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Magnetic Resonance Imaging in Traumatic Brachial Plexus Injuries: A 6-Year Experience.

Clarissa Gadelha Maia Vieira,MD
São Carlos Imaging/São Carlos Hospital, Fortaleza, CE, Brazil.

Cláudio Régis Sampaio Silveira, MD
Musculoskeletal Radiology Division,
São Carlos Imaging/São Carlos Hospital, Fortaleza, CE, Brazil.

Brenda Machado Pereira,MD
São Carlos Imaging/São Carlos Hospital, Fortaleza, CE, Brazil.

Ingrid Carvalho de Holanda,MD
São Carlos Imaging/São Carlos Hospital, Fortaleza, CE, Brazil.

Ariana Sorah Serra dos Santos Jacinto,MD
São Carlos Imaging/São Carlos Hospital, Fortaleza, CE, Brazil.

Francisco Flávio Leitão de Carvalho Filho, MD
Neurosurgery Division, Doutor José Frota Institute, Fortaleza, CE, Brazil.

Daniel Gurgel Fernandes Távora, MD
Neuroradiology Division, São Carlos Imaging /
São Carlos Hospital, Fortaleza, CE, Brazil.

Avneesh Chhabra, MD
Chief of Musculoskeletal Radiology Division,
UT Southwestern Medical Center, Dallas, Texas.

Abstract

Background and Purpose: There is limited information in the literature on epidemiology of high-energy brachial plexus injuries evaluated with MR neurography (MRN). The aim of the present study is to describe the demographic characteristics of brachial plexus injuries secondary to motorcycle accident patients in the city of Fortaleza-Ceara, Brazil, and analyze the association of those data with the features of the brachial plexus lesions observed on MRN findings. Materials and Methods: A review of sixty medical charts and MRN findings of victims of motor vehicle accidents (MVA) in northeast, from November 2011 to November 2017. Demographic and imaging data collected included age, sex, laterality and level of the lesion and time interval between trauma and MRN examination. The MRN examinations were carried out on a GE 1.5T MR unit (Signa HDxT- General Electric, Milwaukee, USA) or on a Phillips 3T MR unit (Philips Achieva X-series - Philips Medical *Systems*, Best, The *Netherlands*). Dedicated multichannel phased-

array coils. Results: The longest time interval from trauma to imaging was 330 days and between trauma and surgery was 692 days. Preganglionic lesions (avulsion) predominated, consisting of 52 patients (86.6%) reflecting the high energy trauma with upper limb traction from the neck. The lesions were most prevalent at the C6-C8 levels. Pseudomeningocele was identified in 62.9% of the preganglionic lesions and in only 1.6% of the postganglionic lesions. Regional muscle denervation changes were seen in all pre-ganglionic injuries and most of post-ganglionic injuries. Conclusions: MRN of the brachial plexus provides important insights into the distribution of neuromuscular lesions in high energy MVA trauma and these findings enrich the literature for researchers and clinicians focused on managing such patients and/or defining prognostic strategies.

Keywords: Brachial plexus, Magnetic Resonance Imaging (MRI), Magnetic Resonance Neurography (MRN), Brachial Plexus Injury (BPI), Epidemiology, Motorcycle accident, Traffic accident

INTRODUCTION

According to data from the Traffic Department in northeast of Brazil, motorcycle accidents account for about 40% of total traffic accidents in the state and were responsible for 31.9% of fatal cases and 43.8% non-fatal victims between the years 2004 and 2015. Traffic accidents, especially by motorcycle, are the most common cause of brachial plexus injury (BPI) [1]. Some authors report that brachial plexus injuries occur in up to 5% of polytrauma cases involving motorcycle accidents, which can result in severe functional impairment of the upper limb [2-4].

The brachial plexus (BP) is a network of nerves that combine in terminal branches to supply the motor and sensory innervation to the upper limb. It is formed by the union of ventral rami of 5th, 6th, 7th, and 8th cervical nerve roots and 1st thoracic nerve root. It is divided into roots, trunks, divisions, and cords [1]. Traumatic lesion of the BP is called preganglionic when an avulsion occurs proximal to the dorsal root ganglion (DRG), and postganglionic when the lesion affects the spinal nerves distal do the DRG.

The intricate anatomy of the BP and a variety of potential injuries yield a wide array of pathological entities, with diverse clinical deficits, different treatment strategies, rendering the management these patients a great challenge [5].

Imaging modalities combined with detailed clinical evaluation play an essential role in differentiating preganglionic from postganglionic injuries of the brachial plexus. They consist of standard myelography, computed tomographic (CT) myelography, and Magnetic Resonance Neurography (MRN). Electrophysiologic examination is useful in confirmation of neuropathy and evaluation of nerve regeneration [3, 4].

Treatment of BPI can be either conservative or operative (neurotization, nerve or tendon transfers) [1].

The MRN has become the standard imaging for BP injury evaluation. In our tertiary care institute, these injuries are not infrequently seen. The aim of the present study was to systematically evaluate and present the distribution and extent of BP injury lesions in patients with motor vehicle accidents (MVA) in northeast-Brazil, and analyze the association of those data with patient demographics of age and gender [6].

MATERIAL AND METHODS

The study was performed under HIPAA (Health Insurance Portability and Accountability Act) waiver following the institutional review board guidelines and informed consent was waived.

This study consisted of a retrospective review of medical charts and MRN findings of victims of MVA in northeast-Brazil, from November 2011 to November 2017. We included a consecutive series of sixty patients referred for MRN of the BP with suspected traumatic BPI in this interval. Patients with non-traumatic causes of BP symptoms were not included.

Demographic data were collected by the attending neurosurgeon and included age, sex, laterality and level of the lesion and time interval between trauma and MRN examination.

Imaging Technique

All examinations were performed in a tertiary care center. The MRN examinations were carried out on a GE 1.5T MR unit (Signa HDxT- General Electric, Milwaukee, USA) or on a Phillips 3T MR unit (Philips Achieva X-series - Philips Medical *Systems*, Best, The *Netherlands*). Dedicated multichannel phased-array coils were used (Tables. 1 and 2). Nineteen patients were examined at 3T (Table 2), and forty-one patients at 1.5T (Table 1). A high field device (General Electric 1.5 T Signa HDxT - MRI System; General Electric Systems, Milwaukee, USA) was used for the plexus brachial MRN the HeadNeckSpine CoilMR coils with the following protocol: coronal 3D volumetric short tau inversion recovery (STIR) imaging, coronal three-dimensional (3D) volumetric T1-weighted imaging, sagittal T1 and T2-weighted imaging, 3D diffusion-weighted imaging (DWI), axial FIESTA, and sagital 3D fat saturated (Fat-sat) T1-weighted sequences both without contrast and after intravenous gadolinium injection. A device (Philips Achieva 3.0 T X-series MRI System; Philips Medical Systems, Best, the Netherlands) was used HeadNeckSpine CoilMR coils with the following protocol: coronal 3D volumetric short tau inversion recovery (STIR) imaging, coronal three-dimensional (3D) volumetric T1 and T2-weighted imaging, sagittal T1 and T2-weighted imaging, 3D diffusion-weighted imaging (DWI), axial balanced FFE, and 3D fat saturated (Fat-sat) T1-weighted sequences both without contrast and after intravenous gadolinium injection. The images were post-processed at a workstation, and multiplanar reconstructions (MPRs) were generated using the thick-slab maximum intensity projection (MIP) technique. The images were post-processed at a workstation, and multiplanar reconstructions (MPRs) were generated using the thick-slab maximum intensity projection (MIP) technique.

Imaging Review

Expert consensus reading of the MRN examinations was performed by two radiologists with more than 10 years of experience in musculoskeletal imaging.

Table 1

1.5T MRN examination protocol for the evaluation of the brachial plexus

Sequence	FOV	Slice Thickness	TR/TE	Matrix
T2 Sagital	23	3.0	4517/110	320 x 256
T1 Sagital	23	3.0	417/9.2	288 x 192
Coronal STIR	40	4.0	3075/50	288 x 160
T1 Coronal	40	4.0	334/10.1	288 x 192
Axial FIESTA	20	4.0	5.0/2.5	288 x 244
T1 Sagital Gd	23	3.0	667/9.2	288 x 192
Diffusion	24	2.4	6000/96.5	128 x 128

Table 2

3.0T MRN examination protocol for the evaluation of the brachial plexus

Sequence	FOV	Slice Thickness	TR/TE	Matrix
Coronal STIR (3D)	40	1.2	2500/120	376 x 217
T1 Coronal (3D)	40	1.0	325/18	512 x 534
T2 Coronal (3D)	40	1.0	1800/120	460 x 405
T2 Sagital	16	3.0	3000/100	248 x 287
T1 Sagital	16	3.0	530/8	200 x 248
Diffusion	45	3.0	10290/230	160 x 159
Axial Balanced FFE	10	1.5	57/2.2	200 x 166
T1 Sagital Gd	16	3.0	576/6.9	264 x 336

Abbreviations are MRN = Magnetic Resonance Neurography, STIR = Short tau inversion recovery, FIESTA **=** Fast Imaging Employing Steady-state Acquisition**,** Balanced FFE is fast field echo, Field of view (FOV) is presented in cm, slice thickness in mm and TR/TE in ms.

MRI datasets were loaded onto a workstation (CARESTREAM Vue PACS - Carestream Health Inc., USA) and interpreted by using multiplanar reconstructions (MPR) and MIP (maximum intensity projection) techniques. The MRN imaging findings were categorized as below-

Preganglionic: The lesions were defined as preganglionic if they occurred proximal to the DRG. The MRI criteria to describe those lesions included the lack of visualization of a ventral and/or dorsal rootlets at the spinal cord entry zone, or in their intrathecal or intra-foraminal courses. These were evaluated on the axial BALANCED FFE or FIESTA sequences [7]. Pseudomeningocele formation is indirect sign of pre-ganglionic injury. Pseudomeningocele was recognized as an extradural fluid collection with / without extension through the corresponding neural foramen, often associated with contralateral deviation of the spinal cord [8].

Postganglionic: The lesions occur distal to the DRG and occur are a result of either a stretch or rupture of a nerve segment from the DRG to the terminal branches. These were considered in

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cases showing asymmetric thickening and / or edema causing increased T2 signal involving a nerve distal to the DRG, sometimes showing discontinuity, neuroma in continuity, or retraction. Those findings were best identified at the 3D coronal STIR sequence and 2D sagittal T2W images [7].

Denervation in the paraspinal and shoulder girdle muscles was defined as diffuse edema like signal on T2W and 2D/3D STIR images in the acute stage and/or fatty replacement with/without atrophy in the subacute and chronic stages [9].

The Sunderland's classification of peripheral nerve injury was used in our study. The lowest degree of nerve injury in which the nerve remains intact but signaling ability is damaged is called neurapraxia. The second degree in which the axon is damaged but the surrounding connecting tissue remains intact is called axonotmesis. The last degree in which both the axon and connective tissue are damaged is called neurotmesis [10].

Statistical Analysis
The analysis was carried out using R software version 4.4.1. The distribution and extent of injuries were tabulated. We compared demographic data with the MRI findings using contingency table, hypothesis testing, independence testing, correlation coefficient. A *p*-value of <0.05 was considered statistically significant.

RESULTS

A consecutive series of sixty MRN studies of sixty patients who were victims of motorcycles accidents with suspected brachial plexus injury were analyzed (Fig. 1).

The age of these patients varied from 13 to 72 years with an average of 32.46 years. Most of the patients were male (95%) and the highest number of lesions involved the right BP (62.2%). The longest time interval from trauma to imaging was 330 days (mean: 119.3 days) and between trauma and surgery was 692 days (mean 351.8 days) (Table 3).

Preganglionic lesions (avulsion) predominated (Fig. 3), consisting of 86.6% patients reflecting the high energy trauma with upper limb traction from the neck. The lesions were most prevalent at the C7 level (25%), followed by C6 (23.9%) and C8 (23.1%). Pseudomeningocele (Fig.6) was identified in 62.9% of the preganglionic lesions and in only 1.6% of the postganglionic lesions (Table 4).

Postganglionic lesions are present in 16.6 % patients. Of these lesions, 70% were classified as Sunderland grade III injury (axonotmesis), 20% presented neuroma in continuity – NIC (Sunderland grade IV) injury, and only 10% did not present denervation with neuropraxia lesion classification (Sunderland grade I) (Table 5).

Denervation was present in all patients with preganglionic lesions. Eighty percent patients with postganglionic lesions had denervation (Fig.4 and 5). The imaging findings of denervation were detected in the following muscles and with a specific approximate frequency: supraspinatus (29.5%), infraspinatus (21.5%), teres minor (13.3%), subscapularis (16.9%), deltoid (7.8%) and paraspinal (11%).

Surgical treatment was performed in twenty-two patients (36%) for BP repair (neurolysis and nerve transfer technique).

The mean age of patients with preganglionic lesions was higher in comparison to patients with postganglionic lesions (Table 6). We found no correlation between mean age of patients with different levels of the BP lesions.

Table 3

Epidemiology of brachial plexus injury presentation and evaluation

Age	Range: 13 - 72 years
	Mean: 32.46 years
Sex ratio	M: F = 57:3
Laterality	R: L = 117:71
Time interval to MR Scan	Range: 8 - 330 days
	Mean: 119.3 days
Time interval to surgery	Range: 104 - 692 days
	Mean: 351.8 days

Table 4

	Preganglionic lesion			Postganglionic lesion		
Pseudomeningocele	No	Yes	Total	No	Yes	Total
No	8	13	21	12	9	21
Yes	0	39	39	38	1	39
Total	8	52	60	50	10	60

Table 5

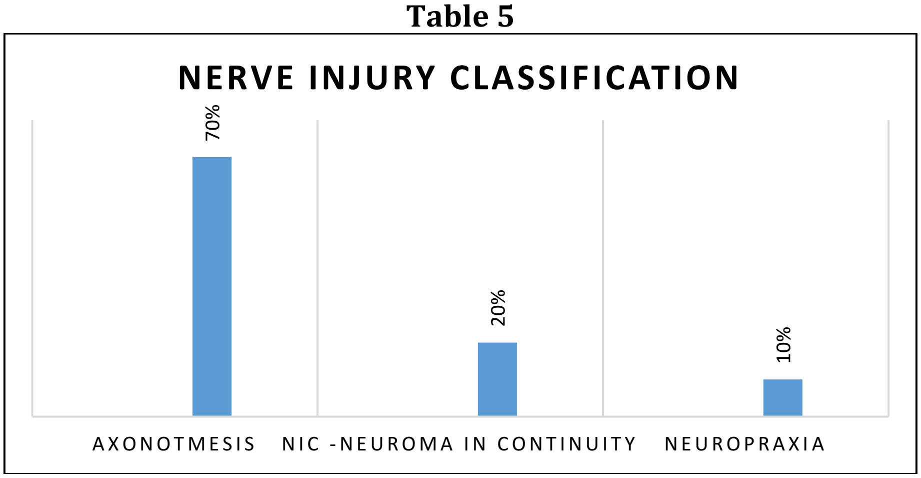

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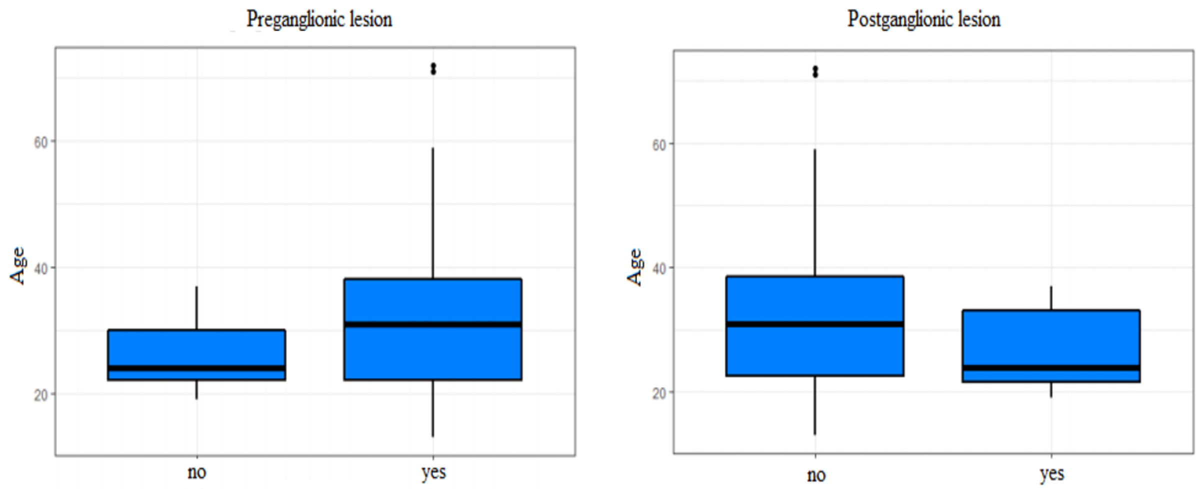
Table 6



DISCUSSION

In the recent years has been an increase in the number of patients presenting with compromise of upper limb function secondary to trauma involving the brachial plexus. Brachial plexus injuries frequently lead to significant physical disability, psychologic distress, and socioeconomic hardship [11].

The traumatic lesions may be preganglionic and postganglionic. Avulsion injury, considered the most severe type of preganglionic injury, is associated with a marked and progressive death of motor neurons with a very poor prognosis for functional recovery [12]. Thus, we can classify avulsion as neurotmesis according to Seddon classification [13] and grade V variant according to Sunderland classification as also described by Chhabra *et al.* [14]. C6-C8 nerve rootlets were found to be most affected in avulsion/grade V injuries in our patient cohort similar to a recent study [6]. The postganglionic injury is defined as a lesion distal to the sensory dorsal nerve root ganglion by stretching and partial rupture, with formation of a neuroma in continuity or complete discontinuity [14,15]. On MRN, there can be involvement of both pre- and post-ganglionic segments as pseudomenigoceles can be seen in predominantly post-ganglionic lesions as well.

MR myelography, accomplished with balanced steady-state gradient echo sequences as part of this MRN protocol allowed a detailed view of nerve rootlets with background hyperintense cerebrospinal fluid and good localization of preganglionic injury [16]. Coronal STIR and diffusion weighted imaging with MPR and MIP reconstructions displayed the post-ganglionic nerve injuries with good vessel signal suppression on 3D imaging and excellent background suppression on DWI. Although an important finding, pseudomeningoceles are not always seen associated with nerve root avulsion and vice versa [17]. Using these high resolution MRN techniques, the reader is able to visualize the nerve rootlet injury associated with pseudomeningocele versus an intact nerve with perineural cyst mimicking the pseudomeningocele.

Signs of muscle denervation as edema like signal on T2-weighted imaging and/or fatty replacement. It was present in all pre-ganglionic injuries and most of post-ganglionic injuries in the visualized paraspinal and the rotator cuff muscles [18]. On electrophysiology, paraspinal muscle denervation potentials indirectly aid in finding the pre-ganglioninc injury while on MRN, both can be directly visualized- nerve rootlet injury (cause) and denervation change (effect).

Motorcycle riders are the most vulnerable group for brachial plexus injury and this is particularly important to the developing countries where the number of people using two-wheeler vehicles are frequent [19]. In our study, the largest period between the accidents and MR imaging was 11 months (mean: 3.9 months. Upadhyaya *et al*. reported the time from injury to MR examination ranged between 1.5 to 6 months with a mean of 2.6 months [20]. This reflects the fact that in a developing country like Brazil, the population depends on socialized public medical services. In Fortaleza city with more than two million of habitants, there is just one MRI scanner in the public service. Jain *et al.* advocate that a population with low educational level, these effects are even exacerbated increasing the time interval between getting injured and seeking medical care for brachial plexus injuries [19]. Faglioni Jr *et al.* also reported similar delay between patient presentation and surgery (7.3 months) in the metropolitan region of São Paulo, given its prognostic relevance [21]. This data shows the difficulty on access of surgery and limited available nerve surgery skills in the developing countries.

The population evaluated in our study showed an average age 32.4 years and predominance of male sex, corroborating data available in the literature. Jain *et al*. reported the average age of the patient in the study was 24 years and the age group 21-30 years and 97.7% male dominance, Hayashi *et al*. presented average age of 24.5 years with the male dominance [16, 19]. Yalawar *et al*., reported age group of 31 to 40 years with male dominance, and Faglioni Jr *et al.,* reported the average age of the patient in the study was 28.4 years (minimum of 9, maximum of 67 years). Of these, 384 (94.6 %) were men and 22 (5.4 %) women [21, 23].

In the study by Marcelo Bordalo, lesions exclusively postganglionic predominated in about 45.4% [24]. Fagloni Jr *et al.* also demonstrated dominance of the postganglionic lesions in 53.9 % [21]. In our study, the prevalence of postganglionic lesions was only 6%. We may suppose that this different data from a same country series is probably because their cases happened in accidents with highest speed and energy.

Moraes *et al.* demonstrated that 50% of the lesion postganglionic predominated axonotmesis, 41,6 % neurotmesis and only 8,4% neuropraxia. The trauma mechanism comprising traction of the brachial plexus in car accidents, due to the high-energy impact, leads to neural injuries of greater severity. This was also corroborated the data in the literature and with our results [25].

The lesion of brachial plexus most frequently results from high-speed motor vehicle accidents that produce a sudden shoulder movement downwards and backwards, and a neck movement in the opposite direction as the patient strikes the ground. The caudal traction of the shoulder and arm usually injures the upper roots of the plexus (C5 and C6), lateral traction injures the C7 root, and cranial traction injures the lower roots C8 and T1 [26].

In our study, in 41.4%- the C5/C6 roots were compromised, in 66.4%- the C5/C6/C7 roots and in 33.5%, the C8/T1 were compromised. This is similar in distribution to results shown by Fagloni Jr *et al.* where in 30.1 %- the C5/C6 roots were injured, in 20.9 %- the C5/C6/C7 roots were involved and in only 2.9 %, the lesion involved only the lower roots, C8 and T1 [24]. Also reported by Hayashi *et al.* the prevalence of avulsion of the most roots were in middle and lower trunks [22]. The differences may be related to more high energy trauma in our series and different patient demographics.

The right side of the plexus brachial was found to be the most commonly injured, similar to many other studies. According with Jain *et al*. the side of the road used for driving does not determine the side of the arm affected [19].

Silbermann-Hoffman and Teboul noted pseudomeningoceles in 80% of avulsions [27]. In their series, Gasparotti *et al*. reported five cases of pseudomeningoceles without nerve root abnormalities, something we did not encounter [28]. It might be related to combined effect of MR myelography and MRN leading to better visualization of nerve rootlets and roots.

In our study, fifty-seven patients with brachial plexus injuries had denervation on paraspinal muscles as had also been shown by Hayashi *et al*. as an accurate sign of preganglionic lesions [22].

In an attempt to recover the function of the affected limb, a number of different techniques has been proposed for brachial plexus reconstruction, including neurolysis, nerve reconstruction (repair or grafting), nerve transfer, tendon transfer, free muscle transplantation, or nerve root reimplantation [10].

Common transfers include flexor carpi ulnaris to musculocutaneous nerve to biceps (Oberlin), distal or end-to-side spinal accessory to suprascapular nerve, and radial nerve long head of triceps branch to axillary nerve [29]. Neurolysis removes scar surrounding intact nerve fibers. This technique is performed with the aim of decompressing any viable fascicles in relation to the fibrotic tissue. Intraoperative nerve stimulation may be useful in identifying and protecting intact fascicles [29]. One limitation of our study was that about half of the patients with brachial plexus injury did not undergo surgery (51%). In our state the more important public trauma center does not have MR Scanner until the 2018 August, so the population must access the private tertiary care centers like ours. It causes a delay in the diagnosis and consequently surgery procedures. The overcrowding in public hospitals also increases patient's morbidity and impacts the prognosis in developing countries like Brazil.

CONCLUSION

Knowledge of topographic anatomy (origin, course, and relations of the involved roots with the neighboring anatomic elements) and the specific MRN technique are the keystones of diagnostic evaluation of brachial plexus injuries.

This study gives an insight into the epidemiological and imaging aspects of brachial plexus injuries in Brazil and such findings enrich the literature with role of MR neurography in high-energy devastating injuries of the cervical peripheral nervous system.

Conflict of Interest Statement

All the authors have no disclosures to make and no conflict of interest.

Disclosures: A. Chhabra receives royalties from Wolters and Jaypee. A. Chhabra also serves as a consultant with ICON Medical and Treace Medical Inc.

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Figures

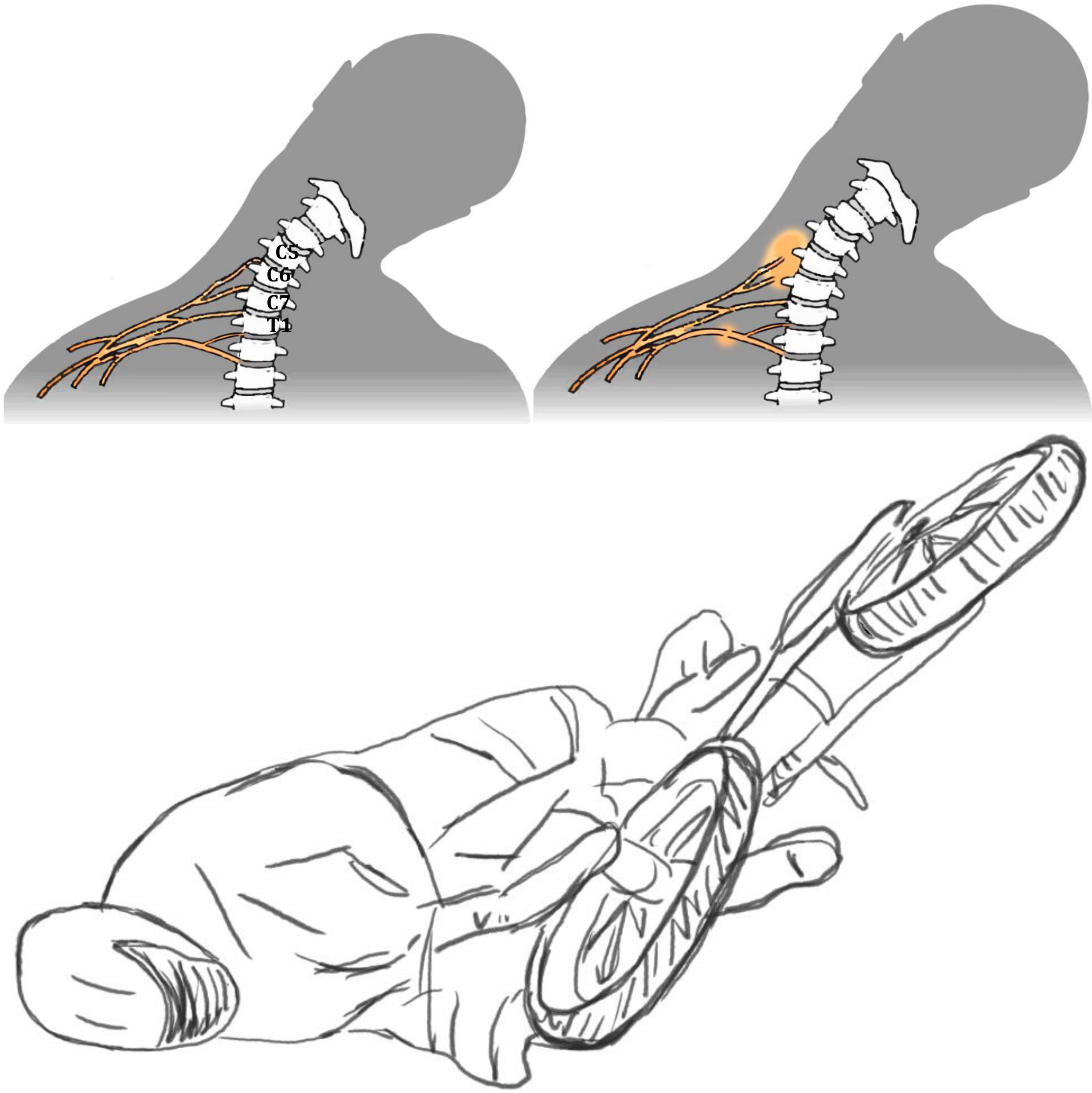

Fig. 1 a, b, c Illustrative drawing of brachial plexus normal (a), injury (b), and the trauma mechanism of MVA (c). Upper brachial plexus injuries occur when the head and neck are violently moved away from the ipsilateral shoulder. The shoulder is forced downward whereas the head is forced to the opposite side. b an avulsion of the upper roots (C5, C6), with preservation of the C7 and postganglionic lesions of the lower roots (C8, T1).

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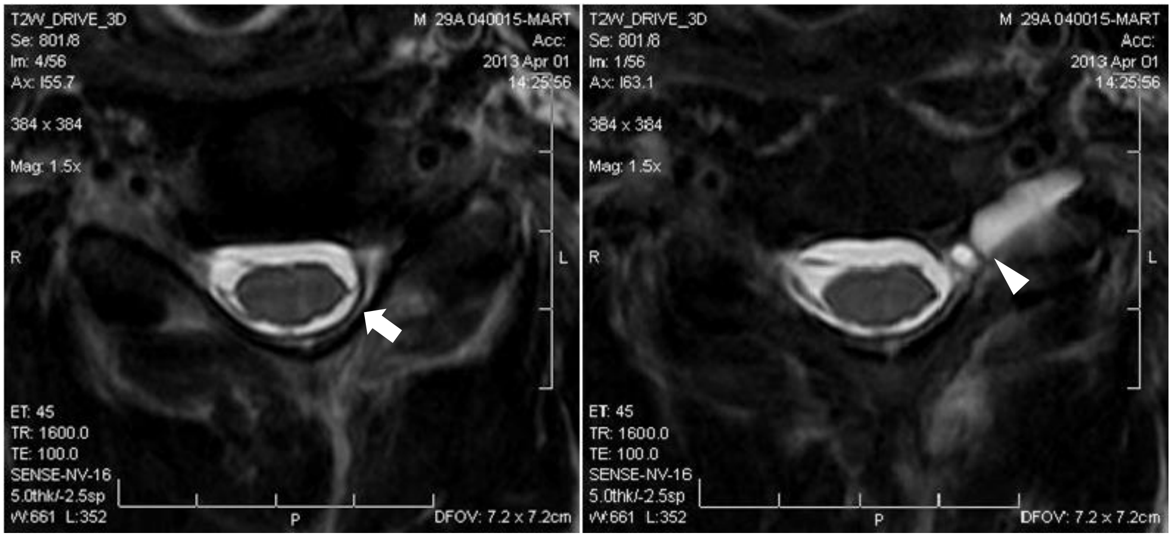

Fig. 2 a, b 3D axial steady state imaging of the cervical spine demonstrates a preganglionic injury with a complete ventral and dorsal left C6 root avulsion (arrow in b), with a small extradural fluid collection (arrow in a) and foraminal pseudomeningocele (arrow head).

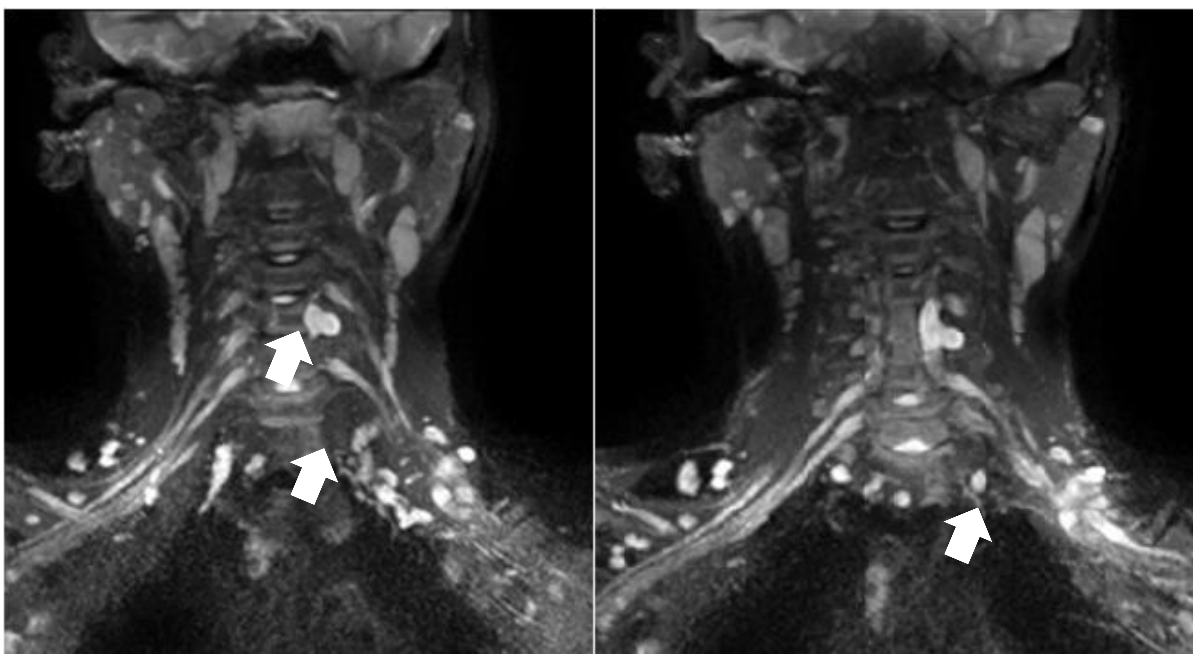

Fig. 3 a, b 3D STIR sequence with coronal MIP reconstructions, demonstrate left-sided C6, C8 and T1 nerve root discontinuity, with preganglionic injuries and avulsions (arrows). Multiple lymph nodes are also present int he left supraclavicular area obscuring the left post-ganglionic segments.

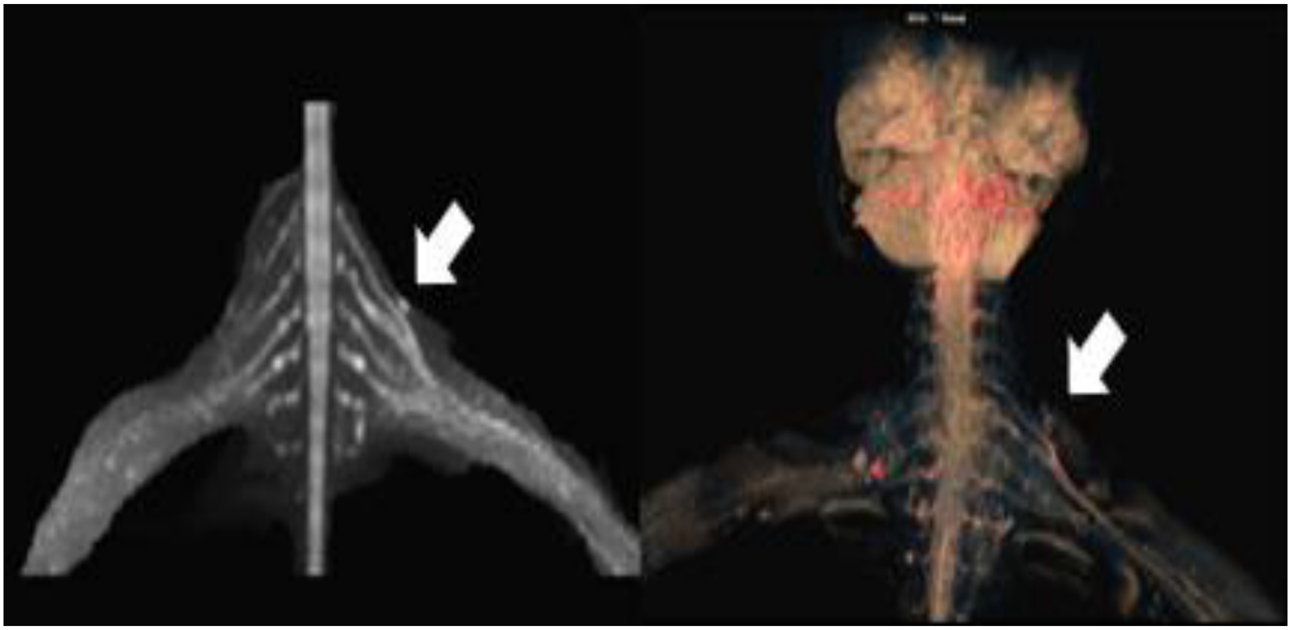

Fig. 4 3D Diffusion-weighted magnetic resonance imaging (DWI) with a coronal MIP reconstruction in grey scale and color shows left-sided C5 and C6 (upper trunk) postganglionic lesions (traction neuropathy).

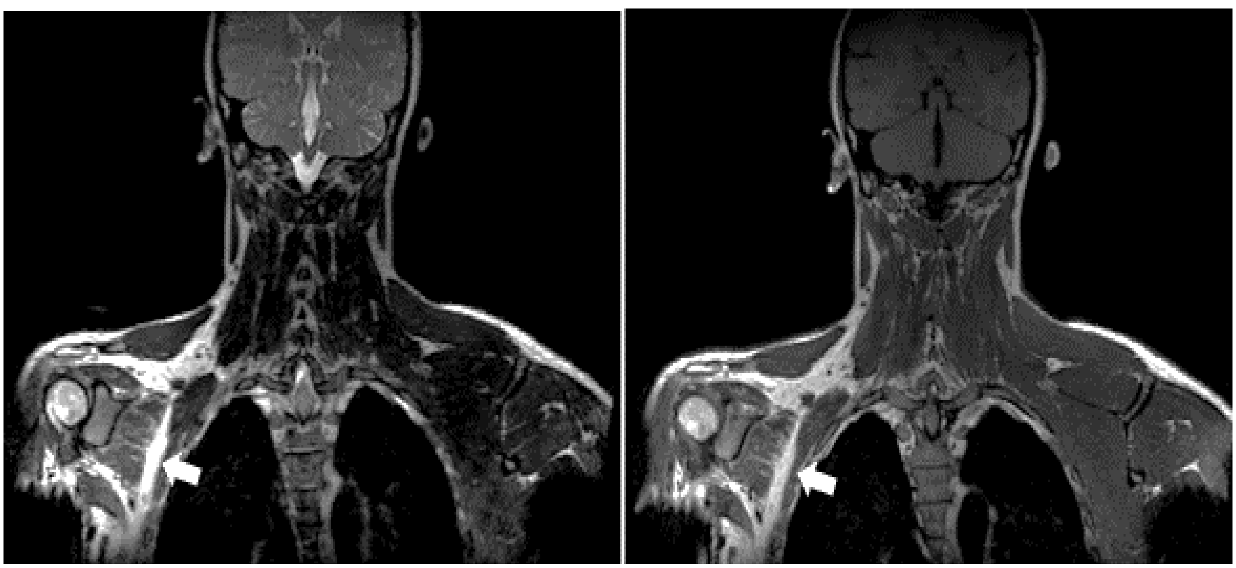

Fig. 5 3D Coronal T2 and T1sequences reveal the right-sided denervation manifested as rotator cuff muscles atrophy (arrow).

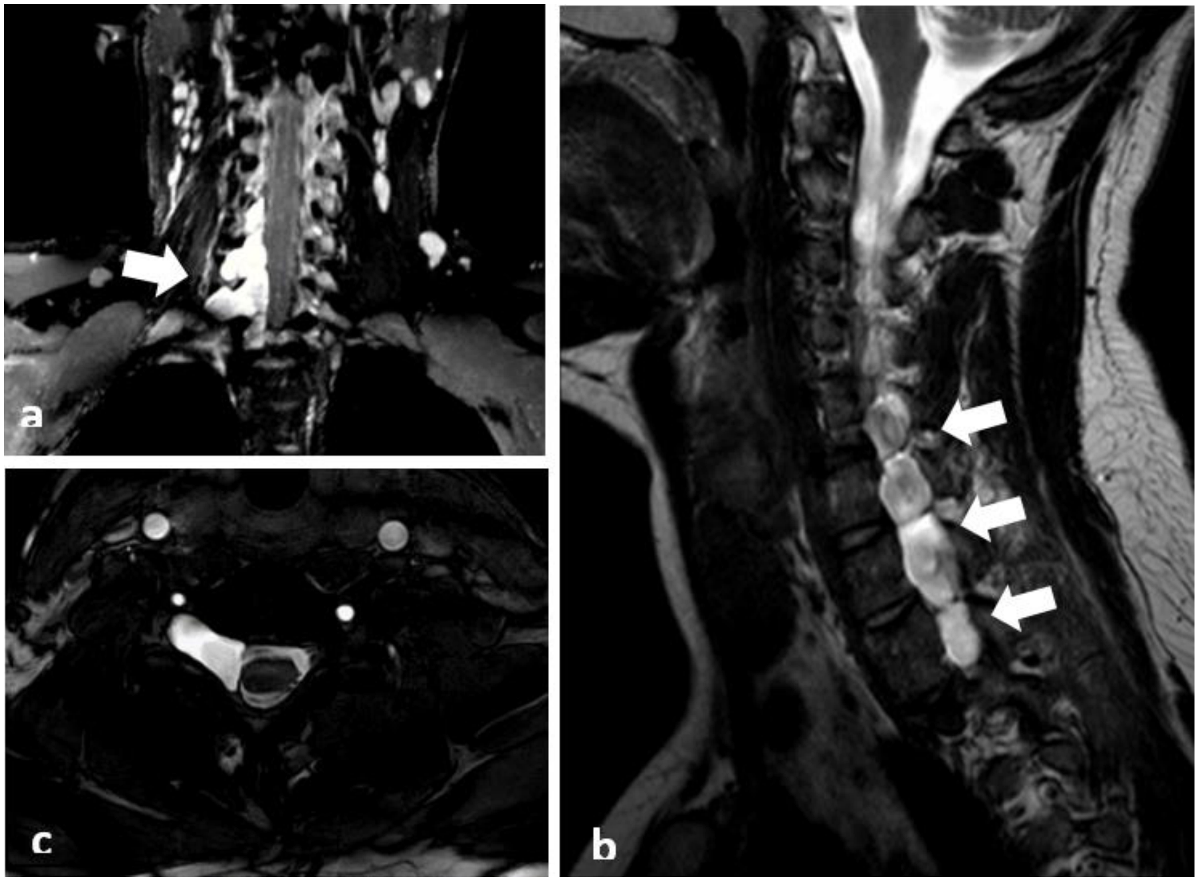

Fig. 6 a, b 3D T2 sequences coronal and sagittal reconstructions and c Fiesta axial through of the cervical spine demonstrate multi-level right-sided pseudomeningoceles with absent rootlets in the lower cervical spine.