

Variability of the pronator teres muscle and its clinical significance

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Abstract

While investigating the cause of entrapment syndrome of the peripheral nerves in the elbow region, we observed variability of the pronator teres muscle and the relationship of this muscle to the median nerve and the surrounding vessels. Attention was also paid to the occurrence of the supracondylar process of the humerus and Struthers' ligament with regard to their ontogenetic and phylogenetic development. For this purpose, a classical anatomical dissection of the upper limbs of 68 adults, three fetuses and a phylogenetic assessment of five mammalian species was performed. In terms of variability in the anatomical structures of the elbow region, we found the most serious clinical condition to be where the median nerve ran through the pronator canal together with the ulnar vessels (1.5%), or when it passed through the ulnar head of the pronator teres (5.9%). The pronator teres examined by us in fetuses showed the same arrangement as in adult individuals, including the created ulnar head. The occurrence of a supracondylar process and Struthers' ligament was not observed in our collection. The presence of these structures was not confirmed during the fetal period, either. The phylogenetic part of the study re-opened the question of the meaning and function of the entepicondylar foramen, because we noted differences in the occurrence of this structure in two related genera with a very similar way of life (Djungarian hamster and golden hamster).

Keywords: anatomical variability, entepicondylar foramen, entrapment syndrome, median nerve, pronator teres muscle, supracondylar process.

Introduction

Median nerve (MN) compression in the elbow region still represents a medical problem. In this region, the most common compression of the nerve occurs when it passes between the humeral and ulnar heads of the pronator teres muscle (PTM), through the so-called pronator canal. The cause is usually muscle hypertrophy due to excessive overloading, or rarely due to inflammatory or post-traumatic changes. This condition is referred to as a pronator syndrome and is manifested by painfulness of the PTM and paresthesia, dysesthesia or even paralysis in the MN innervation zone [1–5]. Entrapment syndrome of the MN in the distal part of the arm may also occur due to the presence of variable anatomical structures at the starting point of the humeral head of the PTM, *i.e.*, a supracondylar process of the humerus and Struthers' ligament. In some cases, these formations can cause supracondylar process syndrome [6], the manifestations of which are sometimes included under the term pronator syndrome. For this reason, the issue of variability of the PTM, the occurrence of the supracondylar process of the humerus and Struthers' ligament have been investigated by many authors [7–13].

The present work aimed to create a comprehensive view of the aforementioned issues based on the study of animal and human cadavers and contribute to the clarification of the development of said anatomical formations.

Materials and Methods

Variability of the PTM was studied in 68 upper limbs of adults (33 left and 35 right), of which 40 were female

and 28 were male. Limbs could not be assessed bilaterally. On the basis on the age at death, which ranged from 47 to 96 years, it was possible to classify most of the studied individuals in the oldest age categories *maturus* II (50–60 years) and *senilis* (over 60 years). For the ontogenetic part of the study, the upper limbs of three human fetuses were dissected at the age of 13, 15 and 25 weeks of intrauterine development. Gestational age was determined according to the length of the palm [14].

All studied human cadavers were fixed in a mixture of alcohol and formalin (96% ethanol, 100% glycerol, 35–40% formalin, 5% phenol); fixation of the fetuses was also carried out, visualization of the vasculature using a colored silicone solution was done.

The anatomical structures of the upper extremities were dissected by conventional methods commonly used in anatomical dissection [15, 16]. The examined human cadavers came from the dissection material of the Department of Anatomy, Faculty of Medicine of the Masaryk University, Brno, Czech Republic. The number and age structure were therefore limited by the amount and the state of the deposited material.

The comparative part of the research included anatomical dissection of unfixed forelimbs of five mammal species: squirrel monkey (*Saimiri sciureus*), domestic dog (*Canis lupus f. familiaris*), five individuals of Djungarian hamster (*Phodopus sungorus*), two individuals of golden hamster (*Mesocricetus auratus*) and four individuals of the domestic cat (*Felis catus* sin. *F. silvestris catus*). All studied cadavers belonged to adult animals, except the cats included two immature individuals (age one day). Furthermore, osteopreparation the biological material was

done using *Dermestes* spp. beetles [17]. In all cases, the sectional material was provided by the Department of Pathological Anatomy of Veterinary and Pharmaceutical University in Brno.

All the anatomical preparations of human and animal limbs were documented regarding the variability of the PTM, as well as the relationship of this muscle to the MN and the surrounding arteries (brachial artery, radial artery, ulnar artery). For the ulnar head, the ratio of tissue types from which it was formed was also evaluated. Muscle types were labelled as a muscular if it was completely composed of muscle tissue, mixed type if it was composed of a visible tendon and muscle belly at the same time or a fibrous type when the entire head was purely fibrous. Attention was also focused on capturing the occurrence of the supracondylar process of the humerus and Struthers' ligament, in animals, the presence of the entepicondylar foramen has also been observed.

Results

The results of the study are divided into three parts. The first part focuses on the study of anatomical structures of the upper limbs of adult human individuals, the second part focuses on human fetuses and the third is focused on animals.

Upper extremities of adult human individuals

Variability of the pronator teres

On the studied upper limbs of adults, the humeral head of the PTM always began from the medial epicondyle of the humerus. In most cases (70.6%, $N=68$), the origin of the muscle was also at the medial intermuscular septum (Figure 1). The width of the beginning of the humeral head from the medial intermuscular septum was on average 28.4 mm ($\sigma=11.4$). For less than a third of the specimens (29.4%, $N=68$), the humeral head started from the medial epicondyle only. In one case (1.5%, $N=68$), the origin of the muscle left the medial epicondyle divided into two parts, the stronger portion was located proximally and the weaker one was located distally (Figure 2, Table 1).

The ulnar head was completely absent on three upper extremities (4.4%, $N=68$). If the ulnar head of the studied limbs was present, it began in the vast majority of cases from the coronoid process of the ulna (96.9%, $N=65$), which corresponds to the norm stated in anatomical textbooks [18, 19]. In two other cases, the ulnar head began at the coronoid process as well as at the trochlea of the humerus (3.1%, $N=65$).

The ulnar head was in most cases muscular (66.2%, $N=65$), to a lesser extent tendinous (20%, $N=65$) or mixed (13.8%, $N=65$). In one specimen, a broad humeral head reached up to the beginning of the ulnar head and fused together (1.5%, $N=68$). Amongst the most interesting

varieties, a rare case (1.5%, $N=68$) was found when both heads did not merge in one belly, but remained separate until the point of insertion on the radius (Table 2).



Figure 1 – The pronator teres originates from the medial epicondyle and from the medial intermuscular brachial septum (in human). PTM: Pronator teres muscle; MIBS: Medial intermuscular septum.

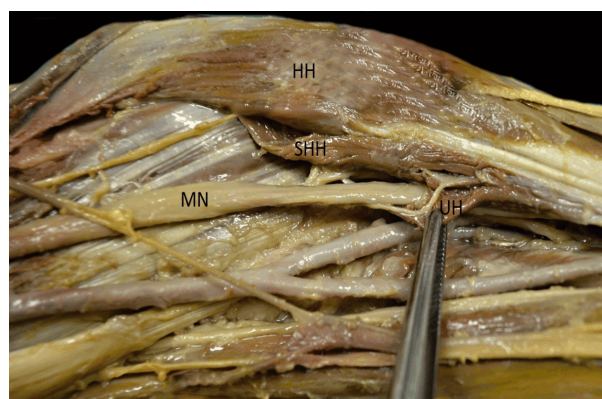


Figure 2 – An accessory head which originates from the medial epicondyle under the humeral head of the muscle (in human). MN: Median nerve; SHH: Separated humeral head of pronator teres; HH: Humeral head of pronator teres; UH: Ulnar head of pronator teres.

Table 1 – The origin of the humeral head of the pronator teres

N	Origin			
	MEH	MEH + MIS	Average width of the beginning from MIS [mm]	Duplicated
68	20 (29.4%)	48 (70.6%)	28.4, $\sigma=11.4$	1 (1.5%)

N: Number of studied limbs; MEH: Beginning of the muscle from the medial epicondyle of the humerus; MIS: Medial intermuscular septum; MEH + MIS: Beginning of the muscle from the medial epicondyle of the humerus and the medial intermuscular septum.

Table 2 – The presence, the beginning and the quality of the ulnar head of the pronator teres

N	Absent	N	Origin		Type			
			CP	CP + TH	Muscular	Tendinous	Mixed	Conjoined with HH
68	3 (4.4%)	65	63 (96.9%)	2 (3.1%)	43 (66.2%)	13 (20%)	9 (13.8%)	3 (4.6%)

N: Number of studied limbs; CP: Beginning of the muscle from the coronoid process of the ulna; CP + TH: Beginning of the muscle from the coronoid process of the ulna and trochlea of the humerus; TH: Trochlea of the humerus; HH: Humeral head of the pronator teres.

Variability of the course of the median nerve through the pronator teres

The MN passed according to the norm between the two heads of the PTM on most of the upper extremities (85.3%, $N=68$), and less often passed through the ulnar head (5.9%, $N=68$) or passed under both heads (2.9%, $N=68$). On the limbs where the ulnar head absent, the MN passed under the humeral head together with the ulnar veins (4.4%, $N=68$). In the studied dissection material, no cases were recorded where the MN passed through the humeral head (Figure 3, Table 3).

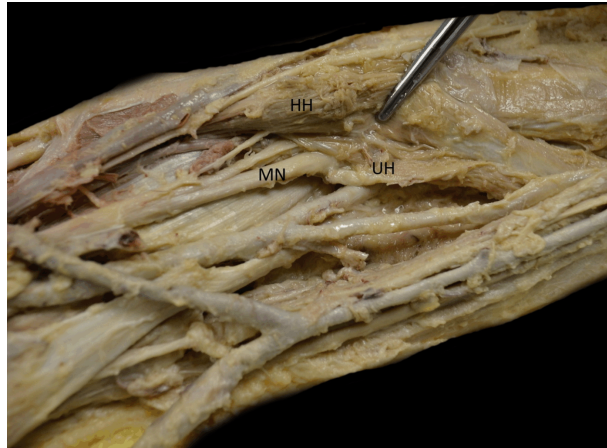


Figure 3 – The median nerve passes through the ulnar head of the pronator teres (in human). MN: Median nerve; HH: Humeral head of pronator teres; UH: Ulnar head of pronator teres.

Table 3 – The relationship between the median nerve and the pronator teres

	Between both heads	Under both heads	Under the humeral head	Pass through the ulnar head	Between both heads together with ulnar veins
N	58	2	3	4	1
68	(85.3%)	(2.9%)	(4.4%)	(5.9%)	(1.5%)

N: Number of studied limbs.

Variability of the course of the surrounding arteries

In the studied human upper limbs, there were no deviations from the norm in the course and branching pattern of the brachial and radial arteries. The brachial artery came into the cubital fossa with the MN along its ulnar side and under the bicipital aponeurosis and divided into its final branches, the radial artery and the ulnar artery. High division of the brachial artery, or simultaneous occurrence of two brachial arteries was not recorded. Also, the course of the radial artery corresponded in all cases to the norm. After an origin from the brachial artery below the bicipital aponeurosis, it continued to the forearm in the groove between the brachioradialis and the PTM, then more distally between the brachioradialis and the flexor carpi radialis. The ulnar artery ran in most limbs in the usual way (98.5%, $N=68$). It started in the cubital fossa from the brachial artery, passed under the group of superficial flexors of the forearm (including the PTM) and continued distally between the flexor carpi ulnaris and the flexor digitorum superficialis, together with the ulnar nerve. In one case, however, a relatively rare variation in its course was recorded, when the artery after its origin in the cubital fossa ran together with the MN between the two heads

of the PTM through the pronator canal (1.5%, $N=68$) (Figure 4).

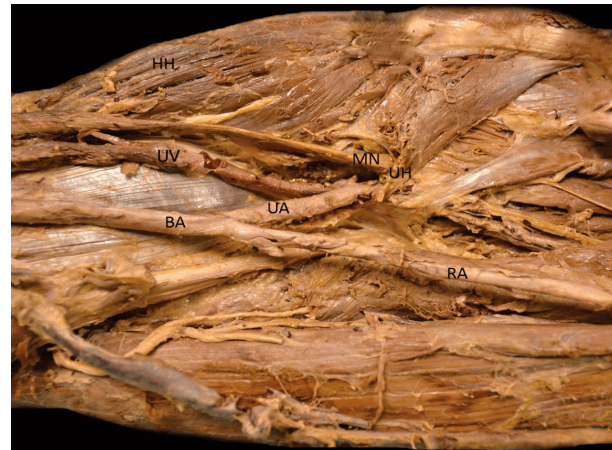


Figure 4 – The ulnar artery passes together with the median nerve through pronator canal (in human). UV: Ulnar vein; UA: Ulnar artery, RA: Radial artery; BA: Brachial artery; MN: Median nerve; HH: Humeral head of pronator teres; UH: Ulnar head of pronator teres.

Supracondylar process and Struthers' ligament

Neither a supracondylar process nor Struthers' ligament were found on the dissected material.

Upper limbs of human fetuses

In the ontogenetic study, a normal origin of the PTM was found in all the studied fetuses (13, 15, and 25 weeks). The humeral head started from the cartilaginous epicondylus medialis of the humerus and the ulnar head from the coronoid process of the ulna. The MN passed in all three cases through the pronator canal, between the two heads of the muscle (Figure 5). Also, the course of the arteries corresponded to the norm, which is common in adults. The brachial artery came into the cubital fossa with the MN along its ulnar side and was divided into its final branches, the radial artery and the ulnar artery, under the bicipital aponeurosis. At the forearm, the radial artery continued in the groove between the brachioradialis and the PTM. The ulnar artery passed distally under the PTM and continued between the flexor carpi ulnaris and flexor digitorum profundus.

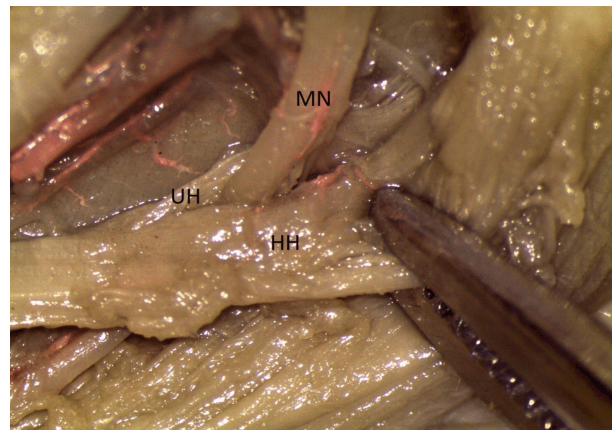


Figure 5 – The pronator teres and the median nerve in the human fetus (15 weeks old). MN: Median nerve; HH: Humeral head of pronator teres; UH: Ulnar head of pronator teres.

Comparative study

In the third part of the study, a comparative dissection of five mammal species was performed, three of which (the squirrel monkey, cat and Djungarian hamster) have, unlike the human anatomy, a hole above the medial epicondyle of the humerus – the entepicondylar foramen.

In the squirrel monkey, the PTM originated as two heads, as in humans. The humeral head started from the proximal part of the medial epicondyle of the humerus and was initially associated with the flexors. The ulnar head started from the coronoid process of the ulna. At the arm, the MN passed together with the brachial artery through the entepicondylar foramen, and in the forearm continued between the two heads of the PTM (Figure 6). In the cat, the PTM started only from the medial epicondylus of the humerus, and the ulnar head was not present. Similar to the squirrel monkey, the MN passed together with the brachial artery through the entepicondylar foramen and under the PTM, then continued distally (Figures 7 and 8). In the Djungarian hamster, only the humeral head was present, which, however, started from both the medial epicondyle of the humerus and the bony arch closing off the entepicondylar foramen. The portion coming from the ulna was not present. The MN ran through the entepicondylar foramen together with the brachial artery and at the forearm continued under the PTM.

In the golden hamster, the entepicondylar foramen was not present and the PTM started from the medial epicondyle of the humerus. The MN ran from the arm to the forearm and further among the forearm flexors. In the dog, the entepicondylar foramen was also not present. The PTM started with two heads from the proximal and middle parts of the medial epicondyle of the humerus. Both heads were later joined together into one muscle belly and the muscle inserted into the radius. The ulnar head was not present. Proximally, the MN ran together with the brachial artery, more distally passed under the flexors of the forearm. Variability in the course of the surrounding arteries was not observed.

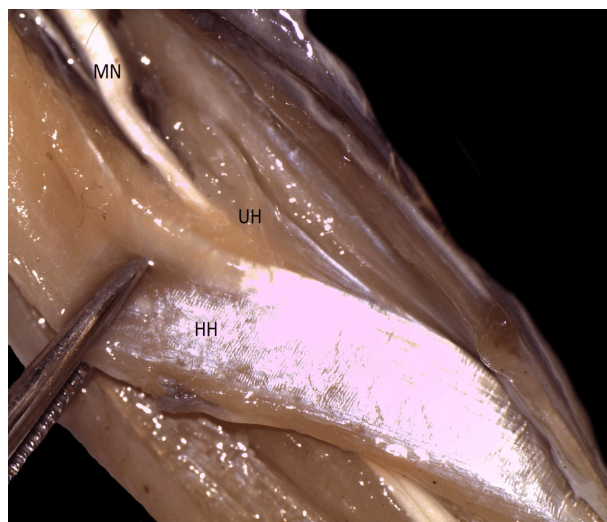


Figure 6 – The pronator teres and the median nerve in the squirrel monkey. MN: Median nerve; HH: Humeral head of pronator teres; UH: Ulnar head of pronator teres.

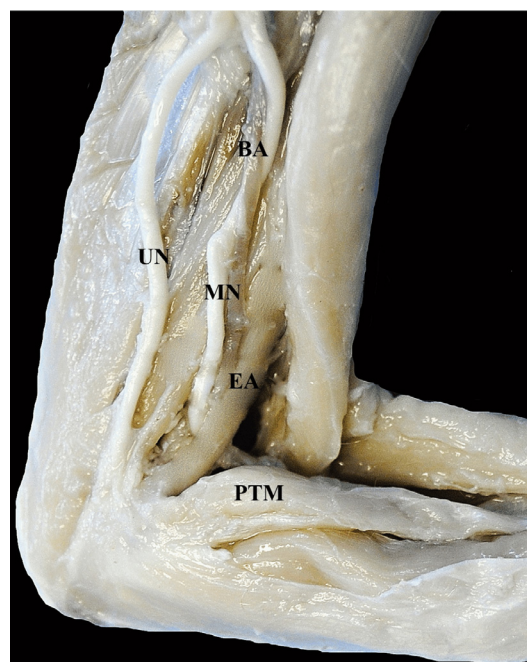


Figure 7 – The pronator teres and the median nerve in the domestic cat (adult specimen). MN: Median nerve; PTM: Pronator teres muscle; BA: Brachial artery; EA: Entepicondylar arch; UN: Ulnar nerve.

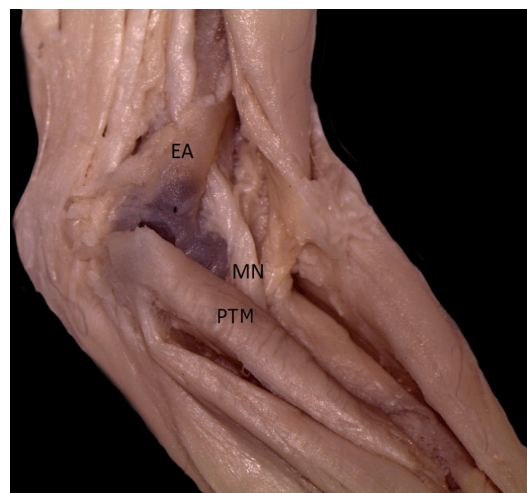


Figure 8 – The pronator teres and the median nerve in the domestic cat (immature specimen). MN: Median nerve; PTM: Pronator teres muscle; EA: Entepicondylar arch.

Discussion

Entrapment syndromes of the MN are still a current medical problem. In the elbow joint region, compression of the MN can originate from muscular (PTM), fibrous (Struthers' ligament) and bony structures (supracondylar process of the humerus). Due to the low frequency of occurrence of these formations, especially Struthers' ligament and the supracondylar process, or ignorance of the variable course of the MN through the PTM, the assessment of the symptoms of entrapment syndrome may result in a misdiagnosis, such as confusion with carpal tunnel syndrome, and therefore also to the inappropriate treatment [1]. Therefore, a number of authors have investigated this issue [9–13, 20, 21], but most of them only

describe a specific case report. For this reason, purpose of our work was to perform a comprehensive study to assess the above-mentioned problem and also with regard to the ontogenetic and phylogenetic development of these anatomical structures.

According the norm mentioned in anatomical textbooks [18, 19], the PTM originates from two heads, *i.e.*, the humeral head from the medial epicondyle of the humerus and the ulnar head from the coronoid process of the ulna. The PTM, however, has a relatively large degree of variability, especially in terms of its origin and in relation to the MN.

The humeral head should be separate from the medial epicondyle of the humerus. However, we also observed as a standard condition the beginning of the humeral head extending to the medial intermuscular septum. This arrangement was found in 46 (71.6%) upper limbs. This high incidence of the muscle beginning from the medial intermuscular septum of the arm, similar to our results, was not observed by other authors. This fact can be explained since the medial intermuscular septum is removed during classical anatomical section preparation and a possible accessory muscle origin therefore may not have been registered. Furthermore, previous works focusing on the studied muscle usually only describe casuistry, and to these authors, this variation may not have seemed significant. The reason for the origin of the PTM to arise from the septum may be related to phylogeny, since in chimpanzees the PTM begins from the medial epicondyle of the humerus as well as from the insertion tendon of the dorsoepitrochlearis muscle [22]. The dorsoepitrochlearis occurs in all quadrupedal mammals; it passes through the arm just at the point of the medial intermuscular septum [23]. The double origin of the humeral head we observed in one case (1.5%) was similar to the findings described by Koshy *et al.* [20] and Barrett [24].

The origin of the humeral head of the PTM from the supracondylar process or Struthers' ligament is often mentioned [9, 13, 20, 21, 25, 26]; however, this anatomical structure was not observed in our set. The start of the ulnar head was in most cases standard, *i.e.*, from the coronoid process of the ulna, and only in two cases (3.1%, $N=65$) did we observe an additional origin from the trochlea of the humerus. The presence and type of the ulnar head is compared with the results from Nebot-Cegarra *et al.* [10], who studied a sample from the contemporary Spanish population (Table 4).

Table 5 – Comparison of the course of the median nerve in relation to the pronator teres

Course of median nerve	Mori, 1964 [32] (Japan) $N=80$	Nebot-Cegarra <i>et al.</i> , 1991–1992 [10] (Spain) $N=60$	Jamieson & Anson, 1952 [27] (USA) $N=60$	Vymazalová <i>et al.</i> , 2015 (Czech Republic) $N=68$
Between both heads	95%	75%	83.3%	85.3%
Between PTM and FDPM	0.25%	–	6%	2.9%
Beneath HH	–	21.6%	8.7%	4.4%
Breaking through HH	0.25%	1.7%	2%	–
Breaking through UH	–	3.4%	–	5.9%
Together with UV	–	–	–	1.5%

N: Number of studied limbs; PTM: Pronator teres muscle; FDPM: Flexor digitorum profundus muscle; HH: Humeral head; UH: Ulnar head; UV: Ulnar veins.

From the Table 5, it is apparent that the observed frequency where the nerve passed between the two heads was almost identical to the results of Jamieson & Anson

Table 4 – Comparison of variability in the ulnar head of the pronator teres

Ulnar head	N	Absence	Type		
			N	Muscular	Tendinous Mixed
Vymazalová <i>et al.</i> (2015)	68	3 (4.4%)	65	69.8%	9.5% 20.6%
Nebot-Cegarra <i>et al.</i> (1991–1992) [10]	60	13 (21.7%)	47	25%	61.4% 13.6%

N: Number of studied limbs.

From a clinical point of view, a tendinous ulnar head is especially important, because due to its greater tension, it can increase the likelihood of MN compression [10].

Absence of the ulnar head seems to be a common variation [10, 11, 21, 27]. This is supported by phylogenetic development, as in most mammals (except anthropoid apes) the ulnar head is completely missing [28, 29].

According to anatomical standards [18, 19], the MN enters the forearm from the cubital fossa through a gap between the humeral and ulnar heads of the PTM. The space between the two heads of the muscle is known as the pronator canal and hypertrophy of the muscle here can lead to compression of the MN, called pronator syndrome [1, 3–5, 30]. In accordance with the standard, we registered the passage of the nerve through the pronator canal in our study in 85.3% ($N=68$) of cases. In 5.9% ($N=68$) of the upper limbs, the MN entered through the ulnar head, similar to that described by Nebot-Cegarra *et al.* [10] and Gessini *et al.* [31]. This variation can be, in our opinion, considered a predisposing factor to the origin of entrapment syndrome. Less frequently (2.9%, $N=68$), the MN passed beneath the both heads of the muscle, thus between the PTM and the flexor digitorum profundus. This was also observed by Nigst & Dick [30], Mori [32] and Hartz *et al.* [33]. This quite favorable variation does not preclude the emergence of pronator syndrome, as stated in the work of Nigst & Dick [30].

Some authors [10, 27, 34] have described a condition where the MN passes through the humeral head of the PTM, but we did not observe this variation.

Table 5 compares the results of previous studies of the course of the MN in relation to the PTM between samples from Spanish [10], American [27], Japanese [32] and Czech populations.

[27]. A clear difference was seen in the results of Nebot-Cegarra *et al.* [10] and Mori [32], in which their results clearly correspond with the frequency of the absence of

the ulnar head. The arteries near the studied muscle showed, with one exception, no deviations from the norm. Only in one case was a variable course of the ulnar arteries observed, which passed together with the MN through the pronator canal. This is a unique variation, which may result in compression of both the nerve and blood vessels, due to the accumulation of structures in the pronator canal. Cases of compression of the nerves and blood vessels between muscle fibers in other locations are common [35].

To the emergence of entrapment syndrome of the MN around the cubital fossa may occur due to the incidence of other anatomical structures – the supracondylar process of the humerus and Struthers' ligament. The supracondylar process is a variable bony spur occurring in front of the shaft of the humerus, about 5–7 cm above the medial epicondyle. Sometimes, Struthers' ligament may pass from it to the medial epicondyle of the humerus. This creates the osteofibrous canal, which the MN and brachial artery can pass through. Just above mentioned spur and ligament may occur MN compression, either together or separately. The humeral head of the PTM often starts from these formations [9, 12, 13, 26, 36, 37] which may also contribute to MN compression. This is called supracondylar process syndrome [6]. This entrapment syndrome is manifested by pain in the forearm and hand in the area of MN innervation and by disorders in sensitivity in the nerve distribution area [38]. Similar symptoms are present with supracondylar process fractures, which result in injury to the MN [39–43].

Struthers' ligament can also occur separately without the presence of the supracondylar process. According to Bilecenoglu *et al.* [11], the ligament passes from the brachialis muscle to the medial epicondyle. Kessel & Rang [44] stated that Struthers' ligament is the remnant of the latissimo-condyloideus muscle, which is typical in climbing mammals. Cases of MN compression through a separate Struthers' ligament have been published by Suranyi [8] and Smith & Fisher [45]. Lee & LaStayo [1] claimed that the compression of the nerve through Struthers' ligament comprises only about 0.5% of cases of MN compression.

The literature also describes an isolated finding of Struthers' ligament ossification in humans and the emergence of a bony canal for the brachial artery and MN [46]. A very similar formation occurs normally in some species, such as the entepicondylar foramen, and can be considered a structure analogous to the supracondylar process [9, 42].

In the studied anatomical preparations, neither the supracondylar process nor Struthers' ligament were found, probably due to the low frequency of their occurrence. Because this took place in connection with a study of anatomical specimens, an osteological analysis was also performed on five variably dated skeletal files (modern, medieval and three prehistoric) for the presence of the supracondylar process. The frequency of occurrence of the supracondylar process at the humerus from the modern age osteological collection amounted to 2.1% ($N=192$), from the medieval Slavic necropolis 0.9% ($N=211$) and from the prehistoric localities ranging from 1.1% to 2.6% ($N=256$). According to this study, the frequency of the supracondylar process in different historical periods was

not significantly different; there has not been an increase or decrease in this variation over time [47].

Very interesting findings about the ontogenetic development of the supracondylar process have been obtained from the work of Adams [48]. According to this author, as the embryo forms, a cartilaginous supracondylar process appears at a certain stage of ontogenetic development, which later disappears again. The spur was most strikingly developed in the embryo with a length of 19 mm, while in the 30 mm embryo, it was only partially visible. In the 19 mm embryo, the PTM had only the humeral head, and the ulnar portion was not present yet. This finding is interesting, especially since the coronoid process of the ulna should already be present. According to Lewis [49], this structure originates in the 16 mm-long embryo. In our study on the variability of PTM, three fetuses at the age of 13, 15 and 25 weeks of intrauterine development were dissected and examined. The supracondylar process of the humerus was not present in any of them. The PTM in the studied fetuses was in the same form as in the adult. The humeral head started according to the norm from the medial epicondyle of the humerus and the ulnar head from the coronoid process of the ulna. Also, the course of the MN corresponded to the status in the adult, passing through the canal between the two heads of the PTM. This finding was not surprising, because the MN begins to appear in embryos 11 mm in length [50]. In the embryonic period, when the PTM is not yet differentiated, the MN passes between the deep and superficial layers of the flexor mass, from which the muscle subsequently differentiates [49]. Also, the formation and course of the arteries in the cubital fossa corresponded in the studied fetuses to standards, according to expectation. The ulnar artery arises in the embryo at the age of 41 days and the radial artery at the age of 44 days [51]. From the above-mentioned observations, it follows that if the cartilaginous supracondylar process is present during ontogeny, it is only during the embryonic period, while during the fetal period it is no longer present.

As was already mentioned above, the humeral head of the PTM, in some cases, can start from the variable supracondylar process of the humerus (or Struthers' ligament) (Figure 9). This state corresponds to the formation of anatomical structures in some mammals in which the PTM starts from the bony arch partitioning the entepicondylar foramen. This is an opening located above the medial epicondyle of the humerus, through which the MN and brachial artery pass [36, 44] (Figure 9). The occurrence of this foramen is quite normal in some species, although in humans, a similar structure has only been described once [46] (Figure 9).

The entepicondylar foramen is present in many amphibians, reptiles and mammals [36]. According to Landry [52], the entepicondylar foramen occurs regularly in marsupials, didelphids, koalas and usually also in kangaroos. Among insectivores, shrews, moles and several species of hedgehog have this foramen. In rodents, the incidence of this opening is quite variable. Among pinnipeds, the foramen quite often occurs in *phocidae*, but is absent in *otariidae* and *odobenidae*. Among the terrestrial carnivores, felids generally have the foramen, along with mustelids, viverrids and procyonids. In canids, hyaenids and ursids,

it is absent. Among the primates, the entepicondylar foramen is found in all prosimians and South American monkeys. Incidence in old world monkeys, apes and humans is not common. Similar results have also been published by Kolster [53]. We cannot therefore specify that the entepicondylar foramen is found in a particular genus, family or order. Also, we cannot say that the foramen occurs in species with a similar way of life. We find it in animals that climb (prosimians, squirrel), that swim (seal, otter), that live in the ground (mole) and in animals that do not need the front legs to move (kangaroo).



Figure 9 – (A) The supracondylar processes of the humerus in man; (B) The supracondylar process of the humerus with ossified Struthers' ligament in man (Dwight, 1904 [46]); (C) The humerus of the domestic cat with the entepicondylar foramen; (D) The humerus of the squirrel monkey with the entepicondylar foramen; (E) The humerus of the olive baboon without the entepicondylar foramen; (F) The humerus of the Djungarian hamster. The arrow signs the entepicondylar foramen; (G) The humerus of the golden hamster.

Among the group of mammals that we examined, we can confirm the presence of the entepicondylar foramen in the Djungarian hamster, domestic cat and squirrel monkey. In contrast, the foramen did not occur in the dog or golden hamster. From this study arose a comparison of two species belonging to the same subfamily, which we assume have a similar body structure and way of life (Djungarian hamster, golden hamster). Nevertheless, in one of them, the entepicondylar foramen occurs and the second is absent (Figure 9). A similar case can be found among some species of hedgehogs [53].

The function of the entepicondylar foramen in mammals was clarified by Landry [52]. He summarized a number of different theories that could be divided into three groups. The first theory prefers a protective function of the entepicondylar foramen for the MN and brachial artery. The second group of theories points at the dependence of the presence of the opening on the width of the distal end of the humerus. A third theory is that the bony arch acts as a brace or strut against the strength of the ulna. All of these hypotheses were refuted. Landry believed that the entepicondylar foramen works in four-legged mammals as a retinaculum for the MN and protects it from declining over the angle of the elbow. In his view, in the four-legged

mammals, the axilla is relatively deep and largely surrounds the humerus, such that the skin in the elbow region is loose and cannot fix the nerve to surrounding structures. The vessels are mounted on the arm with their numerous branches, and the radial nerve and ulnar nerve do not need fixing because they pass in the distal third of the arm on the dorsal side behind the humerus, and on the ventral side only in the forearm. The MN is therefore the only filiform structure in the arm, which requires fixation. The absence of the entepicondylar foramen is explained by Landry [52] in that the cursorial and ungulate mammals have lost this structure, because abduction of the humerus does not occur and therefore the MN is not exposed. Anthropoid primates (including humans) in his opinion also do not need the foramen because the humerus in these species can undergo considerable abduction. The axilla is significantly shortened in these species, and the skin around the elbow firmly adheres to the surface and effectively holds the MN in place. However, this theory does not explain why the incidence of the entepicondylar foramen is discontinuous among members of closely related genera (Figure 9).

The present communication also focused on monitoring the relationship of the supracondylar process and the PTM. An interesting finding is that the presence of the supracondylar process in humans is often associated with a high origin of the PTM, *i.e.*, right from this spur [9, 13, 21, 25]. Likewise, among some species of mammals, this muscle originates from the bony arch closing the entepicondylar foramen [53]. However, this is not a general rule for all mammals, as evidenced by the results of our study.

The entepicondylar foramen was present in three species of mammals dissected by us – the squirrel monkey, Djungarian hamster and domestic cat. In the squirrel monkey and hamster, the humeral head of the PTM occurred in two parts, *i.e.*, proximally from the bony arch enclosing the entepicondylar foramen and distally from the medial epicondyle of the humerus. In the cat, the muscle started from the medial epicondyle only. The location of the muscle origin is probably affected by its function, specifically by the range of possible movements in the individual species.

The PTM is commonly found in many species of mammals capable of pronation. It responds to a part of the flexor antebrachii, occurring in amphibians [54]. According to Kolda [55], it is a particularly well developed muscle in the dog and in the pig; however, it is very thin and narrow in ruminants and rudimentary in horses as it occurs only rarely in the form of several muscle fibers. These facts confirm that the presence of a muscle is directly related to the momentum of the limbs. In animals lacking the ability to pronate, the muscle may be absent or rudimentary. In most mammals, the PTM has only the humeral head [28, 56, 57], beginning from the medial epicondyle, or from the entepicondylar arch [53]. In the anthropoid apes and humans, the ulnar portion also occurs from the coronoid process of the ulna. According to Lewis [49], the humeral head develops from the radial part of the superficial flexor mass. In contrast, the ulnar head arises from the deep flexor mass, from which the pronator quadratus also develops [56]. It is thus obvious that both heads differ in their origin.

For all subjects, the examined PTM was well developed. The humeral head began from the entepicondylar arch and from the medial epicondyle of humerus in the squirrel monkey and hamster. In the cat, the muscle started from the medial epicondyle only. In the dog, where the entepicondylar foramen was not present, the PTM began at the upper and middle part of the medial epicondyle. The ulnar head was observed only in the squirrel monkey and humans, which corresponds with statements by Macalister [28, 56] and Straus [57].

Conclusions

The present study on the variability of the PTM summarizes all existing knowledge about this issue and adds some new information from ontogenetic and phylogenetic development. Detailed knowledge of the anatomical structures around the elbow joint is necessary in connection with compression of the MN in this region, because the likelihood of entrapment syndrome usually increases substantially with the occurrence of some variable structures. Most often, the MN is compressed as it passes between the humeral and ulnar heads of the PTM with hypertrophy of this muscle. The risk of MN compression significantly increases in cases where the ulnar veins pass through the pronator canal with the MN. Entrapment syndrome cannot be ruled out in cases when the MN runs through the ulnar head or when the ulnar head is fibrous. A less risky condition is where the nerve passes under the two heads of the PTM. Predisposition to nerve compression may occur with some rarer varieties, such as a supracondylar process of humerus or Struthers' ligament, which we failed to capture in the studied material. The presence of the supracondylar process was not recorded in the analyzed fetuses either. From our results, that if a cartilaginous supracondylar process is present during ontogeny, it is only during the embryonic period, while during the fetal period it is no longer present. From the phylogenetic point of view, the PTM occurs in many species of mammals capable of pronation. For most of them, however, only the humeral head is present, and the ulnar head is present only in humans and anthropoid apes. The humeral head originates from the medial epicondyle of the humerus, or from the arch partitioning the entepicondylar foramen. The entepicondylar foramen is present only in some mammalian species. The occurrence and function of this structure is not entirely clear and will be the subject of further study.

Conflict of interests

The authors declare that they have no conflict of interests.

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