



## A cadaveric study of anatomical variations of the radial nerve and their clinical significance

Kadaverska studija anatomskih varijacija žbičnog živca i njihov klinički značaj

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### Abstract

**Background/Aim.** The radial nerve (RN) is the largest terminal branch of the posterior cord of the brachial plexus. Upon leaving the axilla, the RN moves to the posterior compartment of the arm, where it makes close contact with the humerus. By penetrating the lateral intermuscular septum, RN enters the anterior compartment and, in the very proximity of the lateral epicondyle, divides into two terminal branches. The anatomy of this nerve is characterized by remarkable variability, the knowledge of which is of utmost importance in the fields of orthopedics and traumatology. The aim of the study was to examine the anatomy of the RN, including two parameters: the location and the way the RN divides into terminal branches, with a particular emphasis on the clinical implications of this data. **Methods.** The research was conducted on 27 cadavers, 15 female and 12 male, with a total of 54 upper extremities. After careful dissection, variations in the location and way of termination of the RN were observed on both the right and left hands. Collected data were then analyzed using Microsoft Office Excel. A classification where the di-

vision of the RN into terminal branches above the biepicondylar line (BEL) is defined as type A, while the division of RN below BEL is defined as type B was used. **Results.** According to the proposed classification, we observed a higher incidence of type A (66.7%) compared to type B (33.3%) in the total sample of 54 extremities. In addition, a higher prevalence of type A was observed in the female population, while a higher prevalence of type B was observed in the male population. There were differences in the distribution of types A and B between the left and right arms, but there were no variations in the way of termination of the RN. **Conclusion.** The present study showed an important complexity in the domain of RN anatomy with significant clinical implications. With that in mind, it is crucial for every patient that the limits of safe zones be defined while performing surgical procedures in the elbow to protect the RN and its branches from iatrogenic injuries.

### Key words:

**anatomy, regional; anatomic variation; cadaver; radial nerve; sex characteristics.**

### Apstrakt

**Uvod/Cilj.** Žbični živac (*nervus radialis* – NR) je najveća završna grana zadnjeg snopa ramenog živčanog spleta. Nakon što napusti pazušnu jamu, taj živac prelazi u zadnji region nadlaktice, gde stupa u bliski odnos sa ramenom kosti. Prolaskom kroz spoljašnju međumišićnu pregradu, NR ulazi u prednju ložu nadlaktice, da bi se na kraju, u predelu spoljašnjeg čvora ramene kosti, podelio na svoje dve završne grane. Anatomiju ovog živca odlikuje izuzetna varijabilnost, čije je poznavanje od velikog značaja u oblasti ortopedске i traumatske hirurgije. Cilj rada bio je da se ispita anatomija NR uključujući dva parametra: mesto i način podele NR na završne grane, sa posebnim naglaskom na kliničkom značaju ovih podataka. **Metode.**

Istraživanje je sprovedeno na 27 kadavera, od kojih je 15 bilo ženskog a 12 muškog pola, sa ukupno 54 gornja ekstremiteta. Nakon pažljive disekcije, varijacije u mestu i načinu podele NR ispitane su i na levoj i na desnoj ruci. Analiza dobijenih podataka izvršena je pomoću kompjuterskog programa *Microsoft Office Excel*. Korišćena je klasifikacija po kojoj je podela NR na terminalne grane iznad biepikondilarne linije (BEL) definisana kao tip A, dok je podela NR ispod BEL definisana kao tip B. **Rezultati.** Prema predloženoj klasifikaciji, uočili smo veću zastupljenost tipa A (66,7%) u poređenju sa tipom B (33,3%) u ukupnom uzorku od 54 ekstremiteta. Osim toga, uočena je veća zastupljenost tipa A kod osoba ženskog pola, dok je kod muškaraca bio zastupljeniji tip B. Rezultati su pokazali i da postoji razlika u procentualnom

udelu tipa A i tipa B između levih i desnih ekstremiteta ali varijacije u načinu završetka NR nisu bile utvrđene. **Zaključak.** Studija je pokazala značajnu složenost anatomije NR, sa važnim kliničkim posledicama. Imajući to u vidu, za svakog bolesnika neophodno je definisati granice „sigurne zone” prilikom hirurških operacija u

regionu lakta, čime će biti obezbeđena zaštita NR i njegovih završnih grana od jatrogene povrede.

#### **Ključne reči:**

**anatomija, regionalna; anatomija, varijacije; kadaver; n. radialis; pol, karakteristike.**

## **Introduction**

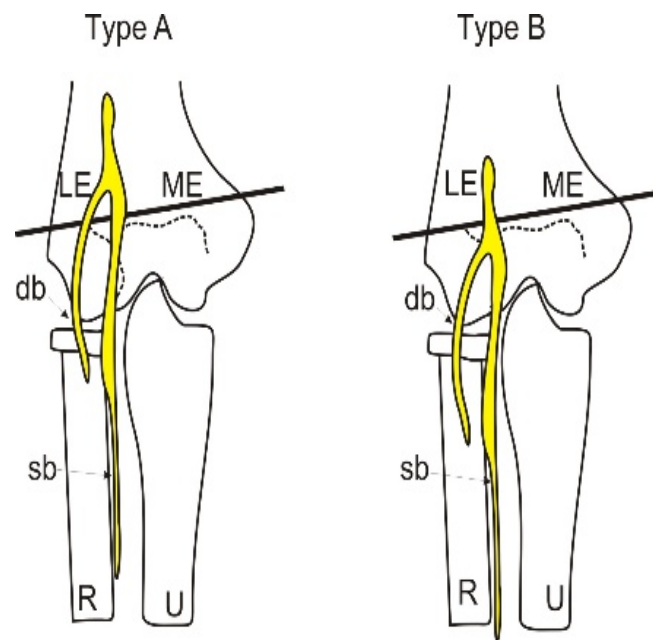
The radial nerve (RN) is the largest branch of the posterior bundle of the brachial plexus<sup>1</sup>. This mixed nerve provides motor innervation of the extensors of the entire upper extremity and sensory innervation of the back of the upper arm, forearm, and outer half of the back of the hand<sup>2</sup>. RN starts from the axillary fossa, passes to the back of the upper arm, and enters the radial groove on the back of the humerus, where it is followed by a deep brachial artery<sup>3</sup>. After breaking through the external intermuscular septum, the RN passes from the back to the front of the upper arm. It descends vertically to the external surface of the lateral epicondyle of the humerus, near which it ends by dividing into two branches<sup>4</sup>. The brachioradialis muscle covers the superficial, sensitive branch in the proximal part of the humerus. In contrast, the distal part is located under its tendon, passes to the back of the forearm, and becomes subcutaneous<sup>5</sup>. The deep, motor branch passes through the osteomuscular channel formed by the supinator muscle and the surrounding bony elements to finally end in the distal half of the forearm, having previously provided branches for the muscles of the back of the forearm<sup>6</sup>.

The clinical importance of knowing the anatomy of an RN is invaluable. As previously mentioned, in the area of the upper arm, RN enters into a close relationship with the humerus, so it is not surprising that as many as 20% of all fractures of this bone are accompanied by injuries to the RN, which, fortunately, are usually of a mild degree, pass spontaneously and do not require surgical treatment<sup>7,8</sup>. In addition to the mentioned primary lesions, there are also frequent secondary iatrogenic lesions of the RN that occur during surgical interventions to repair complicated humerus fractures<sup>8</sup>. In the region of the cubital fossa, the RN divides into two final branches. At this point, it is highly susceptible to injury during the anterior-external approach to the elbow joint<sup>9</sup>. In addition to orthopedic surgery and traumatology, knowledge of the anatomy of the RN has found practical applications in other fields of medicine. Thus, for doctors specializing in neurology, it is imperative to precisely define the pattern of separation of the motor and sensory branches of RN so that, based on clinical examination, they can determine the level of the lesion in chronic compressive neuropathies, such as radial tunnel syndrome<sup>10</sup>. As the clinical anatomy of the RN is directed towards a wide range of medical specialties, it should not be surprising that a large number of cadaveric and radiographic studies of the RN have been conducted. Most researchers' focus of interest was the RN position in the area of the upper arm (*regio brachii*). These studies aimed to define and precisely determine the boundaries of the 'safe

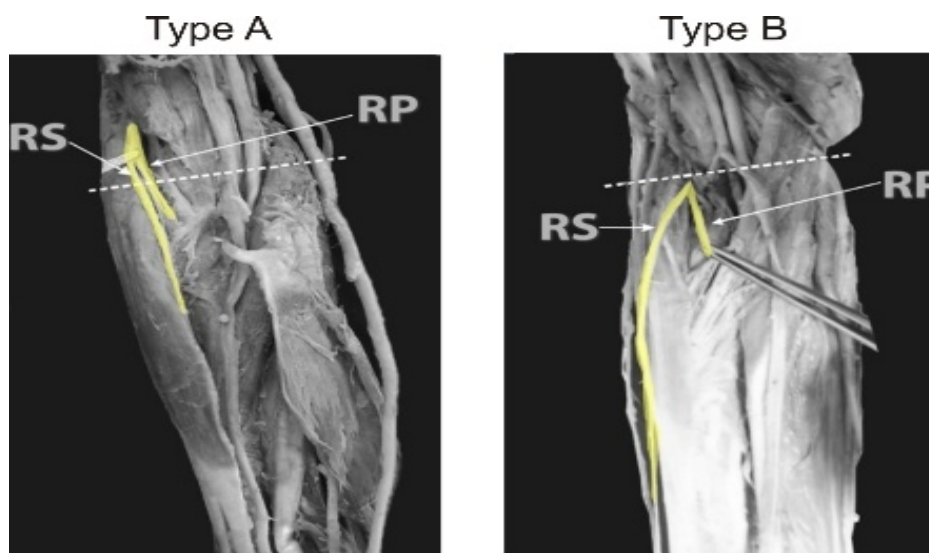
zone' during surgical interventions in the region of the distal part of the humerus to minimize the possibility of iatrogenic injury to this nerve<sup>11</sup>. For this purpose, various anatomical and topographic landmarks were used, which served as reference points in relation to which distance of RN was measured, expressed in absolute or relative numbers<sup>12</sup>. It is important to note that, despite efforts to clearly define the path and relationships of RN, the segment of anatomy related to the place of the division of RN into its final branches remains unexplored. To the best of our knowledge, this study is among the first to examine the anatomical variations of the final part of RN. This study aims to examine the anatomy of the RN in the region of the cubital fossa, which will include two parameters: 1) the determination of the place and 2) the manner of termination of the RN, with a particular emphasis on the clinical significance of the results.

## **Methods**

Our research was conducted on cadaveric material of the Institute of Anatomy "Niko Miljanić", Faculty of Medicine, University of Belgrade, with the approval of the Ethics Committee for the use of human and laboratory animal material, Faculty of Medicine, University of Belgrade, Serbia (No. 325-07-01245/2014-05/2). The study included a total of 27 cadavers, of which 12 were male and 15 female, aged from 64 to 79 years. Initially, a visual check of each extremity was performed to exclude samples with deformities and traces of trauma or surgery. After fixation in formalin solution, the extremities were carefully dissected, following standard procedures from dissection manuals. For our study, two groups of samples were formed, which included 54 upper extremities, of which 24 were in the male group and 30 in the female group. The first aim of the examination was to define the place where the RN terminates and divides into its final branches, the superficial and deep branches. Based on previous research<sup>1-6</sup>, it was hypothesized that RN can end in two ways, which we defined as type A and type B (Figure 1). The division of the RN into terminal branches above the biepicondylar line (BEL) (Hueter's line – an imaginary line passing through the most prominent points of the lateral and medial epicondyle of the humerus, named after the author) when the forearm is in a position of extension and supination is defined as type A, while the division of the RN below the BEL is defined as type B. All parameters were measured bilaterally. The measuring instruments used in the research were a ruler and an electronic digital caliper (measuring range 0–500 mm, resolution 0.01 mm). The study's second aim was the manner of termination of the RN, defined as the number of terminal branches into which this nerve is



**Fig. 1** – Schematic view of the division of the radial nerve (RN) above (type A) and below (type B) the Hueter's biépicondylar line (bolded black line). db – deep branch of RN; sb – superficial branch of RN; LE – lateral epicondyle; ME – medial epicondyle; R – radius; U – ulna.



**Fig. 2** – Example of dissected cadaveric material which shows the division of the radial nerve (RN) above Hueter's line (type A) and division of the RN below Hueter's line (type B) (dashed line). RS – *ramus superficialis* (superficial branch of RN); RP – *ramus profundus* (deep branch of RN).

divided. The research methodology is shown schematically (Figure 1), while the results of examined parameters are shown in Figure 2.

### Results

The total number of examined cadavers was 27, of which 12 were male and 15 were female, and the investigation was conducted on both arms of each cadaver (total of 54 arms). The prevalence of type A of RN termination (point of

division) was observed in 36/54 extremities, representing 66.7% of the total examined sample. In comparison, division point according to type B was found in 18/54 extremities, representing 33.3% of the total sample. The results of our research are presented in Table 1. The goal of further processing of the data was to examine the distribution by gender for both types of division points of the RN and whether there are any differences in the frequency of type A or type B between the left and right extremities. Thus, in the group of male cadavers, type A was observed in 14 (58.3%) limbs and

type B in 10 (41.7%) limbs. In this group, no differences in frequency between the left and right extremities were found, meaning type A and type B occurred equally often on both extremities. In the group of female cadavers, type A was found in 22 (73.3%) limbs and type B in only 8 (26.7%) limbs. Here, variations in frequency between the left and right extremities were observed, with type A occurring more often on the left side (2:1 ratio) and type B occurring more often on the right side (3:1 ratio). On all of the preparations that made up the sample material, the division of the RN into superficial and deep ending branches was established as the only way of termination of the RN.

**Table 1**

**Prevalence of type of the radial nerve (RN) division obtained from extremities of cadavers**

Parameter	Type A	Type B
Male (n = 24)	58.3	41.7
Female (n = 30)	73.3	26.7
Total (n = 54)	66.7	33.3

**Results are shown as a percentage of prevalence. Type A – division point of the RN above the Hueter's line; type B – division point of the RN below the Hueter's line; n – number of extremities.**

### Discussion

RN is one of the largest and longest nerves of the upper limb, with an extensive motor and sensory innervation field. This nerve, among other things, is characterized by extraordinary diversity regarding the place and manner of division into its two terminal branches, superficial and deep.

As it descends, the RN enters into significant anatomical relations with the surrounding structures, a good knowledge of which is of immense importance in everyday clinical practice. By reviewing the available literature, we found many studies and articles where the manner of its origin, path, and relations with adjacent bony and blood vascular elements (humerus and deep brachial artery) are described in detail<sup>11-14</sup>. Studies also described the place and the level of separation of the motor branches<sup>6, 15</sup> and the anatomical varieties of its sensitive end branch<sup>5, 16-18</sup>. However, the precise determination of the location of the RN's final division remained in the shadow of the aforementioned research. Defining where the RN ends can also be found in standard anatomy textbooks, in which it is briefly described that the RN ends in the immediate vicinity or in front of the lateral epicondyle of the humerus<sup>3</sup>.

Considering all the facts mentioned above, the main task of our study was to shed new light on this important aspect of the anatomy of the RN. The first goal of our study was to examine the exact place of division, i.e., termination of RN. We presumed, which was confirmed during the examination itself, that the place of the division of the RN could be found above or below the BEL. Based on the obtained results, we proposed two types of termination of the RN: type A (above BEL, i.e., high division) and type B (below BEL, i.e., low division). One of the first studies that

dealt with the problem of variations in the termination of the RN was conducted by Fuss and Wurzl<sup>13</sup> in 1991. They showed that the site of division of RN can be found anywhere within a 5.5 cm segment extending from 2.5 cm above BEL to 3 cm below BEL<sup>13</sup>. Similar results were obtained by Artico et al.<sup>19</sup>, who measured the average distance between the division site of RN and the lateral epicondyle, which was 2.9 cm. The mentioned studies<sup>13, 19</sup> did not analyze the frequency of high or low location of division of RN in the total population, nor its structure according to gender. In the present study, we reached three important conclusions regarding the frequency of different types of division sites of the RN. First, the entire sample material showed a higher prevalence of type A (66.7%) compared to type B division location of RN (33.3%). By further studying the data by gender, it was observed that in both genders, type A of RN is found more often in regard to the total sample of 54 limbs, but in females, type A occurs more often than in males. The obtained results only partially agree with the study conducted by Sapage et al.<sup>1</sup>, which established that gender is not a factor that determines where the RN will divide into its final branches. The last level of analysis involved examining differences in the frequency of type A and B between the left and right extremities in both genders. In the group of male cadavers, the mentioned differences were not observed, i.e., high and low types of division of RN occurred equally often on both sides. On the other hand, in the group of female cadavers, the following rule was established: type A occurred more often on the left side, while type B of the division occurred more often on the right side. Next, when we asked what is the basis of the anatomical variations of the place of termination of the RN (point of division of this nerve into two final branches), there was still no adequate answer. However, two assumptions may be helpful on the way to finding the answer. According to the first assumption, the key factor that determines the type of division we encounter in adulthood (high or low) is disproportion, i.e., the disproportion in the growth rate of the long bones of the upper limb on the one hand and the rate of elongation of the nerve elements during the development phase on the other<sup>20</sup>. The second assumption, probably even more interesting than the first one, is that the dominance of the hand, i.e., the characteristic of whether one is right-handed or left-handed, can also condition the very place of the division of the vertebral nerve, as is the case with the palmar arterial arches<sup>21</sup>. In the future, it is necessary to carry out adequate tests to prove or disprove the mentioned hypotheses. Another aim of our study was to determine the manner of termination of the RN. This parameter is defined as the number or type of terminal branches of the RN. On a total of 54 observed limbs, the division of the RN into two final branches – the superficial (sensory) and the deep (motor) branch – was established as the only way of termination, which is in accordance with the description that can be found in anatomy textbooks<sup>2, 3</sup>. Yet, there is extensive data in the literature about numerous variations regarding the way of termination and the number of final branches of the RN. Thus, cases with three terminal branches (superficial, deep, and the branch in-

tended for the long external extensor of the hand) have been described<sup>22</sup>, with only one terminal branch (superficial, the sensory branch is omitted)<sup>13</sup>, with the doubling of the surface branch of the RN<sup>17</sup> and with the separation of the branches intended for the upper arm muscle<sup>23</sup>, which is predominantly innervated by the median nerve. The mentioned variations, which are extremely rare, were not observed in the present study, probably due to the small sample size<sup>1</sup> and the existence of ethnic differences between the study populations<sup>2, 24–26</sup>.

Finally, it is necessary to point out that knowledge of anatomical variations when it comes to the point of the division of RN into its final branches is crucial, especially in the field of orthopedic surgery<sup>27</sup>. The main aim and purpose of a careful and dedicated study of the anatomy of the RN is to avoid injury to this nerve during surgical interventions in the elbow region (*regio cubiti*). Nowadays, this is considered essential, bearing in mind the constant strive to improve the safety of all medical procedures, including surgical ones. Namely, due to the high sensitivity of nerve structures and the low capacity for regeneration (especially if there is neurotmesis, i.e., complete transection of the nerve), any injury to the RN can leave far-reaching negative consequences for the patient's health<sup>28</sup>. That is especially true for those cases where there is a type B division of RN (i.e., low division) when, in case of a nerve lesion, there would be an outage of both the sensory and motor components, with the loss of extension of the hand and fingers ("hanging hand", a cardinal sign of injury of the RN) as well as the loss of sensitivity on the back of the forearm and the outer half of the back

of the hand, with the appearance of painful paresthesias. The probability that an iatrogenic lesion will occur depends on several factors and, above all, on the nature of the disease itself, which needs to be solved surgically because the nature of the disease affects the applied surgical approach<sup>29, 30</sup>. Thus, the lowest risk will exist with the posterior approach (through which complicated fractures of the distal part of the humerus bone are solved). In contrast, a significantly greater risk will exist with the anterior and anterior-lateral approaches, which serve for the repair of complicated fractures in the area of the elbow joint (through open reduction and internal fixation), for arthrocentesis (to treat joint infection), total arthroplasty and treatment of compressive neuropathies of the RN<sup>9</sup>. In the end, it is crucial for each patient to preoperatively define the limit of the 'safe zone' in the region of the elbow joint in order to avoid injuries to key anatomical structures in this region, including the RN.

### Conclusion

In order to acquire detailed information on all possible variations of the final part of RN, in the present study, a new system was proposed that includes type A and type B divisions of the RN. The results have shown a higher prevalence of type A in the total sample, but certain differences in frequency depending on gender and laterality were also recorded. The obtained results, although significant as such in the field of orthopedic surgery, indicate the necessity of further research in this area to more precisely define the safe limits during surgical interventions in the elbow joint area.

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