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# Topographical anatomy of the pronator teres muscle and median nerve: a study using histological sections of human fetuses

By

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**Key Words:** pronator teres muscle, median nerve, humero-ulnar joint, distal migration of the deep flexor, human fetus

**Summary:** The median nerve passes through the humeral and ulnar heads of the pronator teres muscle (PT), although variations such as absence of the ulnar head may exist. We observed histological sections of the upper extremity from 24 embryos and fetuses. In the early stage, the PT extended between the radius and the medial epicondyle of the humerus, but no candidate for the ulnar head was found. In mid-term fetuses, the ulnar margin of the PT was attached to the elbow joint capsule. Moreover, in late-stage fetuses, a small deep part of the PT arose from the thick joint capsule of the humero-ulnar joint near the coronoid process of the ulna. This joint capsule also provided the most proximal origin of the flexor digitorum profundus muscle. Therefore, we considered fetal PT origin from the capsule as a likely candidate for the ulnar head. Consequently, the PT seemed to develop from a single anlage through which the median nerve passed, but later – possibly after birth – a small PT origin from the joint capsule appeared to obtain an aponeurosis connecting the muscle fiber to the ulna. This secondary change in PT morphology might explain the muscle variation seen in adults.

## Introduction

It is well known that, at the human adult elbow, the median nerve passes through the humeral and ulnar heads of the pronator teres muscle (PT). The large humeral head arises from the medial epicondyle and fasciae around it, while the small ulnar head has an aponeurotic origin from the medial side of the coronoid process of the ulna. We have hypothesized three patterns of morphological development whereby the thick and long median nerve adopts a course running between the two heads of the PT (Fig. 1): pattern A in which the topographical relationship between the nerve and two muscle heads is established at an early stage; pattern B where the nerve penetrates a single muscle anlage at an early stage, and later the anlage becomes divided into the two heads; pattern C where two

anlagen are separated at an early stage, the muscles then meeting later to provide the final topographical anatomy.

Recently, our group have reported that, in the fetal forearm, distal migration of deep flexor origins from the ulna forms a new fibrous tissue: the chorda obliqua or oblique cord (Jin et al., 2016). The oblique cord is located adjacent to the aponeurotic origin of the ulnar head of the PT. For the present study, based on our previous experience, we chose sections of the elbow from human fetuses at 7–30 weeks of gestation. Consequently, to provide better understanding, we attempted to describe the fetal development of the PT, especially the establishment of the topographical relationship between the muscle and the median nerve.

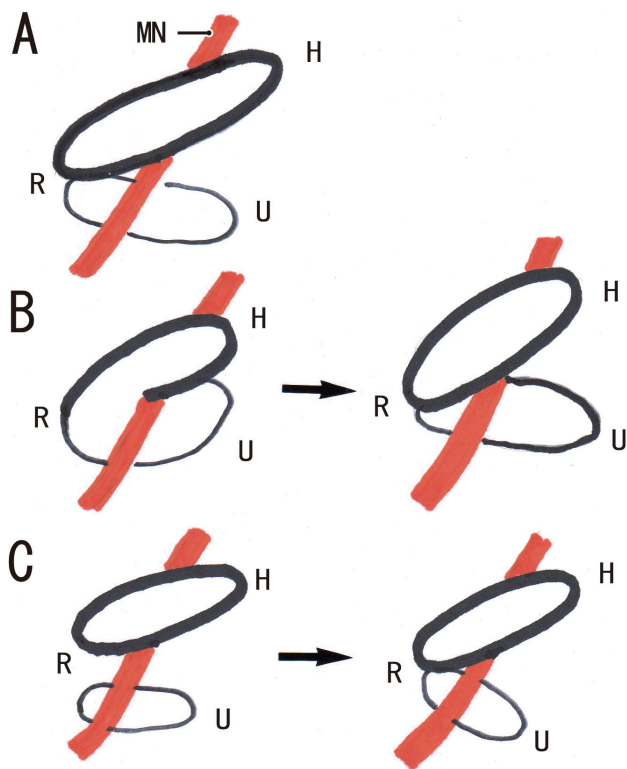


Fig. 1. Diagrams showing the hypothetical developmental process of the pronator teres muscle.

In panel A, the topographical relationship between the median nerve (MN), the humeral head (H-R) and the ulnar head (U-R) is established at a very early stage. In panel B, a single anlage, that contains the median nerve course, is divided into two heads. In panel C, the humeral head is distant from the ulnar head at an early stage, but these heads later meet. H, humeral attachment; R, radial attachment; U, ulnar attachment.

## Materials and Methods

This study was performed in accordance with the provisions of the Declaration of Helsinki 1995 (as revised in 2013). We observed histological sections of the upper extremity from 24 embryos and fetuses: 8 embryos and fetuses at 7–8 weeks of gestation (crown-rump length (CRL) 22–35 mm); 9 fetuses at 12–16 weeks (CRL 60–125 mm); and 7 fetuses at 25–30 weeks (CRL 200–250 mm). The sections from early and mid-term specimens (thickness 5–10  $\mu\text{m}$ ) were serial and part of the large collection kept at the Embryology Institute of the Universidad Complutense, Madrid, being the products of miscarriages and ectopic pregnancies at the Department of Obstetrics of the University. Most sections were stained with hematoxylin and eosin (HE), and a minor proportion with azan, orange G or silver staining. The study was approved by Complutense University ethics committee (B08/374). We chose these 17 specimens because the target area including the PT was cut along the long axis of

the extremity. However, depending on the posture of the extremity relative to the body, and the degree of flexion at the elbow, the sectional planes of mid-term fetuses differed among the specimens, being sagittal, frontal or oblique to various degrees.

The 7 late-stage fetuses were part of a collection kept at the Department of Anatomy, Akita University, Akita, Japan. They had been donated to the Department by the families concerned during the period 1975–1985, and preserved in 10% w/w neutral formalin solution for more than 30 years. The available data were limited to the date of donation and the number of gestational weeks. There were no related documents giving details of the family name, the name of the attending obstetrician or hospital, or the reason for abortion. The use of the specimens for research was approved by the ethics committee of Akita University (No. 1378). The upper extremities obtained from these 7 specimens were incubated at room temperature in Plank-Rychlo solution ( $\text{AlCl}_3/6\text{H}_2\text{O}$ , 7.0 w/v%; HCl, 3.6;  $\text{HCOOH}$ , 4.6) for 1–2 weeks. After routine procedures for paraffin-embedded histology, semiserial sectioning (thickness 7–10  $\mu\text{m}$ ; interval 0.5–1.0 mm) and staining with HE were performed. The sectional planes were always longitudinal and sagittal.

## Results

### *Observations of embryos and fetuses at 7–8 weeks*

Muscles at the shoulder and arm were composed of differentiated muscle fibers or primary myotubes (Figs. 2–4). The biceps tendon inserted to the radius, while the brachialis muscle ended at the ulna near the humero-ulnar joint (Fig. 2A). Likewise, near the medial epicondyle of the humerus, muscle fiber differentiation was evident in the PT as well as in the flexor carpi radialis and ulnaris muscles, in contrast to the undifferentiated morphology of other flexors in the forearm (Fig. 4). The flexor carpi radialis muscle was adjacent to the PT (Figs. 2H, 3D and 4C), while the flexor carpi ulnaris muscle covered the ulnar nerve course (Figs. 2EF, 3AB and 4G). The flexor digitorum profundus muscle was clearly identified by its double supply from the median and ulnar nerves (Figs. 2EF and 3AB). However, the flexor digitorum superficialis muscle was often difficult to identify, possibly because of the thick median nerve running along it (Figs. 2 and 3). Anlagen of the flexor digitorum superficialis were most likely to be divided into a distal mass at the level of the wrist joint and another, proximal mass adjacent to the PT and flexor carpi radialis (Fig. 4AD). When compared with the size of the arm or hand, the forearm was very short: the length of the humerus from the deltoid muscle insertion to the epicondyle was almost equal to or greater than the entire length of the forearm from the epicondyle to the wrist joint (Fig. 4D vs. Fig. 4F).

The PT muscle was clearly identified as a wide muscle

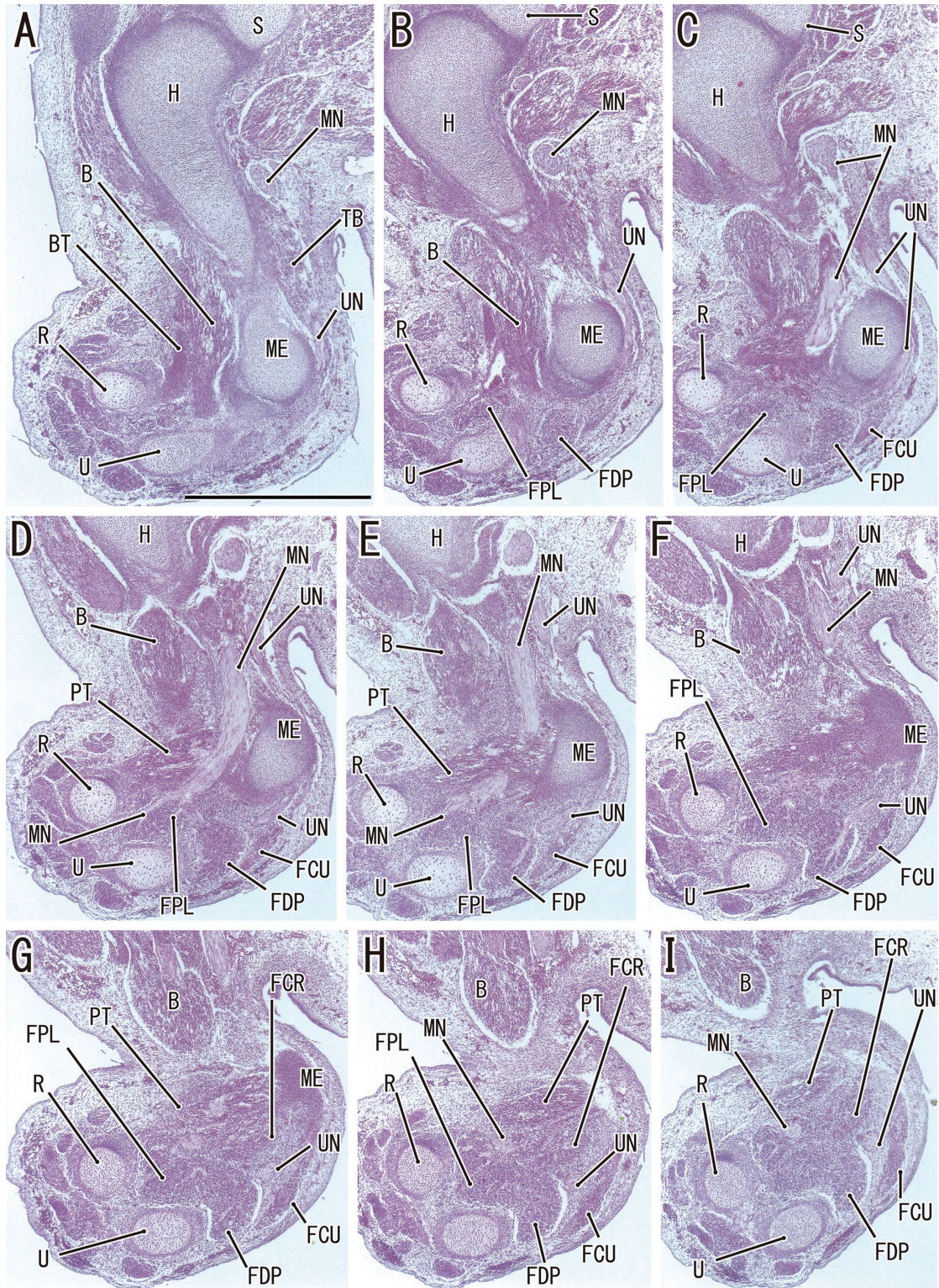


Fig. 2. Pronator teres muscle and the median nerve.

HE staining. Almost sagittal sections from a specimen at 7 weeks (CRL 27 mm). Panel A shows the most lateral plane in the figure, and panel I the most medial plane. Intervals between panels are 0.2 mm (A–B) and 0.05 mm (B–C, C–D, D–E, E–F, F–G, G–H, H–I). The pronator teres muscle (PT) is clearly seen extending between the medial epicondyle (ME) of the humerus and the radius (R). In front of and behind the median nerve (MN), the muscle fibers are present (panels C–F). The flexor digitorum profundus muscle is supplied by the ulnar nerve (UN in panel F) as well as the median nerve (panel E). All panels were prepared at the same magnification (scale bar in panel A, 1 mm). For other abbreviations, see the list of common abbreviations.

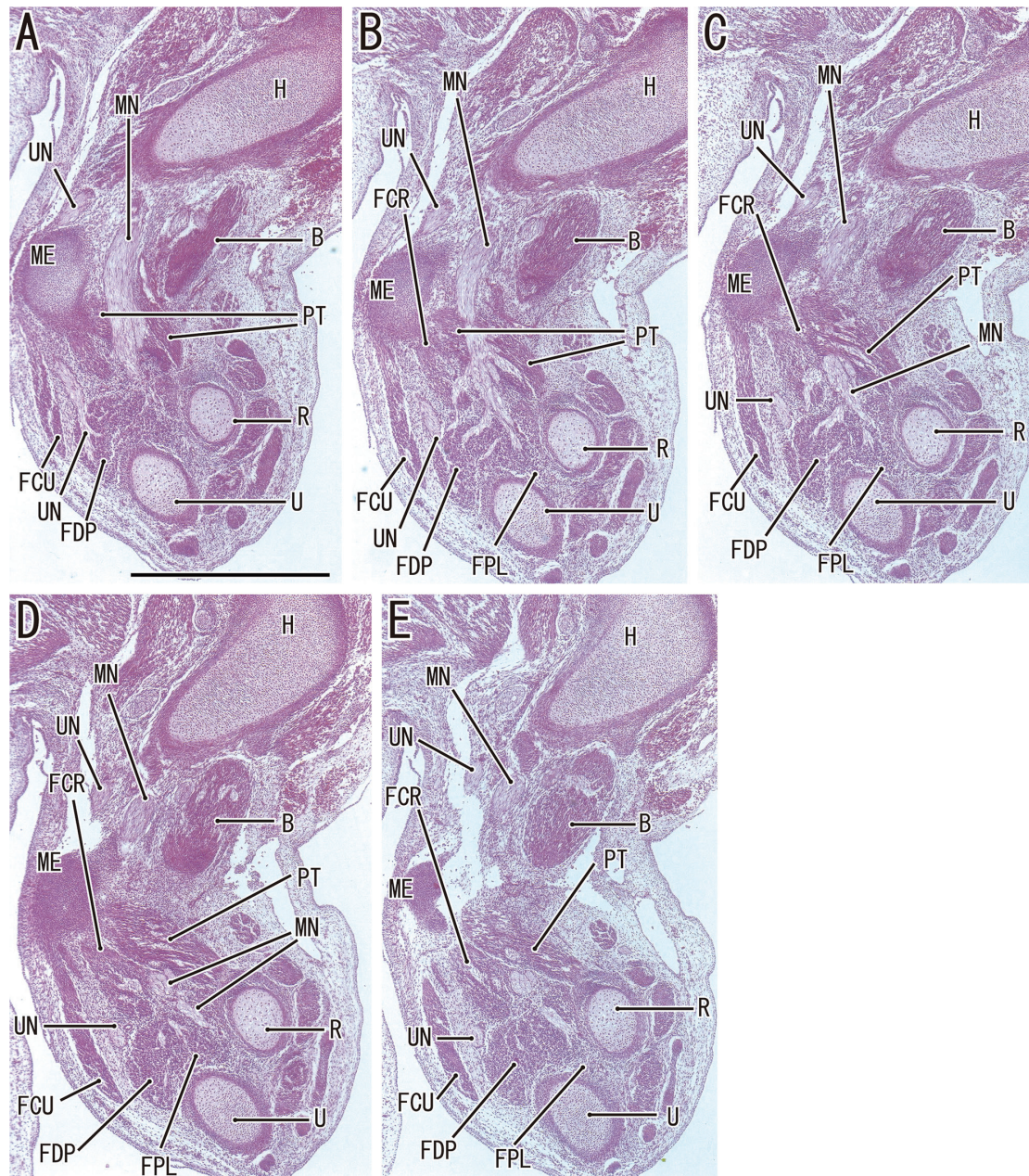


Fig. 3. Median nerve passing through the pronator teres humeral head.

HE staining. Almost sagittal sections from a specimen at 7 weeks (CRL 24 mm). Panel A shows the most lateral plane in the figure, and panel E the most medial plane. Intervals between panels are 0.05 mm (A–B, B–C, C–D, D–E). The median nerve appears to pass through the pronator teres muscle (PT in panels A–C). The flexor digitorum profundus muscle is supplied by the ulnar nerve (UN in panel A) as well as the median nerve (panel B). All panels were prepared at the same magnification (scale bar in panel A, 1 mm). For other abbreviations, see the list of common abbreviations.

plate extending between the humerus and the radius (i.e., the future humeral head; Figs. 2D, 3D and 4E), but the future ulnar head appeared to be absent. According to the fiber direction as well as the close relationship with the flexor digitorum profundus, a muscle anlage located between the radius and ulna corresponded to that of

the flexor pollicis longus, not that of the PT ulnar head. Notably, the median nerve did not run deep or posterior to the PT humeral head, but passed “through” it (Figs. 2E, 3B and 4D). Thus, the PT muscle fibers were seen in sections in front of and behind the thick nerve. However, when the nerve ran near the medial or posterior aspect

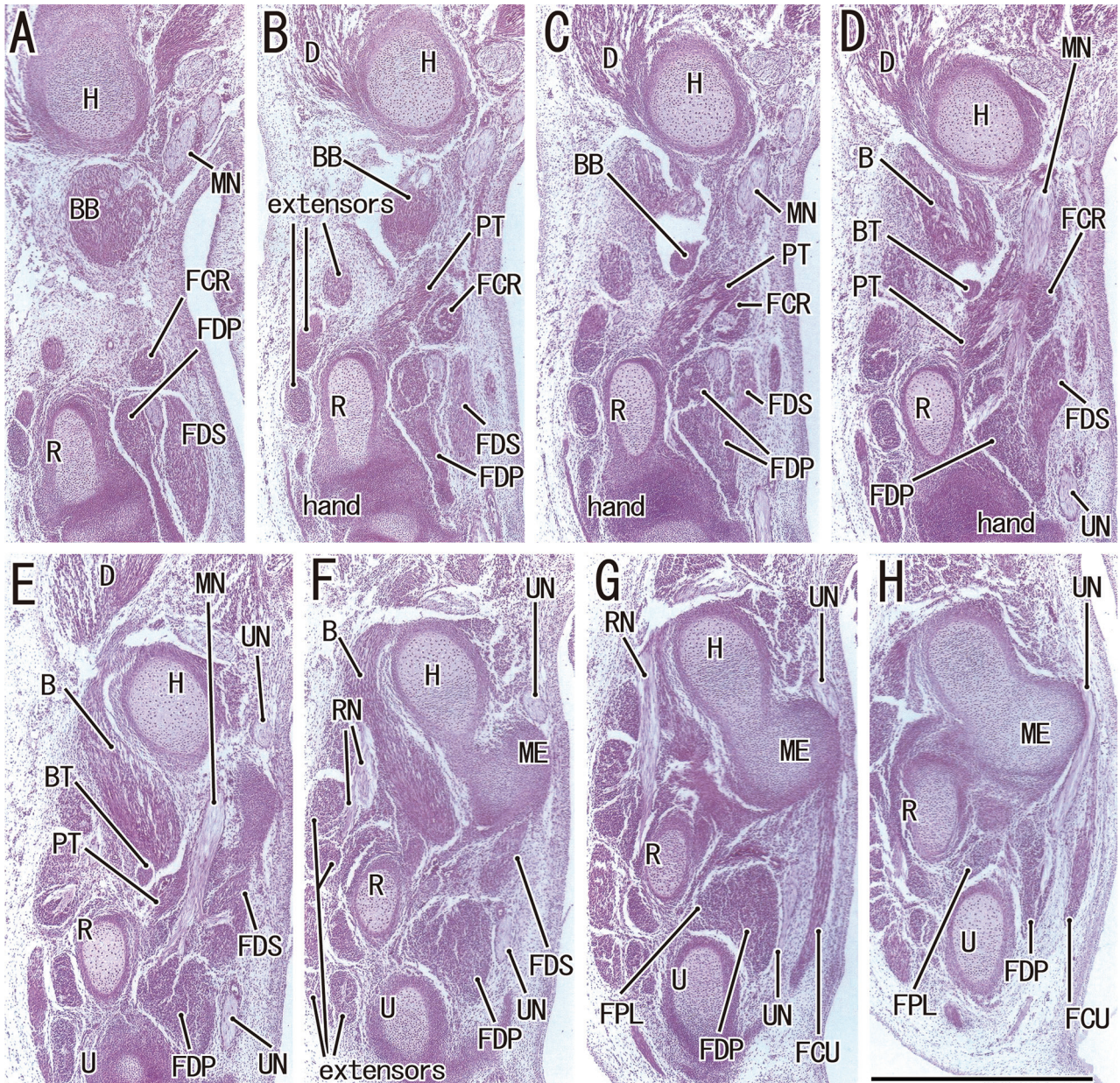


Fig. 4. Pronator teres muscle and three major nerves of the forearm.

HE staining. Almost sagittal sections from a specimen at 7 weeks (CRL 25 mm). Panel A shows the most lateral plane in the figure, and panel H the most medial plane. Intervals between panels are 0.1 mm (A–B, B–C), 0.05 mm (C–D), 0.1 mm (D–E, E–F, F–G) and 0.2 mm (G–H). This figure contains the courses of the median, ulnar and radial nerves (MN, UN, RN) at and near the elbow. The median nerve passes through the pronator teres muscle (PT in panel D). Anlagen of the flexor digitorum superficialis muscle appeared to be divided into a distal mass (panel A) and a proximal mass (panel E). All panels were prepared at the same magnification (scale bar in panel H, 1 mm). For other abbreviations, see the list of common abbreviations.

of the muscle plate, few muscle fibers covered the nerve. The PT was separated from the elbow joint by the thick muscle bundles and tendon of the brachialis and biceps brachii

#### *Observations of fetuses at 12–16 weeks*

In all 9 specimens, the PT was well developed and located between the brachialis and flexor digitorum profundus muscles. Along the border between the brachialis and the PT, these muscles provided wavy surfaces at their tight interface. The muscle bundle of the PT appeared to

be thickest in sections including the humero-ulnar joint. In 7 of the 9 specimens, we confirmed the median nerve running through the PT. In the ulnar, medial or posterior side of the median nerve, a deep portion of the PT was attached to the distal end of the elbow joint capsule (figures not shown). The attachment to the capsule was large or small, varying between specimens, but the strict evaluation was difficult because of the differences in sectional planes between specimens. Possibly due to the topographical anatomy of the bony elements, we were unable to find a plane showing the PT muscle fibers extending from the humerus to the radius. In contrast, the flexor digitorum superficialis muscle was clearly identified immediately distal to the PT.

#### *Observations of fetuses at 25–30 weeks*

Since all sectional planes were sagittal, the topographical anatomy of muscles at or near the elbow was easily comparable between specimens. In all 7 specimens, the median nerve passed through the PT. The PT was seen originating from the medial epicondyle of the humerus, and the muscle plate was evident between the brachialis and the flexor digitorum profundus muscles. Notably, at the ulnar margin, some muscle fibers of the PT originated from a thick joint capsule of the humero-ulnar joint (Fig. 5). This small part of the PT was not always equivalent to the PT lying below the median nerve course, as the superficial muscle fibers also contributed to the origin from the joint capsule (Fig. 5DE). The thick joint capsule provided the most proximal origin of the flexor digitorum profundus muscle (Fig. 5BE). After passing through the PT, the median nerve ran distally between the PT and the deep flexors.

## **Discussion**

The most striking observation in the present study was that no definite ulnar head of the PT was evident at the early stage. Thus, as detailed in the Introduction (Fig. 1B), it seemed likely a single anlage (i.e., a muscle plate connecting the humerus to the radius) divided to form the two heads of the PT (Fig. 6A). In late-stage fetuses, we considered a small origin from the thick joint capsule of the humero-ulnar joint as a likely candidate for the ulnar head, since the origin was located closely to the coronoid process of the ulna. Notably, this joint capsule also provided the most proximal origin of the flexor digitorum profundus muscle (Fig. 6B). Jin *et al.* (2016) considered that, possibly after birth, the flexor origin from the joint capsule is replaced by a fibrous band that forms the oblique cord, or chorda obliqua. In other cases, the deep flexor origins seem to migrate distally. Therefore, we hypothesized that, also possibly after birth, the small PT origin from the joint capsule might create an aponeurosis connecting the muscle fiber to the ulna (Fig. 6C). An apo-

neurotic origin of the PT ulnar head seemed to develop together with the oblique cord during distal migration of the deep flexors.

A similar example is known in the human head: the buccal nerve usually runs between the upper and lower heads of the lateral pterygoid muscle, but many variations such as three or more heads have been reported. Katori *et al.* (2012) demonstrated that, because of delayed growth of the ala major of the sphenoid, the upper head arises later from a single anlage of the muscle to provide the final topographical anatomy. Thus, depending on timing, and the direction and length of the upper muscle anlage protrusion, the topographical anatomy is likely to change. Therefore, pattern B described in the Introduction may explain variations in which the two heads of the lateral pterygoid do not sandwich the buccal nerve. Being similar to the buccal nerve, in adults, the median nerve issues muscle branches to supply the PT before passing between the two heads of the muscle (Yamada, 1986).

The hypothetical transition from the joint capsule to the aponeurosis for the muscle origin seemed to depend on the timing, direction and strength of traction provided by growing bony elements after birth. This mechanism of muscle splitting was likely to create variations in topographical relationship between the PT and the median nerve. In fact, it has been reported that in 10.8% of 1000 dissections, the nerve was posterior to the humeral head of the PT and that the ulnar head was absent; in 4.6% the nerve was posterior to both heads and in 1.8% it passed through the humeral head. In other words, the typical topographical relationship was seen in 82.8% of cases (Williams, 1995). Absence of the ulnar head noted in 10.8% of cases seemed attributable to a failure in splitting. In the 4.6% of cases where the nerve was located behind the ulnar head, the nerve might have run behind the single anlage at an early stage, whereas in the 1.8% cases where the nerve passed through the humeral head, the nerve might have passed through the superficial part of the single anlage.

The median artery of the forearm is a well-known primitive arterial trunk seen in developing limbs at an early stage, and is rarely maintained in the late stage and after birth. Although we did not find it in the present materials, Aragão *et al.* (2017) reported a higher incidence in fetuses than in adults. However, even in fetuses, the median artery does not pass through the PT, but appears as a branch of the ulnar artery distal to the PT. In fact, in adults, a deep arterial route from the ulnar artery does not pass through the PT and winds around the muscle. The mechanical stress for secondary division of the PT would be harmful for maintenance of the primitive median artery. In addition, the present observations suggested that anlagen of the flexor digitorum superficialis were most likely to be composed of two parts: a distal mass at the level of the wrist joint and another, proximal, mass adjacent to the PT and flexor carpi radialis. This finding was

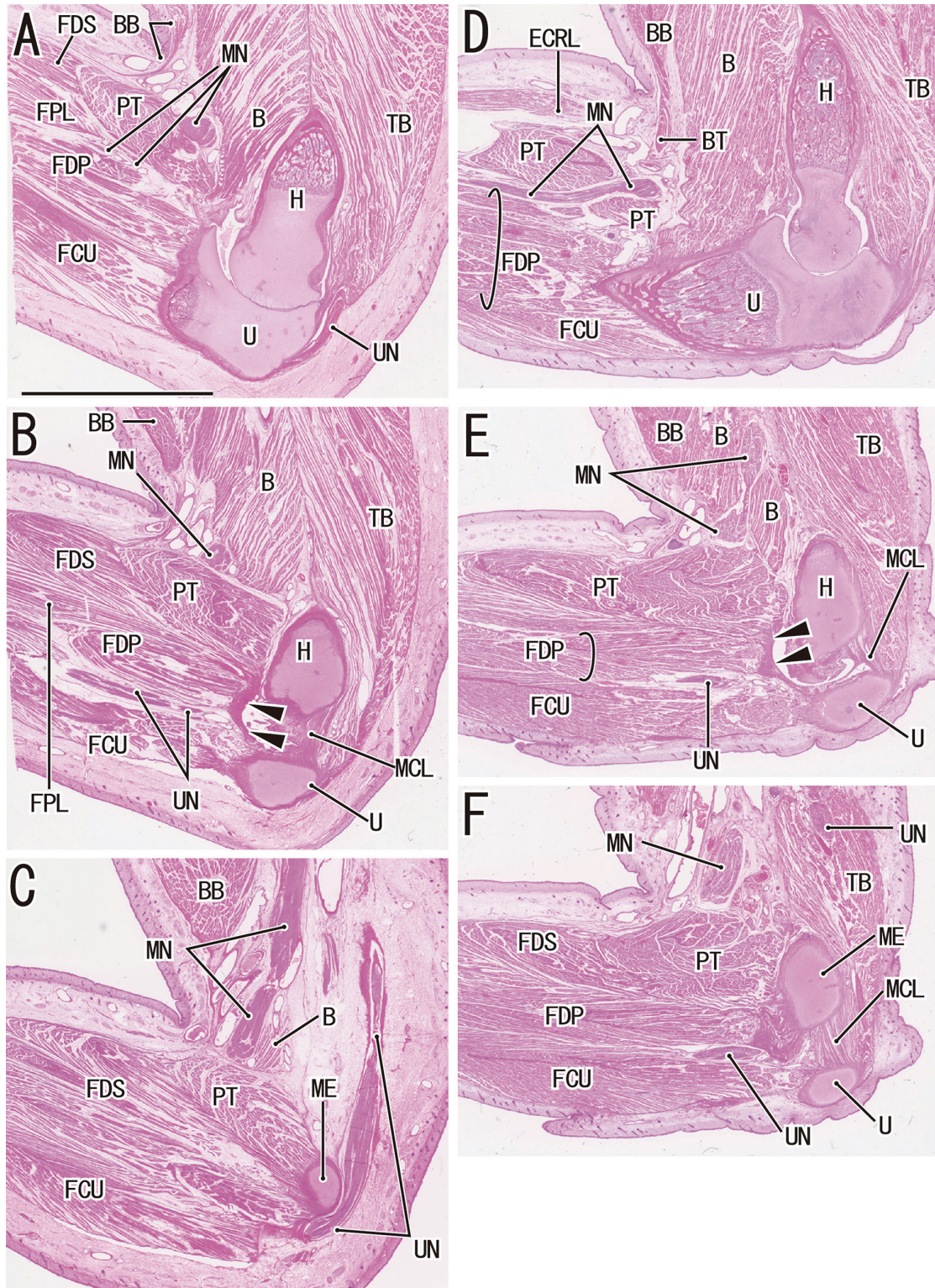
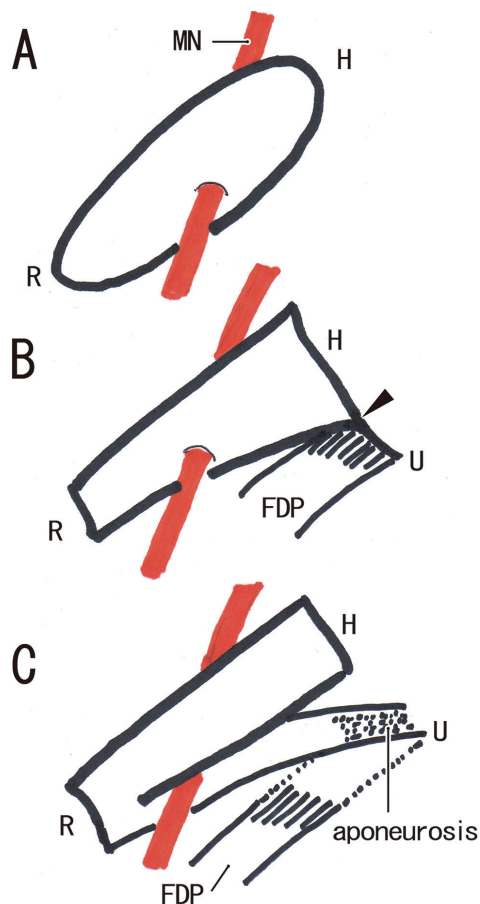


Fig. 5. Pronator teres muscle attachment to the capsule of the humero-ulnar joint.

HE staining. Panels A–C, almost sagittal sections of a specimen at 30 weeks (CRL 255 mm); panels D–F, those of a specimen at 25 weeks (CRL 230 mm). Intervals between panels are 1.1 mm (A–B, B–C), 2.4 mm (D–E) and 0.5 mm (E–F). The pronator teres muscle (PT) originates from the medial epicondyle of the humerus (ME in panels C and F). At the ulnar margin, the PT is attached to the thick capsule of the humero-ulnar joint (arrowheads in panels B and E). The thick joint capsule also provides the most proximal origin of the flexor digitorum profundus muscle (FDP). All panels were prepared at the same magnification (scale bar in panel A, 1 mm). For other abbreviations, see the list of common abbreviations.





**Fig. 6.** Development of two heads of the pronator teres muscle. The PT most likely originated from a single anlage connecting the humerus medial epicondyle to the radius. The median nerve passed through the anlage near its posterior aspect (panel A). In late-stage fetuses (panel B), the humeral origin reached the thick capsule of the humero-ulnar joint. Thus, part of the PT originated from the joint capsule (arrowhead), which also provided the origin of the flexor digitorum profundus muscle (FDP). We hypothesized that, depending on the distal migration of the FDP, the PT origin from the joint capsule changed to an aponeurotic origin of the ulnar head.

consistent with Gräfenberg (1906).

There were three possible limitations to this study. First, the need to ensure “absence” of the ulnar head of the PT was a major limitation, since confirmation of absence is logically difficult. Second, the posture or degree of flexion at the elbow differed among the specimens. This made it difficult to choose multiple specimens in which the sectional planes were almost the same, especially for demonstration of both the origin and insertion of the PT within a single section. Third, the process leading to the final establishment of the ulnar head of the PT was almost impossible to demonstrate, since it may occur after birth.

## Conflicts of interest

The authors have no financial conflicts of interest to declare.

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## Figure legends

Common abbreviations for figures:

- B, brachialis muscle;
- BB, biceps brachii muscle;
- BT, biceps tendon;
- D, deltoid muscle;
- ECRL, extensor carpi radialis longus muscle;
- FCR, flexor carpi radialis muscle;
- FCU, flexor carpi ulnaris muscle;
- FDP, flexor digitorum profundus muscle;
- FDS, flexor digitorum superficialis muscle;
- FPL, flexor pollicis longus muscle;
- H, humerus;
- MCL, medial collateral ligament;
- ME, medial epicondyle of the humerus;
- MN, median nerve;
- PT, pronator teres muscle;
- R, radius;
- RN, radial nerve;
- TB, triceps brachii muscle;
- U, ulna;
- UN, ulnar nerve.