Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 1, 2021, Pages. 3216 - 3226

Received 15 December 2020; Accepted 05 January 2021.

Study on Imaging Characteristics and Value of MRI in Diagnosis of Traumatic Brachial Plexus Injury

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Abstract: Surgical treatment and prognosis of brachial plexus tract injuries depend on the precise diagnosis of the root detachment from the spinal cord. Myelography, computed tomography (CT), magnetic resonance imaging (MRI) have become the main radiological methods of preoperative diagnosis of cervical roots detachment. Most previous studies of CT myelography accuracy and MRI studies correlated radiological results with the results of extra-spinal brachial plexus surgeries. Surgical experience shows that in many cases extra-spinal data differ from intradural definitions. Therefore, only the correlation of the intradural surgical results will allow to estimate the actual accuracy of CT and MRI studies. This study analyzes image characteristics and MRI value in the diagnosis of traumatic brachial plexus injury. The research was conducted on 60 patients who were diagnosed and operated brachial plexus injury. Within this prospective study, cross-sectional description, comparing diagnosis of brachial plexus injury on 3 Tesla MRI imagine before surgery with postoperative diagnosis were applied. Improved respiratory compensation systems, new methods for suppressing artefacts and the use of special coils to improve the signal-to-noise ratio in high field MRI provide us with a more accurate assessment of the intradural roots images in the brachial plexus and injuries.

Keywords
Brachial plexus; Root detachment; Computed tomography; Magnetic resonance imaging; Computerized tomographic myelography

INTRODUCTION

Traumatic injuries of the brachial plexus are frequent lesions to which mostly young people are exposed. According to the main data published in the literature, motorcycle accidents are the most frequent cause of traction injuries of brachial plexus.

Despite the growing experience in treating brachial plexus lesions in recent decades, the functional outcome remains quite limited in many of these often young patients, resulting in serious consequences leading to disability.

The detachment of brachial plexus roots is one of the most important factors affecting the prognosis of such patients. In theory, the cervical roots can be completely torn off (ventral and dorsal) or any ventral or dorsal spine roots can be torn off by itself [1].

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Received 15 December 2020; Accepted 05 January 2021.

Additionally, the roots can be connected to the spinal cord, but they can still be torn in the intervertebral foramen. Also, one of the most important facts is that cervical roots can be intact extrudurally despite being completely or partially torn from the spinal cord.
Several reports have suggested ways to determine whether the lesion is intradural (pre-ganglion) or peripheral (post-ganglion).
The clinical aspects and results of electromyography (EMG) can be informative, but unfortunately in most cases they are not reliable enough to distinguish between pre and post-ganglionic nerve lesions [2].
Many reports have been published on the usefulness of myelography and computed tomography (CT) in the diagnosis of brachial plexus roots detachment. However, almost all analyzes took into account only extradural data obtained during brachial plexus surgery.
Increasing surgical experience has shown that the supraclavicular study of the brachial plexus is often not enough to diagnose root detachment. That is a diagnosis that is fundamental to making decisions about the type of nerve recovery. In fact, the results of extra- and intradural surgery may vary. Therefore, the accuracy of any radiological method will only be fully reliable when compared to the intradural condition of the nerve roots.

Surgical anatomy

Knowledge of the cervical region of spine microsurgical anatomy is fundamental to assessing the condition of cervical roots after brachial plexus injuries. It is important to identify the exit zone of the anterior root and the entry zone of the posterior root at different cervical levels [3].
The anterior cervical roots are formed by a group of roots that leave the spinal cord at a distance of 1–3 mm from the median line. Their diameter varies from 1.5 to 3 mm. The longitudinal length from the spinal cord to the intervertebral aperture varies from 5 to 20 mm.
Dorsal roots are usually thicker than abdominal roots and are slightly shorter in length. As for the level of the anterior root exit zone and the posterior root entrance zone, a microsurgical dissection showed that the ventral and posterior roots are connected to the spinal cord by almost one intervertebral disk above their intervertebral foramen. It means that the C-5 root is connected to the spinal cord at or just below the C3–4 level of the intervertebral disk, for example [4].
In a prospective study, 135 cervical roots (C5–8) were examined by CT myelography or MRI and additionally investigated intradurally by hemilaminectomy.
The accuracy of the diagnosis based on preoperative CT myelography in relation to intraoperative data was 85%. On the other hand, the MRI showed an accuracy of only 52%.
The most frequent causes of false positives or false negatives were:

- partial detachment of the root;
- intradural fibrosis;
- cystic lesions of the dura mater.

Computed tomography scanning using axial slices ranging in size from 1 to 3 mm proved to be the most reliable method of evaluating the presence of complete or partial root detachment in cases of traumatic brachial plexus injuries [5]. Since an extardural evaluation of cervical spine roots detachment may be unreliable, an accurate evaluation of spinal cord roots detachment greatly simplifies the decision regarding the choice of donor nerves for transplantation and/or neurotisation during brachial plexus surgery.

MATERIALS AND METHODS

Patients

During the conducted research, there were 40 patients who needed treatment for post-traumatic brachial plexus lesions (Table 1). Clinical and electrophysiological studies carried out in these patients did not completely exclude the possibility of cervical roots being torn off at one or more levels of brachial plexus. Therefore, a prospective study was carried out to determine the intraspinal integrity of the affected cervical roots, as well as the accuracy of CT myelography and magnetic resonance imaging (MRI) in the diagnosis of root detachments after traumatic brachial plexus injuries [6].

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All patients were included in the prospective study. Among 40 patients, 38 were men and two were women. The average age at the time of hospitalization was 27 years (from 17 to 59 years). Clinical and EMG assessment revealed complete upper and lower brachial plexus lesions in 28 patients. In 12 cases, despite the clinical diagnosis of "brachial plexus paralysis," EMG researches have revealed signs of reinnervation of some muscles. Motorbike accidents caused injuries in 95% of patients. The interval between the accident and hospitalization for the treatment of post-traumatic symptoms was between 3 and 15 months, on average 7.2 months [7].

Table 1. Brachial plexus trunk lesions on axial T2W image

Lessions		**Location** Superior trunk	Middle trunk	Inferior trunk	**Total***
Contusion	Amount	1	0	0	1
	%	0.6	0	0	0.6
Edema	Amount	**11**	9	7	**27**
	%	**6.1**	5.0	3.9	**15.0**
Axonotmesis	Amount	1	0	0	1
	%	0.6	0	0	0.6
Complete rupture	Amount	**14**	5.0	4.0	**23**
	%	**7.8**	2.8	2.2	**12.8**
No lesion	Amount	35	47	50	132
	%	19.4	26.1	27.8	73.3

*(180 trunks of 60 patients)

Neuroradiological assessment was performed prior to surgery in all patients to diagnose the brachial plexus root detachment. Computerized tomographic myelography was performed in 90–120 minutes after intrathecal injection of 15-20 ml of contrast agent into the lumbar spine. Computed tomography was obtained from C4-T1 with axial slices of 3 mm [8].

In the case of pathological or doubtful results, axial slices with a diameter of 1 mm were made additionally. The angle of scanning was parallel to the cervical discs. A total of 75 cervical roots were preoperatively evaluated by CT myelographic, scanning. Magnetic resonance imaging was performed using a 1.5 tesla device.

A matrix of 128 3 256 and a field of vision of 120 mm were used. T1- (repetition time of 21 seconds, echo time of 6,8 seconds) and T2-weighted sequences (repetition time of 5380 ms, echo time of 300 ms) were obtained in coronal and axial planes (Table 2, Table 3). The axial sections were of 3 mm in thickness. Flash sequences and artifact suppression methods were also used. The intradural integrity of 60 cervical roots was assessed using MRI before surgery [9].

Before the surgery, CT myelography and MRI images were evaluated by at least two different specialists to analyze cervical roots from C5–8. CT myelography and MRI images where specialists could not identify the ventral and dorsal roots of the intact side were excluded and classified as non-interpretable scans due to technical errors.

Table 2. Injury on sagittal T1W image

Symptom \ **Patients**	**Amount**	**Ratio %**
Loss of spinal curvature	3	5.0
Unchanged spinal curvature	**57**	**95.0**
Vertebral body injury	**0**	**0.0**
Total	60	100.0

The image criteria for root detachment diagnosis were based on the absence of one (partial detachment) or both roots (total detachment), but not on the presence of a meningocele [10].

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When both the ventral and dorsal roots from the spinal cord to the intervertebral foramen were visualized on axial slices, an undamaged root was discovered. The analysis of each severed or intact root was compared with the counter-lateral intact side on CT myelography and axial MRI slices.

Table 3. Brachial plexus cord injury on T2W Vista Sense axial

Lesion		Location			
		Laterial cord	**Medial cord**	**Posterial cord**	**Total***
Edema	Amount	**21**	**20**	**22**	**63**
	%	**11.7**	**11.1**	**12.2**	**35.0**
Complete rupture	Amount	4	2	3	9
	%	2.2	1.1	1.7	5.0
Atrophy	Amount	1	0	0	1
	%	0.6	0	0	0.6
No lesion	Amount	34	38	35	107
	%	18.9	21.1	19.4	59.4

*180 cords of 60 patients

Surgical technique

An intradural surgical research of cervical roots was performed via hemilaminectomy at C-5 and/or C-7. A partial C-4 hemilaminectomy was performed additionally to reveal the C-5 root where it is connected to the spinal cord [11].

Thus, with a microscope, the surgeon could examine both ventral and dorsal roots from the C5-8. If only the upper cervical roots (C-5 and C-6) needed to be examined as in the case of isolated upper brachial plexus paralysis, the C-7 plate was left untouched.

Each root (ventral and dorsal) was assessed from the spinal cord to the intervertebral foramen, because roots can be torn in different places, even intradurally [12].

Intraoperative monitoring

Each patient was monitored during the operation by means of somatosensory evoked potentials. In addition, stimulation of undamaged dorsal roots was performed intradurally, and somatosensory evoked potential was recorded from the sensory cortex by means of subcutaneous needle electrodes implanted in the scalp. Stimulation was usually between 0.5 and 3 mA.

RESULTS AND DISCUSSION

60 roots (in 15 patients) among the 135 roots that were examined intradurally to determine the extent of preganglionic lesions were exposed to MRI before surgery. Magnetic resonance imaging showed 10 undamaged roots, 23 completely torn roots and four partially torn roots. Magnetic resonance images were technically unsuitable for diagnostic tests of 23 cervical roots. In this series, MRI made it possible to make an accurate diagnosis only in 52% of cases. In 48% of cases, MRI images showed unreliable or inconsistent results when compared to the results of hemilaminectomy surgery. The results of the surgical intervention. In total, 135 roots have been examined intradurally [13].

In 64 cases, a complete root tear was observed. Undamaged roots (ventral and dorsal) were found in 56 cases.

The partial detachment of the ventral or dorsal root was detected in only 15 cases.

The complete root separation was more frequently found near the C-7 and C-8 roots. Out of 64 cases of complete root separation, 43 cases (67%) occurred at the cervical roots C-7 or C-8. In contrast, 44 roots (78.5%) of the 56 cases of intact cervical roots were C-5 or C-6. There were also combinations of intact ventral roots and torn dorsal roots or vice versa [14].

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In 11 cases (73.3%), the abdominal root was torn off and the dorsal root was not damaged. In one case of our series, the ventral root was torn off at the level of the intervertebral foramen. Moreover, 73.3% of all partial detachments of the roots occurred on the nerve roots C-5 or C-6.

An accurate assessment of the location and extent of the injury is mandatory for patients with traction lesions of brachial plexus. Thus, determining whether the lesion area is pre- or post-ganglionic has a direct impact on the patient's prognosis and surgical strategy.

As for the preoperative diagnosis of cervical root detachment, clinical and especially electrophysiological exams are useful, but unfortunately in many cases they are not sufficiently reliable [15].

Standard myelogram

Some authors tried to show the various changes found on the myelogram. The large series have demonstrated an accuracy of 60% and 70% and emphasised the importance of false positives or false negatives results.

It should be emphasized that these results were correlated with surgical data on the extradural study of the brachial plexus. Similarly, cases in which the root was not extraphoramically damaged but was damaged intradurally were considered normal surgical results and were erroneously associated with myelographic data [16].

Thus, it can be assumed that the actual accuracy of the standard myelogram is even lower than what is stated. In addition, partial root detachments (ventral or dorsal) cannot be detected by myelography.

Computerized tomographic myelography

Due to the technical improvements and growing experience, CT myelography has provided a reliable correlation and diagnostic of the intradural damage level after traction lesions of brachial plexus in 85% of our cases.

To visualize all the roots of the brachial plexus (C4–8 roots), axial slices must start at the upper boundary of C-4 and reach the lower boundary of the first thoracic vertebra body. On good quality CT myelographic images with 3 mm axial slices, ventral and dorsal roots can be visualized on both sides in the case of intradural roots [17].

Traumatic meningocele and intradural fibrosis are usually the factors responsible for the preoperative wrong diagnosis when interpreting the CT myelography results. Similarly, traumatic cystic lesions caused by dura mater leakage should also be carefully assessed using axial slices 1 mm in diameter.

In such cases, intradural surgery may cause partial root breaks or even in some cases intact roots breaks. Intradural fibrosis, especially in cases of partial root tears at the upper levels (C-5 and C-6), is also often the cause of false positives or false negatives preoperative radiological diagnosis [18].

Even with a 1 mm diameter axial cut technique, only a surgical examination can clarify the condition of cervical roots in some patients. It is interesting that most cases of preoperative misdiagnosis occurred at C-5 and C-6 levels.

The narrow subarachnoidal space at the upper levels of the spinal cord, due to cervical intumescence and the fact that most of the partial root tears are located at these levels, can play an important role.

Magnetic resonance imaging

Currently, magnetic resonance imaging (MRI) is the best indicator of various brachial plexus pathologies, and in the context of trauma it surpasses the preoperative nerve conduction studies, high-resolution ultrasound scan, and the intraoperative somatosensory evoked potentials [19].

However, MRI still does not allow to differentiate between nerve damages that require reconstructive surgery and those that are regenerated spontaneously. In addition, MRI does not allow to differentiate between post-ganglionic (green arrows at the Figure 1) and pre-ganglionic (red arrows at the Figure 1) nerves damage, which is of paramount importance because their reconstruction and prognosis are different.

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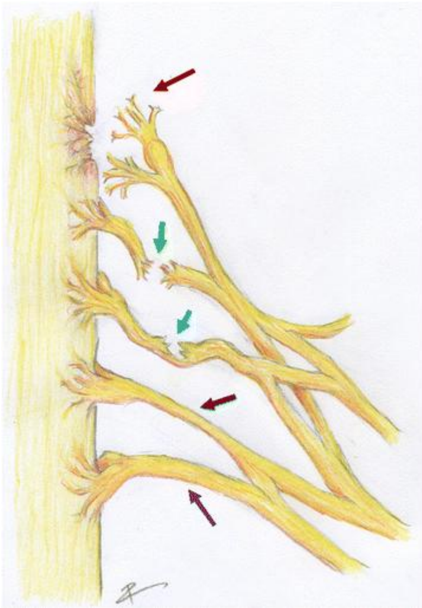

Figure 1. Differentiation between post-ganglionic (green arrows) and pre-ganglionic (red arrows) nerves damage by MRI

Post-ganglionic nerves damages (tears or weakening) have a more pronounced, favorable prognosis, since the anterior corneal cells in the spinal cord are saved; therefore, if it is possible to restore continuity in time, then motor skills recovery can be expected [20].

In the contrary, the reconstruction of pre-ganglionic nerve damages (known as root tears) requires the nerves to be transplanted as the bodies of the native motoneuron cells recede and are restored. Thus, the definition of a root tear has a crucial value, as it changes the operation plan and prognosis.

Delay before the surgical reconstruction is a major cause of poor outcomes, that is why most surgeons use pre-operative MRI and neurophysiological tests to identify patients with tear-off lesions [21].

However, the reliability of a preoperative MRI is questionable and therefore most surgeons still perform an early surgical examination to detect root tear(s). Numerous studies have investigated the diagnostic accuracy of the MRI of traumatic DPN, but only a few of them specifically examined tear root injuries and a smaller number still had an adequate reference standard as many of them used clinical observation (e.g. extremitas resuscitation) or electrophysiological observation as the study's surrogate markers. That is why it is not surprising that there are contradictions in the literature regarding the “overall accuracy” of MRI for traumatic root tear [22].

Our rationale for conducting the present study is to summarize the diagnostic accuracy of the MRI to detect a root tear in the case of traumatic BPI in adults. Radiologists and surgeons can use this information to streamline such imaging, assist in its interpretation, and guide future studies to improve BPI imaging.

There are such goals as:

1. Determination of MRI diagnostic accuracy to reveal root tears in adults with traumatic BPI;
2. Determination of MRI diagnostic accuracy to reveal pseudomeningocele(s) as a surrogate root tear-off marker in adults with traumatic BPI.

The function of MRI is to detect a root tear. This type of scan is usually used before surgery between the moment of injury and nerve surgery, which can happen at any time from the day of injury until several years later. It is usually done within a few weeks after the injury [23].

Several factors differ depending on the MRI scanner, including the brand (e.g. Siemens or General Electric) and model, field strength (e.g. the 3 Tesla system is more powerful, so it can generate a better image than the 1.5 Tesla system), the software of the device (the setting differs between brands, as well as post-processing parameters), the location of the coils and bandwidth, the diameter of the scanner hole (the smaller the hole diameter is, the larger the signal generated), gradients (more efficient gradients can provide better images), etc. Thus, there are important physical differences between scanners that we plan to study in the present study.

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Interpretation of MRI when the root is removed is difficult. The diagnosis is subjective, since the decision on whether an MRI result is positive or negative is made by the radiologist who examines the images.

MRI images are usually viewed by a radiologist who has specialized training in the field of musculoskeletal and neurological visualization. An MRI image can be considered positive for the root detachment when there is no continuity or lack of nerve root between the spinal cord attachment and the exit foramen [24].

The normal nerve root passes in an inclined course (from posterior to anterior and from cranial to caudal) from the spinal cord to the outgoing intervertebral foramens.

Consequently, an MRI can also be considered positive for tear-off if there is an abnormal direction/position of the nerve root, because if the root has been torn off proximally from the spinal cord, it will sink into the space of cerebrospinal fluid (CSF), taking a more caudal and horizontal position adjacent to the foramens. In general, the diagnosis of a detached root is binary (present or absent) and any change in these signs can lead to a radiologist deciding on a positive MRI result [25].

In addition to the above findings, MRI images are usually examined for the presence of a pseudomeningocele (sometimes mistakenly called a meningocele). Pseudomeningocele is defined as an extension of the space containing the root of a nerve and CSF within an intervertebral foramen, and is usually associated with an abnormal circuit of the dura mater within a spinal canal where dural leakage occurs.

Sometimes a spinal fluid leak goes beyond the foramen in the cystic cluster lying in the paraspinal soft tissues, and it is also part of the definition. Pseudomeningoceles has been popularized as a surrogate marker of root detachment because it is believed that a rupture of the dura mater corresponds to a rupture of the nerve root; however, it is not a reliable sign of a true root detachment because at best the consent is moderate and again contradicts studies [26].

A root tear or pseudomeningocele can be observed at any level of the spine that can affect the brachial plexus, from C4 to T2.

Considering that BPI are usually one-sided but they have been announced to be two-sided, there are potentially 14 levels of spine that can be commented on.

It is largely irrelevant, because the most important feature of the test is the identification of non-accidents (true negatives), because if such people did not also have post-ganglionic injuries, the research operation would not have been necessary. Therefore, we consider one suspicion of a tear to be as important as any frequency to achieve the goal of the research, because any tear would require surgery (in the form of nerve transfer). That is why the reduction in incidence would be negligible.

At a major trauma centre, as part of the clinical care, patients are regularly examined by medical professionals for symptoms and signs of serious trauma, especially for serious nerve or spinal cord injuries.

In the same way, most patients will undergo both regular X-rays and computed tomography of injured body parts, as well as other injuries (e.g. fractures, vascular injuries, etc.). All such a priori test results are usually available to the radiologist who interprets the MRI scan to indicate the injured side and the possible location of the neurological deficit.

The reference standard for the diagnosis of brachial plexus root detachment is an operational examination. It is a surgery under general anesthesia. The incision is located in the supraclavicular fossa and can reach the deltopectoral sulcus.

The roots of brachial plexus are visualized from C4 (for pre-fixed plexus) to T1 when they come out between the staircase muscles. Some surgeons do a hemilaminectomy of C5-C7 included for imaging the intra-foraminal and intradural roots (Table 4, Table 5).

Additional intraoperative tests can be used in addition to the reference and thus help to determine continuity between the spinal cord and brachial plexus roots, including somatosensory evoked potentials (SEP) and bipolar motor nerve stimulation. The SEP includes the application of monophase rectangular pulses with a duration of < 300 ms of different frequencies to the roots of the brachial plexus. A healthy nerve in continuity with the spinal cord will transmit this action potential to the cortex, which can be then measured by means of a filtered electroencephalogram, but the damaged or torn nerve will not transmit.

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 1, 2021, Pages. 3216 - 3226

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Intra-operative nerve stimulators/locators are two-phase instruments which deliver a weak current (< 20 mA) through the nerve section; a healthy nerve will cause a potential action and the innervated muscle will retract, but there will be no impact on the target organ for the damaged nerve.
These electrophysiological tests can only be performed during a surgery and provide additional information, and therefore we consider them to be part of the "operational examination" reference standard [27].

Table 4. Spinal cord injury and brachial plexus root injury on myelography

	Lesion		No lesion		Total	
Location	Amount	Ratio, %	Amount	Ratio, %	Amount	Ratio, %
C5	2	3.3	58	96.7	60	100.0
C6	9	15.0	51	85.0	60	100.0
C7	**27**	**45.0**	33	55.0	60	100.0
C8	**20**	**33.3**	40	66.7	60	100.0
T1	9	15.0	51	85.0	60	100.0
Total	**67**	**22.3**	**233**	**77.7**	**300**	**100.0**

On the basis of the survey results, the risk of systematic error and the applicability of the included examinations are assessed using an adapted version of the diagnostic accuracy assessment.
The strength of the body of evidence will be assessed through an instrument of recommendation, assessment and development levels.
This study summarizes the diagnostic accuracy of an MRI to detect a root tear in an adult traumatic DNP. The results data can serve as a basis for future studies (aimed at eliminating deficiencies in imaging), explain discrepancies between studies and ultimately help to improve visualization of major nerve injuries.
There are many potential sources of systematic error in diagnostic accuracy studies. We expect that a small number of patients with BPI will not undergo a surgical examination for various reasons, for example, they did not accept the surgery, anesthesia was unsafe or the treatment of other injuries took priority.

Table 5. Spinal cord injury and brachial plexus root injury on MRI

Lesion		**Location**					
		C5	**C6**	**C7**	**C8**	**T1**	**Total**
Nerve root alvusion	Amount	7	10	**14**	10	5	**46**
	%	2.3	3.3	**4.7**	3.3	1.7	**15.3**
Pseudomeningocele	Amount	2	10	**27**	13	8	**60**
	%	0.7	3.3	**9.0**	4.3	2.7	**20.0**
Contusion	Amount	2	2	1	0	1	**6**
	%	0.7	0.7	0.3	0.0	0.3	2.3
Edema	Amount	6	4	3	3	2	18
	%	2.0	1.3	1.0	1.0	0.7	6.0
Complete rupture	Amount	**27**	**29**	**30**	25	19	**130**
	%	**9.0**	**9.7**	**10.0**	8.3	6.3	**43.3**
No lesion	Amount	18	15	12	22	32	99
	%	6.0	5.0	4.0	7.3	10.7	33.0

*300 roots of 60 patients

It will increase MRI sensitivity if the proportion of false negative results is underestimated. This problem cannot be reliably alleviated by replacing or supplementing research surgery with another reference standard, such as clinical observation due to:

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 1, 2021, Pages. 3216 - 3226

Received 15 December 2020; Accepted 05 January 2021.

- limb resuscitation can develop over several years, and simultaneous stiffness and contractures can prevent reliable and repeatable conclusions about the function;
- testing a single muscle (and also the nourishing root) can be impossible because many movements involve several muscles working together, each of which receives input signals from different nerves and from different cervical roots;
- reorganization of the cerebral cortex can undermine clinical observations of muscle strength and sensations, for example, when two roots supply one muscle and one is damaged, the cortex can redirect more input signals to the remaining fibers, which makes it difficult to assess function;
- the final limb organs (muscles, skin, joints, tendons, etc.) can receive data from several roots, and equally one root can innervate several structures, therefore a set of clinical anomalies cannot be attributed with certainty to any specific place of injury.

On the contrary, the MRI diagnostic accuracy can be reduced because patients may have been referred based on MRI results, not just the presence of symptoms. We also expect most studies to be retrospective, and some studies may have involved a non-representative sample of patients, which may affect diagnostic accuracy and raise doubts about applicability. These and other issues will be considered in the quality assessment, and we interpret the findings of the study taking into account these potential limitations [28].

Magnetic resonance imaging provides good visualization of brachial plexus beyond the vertebral foramen. Several reports have proven the usefulness of this method in the diagnosis of distal lesions.

High field strength MRI with multiplane images can clearly distinguish nerves at the periphery from surrounding vessels and muscles.

On the other hand, the identification of intradural roots (ventral and dorsal) can be difficult in most patients with traction injuries of brachial plexus. These patients usually suffer from severe deafferentation pain and cannot lie as motionless as required during an MRI procedure. Consequently, most questionable and technically inadequate MRI images are associated with motion artifacts. In addition, axial slices are usually between 3 and 5 mm thick, which is badly correlated with intradural roots, which are between 1.5 and 3 mm in size.

In our experience, the correlation between the results of intradural surgery and an MRI studies is not reliable in preoperative root separation diagnosis in approximately 48% of patients. Most often in our series, it was due to partial root separation, intradural fibrosis and traumatic meningocele, as well as technical errors.

An accurate assessment of the localisation (pre- or post-ganglionic) and the degree of individual damage to the root of the cervical nerve is mandatory and has a direct impact on the surgical strategy and prognosis in patients with traumatic brachial plexus injuries.

One of the main problems and usually the first step during surgical treatment of brachial plexus lesions is the decision on the integrity of the C5-8 cervical roots.

Depending on the integrity of the cervical root, nerve with transplants and/or nerve transfers should be performed to restore the important structures of the brachial plexus. Because of the strong fibrosis that usually occurs in such cases, proximal exposure of the cervical roots up to the neuroforamen can take a very long time and involve certain risks.

Intraoperative nerve action potentials obtained in the proximal section of the cervical root (just behind the neuroforamen) attempt to assess the intraspinal status of the roots outside the back.

However, nerve potential studies assess only the dorsal root. Consequently, even a positive nerve potential does not rule out an intradural detachment of the abdominal root [29].

Thus, even an undamaged root coming out of an intervertebral foramen does not ensure its intraspinal integrity. Our experience in brachial plexus surgery has revealed many cases where intraspinal findings have demonstrated a complete or partial root detachment despite the integrity of the extrudural root.

Consequently, some cases of unsuccessful nerve transplantation may result from a previously unidentified isolated intraspinal total or partial root detachment. In our opinion, hemilaminectomy and examination of cervical roots in the cases of unsuccessful pre-operative radiological studies will provide the following benefits for further surgical treatment:

1) it is possible to avoid nerve transplantation to doubtfully undamaged extradural roots, which are actually intradurally damaged;

2) precise preoperative diagnosis of available cervical roots for transplantation has been obtained;

Received 15 December 2020; Accepted 05 January 2021.

3) precise pre-operative planning with the patient regarding the need for nerve transfer is possible;
4) in cases of documented root detachment, direct exposure and extraplex nerve transfer is possible without further peripheral surgical examination of the cervical roots.

CONCLUSIONS

Magnetic resonance imaging using standard methods can only accurately diagnose a root tear in 52% of cases. Movement artifacts are one of the main causes of inadequate MRI images, making it very difficult for preoperative neuroradiological interpretation of these studies.
Improved respiratory compensation systems, new methods for suppressing artefacts and the use of special coils to improve the signal-to-noise ratio in high field MRI will definitely provide us with a more accurate assessment of the intradural roots images in the brachial plexus and injuries in the future.
Thus, the pre-operative radiological assessment should include a CT myelography examination and, in approximately 15% of patients for whom CT myelography does not show the nerve roots and a hemilaminectomy should be performed to clarify the status of affected cervical nerve roots of the brachial plexus. As for further surgical treatment of these patients, a precise preoperative diagnosis of complete or partial root separation has a definite advantage.
Nerve transplantation to doubtfully intact roots should be avoided, as it was defined in extradural studies, and support should be provided for the intraoperative selection of potentially useful donor nerves for brachial plexus transplantation and/or neurotisation.

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Received 15 December 2020; Accepted 05 January 2021.

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