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Correlation of Magnetic Resonance Imaging (Neurography) and Electrodiagnostic Study Findings with Intraoperative Findings in Post Traumatic Brachial Plexus Palsy

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Abstract

Background The majority of brachial plexus injuries (BPIs) are caused by trauma; most commonly due to two-wheeler road accidents. It is important to determine whether the lesion in question is pre-ganglionic or post-ganglionic for purposes of surgical planning and prognosis. Diagnostic testing helps the surgeon to not only decide whether surgical intervention is required, but also in planning the procedure, thereby maximizing the patient's chances of early return to function. The aim of the study was to determine the diagnostic efficacy of electrodiagnostic studies (Edx) and magnetic resonance imaging (MRI) individually, and in unison, in detecting the type and site of BPI by comparison with intraoperative findings (which were used as the reference standard) in patients with posttraumatic BPI.

Methods It is an observational cross-sectional prospective randomized study, wherein 48 patients with BPI underwent a detailed clinical and neurological examination of the upper limb, Edx, MRI neurography and were subsequently operated upon. We assessed a total of 240 roots. The diagnosis of all spinal roots was noted on Edx. MRI was performed to look for root avulsion, pseudomeningocoele, and/or rupture injury. The patients were subsequently operated upon. All roots were traced from infraclavicular level right up to the foramen to ensure continuity of root or note rupture/ avulsion. The findings were tabulated.

Results MRI accurately diagnosed 138 of the 147 injured roots and MRI sensitivity for the detection of BPI was 93.88%, whereas Edx correctly identified 146 out of 147 injured roots and thus, had sensitivity of 99.32%; however, both lacked specificity (18.28 and 20.43%, respectively). With Edx and MRI in unison, sensitivity was 100% which meant that if a given patient with a BPI is subjected to both tests, not a single abnormal root will go unnoticed.

Keywords
- brachial plexus
- electrodiagnostic studies
- magnetic resonance imaging
- sensitivity and specificity
- nerve roots

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Conclusion Edx and MRI are two highly sensitive investigation modalities whose combined sensitivity is 100% for the detection of a root injury. Therefore, we recommend both tests as they are excellent screening tests.

Introduction

Tools such as magnetic resonance imaging (MRI) and electrodiagnostic studies (Edx) are useful in providing details regarding the injury pattern, however, neither of the two is considered the reference standard as yet.[1–6] It is important to determine whether the lesion in question is pre- or post-ganglionic for surgical planning.[7–9]

It has been observed that there are some differences in our preoperative judgment of an injury and the intraoperative findings.[8,10] Therefore, at our institute, we opted to investigate patients with traumatic brachial plexus injuries (BPI) by means of both Edx and MRI and to determine their diagnostic efficacy by comparison with intraoperative findings, thereby allowing us to choose an appropriate investigation modality, for better management of patients with BPI.

Our objective was:

1. To determine the sensitivity, specificity, negative and positive predictive value of Edx in detection of BPI by correlation with intraoperative findings.

2. To determine the sensitivity, specificity, negative and positive predictive value of MRI in the detection of BPI by correlation with intraoperative findings.

3. To determine the diagnostic efficacy of MRI and Edx by correlation with intraoperative findings both individually, and in unison.

Materials and Methods

The observational cross-sectional prospective randomized study was approved by the Institutional Ethics Committee. Informed consent was taken from all patients whose data are included in the study.

Inclusion Criteria

1. Traumatic BPI patients.
2. Patients who have undergone MRI of the brachial plexus and Edx of the upper limbs prior to surgery.
3. No previous treatment.

Exclusion Criteria

Patients with implants (and therefore not compatible with MRI).

Patients of BPI were seen on an outpatient basis, where they all underwent a complete clinical examination and detailed neurological examination of the upper limb. Following this they underwent a detailed Edx. This consisted of the following: All NCV values were documented. Representative muscles for all levels underwent needle EMG. If needed, patients also got SSEP study done additionally. After interpreting the data, the condition of all spinal roots from C5 to T1, i.e., their level of injury (whether pre-ganglionic or post-ganglionic), the amount of axon degeneration (mild, moderate, or severe), and ongoing reinnervation (if any) were noted. This was tabulated.

MRI of the affected brachial plexus was performed (if not previously done) to look for root avulsion, pseudomeningocoele, and post-ganglionic injury, and was documented for each root from C5-T1. The imaging was performed on a 3T Philips MRI machine with 2.5-mm thickness slices and 0.25-mm inter-slice gaps in the axial, coronal, and sagittal plane with T1 and STIR sequences along with T2 drive axial. Diffusion-weighted whole-body imaging with background body signal suppression (DWIBS) sequence was taken as per the need of the case.

Neuropraxic injury was seen as T2 hyperintense signal in the roots, trunks, or cords with or without enlargement. Nerve ruptures were seen as discontinuity in the neural structures. Associated findings of denervation edema in the muscle were seen. MRI showed pseudomeningoceles formed due to extravasation of CSF through tear of the perineural sheath which were seen on T2-weighted images as fluid-intensity lesions at the site of nerve root avulsion. We also looked at neural continuity in the intraspinal region to confirm avulsion at each level. All data were then tabulated.

Findings of each root on both, MRI and Edx were entered into the data tables along with the demographic and other details of each patient. The senior author routinely waited for a period of 4 to 6 months from the date of injury to see if there is any clinical improvement of the injured roots in question, and if necessary a repeat Edx test was also performed to ascertain the same before planning for surgical exploration. The patients then underwent routine work-up prior to surgery and were subsequently operated upon. Intraoperative findings were noted. All roots were traced from infraclavicular level right up to the foramen to determine continuity of root/rupture/avulsion and findings were tabulated as pre-ganglionic injury/post-ganglionic injury or normal root. Pre-ganglionic injury was defined when a particular root was found to be avulsed with/without presence of pseudomeningocele. Post-ganglionic injury was defined as the presence of an intraplexal rupture or presence of a neuroma. A root was said to be intact when no injury was found from the foramen to the infraclavicular level.

Intraoperative nerve stimulation was done for individual roots and findings were noted which were then recorded (rootwise) for each patient. Comparison of intraoperative findings with the preoperative MRI and Edx reports were tabulated.

The operative procedure for each patient was planned, depending on the preoperative examination, MRI, and Edx reports and was customized as per the intraoperative findings.

The various combinations of findings are listed in ►**Figs. 1–4**.

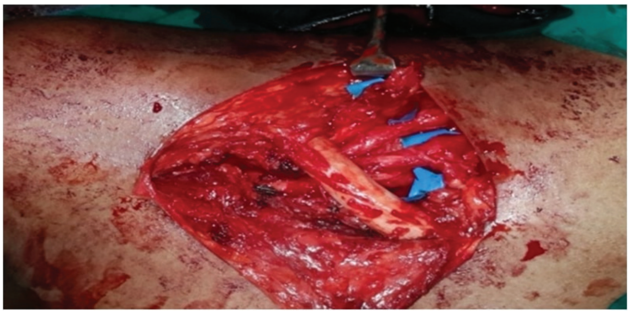

Fig. 1 All roots C5-T1 avulsed in a right-sided BPI. BPI, brachial plexus injuries.

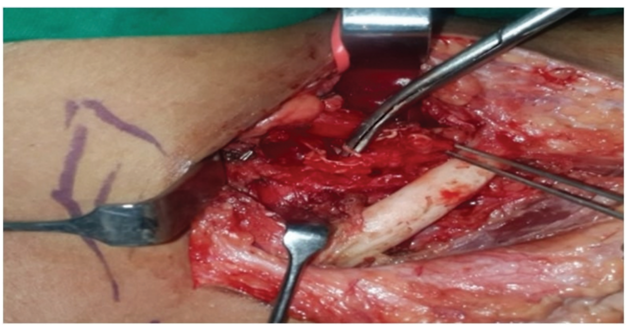

Fig. 2 Avulsed roots with visible rootlets in a left-sided BPI. BPI, brachial plexus injuries.

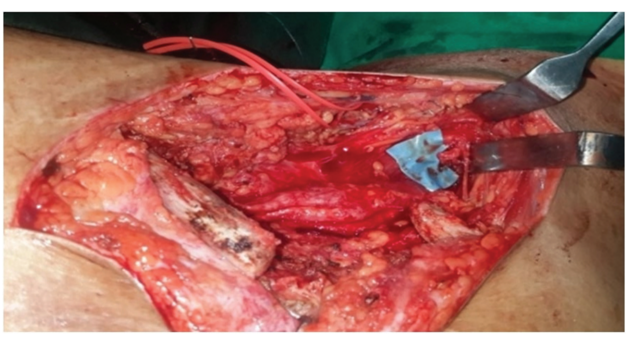

Fig. 3 Right-sided BPI with pseudomeningoceles at C7 and C8 levels with an associated clavicular fracture. BPI, brachial plexus injuries.

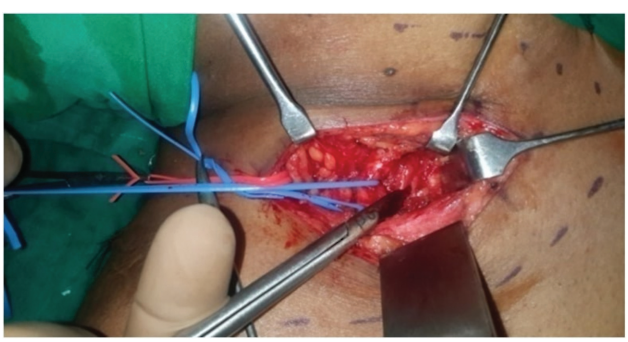

Fig. 4 Upper trunk neuroma in a right-sided BPI. BPI, brachial plexus injuries.

Qualitative data were represented in form of frequency and percentage. Qualitative data included preoperative Edx, preoperative MRI findings, and intraoperative findings.

Association between qualitative variables were assessed by Chi-square test, with continuity correction for all 2×2 tables and by Fisher's Exact test for all 2×2 tables where Chi-square test was invalid due to small counts. In presence of small counts in tables with more than two rows and/or columns, adjacent row and/or column data were pooled and Chi-square test reapplied. Continuity correction was applied for all 2×2 tables after pooling of data. Fisher's Exact test was applied for all 2×2 tables where *p*-value of Chi-square test was not valid due to small counts, in spite of pooling the data (e.g., association between the type of injury and Edx).

Diagnostic efficacy of Edx findings and MRI findings as compared with intraoperative findings was assessed by calculating sensitivity, specificity, positive predictive value, negative predictive value, positive likelihood ratio and negative likelihood ratio, for Edx findings and MRI findings separately. Results were graphically represented where deemed necessary. Appropriate statistical software, including but not restricted to MS Excel and PSPP (0.8.5) was used for statistical analysis. Graphical representation was done in MS Excel 2010.

Results

A total of 48 patients were enrolled in the study who underwent surgical exploration and repair of the brachial plexus after detailed Edx and MRI of the plexus. Thus, 240 roots were evaluated. Intraoperative finding was taken as the standard against which the data was evaluated for both MRI and Edx.

Status of roots (intraoperative) across all levels (C5-T1) is shown in ►**Table 1**.

Maximum post-ganglionic injuries, i.e., 60 of 79 were seen at the C5 and C6 levels. Out of the 68 avulsed roots, 46 were at C7, C8, and T1 levels.

Association among the cases of MRI status *and* intraoperative finding status (detection of BPI) is shown in ►**Table 2**.

It was observed that of the 147 injured roots, MRI accurately diagnosed 138 roots as injured. However, of the 93 normal roots only 17 were detected as normal by MRI.

MRI was highly sensitive to the detection of BPI, but, it lacked specificity.

Table 1 Status of roots (intraoperative) across all levels. (C5-T1)

Root	Status		
	Pre-ganglionic	Post-ganglionic	Normal
C5	9	29	10
C6	13	31	4
C7	20	9	19
C8	14	4	30
T1	12	6	30

Table 2 Association among the cases of MRI status and intraoperative finding status (detection of BPI)

MRI status		Intraoperative finding status		Total
		Abnormal	Normal	
Abnormal	No.	138	76	214
	%	64.50%	35.50%	
Normal	No.	9	17	26
	%	34.60%	65.40%	
Total	No.	147	93	240
	%	61.30%	38.80%	
Index	**Estimate**	**Lower 95% CI**	**Upper 95% CI**	
Sensitivity	93.88%	88.70%	97.16%	
Specificity	18.28%	11.02%	27.65%	
Predictive value of positive test	64.49%	57.67%	70.89%	
Predictive value of negative test	65.38%	44.33%	82.79%	
Likelihood ratio of positive test	1.1488	1.0347	1.2755	
Likelihood ratio of negative test	0.3349	0.1558	0.7198	

Association among the cases of Edx status and intraoperative finding status (detection of BPI) is shown in ►**Table 3**.

Edxs correctly identified 146 out of 147 injured roots. Thus, sensitivity of Edx was as high as 99.32% in the detection of BPIs. However, 74 of the 93 normal roots were erroneously diagnosed as injured which meant that the study lacked specificity. Predictive value of negative test was very high.

Association among the cases of MRI and Edx status and intraoperative finding status (detection of BPI) is shown in ►**Table 4**.

When a patient was subjected to both MRI+ Edx, all the 147 injured roots were correctly diagnosed with a sensitivity value of 100% which implied that if a given patient of BPI is subjected to both tests not a single abnormal root will go unnoticed.

Association among the cases of MRI and intraoperative findings (status of root) is shown in ►**Table 5**.

Of the 90 roots that MRI diagnosed as pre-ganglionic, 49 were pre-ganglionic on intraoperative examination and of the 26 diagnosed as intact, 17 were in fact intact roots.

The association of MRI and status of the root (whether intact or injured, and if injured, at pre-ganglionic/post-ganglionic level) was found to be statistically significant.

The graph in ►**Fig. 5** depicts that in approximately 50% or more cases MRI was accurately able to interpret the status of the root.

Table 3 Association among the cases of electrodiagnostic study status and intraoperative finding status (detection of BPI)

Electrodiagnostic Study status		Intraoperative finding status		Total
		Abnormal	Normal	
Abnormal	No.	146	74	220
	%	66.40%	33.60%	
Normal	No.	1	19	20
	%	5.00%	95.00%	
Total	No.	147	93	240
	%	61.30%	38.80%	
Index	**Estimate**		**Lower 95% CI**	**Upper 95% CI**
Sensitivity	99.32%		96.27%	99.98%
Specificity	20.43%		12.77%	30.05%
Predictive value of positive test	66.36%		59.70%	72.58%
Predictive value of negative test	95.00%		75.13%	99.87%
Likelihood ratio of positive test	1.2482		1.1251	1.3848
Likelihood ratio of negative test	0.0333		0.0045	0.2446

Table 4 Association among the cases of MRI+ electrodiagnostic study status and intraoperative finding status (detection of BPI)

MRI+ Electrodiagnostic study status		Intraoperative finding status		Total
		Abnormal	Normal	
Abnormal	No.	147	85	232
	%	63.40%	36.60%	
Normal	No.	0	8	8
	%	0.00%	100.00%	
Total	No.	147	93	240
	%	61.30%	38.80%	
Index	**Estimate**	**Lower 95% CI**	**Upper 95% CI**	
Sensitivity	100.00%	97.52%	100.00%	
Specificity	8.60%	3.79%	16.25%	
Predictive value of positive test	63.36%	56.81%	69.57%	
Predictive value of negative test	100.00%	63.06%	100.00%	
Likelihood ratio of positive test	1.0941	1.0280	1.1645	
Likelihood ratio of negative test	0.0000			

Table 5 Association among the cases of MRI and intraoperative findings (status of root)

MRI		Intraoperative findings			Total
		Preganglionic	Intact	Postganglionic	
Preganglionic	No.	49	28	13	90
	%	54.4%	31.2%	14.4%	
Intact	No.	4	17	5	26
	%	15.4%	65.4%	19.2%	
Postganglionic	No.	15	48	61	124
	%	12.1%	38.7%	49.2%	
Total	No.	68	93	79	240
	%	28.3%	38.8%	32.9%	
Chi-square test		**Value**	**df**	***p*-Value**	**Association is-**
Pearson Chi-square		61.638	4	<0.001	**Significant**

Association among the cases of Edx and intraoperative findings (status of root) is shown in ►**Table 6**.

Edx studies reported 20 roots as being intact and 59 roots with post-ganglionic level injuries. Of these, intraoperatively, 19 roots were in fact intact and 38 of the 59 reported roots were post-ganglionic level injuries.

Pearson Chi-square test showed that the association between Edx and root status was significant.

The graph in ►**Fig. 6** depicts root status as per Edx and their correlation with intraoperative findings.

Of the 240 roots, 93 roots were visibly intact till the level of the foramen.

Eighteen of these 93 did not respond to electrical stimulation which implies that they could have an avulsion probably at an intraspinal level.

However, since this fact could not be ascertained intraoperatively, these 18 roots were subsequently excluded from the analysis and the data was re-interpreted with 222 roots under evaluation. ►**Tables 7** and **8** represent the evaluation with the original 240 roots in contention whereas in ►**Tables 9** and **10** the dubious 18 roots have been excluded from the analysis.

It was observed that the specificity of both MRI and Edx, improved after having excluded those roots, not only for the detection of an injured root, but also for pre-ganglionic injuries assessed separately.

Discussion

BPI include a wide spectrum encompassing individual nerve/root rupture to pan BPI that result in a flail upper extremity.

As per Sunderland classification of nerve injury, a neurapraxia or type 1 injury is an injury in which the nerve axons and surrounding connective tissue remain intact. It has an excellent prognosis for recovery. In a type II injury, there is axonal rupture without interruption of the basal lamina

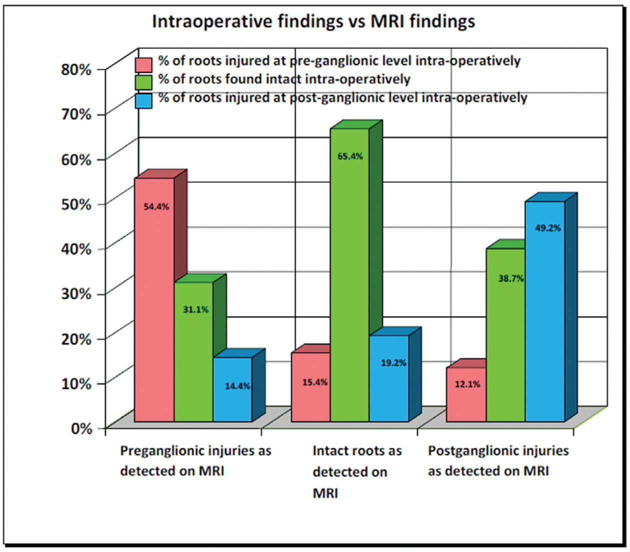

Fig. 5 The graph depicts that in approximately 50% or more cases MRI was accurately able to interpret the status of the root.

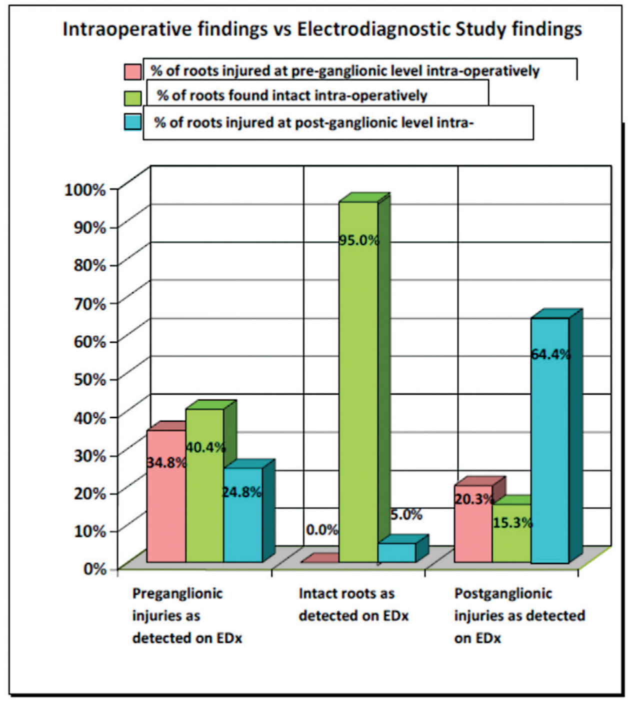

Fig. 6 The graph depicts root status as per Edx and their correlation with intraoperative findings.

tubes. In type III injuries axons and endoneurium are involved, while perineurial and epineurial structures are intact. Injury associated with division of axon, endoneurial, and perineurial structures is a type IV injury that is a more significant injury, which often leads to intraneural scarring and requires surgical intervention. Neurotmesis or type V injury implies rupture of the axons and surrounding connective tissue.[11,12]

Healing in Sunderland type IV and V injuries often results in the formation of a neuroma, as regenerating axons and connective tissue becomes entangled in scar in their attempt to route successfully. Because of the discontinuity of the nerve, muscle function is severely limited. Surgical intervention, to join nerves, if successful, results in regeneration across the rupture and improved function. Avulsion of the nerve root from the spinal cord may be treated with nerve transfer or neurotization using other plexus donors or intercostal nerves.[13]

Table 7 $n = 240$ roots

	MRI	Edx	MRI + Edx
Sensitivity	93.88%	99.32%	100.00%
Specificity	18.28%	20.43%	8.60%

Table 8 Type of injury $n = 240$

	Pre-Ganglionic		Post-Ganglionic	
	MRI	Edx	MRI	Edx
Sensitivity	72.06%	82.35%	77.22%	48.10%
Specificity	76.16%	38.95%	60.87%	86.96%

Table 6 Association among the cases of electrodiagnostic study and intraoperative findings (status of root)

Electrodiagnostic study		Intraoperative findings			Total
		Preganglionic	Intact	Postganglionic	
Preganglionic	No.	56	65	40	161
	%	34.8%	40.4%	24.8%	
Intact	No.	0	19	1	20
	%	0.0%	95.0%	5.0%	
Postganglionic	No.	12	9	38	59
	%	20.3%	15.3%	64.4%	
Total	No.	68	93	79	240
	%	28.3%	38.8%	32.9%	
	Value	**df**	***p*-Value**	**Association is-**	
Pearson Chi-square	59.903	4	<0.001	**Significant**	

Table 9 $n = 222$ roots

	MRI	Edx	MRI + Edx
Sensitivity	93.88%	99.32%	100.00%
Specificity	22.67%	25.33%	10.67%

Table 10 Type of injury $n = 222$

	Pre-Ganglionic		Post-Ganglionic	
	MRI	Edx	MRI	Edx
Sensitivity	72.06%	82.35%	77.22%	48.10%
Specificity	83.12%	42.21%	58.04%	86.71%

Distinguishing between types of injury at initial presentation can be difficult using clinical examination findings alone. Other studies by Terzis et al and Leffert et al have also demonstrated several limitations.[8,10] Both Edx and MRI, together, give us a fair idea of the roots involved in the injury, the level and extent of involvement, the status of the surrounding tissues and the presence of regenerating axons (if any) in the injured segments. Moreover, serial Edx also help us track progress/deterioration after an attempt at conservation or post-neurotization.

We therefore decided to study the diagnostic accuracy of both these investigation modalities considering the intraoperative findings as a gold standard in a statistical sense. We evaluated 240 roots (in 48 patients) intraoperatively of which 68 were avulsed (pre-ganglionic injuries). In total, 79 roots were "post-ganglionic injuries" that were either completely ruptured or which resulted in neuroma formation. Ninety-three roots were visibly intact till the level of the foramen, however, 18 of these 93 did not respond to electrical stimulation which implies that they could have an avulsion probably at an intraspinal level. However, since this fact could not be ascertained intraoperatively they were considered as intact and were thus included in the "intact root" category. This could generate fallacies in our statistical analysis and should be noted.

Maximum post-ganglionic injuries, i.e., 60 of 79 were seen at the C5 and C6 levels. Out of the 68 avulsed roots, 46 were at C7, C8, and T1 levels. Anatomy findings show that as C4–C6 roots exit the spinal canal, they are strongly attached by fibrous slips to the periosteum of the transverse processes that blend with their nerve sheath. The attachments become less robust at C7 whereas there are no attachments at C8 and T1 levels.[14] The results of this study are thus consistent with these findings. They are also consistent with the findings of VanderHave et al in a similar study on neonatal brachial plexus roots on a smaller population.[15]

The gold standard for the determination of the type, level, and extent of injury was surgical exploration. Each root was always dissected proximally up to the vertebral foramen to visualize and palpate/visualize the dorsal root ganglion and rootlets, in case they had avulsed out. Findings were tabulated patient wise for each root as pre-ganglionic, post-ganglionic, or intact.

The ideal test to detect these findings preoperatively would have to be sensitive and specific for the injury type and level, performed efficiently, reproducible (with minimal interobserver variation), performed without the use of anesthesia, cost effective, and subject the patient to minimal radiation.

A single diagnostic strategy to determine the location and severity of injuries would not be feasible because of the variability of imaging equipment, surgical therapeutic measures, and, most importantly, clinical presentation.[7] We thus subjected all patients satisfying inclusion criteria to two tests —an MRI scan of the brachial plexus and Edx of the upper limbs to evaluate the diagnostic efficacy of both these instruments in BPI patients.

The results were two highly sensitive tests for BPI patients which, however, lacked specificity. When evaluated in unison, their sensitivity was 100% but specificity was poor. As Edx and similar studies have had relatively low specificity, some authors, such as Gilbert,[16] have, in the past, suggested avoiding preoperative studies and proceeding to surgical exploration. That was, however, for infants with birth brachial plexus palsy not exhibiting clinical improvement by 3 to 6 months of age.

It is evident in our study, that though the sensitivity of MRI in detecting an injured root was better, the specificity was significantly poor. A multicenter study by Tagliafico et al[17] to evaluate MRI accuracy with surgical findings and clinical follow-up as reference standard, however, showed MRI specificity to be 91.4%. It included patients with mass lesions of the plexus and other entrapment syndromes wherein patient follow-up along with intraoperative findings was their reference standard. It was a retrospective study performed in three centers collectively on 157 patients over a span of 5 years on both, 1.5 and 3T machines.[17] We feel that in a retrospective analysis (where-in a patient has already been operated), it is less taxing for the Radiologist to under report a dubious root and owe this fact also, to the high specificity of their study.

Our study demonstrated that MRI evaluation was sensitive for the detection of pre-ganglionic injuries (sensitivity 72.06%). These findings were exactly as per a report by Blum et al[18] where 70% of surgically proven root avulsions were correctly interpreted by MR imaging. It was also on the lines of the study by Doi et al[19] which demonstrated an even higher sensitivity of MRI of 92.9% for root avulsion. This study was, however, performed on a total of 175 roots in contrast to the 240 roots evaluated by us.

Of the 68 avulsed roots (detected intraoperatively), sensitivity and specificity of Edx was 82.35 and 38.95%, respectively. These findings were in sharp contrast to the findings of Terzis et al,[14] where sensitivity and specificity were 39.5 and 93.2%, respectively. However, their study was performed retrospectively on 135 avulsed roots and a much larger population over a span of a couple of decades.

Sensitivity of Edx for pre- and post-ganglionic injuries were 82.35 and 48.10%, respectively which were not in accordance with that reported by VanderHave et al[15] (their reported sensitivity for Edx for pre- and post-ganglionic injuries was 27.8 and 92.8%, respectively). However, their study was retrospective and was on a much smaller population of 21 patients (less than half of our sample size).

Some weaknesses of our study must be mentioned:-

1. The inaccuracy inherent in using surgery as the reference standard (because an intact root may be centrally avulsed and may not get detected on MRI too).
2. Edx is an operator-dependent procedure.
3. Interobserver variation in MRI interpretation.

Conclusion

The results of our study are the product of a multispecialty team approach including radiologists, Edx experts, and a hand surgeon.

Though our results did not show substantial agreement of the two diagnostic instruments in accurately assessing the injury patterns, both Edx and MRI are two highly sensitive investigation modalities whose combined sensitivity is 100% for the detection of a BPI.

Once the decision has been taken to operate, the exact procedure to be done will be decided when the lesions are identified, be it root avulsion, neuroma in continuity, or rupture of parts of the plexus; however, pre-assessment by Edx and/or MRI certainly aids in preplanning.

We put forth the following recommendations that: Edx and MRI, when used in combination, since their sensitivity is 100%, should both be done as they are excellent screening tests. Further studies should attempt to determine whether these studies affect the decision-making process. The cost effectiveness of the routine use of diagnostic tests such as MRI and Edx should be evaluated. Ideally each patient ought to have a long follow-up to determine if decisions taken based on these studies resulted in appropriate outcomes. The study should be conducted on a larger sample size. Intraoperative findings with on table electrophysiology studies including somatosensory-evoked potential (SSEP) should be the reference standard.

Conflict of Interest
None declared.

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