ORIGINAL ARTICLE

The interosseous tuberosities of the forearm exist from 1-year-old: a pediatric radiological study describing the ages of appearance of the different forearm reliefs

Nicolas Mainard[1,2] · Tristan Langlais[3] · Marc Soubeyrand[4] · Raphaël Vialle[1,5] · Maud Creze[6] · Gregoire Rougereau[1,7]

Abstract

Purpose Interosseous tuberosities have been described in adults on the radial and ulnar sides. However, their presence at birth and their development during growth is still unknown. The objective of this work is to establish the age of onset of this tuberosity among a cohort of children aged 1-year-old or older.

Methods All anterior–posterior and lateral radiographs performed in our hospital during a consecutive period of 6 months were retrospectively analyzed. Exclusion criteria were: presence of a fracture, a tumor, an age higher than 16 years, radiograph not performed strictly from the front with supination or from the side. On the anterior–posterior radiograph, the presence of the following structures was sought: radial interosseous tuberosity and determination of its length and width; the appearance of the epiphyseal nucleus of the radial head, of the bicipital tuberosity, and of the distal epiphysis. On the lateral views, the presence of the following structures was sought: ulnar interosseous tuberosity and determination of its length and width; the appearance of the olecranon epiphyseal nucleus, and the distal epiphysis.

Results Over the review period, anterior–posterior and lateral radiographs were performed on 368 consecutive children. Finally, 179 patients were included in the radiographic analysis. The radial and ulnar interosseous tuberosities and bicipital tuberosity were present in all cases, from 1-year-old. Only the distal radial epiphysis began to appear at the age of one year, the others ossifying progressively during growth.

Conclusion Tuberositas interossea ulnarii and radii exists, are present from 1-year-old and continue to develop during growth.

Keywords Anatomy · Forearm · Radial interosseous tuberosity · Ulnar interosseous tuberosity · Interosseous membrane

✉ Gregoire Rougereau
  greg.rougereau@gmail.com

1 Department of Orthopaedic and Reparative Surgery for Children, Sorbonne University, Armand Trousseau Hospital, AP-HP, Paris, France

2 Department of Pediatric Orthopedic, Hospital Jeanne de Flandre, CHU LILLE, Lille, France

3 Department of Pediatric Orthopedic and Reconstructive Surgery, Children's Hospital, Purpan, University of Toulouse, Toulouse, France

4 Department of Orthopedics and Traumatology, Clinique Saint Jean L'Ermitage, 272 Avenue Marc Jacquet, 77000 Melun, France

5 The MAMUTH Hospital University Department for Innovative Therapies in Musculoskeletal Disease Sorbonne University, Paris, France

6 Department of Radiology, Bicêtre Hospital and Paris Sud University, 78 Rue du Général Leclerc, 94270 Le Kremlin-Bicêtre, France

7 Department of Orthopedics and Traumatology, Pitié-Salpêtrière Hospital, Sorbonne University, 47-83 Boulevard de L'Hôpital, 75013 Paris, France

Introduction

The anatomy of the ulna and radius have been represented for a long time with tuberosities on their interosseous sides [9, 10, 14, 17]. Nevertheless, true interosseous tuberosities have been described recently [11, 12]. They correspond to cortical thickenings that may play a role in forearm stability and fingers mobility, especially the thumb.

On each of the interosseous tuberosities is found the biomechanically active part of the interosseous membrane: the central band [4, 13, 15, 16]. On the radial interosseous tuberosity, most of the extrinsic muscles for the thumb (flexor pollicis longus and extensor pollicis brevis) are also found [11]. The abductor pollicis longus is attached to the upper third of the lateral side of the ulnar interosseous tuberosity and on the upper two-thirds of the radial interosseous tuberosity [11, 12]. On the lateral side of the ulnar interosseous tuberosity, the extensor pollicis longus as well as the extensor indicis are inserted, and the flexor digitorum profundus muscle is on the medial side [12]. Nevertheless, the age of appearance and ossification of this structure, as well as its development during growth, are unknown.

The objective is to describe a radiographic cohort of pediatric patients of varying ages to estimate the age of onset of these interosseous tuberosities, as well as describe their evolution. The hypothesis is that these structures could ossify during growth in response to traction phenomena at the time when the child begins to acquire a certain level of digital mobility, grip or forearm prono-supination.

Materials and methods

The study was registered with the Commission Nationale de l'Informatique et des Libertés (CNIL—no. 2227470 version 0). The review of the data was conducted in accordance with the ethical standards of the 1964 Declaration of Helsinki and the reference methodology MR-003.

Cases identification

The hospital's database was analyzed for the period between January 1, 2021 and June 30, 2022. All anterior–posterior and lateral radiographs taken over this period were retrospectively analyzed using the image archiving and communication system (PACS, Carestream Vue Pacs, version 12.1, Carestream Health, Rochester, New York, USA). Inclusion criteria were: absence of a fracture or a tumor, and age higher than 16 years.

Exclusion criteria were: radiograph not made strictly from the front with supination position or the side.

Study protocol and data collection

Two observers blinded to each other were included in the analysis of the radiographs (one resident and one senior, both orthopedic surgeons). All the measurements were carried out according to the same protocol defined before the study, on a computer. The observers could zoom and manage the contrasts to obtain the most precise measurements possible.

The ulna was analyzed on the lateral radiographs and the radius on the supinated anterior–posterior radiograph. They used the same methodology previously described on the radiograph to analyze the presence of an interosseous tuberosity [11, 12]. They looked for diaphyseal cortical thickening on the interosseous side of the bone studied: if thickening was identified, the tuberosity was considered present. The beginning of the tuberosity was considered to be at the level of the start of cortical thickening, and its end at the moment when the cortical width decreased until it reached a constant value.

The following measurements were made on the anterior–posterior radiographs: length of the radial interosseous tuberosity (RTL), as well as the cortical width proximally (RT1), at its level (RT2), and distally (RT3). Then, the presence of the following structures was sought: appearance of the epiphyseal nucleus of the radial head, the bicipital tuberosity, and the distal epiphysis. On the lateral radiographs, the following measurements were made: length of the ulnar interosseous tuberosity (UTL), as well as the cortical width proximally (UT1), at its level (UT2), and distally (UT3). Then, the presence of the following structures was sought: the appearance of the epiphyseal nucleus of the olecranon and the distal epiphysis. Finally, the total length of the radius and ulna was measured between the two growth plates. The radiographic measurement protocol is shown in Fig. 1.

For all radiographic measurements performed the inter-observer reproducibility was determined for the first 50 patients of the radiological series. The intra-observer reproducibility was determined with the senior observer, having performed his second series of measurements on the same patients with a delay of two months, blinded to his first results.

Statistical analysis

The Wilcoxon–Mann Whitney for unpaired data was used to analyze the association between the different variables. The alpha risk was set to 0.05. The intra-class correlation coefficient (ICC) was used to evaluate the intra-rater and inter-rater agreements in radiological measurements. An
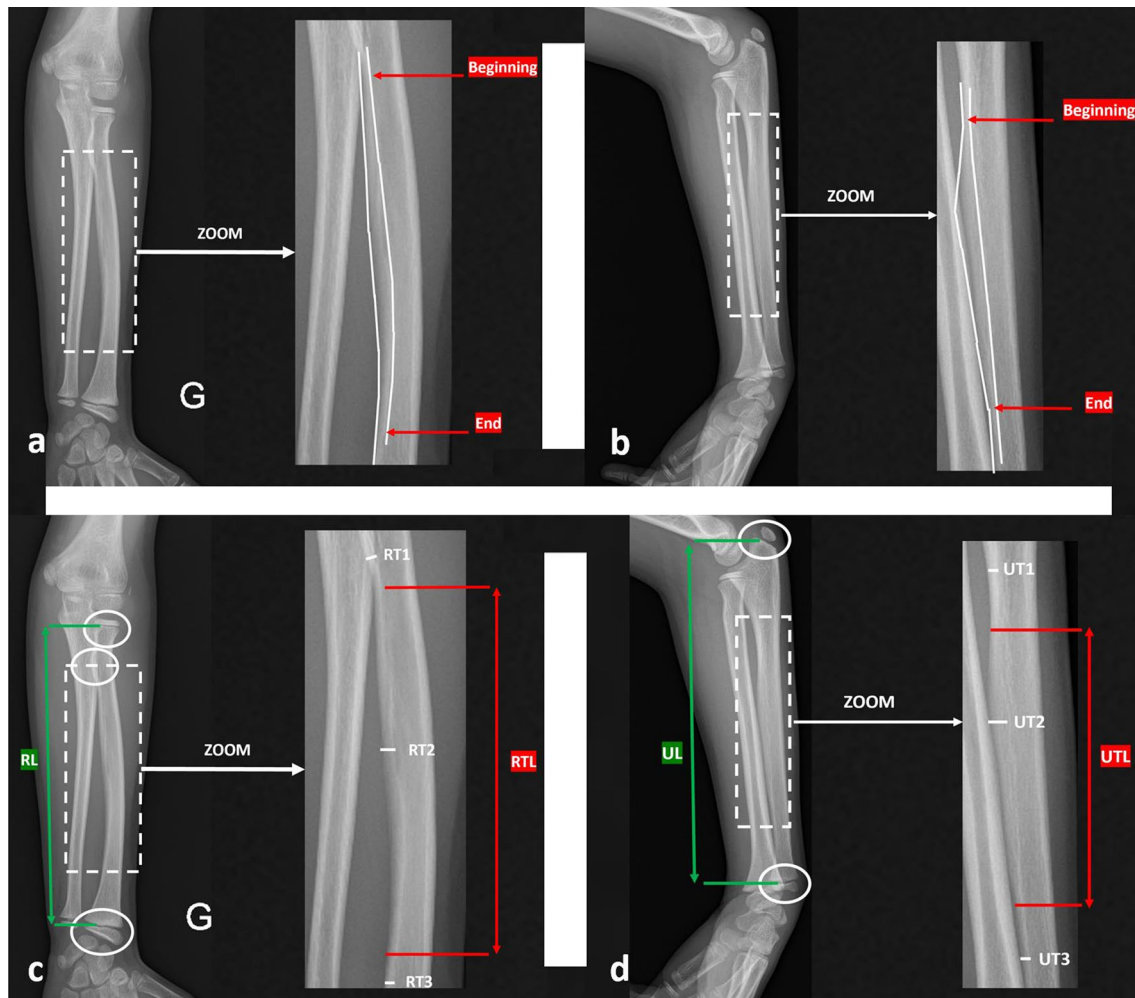
Fig. 1 Protocol for identification and measurement of interosseous tuberosity. Identification of the radial (**a**) and ulnar (**b**) interosseous tuberosity at the level of the interosseous cortical thickening. Protocol for measuring the length of the radial interosseous tuberosity (RTL), as well as the width proximally (RT1), at its level (RT2), and distally (RT3) (**c**). Then identification of the ossification of the radial head, bicipital tuberosity, and distal radial epiphysis (**c**). Protocol for measuring the length of the ulnar interosseous tuberosity (UTL), as well as the width proximally (UT1), at its level (UT2), and distally (UT3) (**d**). Then identification of the ossification of the olecranon and the distal ulnar epiphysis (**d**)

ICC value below 0.4 was considered as a poor agreement, between 0.4 and 0.75 as a good agreement, and above 0.75 as an excellent agreement. Statistical analysis was performed using software developed by Sorbonne University (R software, INSERM UMR S1136).

Results

Finally, 179 patients were included in the radiological study: 80 girls and 99 boys. The patient selection process is reported in Fig. 2. The distribution of girls and boys by age group is reported in Table 1.

Sequential development of tuberosities and ossifications of epiphyseal nuclei (Fig. 3)

On anterior–posterior radiographs, the radial interosseous tuberosity was identified from the age of one year in all cases. Ossification of the distal radial epiphyseal nucleus was present in the majority of 1-year-old subjects, and in all 2-year-old subjects. Ossification of the radial head began at the age of three years, in all girls at the age of five years, and six years for boys. In all cases, both observers were always in agreement on the identification of the presence/appearance of the radial interosseous tuberosity, the epiphyseal ossification nuclei of the radial head, the bicipital tuberosity, and the distal epiphysis. The results
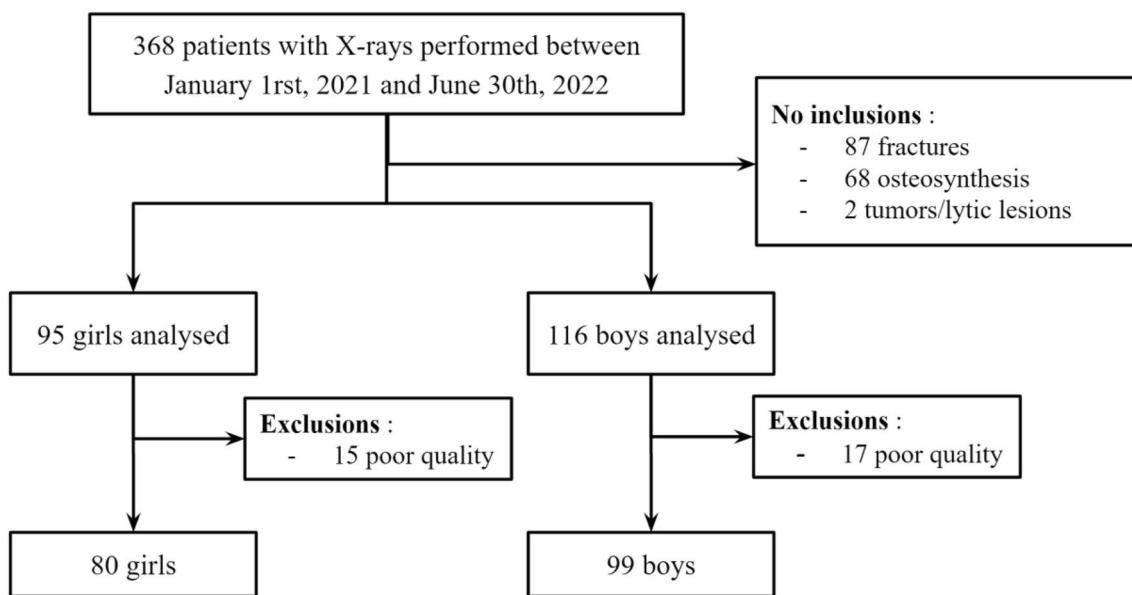
Fig. 2 Patient selection process

Table 1 Age distribution among the boys and girls analyzed in the radiological study

	Girls	Boys
[1–2]	8	9
[2–3]	8	3
[3–4]	5	9
[4–5]	7	6
[5–6]	6	7
[6–7]	5	3
[7–8]	3	3
[8–9]	14	6
[9–10]	4	8
[10–11]	3	5
]11–12]	5	10
[12–13]	5	9
[13–14]	1	6
[14–15]	5	10
[15–16]	1	5
Total	80	99

Evolution of interosseous tuberosities length during growth

The length of the radial and ulnar interosseous tuberosities increases during growth, as does the total bone length. The radial interosseous tuberosity represents between 25 and 34% of the total bone length depending on age. The ulnar interosseous tuberosity represents between 29 and 36% of the total bone length depending on the age. The results are shown in Fig. 6.

Evolution of interosseous tuberosities width during growth (Table 2)

The radial and ulnar interosseous tuberosities are significantly thicker than the proximally and distally located cortices at all ages analyzed, starting at 1-year-old. The radial interosseous tuberosity averaged 2 ± 0.3 mm at 1-year-old, and thickened to an average of 6.9 ± 1.1 mm at 15 years old. The ulnar interosseous tuberosity averaged 2 ± 0.3 mm at 1-year-old, and thickened to an average of 6.2 ± 1.2 mm at 15 years old.

Reproducibility of the different radiological measurements

Inter- and intra-observer reproducibility was excellent for all radiological measurements of bone length or cortical width. The results are summarized in Table 3.

for the radius are shown in Fig. 4. On lateral radiographs, the ulnar interosseous tuberosity was always present from 1-year-old. Ossification of the olecranon began at the age of seven years in girls and eight years in boys. Ossification of the distal ulnar epiphysis occurred from the age of four years in girls and five years in boys. In all cases, the two observers always agreed on the identification of the presence/appearance of the ulnar interosseous tuberosity, the epiphyseal ossification nuclei of the olecranon and the distal epiphysis. The results for the ulna are shown in Fig. 5.

Fig. 3 Illustration of the appearance and evolution of the tuberosities and epiphyseal nuclei in 1-year-old (**a**), 3-year-old (**b**), 6-year-old (**b**) and 8-year-old (**d**) children. In all cases, radial and ulnar interosseous tuberosities are present
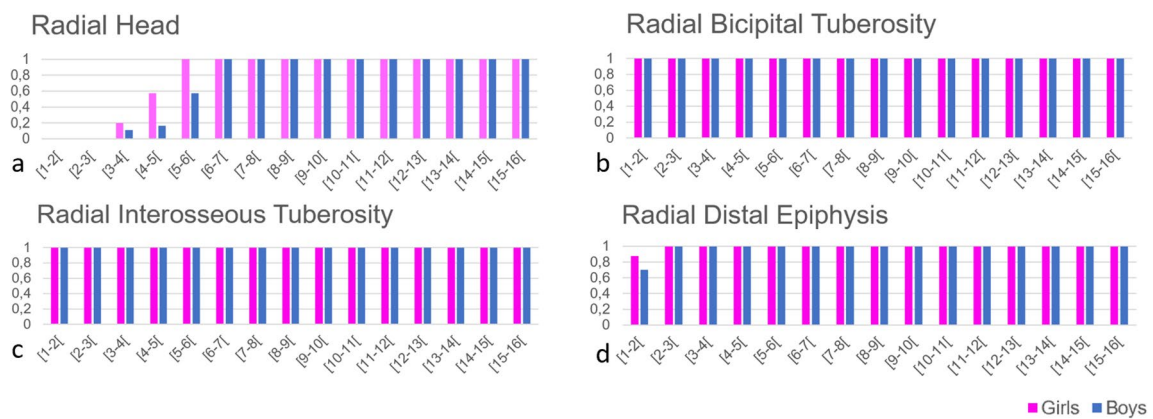

Fig. 4 Ages of appearance of bicipital tuberosities, radial interosseous tuberosities, and epiphyseal nuclei of the radial head and distal epiphysis
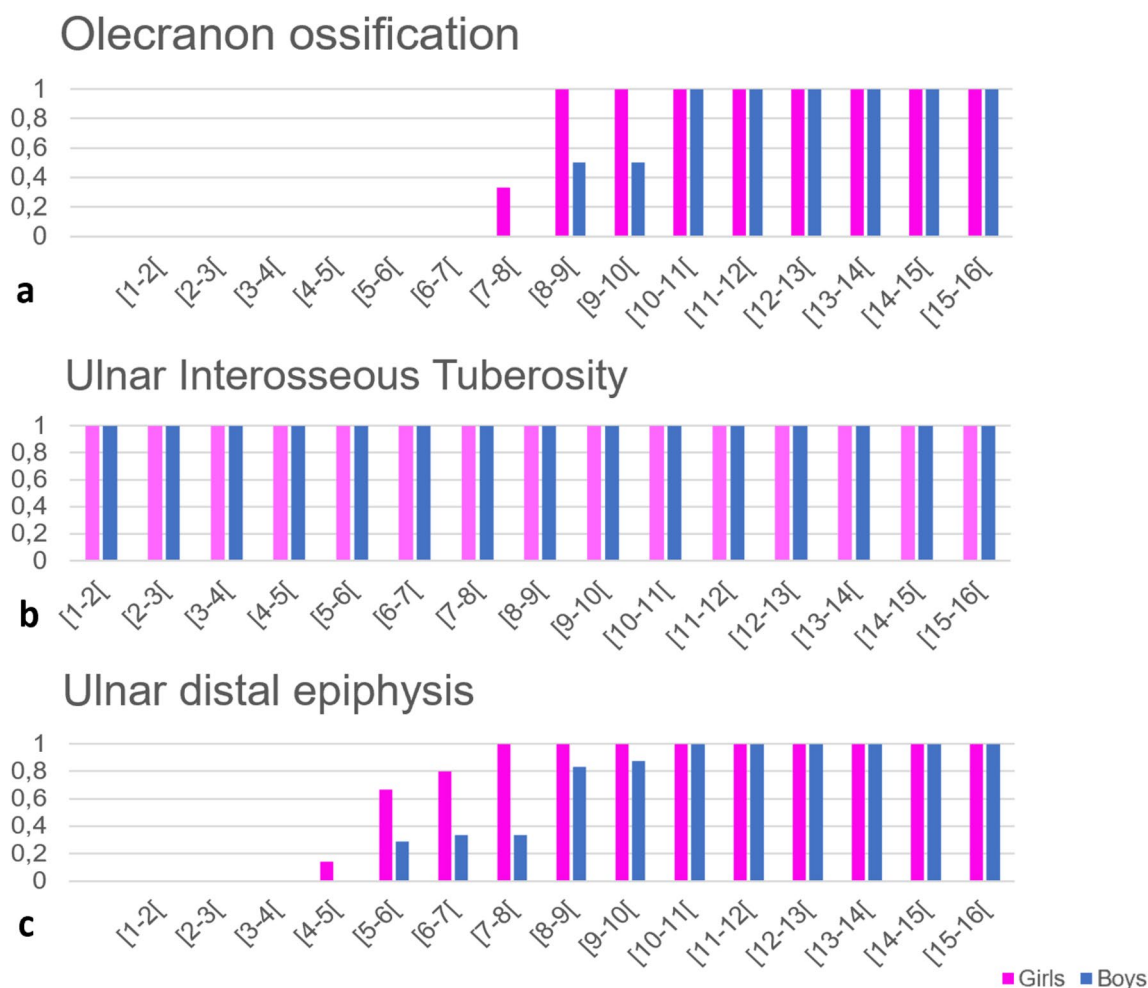
Olecranon ossification

Ulnar Interosseous Tuberosity

Ulnar distal epiphysis

Fig. 5 Ages of appearance of ulnar interosseous tuberosities, and epiphyseal nuclei of the olecranon and distal epiphysis

Discussion

The main finding of this study is the existence of radial and ulnar interosseous tuberosities from 1-year-old, regardless of gender. In the same way, as in adults, children from the age of 1-year-old showed a significant thickening of the cortex at this level. The growth of the different interosseous tuberosities was linear in length and width throughout growth.

In adults, the mean length of the radial interosseous tuberosity was estimated to be 93.9 ± 15.8 mm, corresponding to 37% of the total radial length [11]. On the ulnar side, the average length of the interosseous tuberosity in adults was estimated to be 107 ± 5 mm [12]. These lengths in adults are slightly greater than those estimated in this series among the 15–16-year-old group. This is also the case for the ratio of tuberosity length to total radial and ulnar bone length, estimated to be approximately 37% and 40%, respectively [11, 12]. Finally, the average width of these interosseous tuberosities in the upper 15–16-year-old group was 6.9 ± 1.1 mm versus 7.6 ± 1.8 mm in adults on the radial

side, and 6.2 ± 1.2 mm versus 6.9 ± 1 mm in adults on the ulnar side [11, 12]. This difference could be explained by the possible residual growth between the 16 years-old in this series, and 18 years old corresponding to the inclusion criterion of the study of adult subjects [12].

Cadaveric studies in adults have confirmed that these bony reliefs were indeed tuberosities on which the central band of the interosseous membrane [1, 2, 4–6] was inserted, as well as the main muscles destined for the thumb and fingers: flexor pollicis longus, abductor pollicis longus and extensor pollicis brevis for the radial interosseous tuberosity; and flexor digitorum profundus, extensor pollicis longus and extensor indicis for the ulnar interosseous tuberosity [11, 12]. The presence of a cortical thickening forming a relief is never a coincidence and is often secondary to the traction forces it absorbs [8, 11, 12]. The early appearance of these interosseous tuberosities could be explained by the fact that finger mobility is acquired very early. Indeed, a fetal ultrasound study found that all fetuses show total finger flexion and extension as early as 16 weeks of amenorrhea [7].
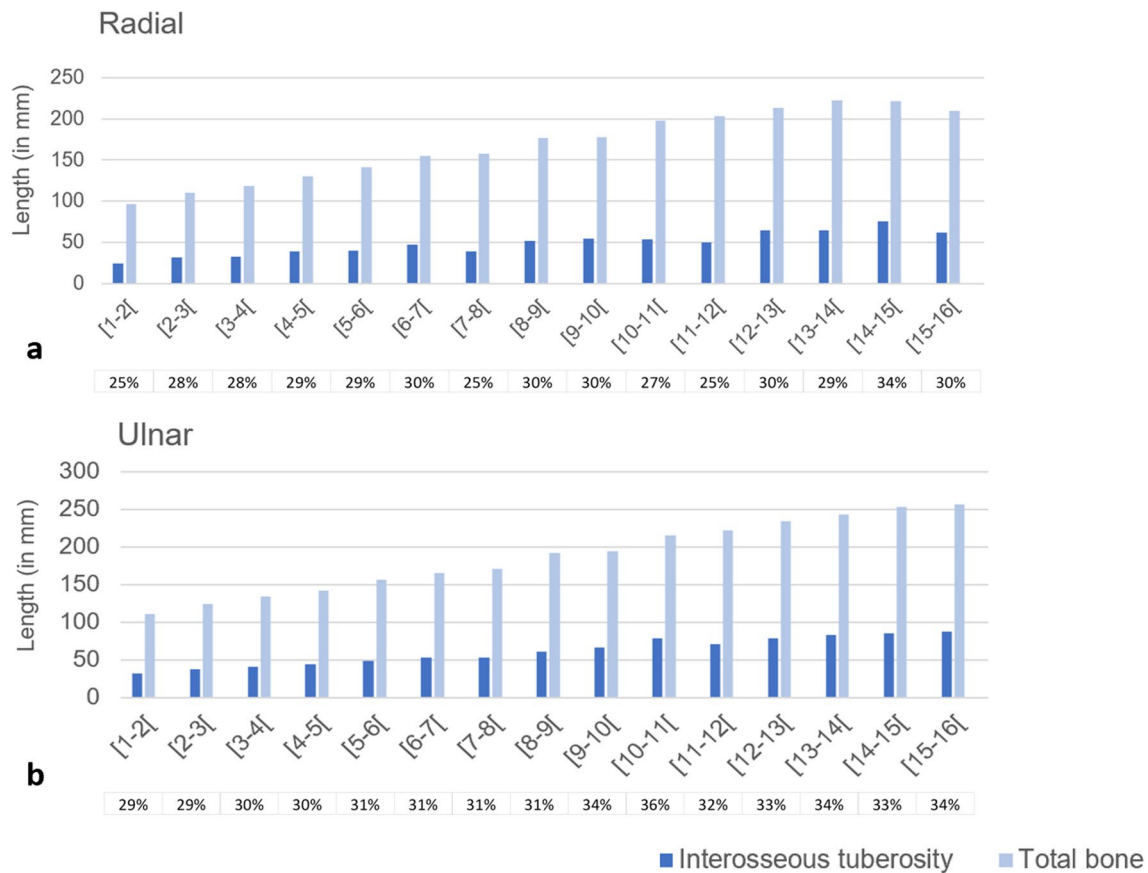
Fig. 6 Evolution of bone length between growth plates, as well as radial (**a**) and ulnar (**b**) interosseous tuberosities according to age groups. All results are expressed in mm, and the ratio of tuberosity/total bone length in %, reported below each column

Numerous archaic reflexes present from birth involve finger mobility such as grasping and could maintain these forces applied to these structures. This is the hypothesis that can be put forward to explain the existence of these structures on radiographs taken as early as one year of life.

During fetal life, no tuberosity or epiphysis is visible [18]. The average age of appearance of the other structures analyzed in this series for boys and girls confirms the previous series (Table 4) [17]. However, only one discrepancy in results was found concerning the estimated appearance of the radial bicipital tuberosity. In their 1938 anatomical report, von Lanz and Wachsmuth estimated the age of onset of the radial bicipital tuberosity to be between 10 and 12 years, with no gender difference [17]. However, Eberhard performed bicipital tuberosity transpositions in children as young as 6 years of age in cases of obstetrical brachial plexus injury [3]. This suggests that the apparition of the bony tuberosity may be earlier than the estimate of von Lanz and Wachsmuth [17]. In the present series, the bicipital tuberosity was always visible, starting at the youngest age of 1–2 years. As an example, these structures are well illustrated in the four cases reported in Fig. 3. The early

appearance of these tuberosities could be explained in the same way as for the interosseous tuberosities. Fetal elbow mobilities during growth and then at the newborn stage could explain the earlier appearance of these structures than previously thought. Indeed, during fetal life and the first months after birth, reflex muscle tension is predominant in the flexion of the upper limb [18]. Nevertheless, these are assumptions because the present study can only prove the presence of this tuberosity from the age of one year. Exploratory ultrasound in children under one year of age and/or newborns could help answer this question.

However, this study has several limitations. The first is its retrospective nature. Indeed, such a prospective analysis protocol is not ethical if carried out in healthy children, because it is irradiating. In addition, unlike other studies performed in adults, it is not possible to perform cadaveric studies in children, especially in the youngest age group [11, 12]. Other possibilities of radiological examinations, such as MRI, could have been considered. However, few examinations are carried out specifically on the forearms, most often for tumoral reasons, which prevents any retrospective analysis of this type of examination. Completing

Table 2 Cortical thickness on the interosseous side of the radius and ulna measured proximally, at the level of, and distally from the presumed tuberosity

| Age | Cortical thickness | | | | | | | | | |
| | Radius | | | | | Ulna | | | | |
	Proximal RT1	Interosseous RT2	Distal RT3	P value RT1 vs RT2	P value RT2 vs RT3	Proximal UT1	Interosseous UT2	Distal UT3	p value UT1 vs UT2	P value UT2 vs UT3
[1–2]	1.3±0.3	2±0.3	0.9±0.2	<0.001	<0.001	1.9±0.3	2±0.4	0.9±0.3	0.03	<0.001
]2–3]	1.6±0.3	2.3±0.4	1.3±0.5	<0.001	<0.001	1.8±0.5	2.3±0.4	1±0.3	<0.01	<0.001
[3–4]	1.5±0.2	2.6±0.4	1.3±0.4	<0.001	<0.001	1.8±0.4	2.5±0.5	1.3±0.3	<0.001	<0.001
[4–5]	1.9±0.5	3.3±0.6	1.6±0.3	<0.001	<0.001	2±0.3	3.1±0.7	1.5±0.4	<0.001	<0.001
[5–6]	2±0.4	3.4±0.7	1.7±0.3	<0.001	<0.001	2.4±0.5	3.4±0.8	1.6±0.4	<0.001	<0.001
[6–7]	1.8±0.4	3.2±0.4	1.5±0.3	<0.001	<0.001	2±0.4	3.6±1.1	1.7±0.5	<0.001	<0.001
[7–8]	2±0.3	3.6±0.7	1.5±0.4	<0.001	<0.001	2.1±0.2	3.3±0.5	1.6±0.4	<0.001	<0.001
[8–9]	2.3±0.4	3.4±0.6	1.8±0.4	<0.001	<0.001	2.2±0.4	3.6±0.6	1.6±0.3	<0.001	<0.001
[9–10]	2±0.4	3.6±0.7	1.9±0.3	<0.001	<0.001	2.3±0.5	3.2±0.9	1.7±0.5	<0.001	<0.001
[10–11]	2.1±0.3	4.1±0.9	2.2±0.3	<0.001	<0.001	2.2±0.3	3.6±0.8	1.9±0.4	<0.001	<0.001
[11–12]	2.4±0.6	4.4±0.9	2.2±0.6	<0.001	<0.001	2.3±0.4	4.3±1	2.1±0.5	<0.001	<0.001
[12–13]	2.3±0.6	4.5±0.9	2.1±0.8	<0.001	<0.001	2.7±0.4	4.7±0.9	2.1±0.6	<0.001	<0.001
[13–14]	3.1±0.6	5.3±0.8	2.5±0.6	<0.001	<0.001	2.8±0.7	5±0.9	2.2±0.7	<0.001	<0.001
[14–15]	2.5±0.5	5.1±0.9	2.3±0.7	<0.001	<0.001	2.7±0.5	5.1±1.3	2.1±0.6	<0.001	<0.001
[15–16]	2.9±0.6	6.9±1.1	2.7±0.9	<0.001	<0.001	3.2±0.4	6.2±1.2	2.1±0.3	<0.001	<0.001

All results are expressed in mm

Table 3 Study of inter- and intra- observer reproducibility on the first fifty patients of the radiological analysis

	Interobserver reliability	95% CI	Intraobserver reliability	95% CI
Radius				
Cortical thickness				
RT1	0.84	[0.73–0.91]	0.85	[0.75–0.91]
RT2	0.87	[0.77–0.92]	0.83	[0.72–0.90]
RT3	0.84	[0.73–0.90]	0.82	[0.69–0.90]
Bone length				
RL (total)	0.97	[0.95–0.98]	0.98	[0.96–0.99]
RTL (interosseous)	0.97	[0.93–0.99]	0.98	[0.96–0.99]
Ulna				
Cortical thickness				
UT1	0.84	[0.73–0.90]	0.81	[0.69–0.89]
UT2	0.88	[0.79–0.93]	0.86	[0.76–0.92]
UT3	0.87	[0.79–0.93]	0.86	[0.73–0.92]
Bone length				
UL (total)	0.97	[0.78–0.92]	0.99	[0.98–0.99]
UTL (interosseous)	0.94	[0.81–0.97]	0.98	[0.96–0.99]

CI confidence interval

this radiological assessment of these bony structures with an ultrasound examination in young children could be of interest to investigate whether these interosseous tuberosities also have a thickening of their periosteum like their cortices. A specific study of the periosteum in children

of each of these age groups could be very interesting and would deepen the knowledge of these structures. Another limitation is the measurement of the actual thickness of the interosseous tuberosities. It would have been preferable to measure the exact thickness by 3D CT scan, which was not

Table 4 Comparison of the average ages (in year-old) of appearance of the different bone reliefs of the forearm between the present series and those in the literature

	Boys		Girls	
	Von Lanz and Wachsmuth (1938) [16]	Present study (2022)	Von Lanz and Wachsmuth (1938) [16]	Present study (2022)
Radius				
Radial head	5	5	4	4
Bicipital tuberosity	10	1	10	1
Interosseous tuberosity	–	1	–	1
Distal epiphysis	1	1	1	1
Ulna				
Olecranon	10	10	8	8
Interosseous tuberosity	–	1	–	1
Distal epiphysis	6	8	5	5

possible for reasons of radiation dose in children and adolescents. Finally, it was impossible to know whether newborns have these structures from birth because no usable radiographs were taken before the age of at least one year. Further work remains to be done to confirm these results.

Conclusion

The radial and ulnar interosseous tuberosities are visible as early as 1-year-old. Their early appearance could be explained by the traction of the fingers and thumb during fetal life and the first months of life. Further studies should be performed to complement this work and investigate the presence of these tuberosities between birth and 1-year-old, particularly using ultrasound.

Declarations

Conflict of interest RV is occasional consultant for Nuvasive, Eos imaging and Stryker, outside the scope of this work. Other authors do not have competing interests.

Ethical approval The study was registered with the Commission Nationale de l'Informatique et des Libertés (CNIL—no. 2227470 version 0). The review of the data was conducted in accordance with the ethical standards of the 1964 Declaration of Helsinki and the reference methodology MR-003.

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