Diagnostic accuracy of MRI for traumatic adult brachial plexus injury: A comparison study with surgical findings

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ABSTRACT

We studied the diagnostic accuracy of MRI in 35 adult patients with traumatic brachial plexus injury in comparison with intra operative findings. The overall sensitivity to detect root avulsions was 39% and specificity was 75%. MRI was more useful in the diagnosis of lower root avulsions. At trunk and division level injuries, the sensitivity was 87% but specificity was only 26%. It was not able to differentiate the type and extent of post-ganglionic injuries. The accuracy of pseudomeningocele as avulsion on surgical finding was 96% (27/28). Pseudomeningocele correlates well with root avulsions. Its presence warrants early referral and surgical exploration.

1. Introduction

Brachial plexus injuries are one of the most devastating type of trauma in the upper limb. Diagnostic evaluation and imaging have become an integral part of its management as they help in locating the level of injury. The prognosis and treatment plan varies with preganglionic avulsion injury and a post ganglionic injury distal to the sensory ganglion.¹ Post ganglionic lesions can be treated by neurolysis, nerve repair and nerve grafting and they tend to have a better prognosis whereas, preganglionic injuries are treated with early nerve transfers and have poorer prognosis.² Generally the pattern of injury is a combination of avulsion and rupture.³ Upper roots are more likely to be ruptured due to the presence of ligaments in foraminal region. However, the ligament support is absent in the lower roots and hence avulsion is more common in this region.⁴ In the early stages clinical evaluation pose a significant challenge and electrophysiological studies may be insufficient to locate the site of anatomical injury.⁵ Imaging of such injuries are difficult and pose a challenge to the radiologist which also include technical problems of location, orientation and tissue relationship.⁶ Cervical myelography which were popular till two decades earlier have been superseded by MR imaging since they offer the additional benefit of multi planar capabilities and superior soft tissue contrast for the assessing extra foraminal and infra clavicular plexus.^{7,8} Systematic reviews have shown inconclusive results on the accuracy of MRI but these tests were based on an earlier generation of MRI

instrument.⁹ The only study using the 1.5 T MRI by Wade et al. showed modest accuracy of the MRI to detect avulsion injuries.¹⁰ But they did not comment on its efficacy in post ganglionic injuries. We decided to evaluate the diagnostic accuracy of MRI in the evaluation of both pre and post-ganglionic brachial plexus injuries and correlate the same with the intra operative findings.

2. Materials and methods

We included all patients with post traumatic closed brachial plexus injuries under the age of 60 years during the study period from 2012 to 2018. All open injuries and plexopathy due to tumors were excluded. MRI was done at a minimum of three weeks following injury and was read by a radiologist interested in brachial plexus injury with ten years of experience. 35 patients with clinical diagnosis of brachial plexus injury was evaluated with MRI using a 1.5 T scanner (PHILIPS ACHIEVA). T1 and T2 weighted imaging in the coronal, axial and sagittal planes of the supra and infra clavicular areas as well as heavily T2 weighted 3D MR neurography for avulsion injury evaluation. The patient is made to lie in supine position with arms at their sides. A sagittal T2-weighted spin-echo sequence for the cervical spine is done followed by an angulated coronal T1- weighted and short tau inversion recovery (STIR) series acquired in the long axis of C4 to C7 vertebrae.¹¹ Oblique sagittal and axial images are planned by checking the coronal plane.¹¹ The oblique sagittal images particularly help in showing the cross-

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section of the plexus more clearly than true sagittal imaging which include variations in quality of signal intensity. The extent of distribution of brachial plexus from spinal cord to the medial border of the humerus was evaluated.¹¹ Axial images are then derived in the coronal plane perpendicular to the long axis of cervical vertebrae.¹¹ Avulsion injury was defined to be detected in following observations: 1) presence of pseudomeningocele: these are dural sac outpouchings filled with cerebrospinal fluid (CSF).¹⁰ 2) Disrupted or discontinuous proximal roots within or immediately distal to the pseudomeningocele.¹⁰ 3) presence of retracted, thick and wavy distal nerve roots or a mass.¹⁰ 4) Spinal cord changes like cord edema, displacement of cord to the opposite side.^{10,12} 5) denervation of the posterior paraspinal muscles especially in the erector spinae.^{10,12} Postganglionic injuries are either nerve disruptions showing nerve retractions or stretch injury with neuroma in continuity suggested by thickened T1 hypo to isointense and T2 hyper intense nerves.¹² Compression or entrapment due to clavicular fracture callus or malunion were also checked.¹²

Patients subsequently underwent surgical exploration for repair or reconstruction depending on the injury at a minimum of eight weeks after injury. Informed consent was taken from all the patients operated. The interval between MRI and surgery was kept at a maximum of three months. A transverse supraclavicular approach was used for the supraclavicular lesions and a deltopectoral and axillary approach for the infraclavicular lesions. However, we did not perform any intra spinal exploration in any of our patients. Avulsion was defined if: 1) the spinal foramen was found empty with no evidence of root.¹⁰ 2) Presence of a thickened or flimsy thinned out scar tissue with no neural element.¹⁰ 3) Relaxed, wavy, and scarred proximal nerve trunks or dorsal root ganglion resembling thickness of a normal root.¹⁰ 4) Absent muscle activity on electrical stimulation.¹⁰ Post-ganglionic injuries were essentially defined as neurotmesis where a viable root could be isolated with healthy neural elements at least at the foramen level which were amenable for nerve grafting.

The intraoperative findings were correlated with the MRI findings. We calculated the sensitivity, specificity, positive and negative predictive value for the MRI findings (Tables 1 and 2).

3. Results

All patients had supraclavicular level injury with a mean age of 33 years (23–46 years). 27 patients had global palsy with root level injury, eight patients had trunk and division level injury. Except one, all were males and motor vehicle accidents were the only cause for the brachial plexus injury.

The overall sensitivity of diagnosing avulsion injury was 39% (27 out of 69) and the overall specificity was 75% (27/36) (Table 1). This means that for every four instance of absence avulsion in surgical findings, the MRI accurately picked the same on three occasions whereas, similarly for every 5 instances of clinical presence of avulsion, the MRI was accurate on only two occasions. Based on the positive predictive values (75%) we can also say that out of every four cases shown by MRI as avulsions, three did indeed turn out to be avulsions on surgical examination (Table 1). Out of 36 occasions where the MRI reported as avulsions, it also reported the presence of pseudomeningocele on 28 (80%) instances. 27 of these 28, indeed turned out to

be avulsions on surgical exploration which suggests that the presence of pseudomeningocele has a high predictability (96%) for avulsion injuries (Figs. 1 and 2). As shown in the Table 2 the sensitivity for C5 and C6 root avulsions were much less when compared to the C7, C8 and T1 avulsions (Figs. 1 and 2). The specificity was much better for C5, C6 though they were still lower than ones predicted for lower roots (Table 2).

For C6 root the sensitivity was 37% (10/27) and specificity was 62.5% (5/8) with three false positives (Table 2). At the trunk/division level injuries it detected with sensitivity of 87% (Table 3). All the eight cases were found to be neuroma in continuity with extensive fibrosis on exploration (Fig. 3). The MRI picked seven of them as thickening and hyper intense signals and reported it as axonotmesis. It was not possible to classify the injuries according to Seddon's classification as significant volume of cases showed abnormal findings in the presence of normal surgical findings. Neither was it possible to accurately pinpoint which trunk, division or cord was involved though it did suggest grossly the site and extent of involvement (Fig. 3).

4. Discussion

Perhaps one of the most important areas in peripheral nerve injuries where delay in treatment has a significant bearing on the outcome of results is that of involvement of brachial plexus. Jivan et al. showed significant difference in outcomes with respect to restoration of elbow function in patients operated before and after two months of delay in surgical exploration.¹³ Signifying the importance of early surgery, they demonstrated absence of difference between mean pre- and post-operative elbow power when surgery was delayed beyond two months.¹³ Subsequent systematic analyses have shown the best results are obtained if surgery is performed before three months for restoration of MRC grades > 3.¹⁴ In this regard it becomes extremely important to arrive at accurate diagnosis in brachial plexus injuries as early as possible. Clinical examination alone may not help in prognostication as it is extremely difficult to differentiate pre- ganglionic from post-ganglionic injuries.^{11,12} There is some role for conservative management in milder post-ganglionic injuries like neuropraxia or axonotmesis where recovery may be expected. However, early surgery is warranted for pre-ganglionic injuries where recovery is not possible without surgery. Information on this matter is vital in the first month from injury. Literature have shown the incidence of presence of avulsion injuries in as high as 89% with majority of them presenting with global palsy.¹⁵ In such circumstances it is imperative to counsel the patient with clinical and investigative evidence of unlikely recovery and the need for early exploration and nerve reconstruction.

MRI have shown promise of high accuracy in the diagnosis of brachial plexus lesions in the last two decades and has emerged as an integral part of investigative armamentarium for such injuries. Literature have shown its overall accuracy of diagnosing avulsion injuries varying from 48% to 88% with limitations based on technical issues.¹⁰ In the only systematic review reported so far on diagnostic accuracy of MRI in post-traumatic brachial plexus injuries, Fuzari et al. reported their inability to create meta-analysis in view of the heterogeneity of studies.⁹ Their trial reported on three studies with 46 participants comparing MRI with the reference standard of CT myelography.⁹ They showed a

Table 1

Table showing the overall accuracy of avulsions in MRI.

Level	MRI findings	Surgical finding		Sensitivity	Specificity	Positive predictive value	Negative predictive value	Accuracy
		Injury present	Injury absent					
Overall evaluation of avulsions	Injury present	27	9	39	75	75	39	51% 95%CI ^a (41–61)
	Injury absent	42	27					

^a Confidence interval.

Table 2

Table showing the accuracy of diagnosis of avulsion of individual roots.

Level	MRI findings	Surgical findings		Sensitivity	Specificity	Positive predictive value	Negative predictive value
		Avulsion present	Avulsion absent				
C5 root Avulsion	present	6	2	22	75	75	22
	absent	21	6				
C6 root Avulsion	present	10	3	37	63	77	23
	absent	17	5				
C7,8,T1 Avulsion	present	11	4	73	80	73	80
	absent	4	16				

Fig. 1. a) showing hyper intense signal with discontinuity of the brachial plexus (yellow arrow), hyper intense signal of C6, C7 root proximal end near the neural foramen (white arrow). b) showing pseudomeningocele involving the C8, T1 roots. c) showing the MR myelography with definitive pseudomeningocele of C7-T1 roots. d) note the surgical findings: all the roots were found completely avulsed (held with forceps) with distal ends lying under the clavicle (under retractor). Avulsion signals were not diagnosed in the MR images for C5, C6 roots. The proximal end stumps were not observed on exploration for C5, C6 roots near neural foramen as expected based on MR images.

lack in methodological rigor in the identified quantitative analysis and stressed for more accurate and rigorous future assessments of modalities.⁹ There are reports of questions being raised on the reliability and accuracy of CT myelography as reference standard and in this regard, the only report where the MRI was compared with findings of surgical exploration with laminectomy and actual spinal cord examination, Carvalho et showed only 48% correlation.^{10,16} They reported this to be due to partial root avulsions, intradural fibrosis, and traumatic meningocele as well as technical pitfalls.¹⁶

Though all these were reported based on earlier generation MRI machines, more recent reports with 1.5 T (T) machines have only reported modest results. In a cohort study involving 29 males, Wade et al. compared the accuracy of 1.5 T MRI for detecting root avulsions in traumatic adult brachial plexus injuries with the reference test of operative exploration of the supraclavicular plexus.¹⁰ The diagnostic accuracy of C5-T1 root avulsions in MRI was found to be 79% and similarly that of pseudomeningocele as a surrogate marker of root avulsions to be 68%.¹⁰ They reported that MRI has modest diagnostic accuracy for root avulsions with pseudomeningocele being non-reliable as a sign of root avulsion.¹⁰ Our study was similar done with a 1.5 T MRI with

routine sequences and the more recent addition of heavily T2 weighted 3D MR neurography for avulsion injury evaluation. This showed an overall specificity of 75% with a similar positive predictive value of 75%. But the overall sensitivity was much poorer at 39%. This was mainly due to the poorer sensitivity of the MRI to pick avulsions involving the upper roots of C5 and C6 (Table 1) (Fig. 1). The MRI was much more accurate in diagnosing the presence of avulsion in the lower roots with a sensitivity of 73% and specificity of 80%. This is similar to other reports in literature. In our opinion the difficulty in picking avulsion in C5 and C6 could be due to its oblique course which may create technical difficulties in picking signals in the MRI sequences.¹² But unlike the report of Wade et al., our results did show a very high accuracy of 96% in picking pseudomeningocele as avulsions. This was particularly important for C5 and C6 level where all the MRI detected avulsions did show a pseudomeningocele (Fig. 2). Based on this information we believe that presence of this sign should be an indication for counselling for early exploration for surgery. For post-ganglionic injuries, we observed that MRI was 87% sensitive but only 26% specific in picking the injuries. Simonetta et al. had shown that they could group according to the Seddon's classification in their series of 37

Fig. 2. A) note the T1 image showing pseudomeningocele of C5 and C6 roots (white arrow). B) showing the MR myelography with pseudomeningocele. C) showing the image on surgical exploration: white arrow shows the C5 root with phrenic nerve (blue arrow) branch emerging with the C6 root immediately below it. Both the roots were found hard (fibrosis) in consistency just proximal to this region. Note the atrophic distal upper trunk (Erb's point) from where the suprascapular nerve (yellow arrow) is emerging along with the diverging anterior and posterior divisions (orange arrows) of upper trunk. The trunk though atrophic were in normal consistency. There was no electrical activity. The exploration suggests a very proximal fibrosis of C5,6 roots near neural foramen, but the same may have had intradural avulsion in addition as seen in MR images. D) MR 3D neurography showing the avulsed C5, C6 roots (white arrow).

Table 3

Table showing the accuracy of post-ganglionic injury in MRI.

Level	MRI findings	Surgical finding		Sensitivity	Specificity	Positive predictive value	Negative predictive value
		Injury present	Injury absent				
Trunk, division and cord level injury ^a	Injury present	7	20	87	26	26	87
	Injury absent	1	7				

^a Injury is referred as neurotmesis.

patients with post traumatic injuries among 115 patients with varied pathologies. But we were unable to grade it according to the Seddon's classifications due to the limited number cases diagnosed as post-ganglionic injuries. All the eight injuries were found to be neuroma in continuity with extensive fibrosis. The MRI was reported as axonotmesis in these cases. The specificity was much lower as it overestimated injuries perhaps in the presence of additional avulsion injuries which could have brought some changes in the more distal segment of the plexus. We do agree with Hems et al. who showed that in the absence of pseudomeningocele, a normal MRI will rule out brachial plexus injury.¹² In their study in 23 patients who underwent exploration, post-ganglionic lesions were observed as swelling on T1 images associated with increasing signal on T2 images.¹² They were able to define the level of the injury within the plexus and provides information about the plexus outside the spinal canal.¹² A more accurate prediction of type and volume of injury affecting individual trunk was difficult to document which was also the finding in our study. The overestimation seen in our series could be attributed to the presence of additional avulsion

injuries which can produce some changes of the distal normal segments which are picked as hyper intense signals.

In all our explorations, definitive injury was observed and reconstruction was done in the form of nerve transfers and grafting. The limitation of the study was that we did not do a laminectomy to confirm the accuracy of the avulsion findings. This may not be practical as results of direct implantation of nerve rootlets to spinal cord had not been popular due to lack of comparable results with traditional nerve transfers.¹⁷ The other limitation is that of the smaller sample size as more rigorous statistical tests could not be done. We have not felt the need to test with the newer generation 3 T MRI as their accuracy has not been found to be superior.⁵ In a study on the use of 3 T MRI in brachial plexus injuries Zhang et al. showed high sensitivity (> 90%) but low specificity.¹⁸ In their opinion, the gold standard for brachial plexus injury diagnosis should be through surgery which although may still not be a very accurate reference standard.¹⁸

From this study we believe that it is very important to rely on corroborative evidence based on a thorough clinical examination, nerve

Fig. 3. A) This patient had extensive multi-level ruptures with neuroma in continuity. Note the fibrosis, beginning at Erb's point (white arrow). note the fibrotic posterior division and suprascapular nerve with forceps placed in between. B) MR image showing hyper intense signal extending from roots to cords. But the type and extent of injury was difficult to interpret. It does help in pointing region wise injury namely supraclavicular vs infraclavicular injury. C) note the patient had injury at the infraclavicular level as well with extensive ruptures with gap involving median (yellow arrow) and radial (pointed by forceps) nerve. Note the musculocutaneous (blue arrow) and ulnar (white) nerve were relatively healthy and found in continuity. Individual trunk/cord and branch injury was difficult to pinpoint with MR images in this patient. Clinically patient had extended C5–C8 root level injury with only the presence of digital flexion.

and muscle conduction studies and MRI to arrive at an accurate diagnosis in brachial plexus injuries. Presence of pseudomeningocele should be a strong indication for an early referral for patients particularly with global palsy where prompt and aggressive surgical intervention is vital.

5. Conclusion

We concluded that MRI is a useful imaging tool in the diagnosis of brachial plexus injuries. Its findings correlate well with avulsion injuries of the lower roots particularly with the presence of pseudomeningocele.

Conflicts of interest

The authors have no conflicts of interest to disclose pertaining to this manuscript. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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