Review paper

Anatomical and clinical aspects of the posterior interosseous nerve of the forearm

Anatomiczne i kliniczne aspekty nerwu międzykostnego tylnego przedramienia

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Medical Studies/Studia Medyczne 2024; 40 (1): 61–68
DOI: https://doi.org/10.5114/ms.2024.137602

Key words: posterior interosseous nerve, Froment-Rauber nerve, arcade of Frohse.

Słowa kluczowe: nerw międzykostny tylny, nerw Fromenta-Raubera, arkada Frohsa.

Abstract

The radial nerve arises from the brachial plexus posterior cord from roots C5-Th1. It divides into two terminal branches: superficial and deep. The superficial branch is mostly sensory. From the deep branch arises the posterior interosseous nerve of the forearm. The deep branch of the radial nerve passes through the arcade of Frohse. The arcade of Frohse begins in the apex of the lateral epicondyle of the humerus and is attached to its medial part. It is the highest, proximal part of the supinator muscle, which may have a tendinous or membranous structure. Significant topographic points that are useful in describing the posterior interosseous nerve of the forearm are the radial channel and arcade of Frohse. There exists the anatomical variation of the distal part of the posterior interosseous nerve of the forearm. It is called the Froment-Rauber nerve. Posterior interosseous nerve of forearm dysfunction leads to radial nerve syndrome. There are two different syndromes which are associated with posterior interosseous nerve of forearm dysfunction: radial tunnel syndrome and posterior interosseous nerve syndrome. These syndromes are distinguished on the basis of characteristic symptoms.

Streszczenie

Nerw promieniowy pochodzi z pęczka tylnego splotu ramiennego z korzeni C5-Th1. Dzieli się na dwie końcowe gałęzie: powierzchowną i głęboką. Powierzchowna gałąź jest głównie czuciowa. Z gałęzi głębokiej odchodzi nerw międzykostny tylny przedramienia. Gałąź głęboka nerwu promieniowego przechodzi przez tzw. arkadę Frohsa. Rozpoczyna się w części szczytowej nadkłykcia bocznego kości ramiennej i rozciąga się, przyczepiając się do jego przyśrodkowej części. Jest to najwyższa, proksymalna część mięśnia odwracacza, która może mieć charakter ścięgnisty lub błoniasty. Istotnymi punktami topograficznymi przydatnymi w opisie nerwu międzykostnego tylnego przedramienia są kanał promieniowy i arkada Frohsa. Istnieje zmienność anatomiczna dystalnej części nerwu międzykostnego tylnego przedramienia. Jest to tak zwany nerw Fromenta-Raubera. Dysfunkcja nerwu międzykostnego tylnego przedramienia prowadzi do zespołu nerwu promieniowego. Istnieją dwa różne zespoły związane z dysfunkcją nerwu międzykostnego tylnego przedramienia: zespół kanału promieniowego i zespół nerwu międzykostnego tylnego. Zespoły te wyróżnia się na podstawie charakterystycznych objawów.

Introduction

The area of the innervation of the radial nerve comprises many structures. In addition, there is great variability of its course as well as variation described in the literature. Due to the deep position of its branches, especially the deep branch and the posterior interosseous nerve ((PIN) of the forearm), this nerve is difficult to measure. Therefore, there is no single measurement point. This nerve is often damaged, which is clinically relevant. This work includes an overview of the available literature covering both the anatomy, the course of the nerve with particular attention to the PIN, its anatomical variations and variations as well as the clinical aspects.

Anatomy of posterior interosseous nerve of the forearm

The radial nerve comes from the brachial plexus posterior cord from roots C5-Th1 [1, 2]. At a distance of 1.3 cm proximal to the elbow joint and 2 cm proxi-

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mal to the head of radius, it divides into two terminal branches: superficial and deep [3, 4]. Before dividing, its diameter is about 7 mm (from 5.5 mm to 9 mm). Nair *et al.* during research on 28 forearms found that the division point of the radial nerve is above the transepicondylar distance (TED) in 18 cases, at the TED level in 6 cases and below in 4 of them [5].

The superficial branch, thinner than the deep branch, is mostly sensory and in its final course it splits into terminal branches as a dorsal nerve of the digits (dorsal digital branches of the radial nerve). Furthermore, the superficial branch of the radial nerve conveys the postganglionic general visceral efferent (GVE) nerve fibers from the middle and inferior cervical ganglia destined for sudoriferous glands in the cutaneous area innervated. From the deep branch, apart from branches supplying muscles of the forearm, arises the posterior interosseous nerve of the forearm [6]. This nerve contains sensory, motor and proprioceptive fibers. Motor fibers prevail in it [6–8]. It provides motor supply to the supinator muscle, extensor carpi radialis brevis, extensor carpi ulnaris, extensor indicis, extensor digiti minimi, abductor pollicis longus, extensor pollicis longus and brevis [3, 7, 9, 10]. It also gives off periosteal branches to the interosseous membrane of the forearm and the periosteum of the ulna and radius [11]. The distal part of the nerve consists mainly of sensory fibers supplying the dorsal part of the carpal joint capsule. It also supplies sensory input to the carpal joints: radiocarpal, midcarpal, and second, third, fourth carpometacarpal joint [6, 10, 12–14]. It should be noted that this nerve does not provide sensory innervation of the skin [8, 15]. The deep branch of the radial nerve (DBRN), supplying deep muscles of the posterior compartment muscles of the forearm, is formed at the division of the radial nerve about 46 mm proximal to the arcade of Frohse (AF) and 8 cm distal from the lateral intermuscular septum of the arm [1]. The DBRN immediately after its formation has a diameter of about 3.5–5.0 mm [6]. At the beginning it is in the ulnar fossa and then it passes between the two heads of the supinator muscle, although cases have been described where the nerve runs at the surface of the supinator muscle and is surrounded by aponeurosis or is under the supinator muscle, running at the surface of the periosteum of the radial bone [16]. The DBRN at a distance of 1.5 cm from the radial bone head gives a branch to the extensor carpi radialis and from 1 to 6 branches to the supinator muscle [3, 11], then it enters at the neck level of the radial bone to the supinator muscle and, on average, 6 cm distal to the lateral epicondyle of the humerus [6]. Most often the nerve enters into the supinator muscle as a single branch, although it is also possible to enter as two equal branches, which arise about 2 cm proximal from the AF [11]. Significant topographic points that are useful in describing the PIN are the radial channel and AF.

In a distal part of the arm, between the brachialis and brachioradialis muscle at the level of the humeroradial joint, the radial canal begins. The base of the canal builds a capsule of the elbow joint and a fragment of the deep head of the supinator muscle, while its roof is created by the brachialis, brachioradialis muscle and extensor carpi radialis brevis [17]. It ends at the distal margin of the supinator muscle [4]. The PIN's canal in the supinator muscle is 3–5 cm long [4, 5, 7, 11, 18]. Sometimes separate parts detach from the supinator muscle to form the medial tensor of the annular ligament of the radius and the lateral tensor of the annular ligament of the radius [19].

AF was described, by Frohse and Frankel, in 1908 for the first time [20–22]. It begins at the apex of the lateral epicondyle of the humerus and is attached to its medial part. It is the highest, proximal part of the supinator muscle, which may be of tendinous or membranous structure. This is the arch from under which the PIN comes out.

The length from the origin to the place where the DBRN is passing into the supinator muscle is about 3.6 cm [1]. Nair *et al.* report an average length of 5.11 cm [5]. Hazani *et al.* described the exact point of the DBRN entry to the supinator muscle at a distance of 34 mm distal from the head of the radial bone [23], while Hohenberger *et al.* reported a value of 28.9 mm [24]. The length of the DBRN measured from the head of the radius to the AF is approximately 66.7 mm in males, while it is 64 mm in females [18]. Immediately before the deep branch entrance into the supinator muscle, it gives a smaller recurrent branch towards the lateral epicondyle of the humerus [25].

In a Hohenberger's *et al.* study, on one hundred bodies, it was found that the DBRN always goes into the supinator muscle as a single branch, in 18% of cases as two branches [24].

Particularly interesting is Tatar's *et al.* research, where DBRN division on the supinator muscle was investigated on twenty fetal cadavers at 20–37 weeks of pregnancy. In 5% of cases the deep branch split before entering the supinator muscle, in 10% of cases the splitting was in the supinator muscle, and in 85% splitting was observed directly after nerve exit from the muscle. Moreover, a membranous arch of the supinator muscle was observed in every case, instead of a fibrous arch [26].

Tubbs *et al.* described an interesting case in which the DBRN was split in two branches immediately after arising. Both of them entered into the supinator muscle, but only one of the branches left the muscle [6]. Similarly, Seradge *et al.* reported a case where the PIN, as it passes through the supinator muscle, was split into two branches. One of them left the muscle proximal to the other and ran on the surface of the supi-

Table 1. Classification of arcade of Frohse – percentage of tendinous or membranous arch in various cases

Number of upper extremities examined	AF tendinous in	AF membranous in	Reference
55	48 (87%)	7 (13%)	Ozturk *et al*. (2005) [27]
100	46 (46%)	54 (54%)	Hohenberger *et al*. (2020) [24]
60	48 (80%)	12 (20%)	Ozkan *et al*. [17]
20	14 (70%)	6 (30%)	Ebraheim *et al*. (2000) [18]
18	14 (78%)	4 (22%)	Hazani *et al*. (2008) [23]
31	21 (68%)	10 (32%)	Thomas *et al*. (2000) [1]
60	34 (57%)	26 (43%)	Prasartritha *et al*. (1993) [4]

nator muscle so that the branches became connected again. The exit points of both branches from the supinator muscle were 3 cm apart [3]. Significant topographic points that are useful in describing the PIN are the radial channel and the AF.

The medium AF width is 10.13 mm, length is 8.6 mm and thickness is 0.77 mm [27]. Ebraheim *et al.* describe AF measurements differentiated by gender: length in men is 18.6 mm, width 2.8 mm, thickness is 0.8 mm, while the length in females is 18.5 mm, width 2.5 mm and thickness is 0.7 mm [18]. Length of the AF can be estimated by dividing the length of the forearm by 5 [27]. The frequency of tendinous and membranous AF is shown in Table 1.

Many publications do not distinguish between the PIN and DBRN [3–6, 8, 11, 17, 28]. However, it seems that the name PIN should be used for the nerve only after it exits from under the AF [23]. The earlier segment, from the radial nerve branch to the AF, should be referred to as the DBRN. The distance of the PIN exit point of the supinator muscle from the lateral epicondyle of the humerus is 12 cm [6], from the apex of the head of the radius it is 7.4 mm [23] or 6.42 cm, it is 6.9 mm from the radial margin of the ulna and 169.9 mm from the styloid process of the radius [24]. The PIN exit point of the supinator muscle has also been described as 15–21 cm (mean 18 cm) distant from the styloid process of the ulna [6].

The figures (Figures 1 and 2) illustrate where the radial nerve divides into the DBRN and superficial branch of the radial nerve. The accompanying muscles are shown, as well as the arcade of Frohse and the DBRN passing beneath it. The figures come from the materials of the Department of Normal Anatomy, Faculty of Medical Sciences in Katowice, Silesian Medical University in Katowice.

Grechenig *et al.* determined the distance of the PIN from the ulnar margin of the radial bone at different levels of the forearm. At a distance of 10 cm from the styloid process of the radial bone, the PIN distance from the margin was 3.75 mm, at a distance of 8 cm from the process it was 8.4 mm, and at a distance of 6 cm it was 6.4 mm [29].

Kamineni *et al.* made the description of the location of the PIN exit of the supinator muscle dependent on the transepicondylar distance (TED) of the humerus. In a study on sixty-three upper limbs taken from deceased donors, they also took into account the position of the limb (pronation, natural position, supination). The average TED for all limbs was 63.59 mm. The averaged results were as follows: in pronation, the distance of the PIN exit point from the supinator muscle to the lateral epicondyle was 100% of the TED, in the neutral position 85% of the TED, and in supination 72% of the TED [30]. With pronation of the forearm, the PIN moves medially by up to 1 cm [31].

Luthringer *et al.* examined the distance of the PIN from the distal attachment of the biceps brachii muscle using MRI images of 10 patients. The mean distance from the PIN to the guidewire exit point was 1.8 mm in pronation, 5.1 mm in neutral, and 10.3 mm in supination. Mean distance from the PIN to the biceps tendon footprint was 20.3 mm in pronation, 20.6 mm in neutral, and 19.8 mm in supination [32].

The PIN, after leaving the supinator muscle, runs forward from the humeroradial joint and then runs laterally and posteriorly. In its initial course it is crossed by the leash of Henry. It is a complex of the radial recurrent artery, diverging from the radial artery and the accompanying vein. The radial recurrent artery further forms an arterial arcade with the radial collateral artery diverging from the deep artery of the arm. The leash of Henry runs about 5 cm from the lateral epicondyle of the humerus (between 3.5 cm and 6 cm) [6, 10]. In some cases, the radial recurrent artery may run under the AF along with the PIN [17]. Numerous connections between the anterior and posterior branches of the radial artery are observed in the distal region of the supinator muscle [7].

At a distance of 0–1.5 cm after exiting from under the AF, the PIN gives off numerous branches to the superficial extensors of the forearm: the extensor digitorum, extensor carpi ulnaris and extensor digiti minimi. In 20% of cases, the initial fragments of these muscle branches form a nerve plexus [7]. Their number and location are variable. The fifth PIN

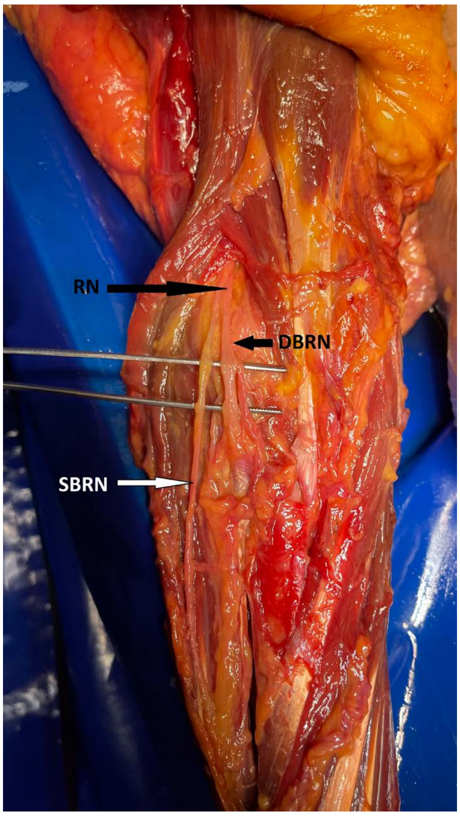

Figure 1. Radial nerve and its branches in the forearm in a cadaver

RN – radial nerve, DBRN – deep branch of radial nerve, SBRN – superficial branch of radial nerve.

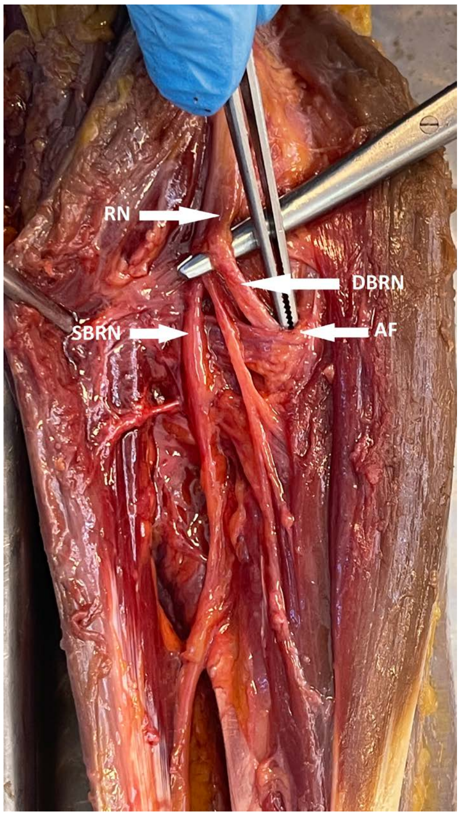

Figure 2. Arcade of Frohse in a cadaver

RN – radial nerve, DBRN – deep branch of radial nerve, SBRN – superficial branch of radial nerve, AF – arcade of Frohse.

branch divides into a radial and ulnar branch at a distance of 12.8 ±2.2 cm proximal to the dorsal radial tubercle [12, 33]. The dorsal radial tubercle is the dorsal tubercle of the radius, located 12.2–18.6 mm from the styloid process of the radius and 11.3–16.9 mm from the ulnar notch of the radius [34]. The anatomical structure of the dorsal radial tubercle distinguishes two bony vertices: radial and ulnar. Chan *et al.* during a study on three hundred sixty wrists using magnetic resonance imaging found that in 69.2% of cases the radial peak was higher than the ulnar one [35]. The tendon of the extensor pollicis longus wraps around the dorsal radial tubercle [34, 35]. This nodule can be palpated and is an important landmark for determining the location of the PIN [35].

The radial branch of the PIN innervates the extensor pollicis longus and brevis, while its ulnar branch innervates the extensor indicis and the extensor pollicis longus [12, 33]. The last muscular branch of the PIN is the branch to the extensor pollicis longus [6].

It extends 7.5 cm proximal to the dorsal radial tubercle [6], Nair *et al*. described this distance as 9.58 cm [5]. On the other hand, Abrams *et al*. located this branching site as 11.6 cm from the styloid process of the radius [36].

Missankov *et al.* examining fifty-eight upper limbs of black people's cadavers determined the most common order of branches departing from the DBRN and PIN. The branch to the extensor carpi radialis brevis was the first to depart, followed by branches to the supinator muscle, extensor digitorum, extensor carpi ulnaris, extensor digiti minimi, abductor pollicis longus, extensor pollicis brevis and longus and extensor indicis. This order occurred in 74% of cases [16].

Portilla Molina *et al*. investigating the course of the PIN on ten cadavers found that the course of this nerve showed great variability within both forearms of the same body (70% of cases) [7]. Kamineni *et al.* also found differences in their study [30]. However, Tubbs *et al.* found no statistically significant differences between the PIN course of the right and left upper limbs of the same cadavers [6]. This aspect requires further research on a larger number of cadavers.

The middle part of the PIN runs between the superficial muscles (extensor carpi radialis longus, extensor carpi radialis brevis) and deep muscles of the forearm (abductor pollicis longus, abductor pollicis brevis, extensor pollicis longus). The PIN crossing the abductor pollicis longus and brevis runs lateral to the extensor pollicis longus and medial to the extensor pollicis brevis, aiming at the dorsal surface of the wrist [10]. This nerve is accompanied by the posterior branch of the interosseous artery. The PIN is positioned dorsal to it [7, 13, 29]. This complex is surrounded by fibro-fatty tissue, which firmly attaches it to the interosseous membrane of the forearm [7].

The distal part of the PIN was determined by Zwart *et al.* based on an analysis of twenty upper extremities. They described the possible course of the distal part of the PIN as medial (65%), when the branches reached the lunate bone and/or capitate bone, ulnar (30%) when they reached the triquetrum and/or hamate bone, or radial (5%) when the branches reached the trapezium [14]. During this study, the researchers also determined how far the PIN's terminal branches reached. They found that in 15% of cases the branches reached the level of the metacarpophalangeal joints, in 15% the shaft of the metacarpal bone, in 55% the carpometacarpal joint, and in 15% the intercarpal joint contained between the scaphoid and lunate bones [14].

The distal part of the PIN divides at the level of the metacarpal joint into 2–4 branches, which supply sensory input to the wrist joints [10, 13, 14]. Rauber described anastomoses between the PIN and the anterior interosseous nerve (AIN) through an opening in the interosseous membrane of the forearm [37]. The AIN is a branch of the median nerve. It usually arises during the course of the median nerve through the pronator teres muscle and follows lateral to the anterior interosseous artery, lying on the anterior surface of the interosseous membrane of the forearm [29].

Bonczar *et al.* conducted histological research of twenty-eight PINs. Ten (35.7%) nerves contained a single bundle of nerve fibers, while 18 (64.3%) had at least two bundles of nerve fibers (from two to nine). However, the study found no statistically significant relationship between gender and the size of the nerves and the number of bundles they contained [38].

Froment-Rauber nerve

The anatomical variation of the distal part of the PIN is the Froment-Rauber nerve. This anatomical variation was first described in 1801 by Bichat. It was later also reported by Froment in 1846, Rauber in 1865, Shevkunenko in 1949 and Spinner in 1978 [8, 39]. The one who proposed the name for this nerve was Spinner [39]. The Froment-Rauber nerve is a rare variant of the terminal branches of the PIN or superficial branch of the radial nerve. This nerve innervates one or less commonly, several dorsal interossei muscles of the hand [8, 39, 40]. The Froment-Rauber nerve does not have a uniform course for itself. Four variations of this nerve are distinguished. As a branch of the PIN, this nerve can innervate the muscles of the hand directly or create an anastomosis with the deep branch of the ulnar nerve, but also as a continuation of the superficial branch of the radial nerve can innervate the muscles of the hand directly or form an anastomosis with the deep branch of the ulnar nerve [8, 40].

Clinical aspects of PIN

Radial nerve compression constitutes about 1% of non-traumatic upper extremity lesions [26]. Other studies report that this figure is less than 0.7% [23]. Most often, the nerve is compressed within the AF, leading to neuropathy – radial nerve syndrome. The possibility of PIN compression was first described in 1905 by Guillain *et al.* using the example of a conductor [41]. The possibility of such compression was later reported in 1963 by Koppel and Thomson, in 1966 by Capener and in 1968 by Spinner [27].

The annual incidence of PIN compression disease is estimated at 0.03%, while superficial radial nerve (SRN) compression disease is estimated at 0.003% [42]. It affects women more often. The peak incidence is between the ages of forty and sixty [10, 42]. Radial tunnel syndrome (RTS) almost always affects the dominant limb [10].

PIN dysfunction leads to radial nerve syndrome. However, due to a different primary direct cause of injury, some believe that two syndromes are associated with PIN dysfunction: RTS, which results from PIN compression within the radial canal, and posterior interosseous nerve syndrome (PINS) as a result of PIN compression within the AF. These syndromes are distinguished on the basis of characteristic symptoms. However, this division is not accepted by all, and some authors treat both syndromes as one [28, 43].

RTS was first described in 1954 by Michelle and Krueger and called "radial pronator syndrome". Then in 1972, Roles and Maudsley proposed the name "resistant tennis elbow with a nerve entrapment". The term "radial tunnel syndrome" was proposed in 1993 by Eversmann. The immediate cause of radial tunnel syndrome is compression of the branches of this nerve due to entrapment. This compression can occur at four sites: in the tendinous band forward of the radial bone, under the AF (the most common cause), at the tendinous margin of the extensor carpi radialis brevis, and through the radial recurrent artery (leash of Henry) [6, 17, 27, 44]. Sponseller and Engber also point to the distal edge of the supinator muscle as a possible site of compression [45]. Some believe that radial canal syndrome is a consequence of intermittent and dynamic PIN compression during repeated pronation and supination, which is compared to skipping rope movements [7, 43]. There is limited evidence describing the causes of RTS.

Symptoms of RTS include generalized pain in the proximal part of the forearm, which may be exacerbated by pronation and supination with increased tenderness at a point 4–5 cm distal to the lateral epicondyle of the humerus, paresthesias in the hand, and pain on the middle finger extension [28]. This pain may be exacerbated at night, making it difficult to fall asleep. Increased pain can also be caused by stretching the nerve by pronating the forearm, straightening the wrist or extending the elbow [46]. The pain associated with radial nerve syndrome is a consequence of two components. The first is that an increase in pressure in the intramuscular compartment around the PIN causes a decrease in blood supply to these muscles, as a result of reduced capillary flow. The second cause may be the release of cytokines, influx of fibroblasts and endoneurial fibrosis, which stimulates nociceptors [28]. It should be noted that the symptoms of radial nerve syndrome develop very slowly and no muscle motor weakness is found. Ang *et al.* described a case of bilateral RTS [47].

Unlike RTS, PINS can be caused by many factors. Among them, there are two types: those arising from trauma, which include fracture of the head of the radius bone, deep penetrating wounds, and deep tissue massage; and non-traumatic causes: prolonged computer use, arthritis, neurofibromas [48], mucinous neurofibroma [44] post-traumatic aneurysms of the posterior intercostal artery [49], synovitis, fibrous band anterior to the head of the radius, loops of vessels from the recurrent radial artery, tendinous edge of the extensor carpi radialis brevis, tendinous edge of the inferior part of the supinator muscle, AF and fat pads [6, 28, 39, 50].

The symptoms of PINS are associated with neurogenic weakness of the muscles innervated by the PIN due to primary motor fiber damage. Symptoms include difficulty in finger extension, weakness of thumb inversion, active wrist extension with radial deviation [43], atrophy of the muscles of the posterior group of the forearm excluding the extensor carpi radialis longus and brachioradialis muscle. The point of tenderness is not always found [28]. It should be noted that the average diameter of the PIN in the course of PINS is larger (1.79 mm) than that of the non-malignant PIN (1.02 mm) [44].

Conservative treatment of PINS consists of the supply of non-steroidal anti-inflammatory drugs, the use of splints and physiotherapy treatments [28, 51]. It is assumed that surgical treatment should be performed after 3 months of pharmacological treatment and in the absence of disease remission [9, 51] or after 6 months of wrist pain [52]. Without the implementation of appropriate treatment, fibrosis of the muscles supplied by the PIN occurs after about 1.5 years [52].

Wilhelm in 1965 described the process of surgical denervation of the wrist, which began with five incisions around the wrist. The method underwent further modifications over the following years. In 1998, Berger described the technique of PIN and AIN neurectomy through a single incision. Currently, this modified procedure also involves the interruption of the lateral cutaneous nerve of the forearm, which is the terminal branch of the musculocutaneous nerve [53]. The severity of PIN damage can be described using Seddon's classification. It includes neuropraxia (demyelination at the site of compression or injury), axonotmesis (demyelination and axonal damage) and neurotmesis (interruption of the nerve) [54].

The PIN supplies the sensory dorsal part of the carpal capsule. Therefore, denervation of this part can be used to treat chronic wrist pain. This pain can be caused by neuroblastoma, PIN nerve fibrosis and osteophytes on the lunate bone of the wrist [6, 12]. An injectable nerve block should be used before denervation. Kachare *et al.* defined the injection site as ¼ of the distance between the dorsal radial tubercle and the radial side of the ulnar styloid process [46].

Conclusions

Many researchers have difficulty describing both the course and clinical aspects of the radial nerve, as the definition of DBRN and PIN is often identical. Clear criteria for the limits of DBRN and PIN are therefore needed. In general, the entrance of the DBRN into the AF is considered as the boundary. We think it makes sense to use the PIN designation consistently from the moment the nerve passes through the AF, or to create new boundaries between the DBRN and PIN.

In addition, due to the clinical implications, many authors sometimes differentiate between the PINS and RTS on the basis of their etiology, although the treatment is identical.

Acknowledgments

Acknowledgments to donors from the donation program of the Medical University of Silesia in Katowice.

Conflict of interest

The authors declare no conflict of interest.

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Received: 26.04.2023
Accepted: 27.06.2023
Online publication: 25.03.2023