Double innervation of the brachialis muscle: anatomic–physiological study
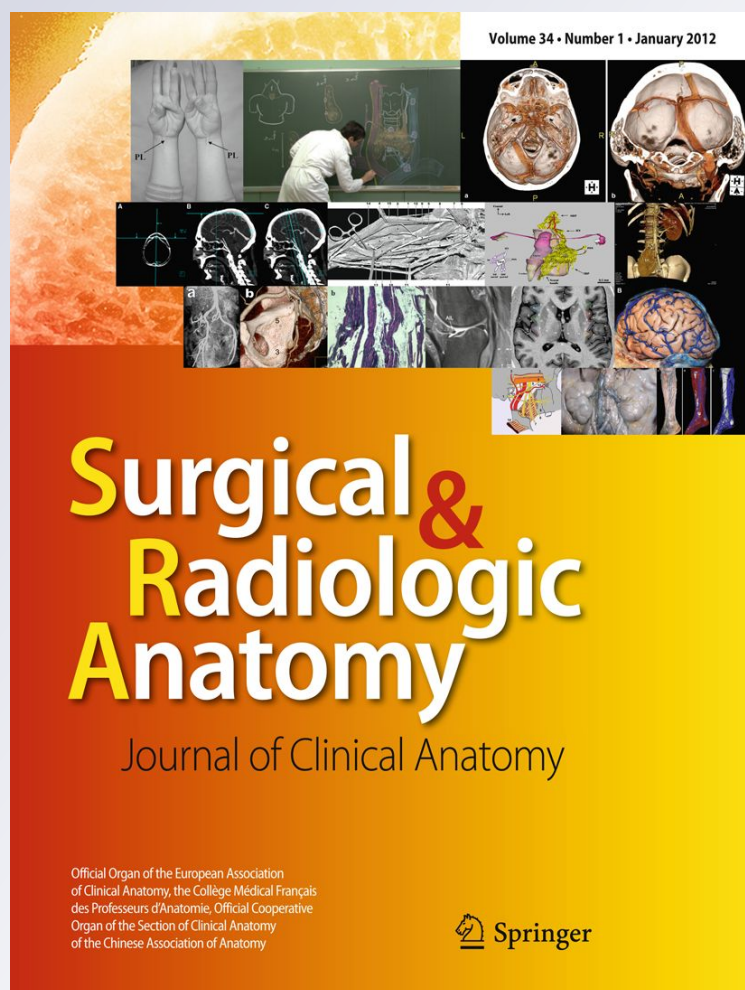
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ORIGINAL ARTICLE

Double innervation of the brachialis muscle: anatomic–physiological study

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Abstract

Introduction Double innervation of the brachialis muscle has been previously reported in anatomical studies. This study aims to investigate the frequency and clinical significance of double innervation of brachialis by anatomical and electromyographic techniques.

Materials and methods (1) The existence, origin and pattern of distribution of a branch from the radial nerve to brachialis were dissected on 20 cadaveric arms. (2) Nerve conduction studies (NCS) of 100 patients were performed. The radial nerve was stimulated, registering muscle potentials (MP) in the brachialis muscle. Subsequently, another MP was obtained by Erb's stimulation, corresponding to the whole brachialis innervation. The relative percentage of innervation from the radial nerve was calculated. (3) Two patients with lesions of the lateral cord of the brachial plexus and preserved elbow flexion were submitted to NCS.

Results Double innervation was found in 65 % of the anatomical preparations, following different patterns of distribution. In the NCS, 90 % of the patients showed MP in the brachialis muscle after stimulating the radial nerve.

The mean percentage of relative innervation was 11 %. Two patients with lesions of the lateral cord showed an important contribution from the radial nerve.

Conclusions Variations in the relative percentage of innervation from the radial nerve could be due to the different sizes and shapes of this branch. The functional significance of this branch can become crucial if the main innervation to the brachialis muscle fails. When planning surgical antero-external approach to the humerus, it should be kept in mind and preserved.

Keywords Brachialis innervation · Radial nerve · Anatomy · EMG

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Introduction

The main innervation of the brachialis muscle is provided by the musculocutaneous nerve [1, 18, 33, 35], but it is well known now that it receives an additional branch from the radial nerve. The first suspicion of a double innervation dates back to 1919, when Jones described a patient who had localized contraction of the brachialis muscle following transection of the musculocutaneous nerve [13]. Later, Hollinshead [10] reported that stimulation of the radial nerve intraoperatively induced contraction of the brachialis muscle. The radial branch to the brachialis muscle has then been reported in detailed anatomical works, in different ethnic groups [11, 20, 27–29, 32]. Those studies show some differences about the frequency of this double innervation, probably due to interracial differences, or different sample sizes, but they generally report a high frequency, ranging between 67 and 100 %. The general consensus is that it is a motor branch destined to the inferolateral portion of the brachialis [13, 20, 29]. Moreover,

Spinner [29] reported an area of denervation of the brachialis muscle in patients with radial nerve paralysis on magnetic resonance imaging. Nevertheless, there are still several questions about this: How much do they contribute to the entire brachialis muscle innervation? Are these merely embryological vestiges with no significant function? Most of the above-mentioned authors recommended that the surgical approach to the humerus must be in the plane between the brachialis and brachioradialis, with careful preservation of the radial nerve. Can its branches to the brachialis be sacrificed, if necessary, without clinical sequelae?

In this study, we combined, on one hand, classical anatomical techniques in fetal and adult postmortem limb preparations, to investigate the frequency of this double innervation in the Argentine population. On the other hand, we employed electromyographic techniques in a larger in vivo sample, allowing us to investigate the existence—or non-existence—of motor fibers and their potential contribution to the global innervation of the muscle. Lastly, we present two clinical cases showing how the presence of a significant innervation coming from the radial nerve contributes to the function of the brachialis.

Materials and methods

Anatomy

Twenty cadaveric Caucasian arms of different ages and sexes were dissected. All of them were prepared as interscapulothoracic amputations belonging to 20 cadavers. The specimens were obtained from the dissecting room of the Normal Anatomy Department of the University of Buenos Aires School of Medicine. Six of them were fetal arms, with gestational ages ranging between 27 and 33 weeks. Fetuses were obtained from spontaneous abortions, through an agreement signed between the Rivadavia Hospital, and the University of Buenos Aires. The study was approved by both institutions' ethical committees.

The remaining 14 were adult embalmed specimens (9 female, 5 male, age range 60–95 years). Twelve arms were right and the remaining eight were left. In each case, musculocutaneous and radial nerves were carefully dissected employing a binocular 2× magnification loupe. The latter was approached from the spiral groove to the lateral epicondyle, between the brachialis and brachioradialis muscles. Each branch and its subdivisions were followed as far as possible into the muscle. Given that the profunda brachii artery gave several branches to the brachialis muscle, we removed this vessel to ensure that the nerve branches observed were not in fact blood vessels or accompanying connective tissue.

In each case, the following findings were recorded:

a. The existence of a branch to the brachialis muscle arising from the radial nerve.
b. The level of origin of the nerve branches considering the distance between the acromion and the medial epicondyle.
c. The pattern of distribution and ramification into the muscle.

Neurophysiology

A total of 100 Caucasian patients of both sexes, aged between 18 and 70 years, were selected for this protocol. They were referred to the Neurophysiology Laboratory of the Argentine Institute of Neurological Investigations to perform upper limb electromyography and nerve conduction velocity for different reasons (radiculopathies, carpal tunnel syndrome, etc.). The in vivo procedures were approved by the institution's ethical committee and conformed to the Declaration of Helsinki. Each subject gave informed written consent for their participation in the study.

The brachialis muscle was explored in all patients with monopolar needles.

Once the correct position of the needles was confirmed by obtaining voluntary activation of the brachialis muscle, we performed a supramaximal stimulation of the radial nerve on the spiral groove, registering the compound muscle action potential (CMAP). The latter is defined as the summation of a group of almost simultaneous action potentials from several muscle fibers in the same area, evoked by stimulation of the supplying motor nerve, amplified and recorded as a di or multiphasic wave on an oscilloscope monitor. Subsequently, an Erb's point stimulation was performed, obtaining a new potential that was drawn from the sum of the entire innervation of the brachialis (Fig. 2). Erb's point is a landmark of the brachial plexus on the upper trunk, located in an angle between the posterolateral border of the sternocleidomastoid muscle and the clavicle. The final task was to perform a nerve conduction test of the musculocutaneous nerve to the brachialis muscle, with the usual technique, that is, stimulating in Erb's point and at the axilla between the axillary artery and the median nerve medially, and the coracobrachialis muscles laterally, just above the tendon of the latissimus dorsi muscle [17, 22, 30, 34]. Special care was taken to avoid stimulation of other nerves by stimulus spread. This could be easily checked by analyzing the shape of the CMAP obtained: the initial deflection of the CMAP should be always upward (negative).

In each case, we recorded the latency and amplitude of the CMAP. Latency is usually measured in milliseconds, from the onset of the stimulus to the beginning of the initial

deflection of the CMAP. The amplitude is measured from peak to peak of the CMAP and is the rough estimation of the number of muscle fibers that are activated by nerve stimulation, and subsequently of the number of nerve fibers that become excitable to nerve stimulation when neuromuscular transmission is normal. From the comparison of both amplitudes, the percentage of muscle innervation coming from the radial nerve was calculated.

Clinical cases

Cases 1 and 2: Both patients had traumatic lesions of the lateral cord of the brachial plexus and preserved elbow flexion in different degrees.

The patients were clinically examined and submitted to the previously described neurophysiologic exploration.

Results

Anatomy (Fig. 1a–d)

The musculocutaneous nerve innervated the brachialis muscle in all specimens. In 13 (65 %) of them, the brachialis also received a branch from the radial nerve. No significant age, side or gender differences were noted.

There were three different patterns of distribution:

1. Distal type: Single or multiple distal branches were found at the lateral bicipital sulcus (Fig. 1a, b, respectively). In the first case, fibers reach the brachialis muscle 3 or 4 cm before their distal insertion. (n = 5 out of 13 of the dissected arms). Otherwise, multiple distal branches supply the lateral part of the muscle (n = 3 of 13).
2. Proximal type: Proximal branches arise before the entrance of the radial nerve in the spiral groove and reach the brachialis muscle 2 cm below the proximal insertion (Fig. 1c). In one case, this filament ends in the middle third of the posterior part of the brachialis (n = 4 of 13).
3. Combined type: It is a combination of a proximal and a distal branch (n = 1 of 13) (Fig. 1d).

The branches arose at a mean of 21.75 % of the distance from the medial epicondyle to the acromion (n = 13, range 20–31 %).

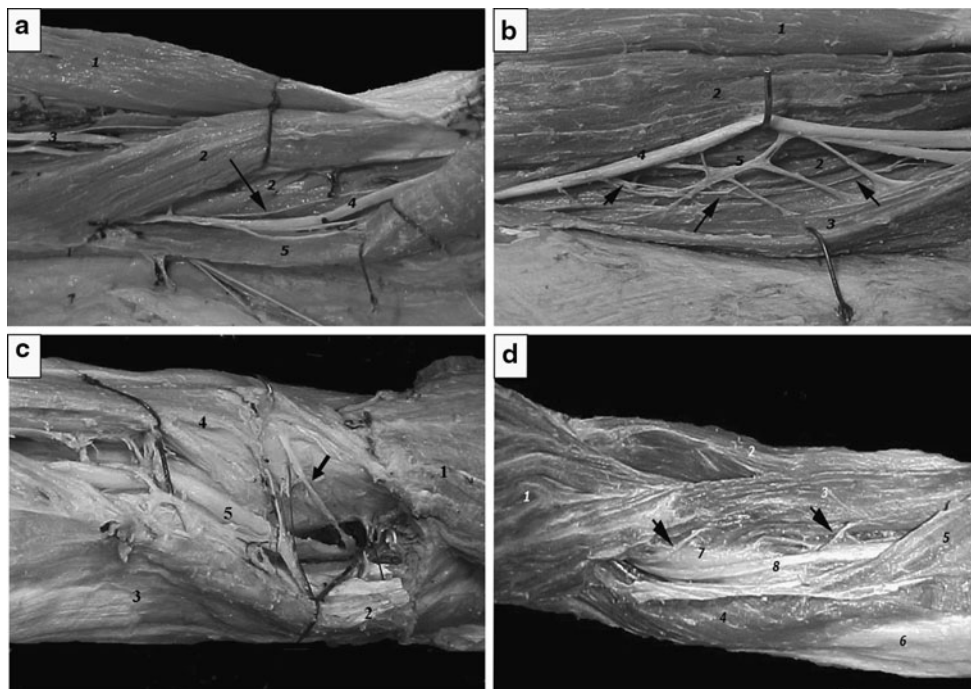We could not find any difference in frequency or distribution of the branches between fetal and adult

Fig. 1 a Distal branch from the radial nerve to the brachialis muscle. *1* Biceps brachii, *2* brachialis, *3* musculocutaneous nerve, *4* radial nerve, *5* brachioradialis. *Black arrow* shows the distal branch of the radial nerve to the brachialis. **b** Distal type, multiple branches. *1* Biceps brachii, *2* brachialis, *3* brachioradialis, *4* radial nerve, *5* multiple radial branches to the brachialis. *Black arrows* show multiple distal branches for the brachialis. **c** Proximal branch from radial nerve to brachialis. *1* Deltoid, *2* long head of triceps brachii, *3* lateral head of triceps brachii, *4* brachialis, *5* radial nerve. *Black arrow* shows the branch from the radial nerve to the brachialis. **d** Double innervation of the brachialis muscle. *1* Deltoid, *2* biceps brachii, *3* brachialis, *4* lateral head triceps brachii, *5* brachioradialis, *6* long head triceps brachii, *7* humerus, *8* radial nerve. *Black arrows* show branches from the radial nerve to brachialis muscle

Fig. 2 An example of compound muscle action potentials (CMAP) recorded in the brachialis muscle after stimulating the radial nerve in Erb's point (*upper trace*) and in the torsion channel (*lower trace*)
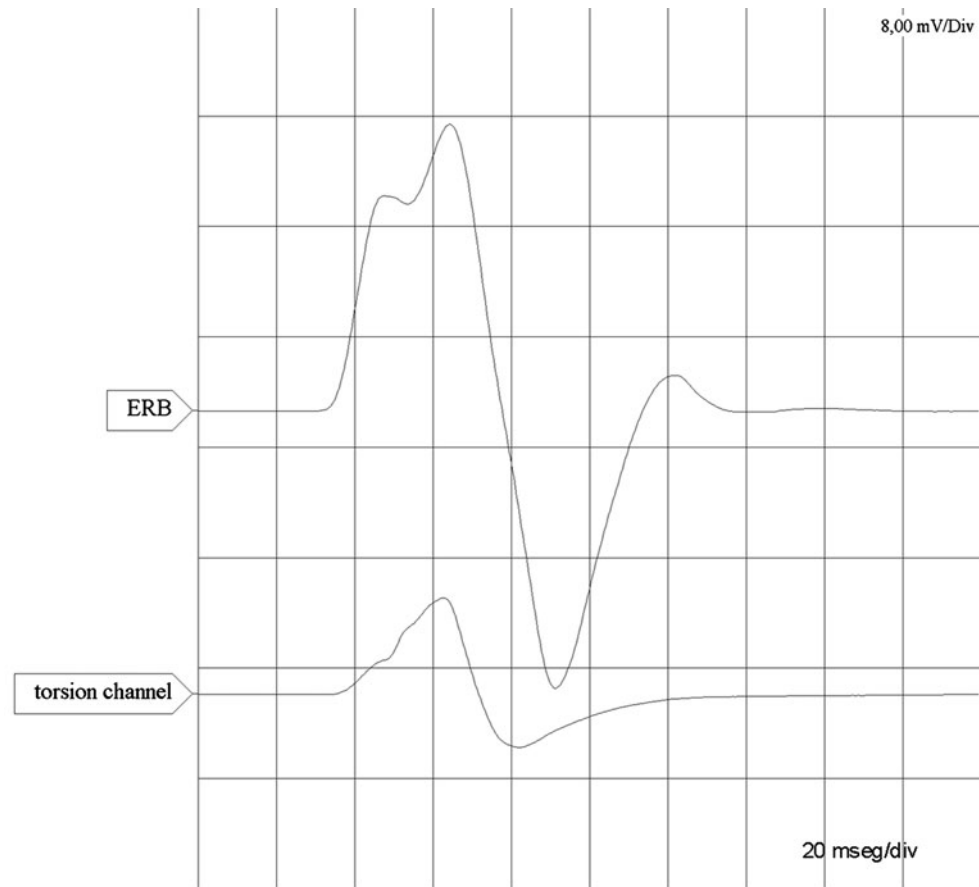
specimens. Nevertheless, our sample is too small to draw any conclusion about this.

Neurophysiology (Fig. 2)

Ninety percent of the patients had motor responses in the brachialis after stimulating the radial nerve, but in an extremely variable degree. In the remaining 10 %, we did not obtain any response. The CMAP amplitudes obtained ranged between 0.05 and 1 mV (media 0.37 mV; SD (standard deviation) 0.19; confidence interval (CI) 95 % 0.40–0.33). This represented variable contributions of the radial nerve to the whole muscle innervation, ranging between 0.33 and 62 % (media 11 %; SD 16; CI 95 % 10.97–11.03). Distal latencies of these CMAP ranged between 4 and 8.6 ms; media 6.03 ms.)

Clinical cases

Case 1: A 55-year-old woman was hospitalized due to agitation and a confusional syndrome. She required physical restraint measures and both her arms were tied. At this moment, she had a generalized tonic–clonic seizure, with an involuntary traction of her left arm. As a result, the lateral cord of the brachial plexus was injured.

On the initial physical examination, nevertheless, antebrachial flexion preserved a strength of 4/5. The EMG examination, performed during that week, could not obtain any response from the musculocutaneous nerve, but an important contribution (60 %) from the radial nerve was found.

Case 2: A 30-year-old man suffered a brachial plexus injury in an occupational accident. The lateral cord was damaged.

As in the previous case, the antebrachial flexion was only slightly impaired, with a strength of 3/5. The EMG showed poor response from the musculocutaneous nerve, but a very good contribution from the radial nerve (43 %). It was performed within the first week of the accident.

Discussion

"*Let there be no more doubt about the relatively consistent motor contribution to the brachialis muscle from the radial nerve*", Spinner RJ wrote [29]. Clinical evidence regarding the functional significance of this branch is becoming increasingly clearer. The radial branches have been even regarded as being purely sensory to the elbow joint [19]. Mahakkanukrauh and Somsarp, [20] refuted that, observing

that the course of the branches ran far from the joint. Other authors considered a motor function of the branches based on findings such as intraoperative contractions of the brachialis while stimulating the radial nerve [13], or brachialis atrophy in magnetic resonance imaging after radial nerve lesions [26, 29]. As far as we know, this is the first time these branches are studied by electrophysiological methods in vivo, in a large series of patients. Double innervation was found in 90 % of them. It is clearly a motor branch, with highly variable amplitude. Variations in the relative percentage of innervation arising from the radial nerve could be due to the different sizes and shapes of the branches directed to the brachialis muscle. There was a significant discordance, however, between the frequencies found by anatomical (65 %) and neurophysiological (90 %) methods. We think this could be due to some tiny intramuscular nerve branches, not seen in dissection with our $2\times$ magnification, but easily stimulated in vivo. In fact, many EMG responses were very low amplitude CMAP, corresponding to very small sized branches. This suggests that anatomical investigations should be more exhaustive and precise when dissections are complemented with histological and/or neurophysiological techniques.

Most of the authors suggested taking these branches into account in anterolateral humeral approaches, given that they are present in a high percentage of patients, even when their functional significance was never precisely clarified. We agree with Mahakkanukrauh and Somsarp [20] that the radial nerve innervation to brachialis is at risk from an anterior approach to the humerus, splitting the plane between the brachialis and brachioradialis. There is scant information in the literature suggesting clinical sequelae following this denervation, maybe due to the variable size of motor contribution. Jordan and Mirzabeigi [14] proposed performing surgical approaches to the humerus by splitting the brachialis in the midline, on the basis that this represents an internervous plane between the radial nerve contribution to the lateral portion of the muscle and the musculocutaneous nerve contribution to the medial portion.

In the present study, radial branches to the brachialis arose at 20–31 % the distance between the lateral epicondyle and the acromion, concurring with the work by Blackburn [2]. He found 31 radial branches to the brachialis (out of 42 observations), emerging at a mean of 23 % of the aforementioned distance. He also found that mostly these branches reach the brachialis near their origin, innervating the middle and distal third of the muscle, but never its upper third. Frazer [8] reported that the branch to brachialis from the musculocutaneous nerve arose at 30.4–47.1 % the epicondyle–acromial distance, and noticed that, in the lower third of the muscle,

musculocutaneous and radial branches are superimposed. In our work, we also found a proximal branch in 4 of 13 (30.77 %) cases. This observation has been also made by Blackburn et al. [2], who suggested that there are two distinct levels of origin of the radial nerve branch to brachialis, with a more common distal branch and a rarer proximal branch. Maybe, a larger sample will be necessary to draw a firm conclusion from this data.

An embryological explanation has been proposed for this double innervation. At Carnegie stage 16, the brachial plexus develops and the future radial, median and ulnar nerves can already be differentiated. Nevertheless, the bones and muscles of the region are still uniform masses of mesenchymal tissue, which will differentiate two stages later. These muscular masses will initially split into two portions: ventral (flexor) and dorsal (extensor). The inferior third of the brachialis and the triceps muscle come from the dorsal mass; this explains their common innervation, as the muscles maintain their original innervation during development, regardless of how far they migrate or rotate from their original position [4, 7]. Other authors think that this portion of the brachialis may be a detached portion of the brachioradialis muscle [27, 31]. Oh et al. [23] had also suggested that this double innervation is due to an aberrant branch.

The functional significance of the branch is variable, but could become crucial if the main innervation to the brachialis muscle fails. Isolated musculocutaneous nerve lesions are rare, but brachial plexus injuries are quite frequent [3, 5, 6, 9, 12, 15, 16, 21, 24, 25]. In our clinical cases, different injuries affected the brachialis nerve supply from the musculocutaneous nerve; nevertheless, the functionality of the muscle was preserved due to a broad radial branch. Moreover, the existence of this anatomical variation could be very useful in the rehabilitation of patients with this kind of lesion.

Conclusions

Ninety percent of our sample of Argentine population showed motor responses in the brachialis muscle after stimulating the radial nerve in the spiral groove. This clears a long-standing question about the functional significance of the radial branches destined to the brachialis muscle. In anatomic specimens, we also found a high incidence of this double innervation, with different patterns of origin and distribution, similar to what other authors describe in Caucasian populations. Our clinical cases illustrate how this double innervation can become crucial in preserving elbow flexion if the musculocutaneous nerve fails. In anterolateral surgical approach to the humerus, this branch should be kept in mind and preserved.

Conflict of interest The authors declare that they have no conflict of interest.

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