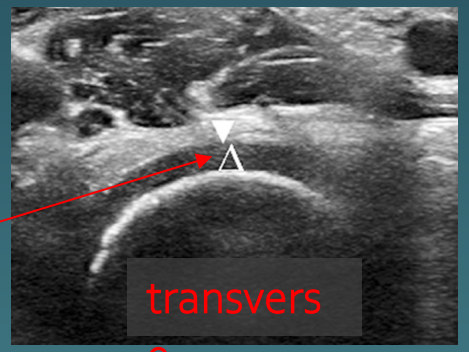
- *Rosendahl et al.* Normative ultrasound references for the paediatric wrist. Dorsal soft tissues. **Rheumatic & Musculoskeletal Diseases (2018)** , 10;4(1)e000642

HIP

- The joint capsule is evaluated at the level of the anterior recess – anterior longitudinal scan
- Anterior and posterior layers of the capsule can be observed – ***stripe sign*** *in between*
- The capsule is echogenic and of concave outline in hip outward rotation
- The thickness of the anterior recess is a good and reproducible parameter for routine hip joint assessment. Small amount of synovila fluid may be seen normally.
- Average thickness 5mm. This parameter changes with age and height of a child : 3.7mm in the first year of life to 6.7mm at the age of 16years
- Comparison with contralateral side with a difference of 2mm or more clinically significant
- Thickness of articular cartilage could be assessed, decreases with age

PROPOSED POSITION





- *Trauzeddel et al* **Pediatric Radiology (2017)**
- *Zuber et al* **Pediatr Rheumtol Online J (2017)**
- *Robben et al* **Radiology (1999), Eur J Radiol (1993)**
- *Rohrschneider et al* **Pediatric Radiology (1996)**

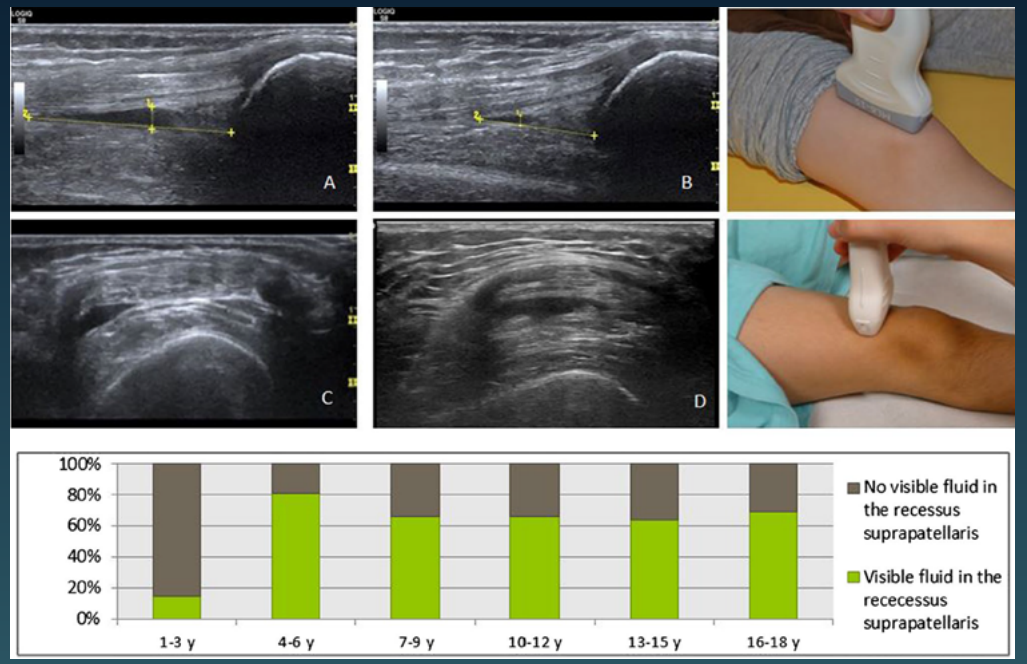
KNEE

Suprapatellar - parapatellar recesses

Anatomic landmarks

- *longitudinal*: superior edge of the patella –distal portion of the femur
- *transverse*: superior edge of the patella – femoral condyle
- Neutral /(slightly flexed in other studies)

- 60-64% of healthy children had fluid within the suprapatellar recess, visible in longitudinal and transverse scan.
- Less common in 1-3y age group
- Maximum values of suprapatellar recess depth up to 6mm, depth increases with age



435 children 1-18y in 6 age groups, gender-related/ 870 joints

- *Windschall et al.* Pediatric musculoskeletal ultrasound: age- and sex-related normal B-mode findings of the knee. **Rheumatol Int (2016)**

- <u>No vessels within or near the suprapatellar recess, only in the fat pad</u>

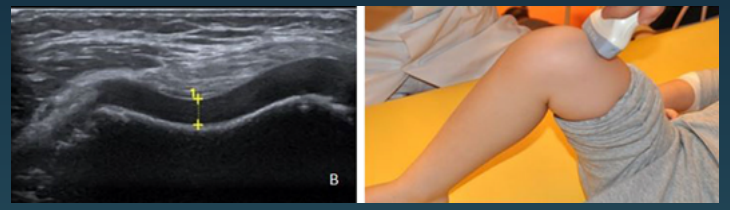
64healthy children , 4 groups 3y to 16y

- *Collado et al.* Toward standardized musculoskeletal ultrasound in pediatric rheumatology: normal age-related ultrasound findings. **Arthritis Care & Research (2016)** , 68:348-356

KNEE

Distal femoral epiphysis intercondylar cartilage thickness

- Knee maximally flexed



Mean values age and sex-related (agreement in different studies)

- *F: 4 to 3.1mm from 7-9y to 13-15y*
- *M: 4.1 to 3.5mm*

Age-group	Intercondylar cartilage thickness, mm			
	Right knee		Left knee	
	Boys	Girls	Boys	Girls
1–3 years				
Mean (95 % RI)	3.9 (3.3–4.6)	3.4 (2.3–4.5)	3.9 (2.3–5.8)	3.7 (2.4–5.0)
Included probands	25	30	25	30
4–6 years				
Mean (95 % RI)	4.3 (2.7–5.9)	3.9 (2.2–8.3)	4.4 (2.7–5.8)	4.3 (2.8–5.5)
Included probands	31	37	32	37
7–9 years				
Mean (95 % RI)	4.4 (2.9–6.0)	4.0 (1.7–6.2)	4.6 (2.8–6.2)	4.0 (2.2–5.9)
Included probands	49	43	49	43
10–12 years				
Mean (95 % RI)	4.1 (2.7–5.5)	3.6 (1.8–5.3)	4.3 (2.7–5.9)	3.5 (1.5–5.5)
Included probands	36	53	36	53
13–15 years				
Mean (95 % RI)	3.5 (1.7–5.2)	3.1 (1.5–4.7)	4.0 (1.9–5.9)	3.0 (1.2–4.6)
Included probands	39	44	39	44
16–18 years				
Mean (95 % RI)	3.6 (1.9–6.9)	2.8 (1.4–4.2)	4.0 (1.4–6.3)	3.0 (1.6–4.4)
Included probands	16	30	16	29

- M thicker cartilage than F
- Age dependent intercondylar cartilage thickness decrease (agreement for the ages between 10-18y)
- No difference between the left and the right side
- Acceptable agreement between US and MRI

- *Windschall et al.* Pediatric musculoskeletal ultrasound: age- and sex-related normal B-mode findings of the knee. **Rheumatol Int (2016)**

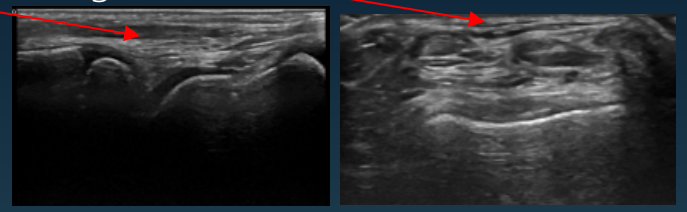
- *Spannow et al.* Ultrasonographic measurements of joint cartilage thickness in healthy children: age- and sex- related standard reference values. J **Rheumatol (2010);37:2595-2601**

- *Spannow et al.* Ultrasound and MRI measurements of joint cartilage in healthy children: a validation study . **Ultraschall Med (2011);S1:110-116**

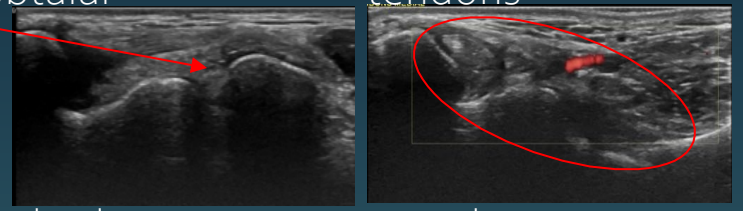
ANKLE

- *131 children LT & RT – ankle & subtalar*
- *3-14y in 4 age groups*

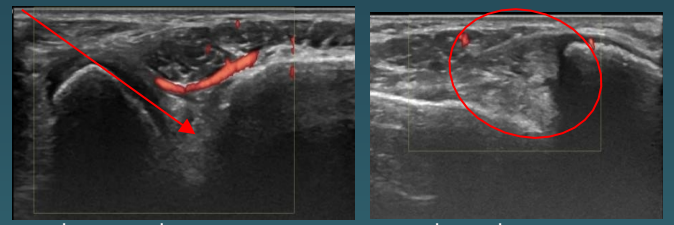
- ANTERIOR long - transverse ,tendons



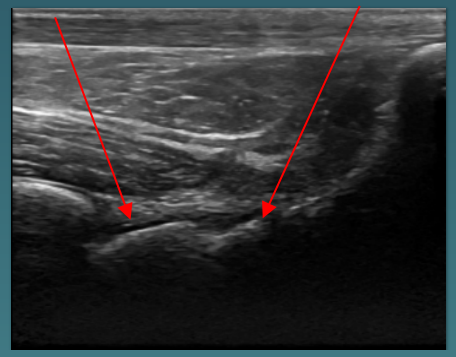
- MEDIAL subtalar - tendons



- LATERAL subtalar - tendons

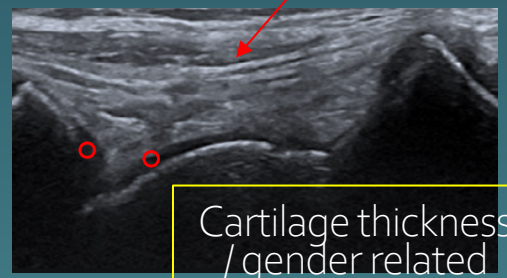


- POSTERIOR tibiotalar - subtalar

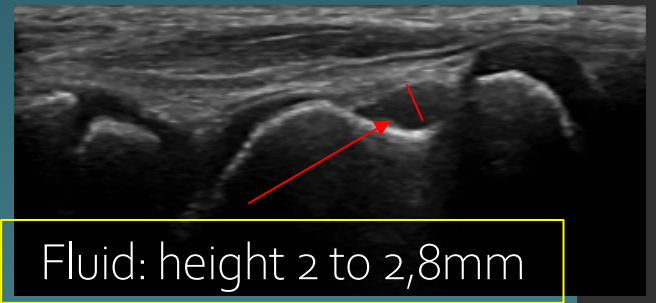


- Appearance of the synovium/ capsule
  scored as 0=not visible
  1=visible – not bulging
  2=bulging
- Intraarticular fluid (ankle, subtalar) and tendon sheath fluid – dynamic assessment
  amount of fluid and fluid echogenicity
- Doppler signals
  within the recess or in proximity
- Articular cartilage thickness :
  distal tibia/ talar dome – gender related

➢ >50% of healthy children had fluid within the capsule of the tibiotalar joints, higher percentage in the younger age groups



Cartilage thickness / gender related



Fluid: height 2 to 2,8mm

CONCLUSION

- Normative data are an important basis for interpretation of findings

- The comparison with normative data should serve as guidance, but not absolute cut-off, for pathology

MORE WORK NEED TO BE DONE TO BUILD THE EVIDENSE BASE FOR THE USE OF MSK US IN PEDIATRICS