

DOI 10.2478/pjvs-2014-0046

*Original article*

# The rabbit brachial plexus as an experimental model – anatomy and surgical approach

**P. Reichert<sup>1</sup>, R. Rutowski<sup>1</sup>, Z. Kielbowicz<sup>2</sup>, J. Kuryszko<sup>3</sup>, M. Kielbowicz<sup>2</sup>,  
Ł. Michalak<sup>1</sup>, A. Bocheńska<sup>4</sup>**

<sup>1</sup> Department of Traumatology, Clinic of Traumatology and Hand Surgery,  
Wrocław Medical University, Borowska 213, 50-556, Wrocław, Poland

<sup>2</sup> Department of Surgery, Faculty of Veterinary Medicine,  
Wrocław University of Environmental and Life Sciences, Pl. Grunwaldzki 51, 50-366, Wrocław, Poland

<sup>3</sup> Department of Animal Physiology and Biostructure, Faculty of Veterinary Medicine,  
Wrocław University of Environmental and Life Sciences, Norwida 31, 50-373, Wrocław, Poland

<sup>4</sup> Department of Internal Medicine, Faculty of Veterinary Medicine,  
University of Warmia and Mazury in Olsztyn, Oczapowskiego 14, 10-719 Olsztyn, Poland

## Abstract

The aim of our study was to analyze the anatomy and surgical approach of the rabbit brachial plexus. The research included 18 rabbits. The rabbit seems to be a good experimental model for spinal nerves injury, especially for the C5 and C6 segments. The anatomical structure of the rabbit's brachial plexus is similar to the human brachial plexus. The structure of the rabbit C5 and C6 segments is analogous to the human structure. The spinal nerves of the C5 and C6 segments in the rabbit are wide and long enough for microsurgical procedures.

**Key words:** spinal nerves, ventral root, brachial plexus, rabbit

## Introduction

High peripheral nerve injury despite of the development of medicine and ongoing research still remains a serious problem. This type of lesions can be divided into pre- and postganglionic. The post-ganglionic injury can be divided into neurotmesis, axonotmesis and neuropraxis (Seddon 1943). The neurotmesis is injury of the whole nerve's structure, axonotmesis is injury of the axon and partial loss of function without structural changes in the nerve is neuropraxis. In the two first cases the changes occur

of degenerative and non degenerative type. A typical picture of breaking the connection between the nerve cell and axon is disintegration with axonal dieback on peripheral parts. This process is called Walerian's degeneration. In the case of preganglionic injury (usually avulsion of the roots of the spinal nerves the changes came from peripheral nervous system and spinal cord. This leads to a complete loss of sensory and motor function (Vekris and Soucacos 2001).

In the case of damage of the supraclavicular and infraclavicular area basic methods of treatment include neurolysis, direct neuroorrhaphy (end to end), or

the use of nerve graft. Neurolysis is used in the case of compressions of a nerve by surrounding tissues, direct neuroorrhaphy (end to end) is used in cases of approximation capabilities and potential-free connection of the cut nerve. In a situation of damage when suture is impossible the nerve grafts are used. The most commonly used sensory nerves are the sural, saphenous, medial brachial cutaneous medial antebrachial cutaneous and superficial radial nerves (Bonham and Greaves 2011). In some cases, the pedunculated nerve grafts are used. (Vascularized nerve grafts) (Taylor and Ham 1976). This provides proper blood supply and environment for the nerve transfer, even in a scarred bed.

The main difficulty caused by the brachial plexus avulsion is the preganglionic injury (Bonham and Greaves 2011). These kinds of injuries are not treatable neither by classical methods such as “end to end”, nor with the use of autogenous nerve grafts. In such cases, neurotization or nerve coaptation surgeries (Brunelli 1980, Viterbo et al. 1992, Lundborg et al. 1994, Millesi and Schmidhammer 2007) are used. In case of neurotization branches of the ipsilateral cervical plexus (Brunelli et al. 1980), intercostal nerve (Chuang et al. 1992), phrenic nerve (Gu et al. 1996), accessory nerve (Allieu et al. 1984), contralateral C7 (Gu et al. 1992), selective ulnar nerve to musculocutaneous (Loy et al. 1997) and hypoglossal nerve (Narakas 1984) are used. Efficacy of coaptation was effective in the case of a coaptation of musculocutaneous nerve with n. ulnaris (Sananpanich 2002, Liao et al. 2009) and tibial nerve with peroneal nerve (De Sa et al. 2004). In recent years experimental attempts were made to implant avulsed brachial plexus elements into the spinal cord. The results are interesting, but this technique has only been used in experimental studies.

Lack of satisfactory results, especially in cases of preganglionic injury requires the use of chemical and physical agents which stimulate nerve regeneration (Geuna et al. 2006). It has been shown that local administration of insulin-like growth factor-I (IGF-I) (Tiangco et al. 2001) or a combination of nerve growth factor (NGF) and ciliary neurotrophic factor (CTF) (McCallister et al. 1998) increases the rate of axonal regeneration and functional recovery after end-to-side nerve repair. Improvement of the treatment results is also described after the use of female hormones, such as estrogen and progesterone (Kovacic et al. 2003) The presence of receptors for estrogens and progesterone on Schwann cells, the key cell population in nerve regeneration, has been demonstrated in vitro (Jung-Testas et al. 1996).

Lack of satisfactory results leads to further research on nerve regeneration. The processes of nerve

regeneration still need more accurate explanation. Therefore, a good experimental model is an important component of scientific research. The aim of our study was to analyze the anatomy and surgical approach of the rabbit brachial plexus and evaluation of the rabbit as an experimental model for high peripheral nerve injury.

## Materials and Methods

The experiments were approved by the II Local Ethics Committee for animal experimentation at the University of Environmental and Life Sciences in Wrocław, permission 54/2012. The study included 18 New Zealand White Rabbits (female), each weighing approximately 4,5 kg, 5 months of age. The animals were sedated with medetomidine (Cepetor) in a dose 150 µg/kg of body weight, butorphanol (Torbugesic) in a dose of 0.2 mg/kg of body weight, and ketamine (Bioketan) in a dose of 35 mg/kg body weight. All medicaments were mixed in one syringe and administered intramuscularly in the thigh muscles. Dissection of the brachial plexus: skin incisions were made along the ventral edge of the splenius and rhomboideus muscles, and then turned downward along the cranial edge of the supraspinatus muscle (Fig. 1). The skin was retracted to expose the muscles. The overlying fascia was removed. The splenius and rhomboideus muscles were exposed by a retractor. The serratus ventralis muscle was prepared ventrally and the forelimb was moved caudally. Thus, in a triangle defined by the three anatomical structures, the brachial plexus was exposed. (Fig. 2) The fat tissue and connective tissue were removed. The nerves and blood vessels were trimmed, identified, and photographed (Figs. 3,4). Each nerve's root was separated, and the diameter was measured. The length of suprascapular nerve with cranial trunk was measured. The individual muscle mass was recorded.

## Results

The brachial plexus of the rabbit is formed by the rami ventrales of fifth cervical spinal nerve (C5), sixth cervical spinal nerve (C6), seventh cervical spinal nerve (C7), eighth cervical spinal nerve (C8) and the first thoracic spinal nerve (Th1) and the caudal branch the second thoracic spinal nerve (Th2). The caudal branch of the C5 and C6 spinal nerves constitutes the cranial trunk. The caudal trunk is formed by a branch originating from the cranial trunk, the rami ventrales of the C7, C8 and T1 spinal nerves.

Table 1. The average muscle mass.

Muscle	Supraspinatus	Infraspinatus	Subscapularis	Teres major
The average muscle weight [g]	13.30	11.40	7.40	6.1

Table 2. The nerve area and diameter for particular spinal nerves.

	C5	C6	C7	C8	Th1	Cranial trunk	Caudal trunk medial part	Caudal trunk lateral part	Suprascapular nerve	Median nerve	Ulnar nerve	Radial nerve
Nerve diameter [mm]	0.6	0.8	1.1	1.0	0.6	1.2	1.3	1.6	0.7	0.5	0.4	0.3



Fig. 1. Anatomical landmarks used to locate the left brachial plexus in a rabbit. Skin incisions were made along the ventral edge of the splenius and rhomboideus muscles, and turned downward along the cranial edge of the supraspinatus muscle: 1 – Splenius muscle, 2 – Rhomboideus muscle, 3 – Supraspinatus muscle, 4 – Infraspinatus muscle, 5 – Deltoideus muscle, 6 – Teres Major muscle, 7 – Serratus Ventralis Cervicis muscle, 8 – Omotransversarius muscle, 9 – Cleidocephalicus muscle, 10 – Triceps Brachii muscle.

The cranial trunk divides into the phrenic nerve and the suprascapular nerve. The caudal trunk divides into the cranial pectoral nerve and the axillary nerve. The suprascapular nerve arises from the C5 and C6 spinal nerves. The axillary nerve begins from the C7 and supplies the deltoid muscles. The musculocutaneous nerve arises from the C6 and C7 and goes to the biceps and supplies the skin of the forearm. The radial nerve originates from the C7, C8, Th1 and innervate

the triceps muscle. The median nerve arises from the C7, C8, Th1 and innervates the muscles of the upper arm. The ulnar nerve arises from the C8 and Th1 and supplies the limb below the elbow. The medial cutaneous nerve goes to the skin of the forearm. In all animals these anatomical structures were present. The length of the suprascapular nerve with cranial trunk was ranged between 2.1 and 3.8 cm, and the mean length was 3.5 cm.

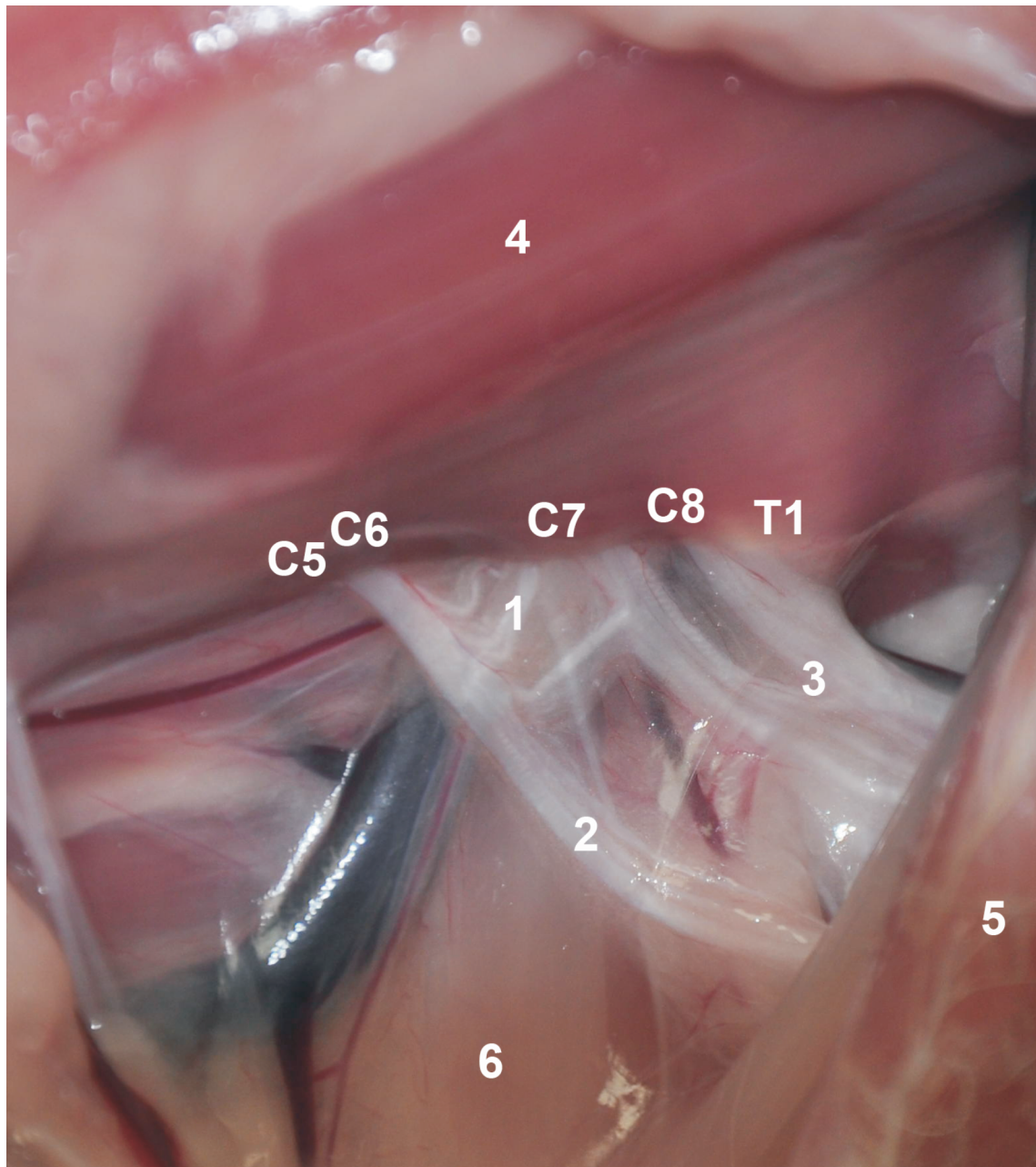


Fig. 2. The macroscopic structure of the rabbit left brachial plexus: 1 – Binding branch from cranial trunk to caudal trunk, 2 – Cranial trunk, 3 – Caudal trunk, 4 – Splenius muscle, 5 – Supraspinatus muscle, 6 – Serratus ventralis muscle.

## Discussion

So far, for single experimental studies relating to high injury of nerves have been performed on rats, mice, monkeys, baboons, dogs, cats and porcupines. A multitude of methods demonstrates a lack of an ideal model.

The anatomy of the brachial plexus is very species-specific. The brachial plexus of rat is formed by contribution of ventral rami of C5, C6, C7, C8, T1 and T2 spinal nerves (Santos et al. 2007). On the other

hand, in literature it is reported that ramus ventralis of T2 spinal nerve in rats is not involved (Bertelli et al. 1992). The brachial plexus is formed by ventral rami of C5, C6, C7, C8 and T1 spinal nerves in mouse (Bogush 1987), by rami ventrales of C5, C6, C7, C8, T1 and T2 spinal nerves in Wervet monkey (Booth 1991) and Chacma baboon (Booth 1997). In case of the dog the brachial plexus is formed by ventral rami of C6, C7, C8, T1 and T2 spinal nerves (Mahler and Adogwa 2008). In case of the cat the brachial plexus is formed by ventral rami of C6, C7, C8 and T1 spinal

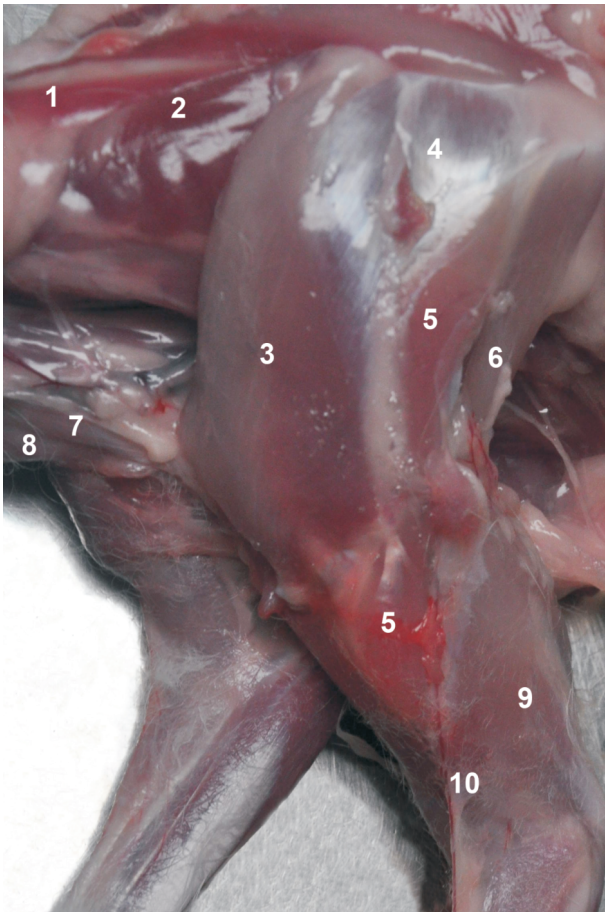


Fig. 3. Muscles of the forelimb and neck: 1 – Splenius muscle, 2 – Rhomboideus muscle, 3 – Supraspinatus muscle, 4 – Infraspinatus muscle, 5 – Deltoideus muscle, 6 – Teres Major muscle, 7 – Omotransversarius muscle, 8 – Cleidocephalicus muscle, 9 – Triceps Brachii muscle, 10 – Brachialis muscle.

nerves (Getty 1975). At the end, the brachial plexus of porcupine is formed by ventral rami of C5, C6, C7, C8, T1 and T2 spinal nerves (Aydin 2003).

To the surgeon, it is important that the anatomy of the rabbit brachial plexus is similar to human anatomy. In our opinion species-related differences are not so significant and make the rabbit's mode useful for other mammals.

Our results of the evaluation of the anatomy of the brachial plexus of the rabbit are comparable to the results presented by Mohiuddin (Mohiuddin et al. 2011). Regularity of the plexus anatomy, easy surgical approach and animal welfare are also important. The slight differences between human and rabbit anatomic structure of the brachial plexus are noticeable. The rabbit brachial plexus is divided into the caudal and cranial trunk. The human brachial plexus has three trunks. Despite the above mentioned differences, we believe that the rabbit is a good experimental model

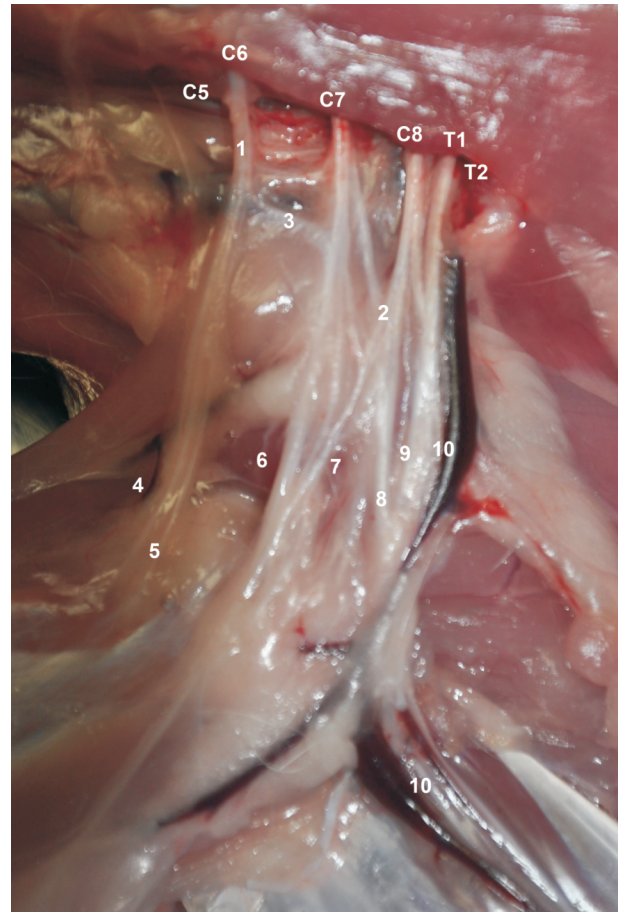


Fig. 4. The macroscopic structure of the rabbit left brachial plexus: C5 – Caudal branch of ramus ventralis of C5, C6 – Ramus ventralis of C6, C7 – Ramus ventralis of C7, C8 – Ramus ventralis of C8, T1 – Ramus ventralis of T1, T2 – Cranial branch of ramus ventralis of T2, 1 – Cranial trunk, 2 – Caudal trunk, 3 – Binding branch from cranial trunk to caudal trunk, 4 – Suprascapular Nerve, 5 – Subscapular Nerve, 6 – Axillary Nerve, 7 – Thoracodorsal Nerve, 8 – Musculo-Cutaneous nerve, 9 – Radial nerve, 10 – Ulnar nerve.

for nerve root injury, especially for the C5 and C6 segments. The structure of the C5 and C6 segments is analogous to the human structure. The nomenclature has some differences, which mainly concerns the inferior part of the brachial plexus. The medial and inferior trunks in human nomenclature correspond with the caudal trunk in the rabbit.

The anatomic structure of the rabbit brachial plexus seems to be ideal for studying the C5 segment, the C6 – cranial trunk, the suprascapular nerve, and the supraspinatus and infraspinatus muscles. The nerve roots of the C5 and C6 segments are wide and long enough for microsurgical procedures. The average length of the supraspinatus nerve with the cranial trunk equals 3.5 cm. This size could be convenient for experienced surgeons. Also giving possibility

for performing avulsion and incision of the nerve roots, nerve suture, coaptation side to side, end to side and procedure with 3 cm nerve's graft. We have noticed individual differences in particular animals. These differences concerned the length of the roots, the level of the nerves roots connection and the place of peripheral nerves derivation. All these differences were not statistically significant and not important for anatomical reproducibility of the brachial plexus.

The choice of this model is supported by the easy and clear assessment of nerve and muscle function. An additional advantage is the simplicity of surgical techniques. Good knowledge of macrostructure is an important element in the development of science (Schaumburg et al. 2010).

Muscle innervation is heterogeneous, due to the mutual interlacing of individual ventral roots and their branches in the brachial plexus. The superficial location of the supraspinatus and infraspinatus muscles gives the possibility of multiple evaluations by electromyography in vivo. The simplicity of sample collection during autopsy is also an important advantage. The anatomy and surgical approach to the rabbit brachial plexus can be used as an experimental model of high-level peripheral nervous system injury, especially for the preganglionic injury and coaptation on the roots/trunks of the brachial plexus.

## Conclusion

The size of the rabbits brachial plexus and the similarity to the human brachial plexus makes one a convenient model for brachial plexus research. The advantage is also the reproducibility of the brachial plexus anatomy.

## References

- Allieu Y, Privat JM, Bonnel F (1984) Paralysis in root avulsion of the brachial plexus. Neurotization by the spinal accessory nerve. *Clin Plast Surg* 11: 133-136.
- Aydin A (2003) Brachial plexus of the porcupine (*Hystrix cristata*) *Vet Med Czech* 48: 301-304.
- Bertelli JA, Mira JC, Gilbert A, Michot GA, Legagneux J (1992) Anatomical basis of rat brachial plexus reconstruction. *Surg Radiol Anat* 14: 85-86.
- Bogusch G (1987) Innervation of the dermatomes in the neck of the mouse. *Acta Anat (Basel)* 129: 275-278.
- Bonham C, Greaves I (2011) Brachial plexus injuries. *Trauma* 13: 353-363.
- Booth KK, Baloyi FM, Lukhele OM (1997) The brachial plexus in the chacma baboon (*Papio ursinus*). *J Med Primatol* 26: 196-203.
- Booth KK (1991) The brachial plexus in the vervet monkey (*Cercopithecus pygerythrus*). *J Med Primatol* 20: 23-28.
- Brunelli G, Monini L (1984) Neurotization of avulsed roots of brachial plexus by means of anterior nerves of cervical plexus. *Clin Plast Surg* 11: 149-152.
- Chuang DC, Yeh MC, Wei FC (1992) Intercostal nerve transfer of the musculocutaneous nerve in avulsed brachial plexus injuries: evaluation of 66 patients. *J Hand Surg Am* 17: 822-828.
- Daniel RK, Terzis J, Schwarz G (1975) Neurovascular free flaps. A preliminary report. *Plast Reconstr Surg* 56: 13-20.
- De Sh JM, Mazzer N, Barbieri CH, Barreira AA (2004) The end-to-side peripheral nerve repair. Functional and morphometric study using the peroneal nerve of rats. *J Neurosc Methods* 136: 45-53.
- Geuna S, Papalia I, Tos P (2006) End-to-side (terminolateral) nerve regeneration: a challenge for neuroscientists coming from an intriguing nerve repair concept. *Brain Res Rev* 52: 381-388.
- Gu YD, Ma MK. (1996) Use of the phrenic nerve for brachial plexus reconstruction. *Clin Orthop Relat Res* 323: 119-121.
- Gu YD, Zhang GM, Chen DS, Yan JG, Cheng XM, Chen L (1992) Seventh cervical nerve root transfer from the contralateral healthy side for treatment of brachial plexus root avulsion. *J Hand Surg Br* 17: 518-521.
- Jung-Testas I, Schumacher M, Robel P, Baulieu EE (1996) Demonstration of progesterone receptors in rat Schwann cells. *J Steroid Biochem Mol Biol* 58: 77-82.
- Kovacic U, Sketelj J, Bajrovic FF (2003) Sex-related difference in collateral sprouting of nociceptive axons after peripheral nerve injury in the rat. *Exp Neurol* 184: 479-488.
- Liao WC, Chen JR, Wang YJ, Tseng GF (2009) The efficacy of end-to-end and end-to-side nerve repair (neurorrhaphy) in the rat brachial plexus. *J Anat* 215: 506-521.
- Loy S, Bhatia A, Asfazadourian H, Oberlin C (1987) Ulnar nerve fascicle transfer on to the biceps muscle nerve in C5-C6 or C5-C6-C7 avulsions of the brachial plexus. Eighteen cases. *Ann Chir Main Memb Super* 16: 275-284.
- Lundborg G1, Zhao Q, Kanje M, Danielsen N, Kerns JM (1994) Can sensory and motor collateral sprouting be induced from intact peripheral nerve by end-to-side anastomosis? *J Hand Surg Br* 19: 277-282.
- Mahler SP, Adogwa A (2008) Anatomical and experimental studies of brachial plexus, sciatic, and femoral nerve-location using peripheral nerve stimulation in the dog. *Vet Anaesth and Analg* 35: 80-89.
- McCallister WV, Tang P, Trumble TE (1999) Is end-to-side neurorrhaphy effective? A study of axonal sprouting stimulated from intact nerves. *J Reconstr Microsurg* 15: 597-603
- Millesi H, Schmidhammer R (2007) End-to-side coaptation-controversial research issue or important tool in human patients. *Acta Neurochir Suppl* 100: 103-106.
- Mohiuddin M, Rahman ML, Alim MA, Kabir MB, Kashem MA (2011) Macro anatomical investigation of brachial plexus of the White New Zealand rabbit (*Oryctolagus cuniculus*). *Int J Nat Sci* 1: 74-76.
- Narakas AO (1984) Thoughts on neurotization or nerve transfers in irreparable nerve lesions. *Clin Plast Surg* 11: 153-159.
- Santos AP, Suaid CA, Sassolifazan VP, Barreira AA (2007) Microscopic Anatomy of Brachial Plexus Branches in Wistar Rats. *Anat Rec (Hoboken)* 290: 477-485.

- Sananpanich K, Morrison WA, Messina A (2002) Physiologic and Morphologic Aspects of Nerve Regeneration After End-to-End or End-to-Side Coaptation in a Rat Model of Brachial Plexus Injury. *J Hand Surg Am* 27: 133-142.
- Schaumburg HH, Zotova E, Raine CS, Tar M, Arezzo J (2010) The rat caudal nerves: a model for experimental neuropathies. *J. Peripher Nerv Syst* 15: 128-139.
- Seddon HJ (1943) Three types of nerve injury. *Brain* 66: 238-288.
- Taylor GI, Ham FJ (1976) The free vascularized nerve graft. A further experimental and clinical application of microvascular techniques. *Plast Reconstr Surg* 57: 413-426.
- Tiangco DA, Papakonstantinou KC, Mullinax KA, Terzis JK (2001) IGF-I and end-to-side nerve repair: a dose-response study. *J Reconstr Microsurg* 17: 247-256.
- Vekris MD, Soucacos PN (2001) Post-traumatic brachial plexus paralysis: current management of reconstruction. *Curr Orthopaed* 15: 76-83.
- Viterbo F, Trindade JC, Hoshino K, Mazzoni Neto A (1992) Latero-terminal neuroorrhaphy without removal of the epineural sheath. Experimental study in rats. *Rev Paul Med* 110: 267-275.