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Role of ultrasonography in evaluation of post ganglionic brachial plexus injury in correlation with magnetic resonance and intraoperative findings

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Abstract
Background: Anatomical, structural as well as severity of brachial plexus injuries is evaluated by magnetic resonance imaging which determines the type of treatment as well as the prognosis. However, limitations such as static imaging, availability, cost-effectiveness & complexity of procedure has led to search of cheaper diagnostic modalities like ultrasonography which has potency to overcome such limitations. Therefore, this study was carried out to assess efficacy of ultrasound in post ganglionic brachial plexus injury.
Materials and Methods: A cross sectional comparative study was conducted in the department of Radio-diagnosis of Mahatma Gandhi Medical College and Research Institute from January 2021 to June 2022 amongst 23 patients diagnosed with traumatic & clinically consistent brachial plexus injury who underwent surgical intervention. The outcome measures assessed were level of injury, site of injury, neuroma, rupture, neuropraxia / nerve thickening / probable scar block.
Results: The majority of the subjects were males, with left sided injuries accounting for 52.2%. Root injuries (47.8%) were more common than trunk, division (26% each). USG showed 81.8% sensitivity & 100% specificity for rupture; 100% sensitivity & 92.3% specificity for neuroma & 50% sensitivity for nerve thickening. We recorded sensitivity & specificity rate of 100% for rupture, neuroma & nerve thickening on assessment by MRI. USG could not pick up T1 root injuries and lower trunk injuries.
Conclusion: Ultrasonography recorded a high degree of accuracy in identifying the postganglionic brachial plexus injury associated with proximal roots, divisions, upper and middle trunks in the lateral region of the neck while the imaging in lower trunk was limited. Therefore, we conclude that ultrasonography supersedes limitations of MRI such as static imaging, expensive & technique sensitivity, which makes it a more lucrative diagnostic modality for studying the brachial plexus in adjunct or absence of MRI.

Keywords: Ultrasonography, magnetic resonance imaging, ganglion, cervical nerve, injury

1. Introduction

Approximately 1% of major trauma patients are reported to suffer from traumatic brachial plexus injuries. Ventral rami of cervical nerve roots C5-C8, & thoracic nerve roots T1 in aid with C4 and T2 portion forms brachial plexus [1, 2].

Brachial plexus injury is reckoned as most serious nerve injury occurring in upper extremities, due to traumatic incidents like motorcycle accidents & neonatal dystocia [3, 4]. Injury can be pre-ganglionic (root avulsion), post-ganglionic (rupture or injury in nerve continuity), or an amalgamation of both [5].

MRI has been widely advocated as a superior diagnostic modality owing to its properties, such as superior soft tissue characterization, multi-planar imaging, non-invasive nature as well as radiation free imaging [2].

However, MRI has certain limitations such as requirement of posture, lack of dynamic imaging, enclosed space, limited imaging capability (patient positioning) & availability which makes ultrasonography an adjunct/alternative as it is faster, readily available, inexpensive and has no contraindications [4].

Ultrasonography has also been found to be proficient in ascertaining anatomical location of the cervical roots by visualizing course of the roots which later fuse to form trunks in interscalene region [4].

Therefore, ultrasonography has been recommended as a diagnostic tool in diagnosing brachial plexus injuries as an adjunctive diagnostic modality to MRI; & in absence of MRI, it can be used as a reliable diagnostic tool [2].

2. Materials and Methods
After obtaining approval from institutional review & ethical committee**,** a cross sectional comparative study was conducted in department of Radiodiagnosis of Mahatma Gandhi Medical College and Research Institute from January 2021 to June 2022. 23 eligible patients referred from department of Plastic Surgery meeting the inclusion and exclusion criteria formed study population.

2.1 Inclusion criteria
Patients 18 years and above who had upper limb trauma and clinical features consistent with brachial plexus injury who underwent surgery.

2.2 Exclusion criteria
- Patients' inability to provide informed consent
- Patients who have implants, pacemakers, paramagnetic foreign bodies, claustrophobia.
- Patients who cannot remain immobile within MRI scanner.
- Pregnant women.

2.3 Procedure
2.4 MRI Imaging Technique
After obtaining informed and written consent from the patient. In addition to the preoperative clinical evaluation, the patients underwent MRI to obtain brachial plexus imagery using specific sequences.

2.5 Sequences

MRI Sequences	Section Thickness (mm)	TR/TE	Matrix
Sagittal T1-W TSE	4	700/10	340x240
Sagittal Oblique T2 TSE	4	3000/50	320x224
Coronal T1-W TSE	2	790/10	320x376
Coronal STIR	2	4700/55	320x315
Axial STIR	2	670/10	320x315

The examinations were performed using a PHILIPS 1.5-Tesla Achieva machine without the usage of any paramagnetic contrast agents. Both right and left sides were examined for better comparison. Images are analyzed on a BARCO 5 mega pixel image viewer by an experienced radiologist who is blinded of ultrasound report.

2.6 Ultrasound Technique
Sonographic imaging was performed with general electric logic expert S7 ultrasound machine with linear probe of high frequency (6-15 MHz). The patients were examined in a semi lateral decubitus position (both affected and contralateral unaffected side) without specific preparation. Coronal oblique planes were used to identify the transverse processes of the vertebrae as hyperechoic bone prominences with posterior acoustic shadowing. In the groove between the transverse processes, the hypoechoic nerve roots were visualized as they left the intervertebral foramina in a downward direction. The roots and trunks were followed continuously into the interscalene, supraclavicular, and infra clavicular region by shifting the probe back and forth in an axial plane. Individual nerve roots were examined closely to identify pathologic conditions, depicted as abnormal soft tissue surrounding the nerve or a transection or loss of clarity of the nerve structure (rupture, neuroma diffuse nerve thickening). Color Doppler sonography was used to differentiate nerve structures from vessels. The level of individual roots was identified on the basis of the different morphology of the cervical transverse processes of the vertebrae: The anterior tubercle of the transverse process is selectively absent in the C7 vertebra. The root levels of the upper vertebrae could be identified by counting the number of transverse processes encountered while sweeping the transducer cranially from C7. All sonographic images were obtained and interpreted by another experienced radiologist who is blinded of MRI report.

Following USG, surgeries were performed by concerned plastic surgery team as per standard institutional protocol. The surgical findings were used as standard reference.

The outcome measures assessed were level of injury, site of injury, neuroma, rupture & neuropraxia / nerve thickening / probable scar block.

2.7 Data collection
All data was entered into a Data Collection Proforma Sheet and was entered into Excel (MS Excel 2019). Other biographical details were also collected including age.

2.8 Statistical methods
Qualitative data will be expressed as frequency and percentage. The variables like rupture, neuroma, nerve thickening were compared in USG, MRI by sensitivity, specificity, PPV, NPV& diagnostic accuracy based on intraoperative findings. Statistical analysis was carried out using SPSS version 22.0 (IBM SPSS, US) software.

3. Results
Among 23 study population, majority of the subjects in our study were predominantly male (21/23, 97%), with left sided injuries accounting for 52.2% (12/23). We recorded 47.8% (11/23) root injuries on MRI and 43.4% (10/23) root injuries on USG, while we had 26% of injuries each in the trunk (6/23), division (6/23) and no recorded injuries in cord. One case (1/23) which was normal on USG was recorded as lower trunk injury in MRI and confirmed intraoperatively. Most common abnormality recorded on USG is neuroma (11/23) while on MRI and intraoperatively is rupture (11/23) (Tables 1&2). USG showed 81.8% sensitivity & 100% specificity for rupture (Table 3); 100% sensitivity & 92.3% specificity for neuroma (Table 4). We recorded a sensitivity & specificity rate of 100% for rupture & neuroma on assessment by MRI (Table 5 & 6). USG showed 50% sensitivity for nerve thickening (1/2) and MRI showed 100% sensitivity for nerve thickening (2/2). USG could not pick up T1 root injuries and lower trunk injuries (2/2).

Table 1: Descriptive analysis of USG findings in the study population (N=23)

USG Findings	Frequency	Percentage
Rupture	9	39%
Neuroma	11	47.8%
Thickening	2	8.7%
Normal	1	4.3%
Total	23	100.0%

Table 2: Descriptive analysis of MRI findings in the study population (N=23)

MRI Findings	Frequency	Percentage
Rupture	11	47.8%
Neuroma	10	43.4%
Thickening	2	8.7%
Total	23	100.0%

Table 3: Comparison of USG rupture across intraoperative rupture (N=23)

USG finding	Intra-operative	
	Rupture	No rupture
Rupture	9	0
	81.8%	0.0%
No rupture	2	12
	18.2%	100.0%
Total	11	12
	100.0%	100.0%

Results

Statistic	Value	95% CI
Sensitivity	81.82%	48.22% to 97.72%
Specificity	100.00%	73.54% to 100.00%
Disease prevalence (*)	47.83%	26.82% to 69.41%
Positive Predictive Value (*)	100.00%	
Negative Predictive Value (*)	85.71%	63.14% to 95.46%
Accuracy (*)	91.30%	71.96% to 98.93%

(*) These values are dependent on disease prevalence.

Table 4: Comparison of USG neuroma across intraoperative neuroma (N=23)

USG finding	Intra-operative	
	Neuroma	No neuroma
Neuroma	10	1
	100.0%	7.7%
No neuroma	0	12
	0.0%	92.3%
Total	10	13
	100.0%	100.0%

Statistic	Value	95% CI
Sensitivity	100.00%	69.15% to 100.00%
Specificity	92.31%	63.97% to 99.81%
Disease prevalence (*)	43.48%	23.19% to 65.51%
Positive Predictive Value (*)	90.91%	60.34% to 98.50%
Negative Predictive Value (*)	100.00%	
Accuracy (*)	95.65%	78.05% to 99.89%

(*) These values are dependent on disease prevalence.

Table 5: Comparison of MRI rupture across intraoperative rupture (N=23)

MRI finding	Intra-operative	
	Rupture	No rupture
Rupture	11	0
	100.0%	0.0%
No rupture	0	12
	0.0%	100.0%
Total	11	12
	100.0%	100.0%

Statistic	Value	95% CI
Sensitivity	100.00%	69.15% to 100.00%
Specificity	100.00%	75.29% to 100.00%
Disease prevalence (*)	43.48%	23.19% to 65.51%
Positive Predictive Value (*)	100.00%	
Negative Predictive Value (*)	100.00%	
Accuracy (*)	100.00%	85.18% to 100.00%

(*) These values are dependent on disease prevalence.

Table 6: Comparison of MRI neuroma across intraoperative neuroma (N=23)

MRI finding	Intra-operative	
	Neuroma	No neuroma
Neuroma	10	0
	100.0%	0.0%
No neuroma	0	13
	0.0%	100.0%
Total	10	13
	100.0%	100.0%

Statistic	Value	95% CI
Sensitivity	100.00%	69.15% to 100.00%
Specificity	100.00%	75.29% to 100.00%
Disease prevalence (*)	43.48%	23.19% to 65.51%
Positive Predictive Value (*)	100.00%	
Negative Predictive Value (*)	100.00%	
Accuracy (*)	100.00%	85.18% to 100.00%

(*) These values are dependent on disease prevalence

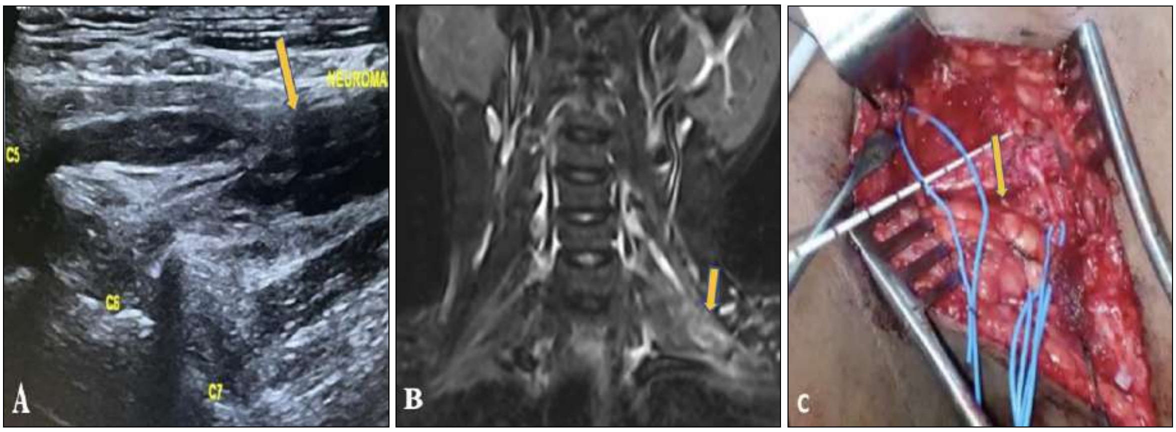

Fig 1: (A) USG showing left brachial plexus neuroma (yellow arrow) in the upper trunk, (B) Cor STIR MRI showing intermediate signal neuroma in the left upper trunk (yellow arrow) (C) Intraoperative image showing left brachial plexus neuroma (yellow arrow)

4. Discussion

The convoluted plexus design in combination with the complex nature of the lesions makes clinical evaluation inaccurate, while EMG is only capable of providing the details with respect to the functional involvement of the lesion, not the location of the lesion [2].

Imaging is one of the diagnostic modalities which have been proficiently used to reach a final diagnosis. However, the complexity of the structures as well as the dynamic activity within the body provides an inconclusive result as the positional changes due to function or due to change in position can sometimes be misleading to the diagnostician.

Traumatic injuries are divided into three groups based on anatomical features for diagnosis & prognosis:

- Pre-ganglionic (root avulsion)
- Post-ganglionic (rupture or injury in the nerve continuity),
- Combination of both [5].

Even though MRI has been well-established as the choice of diagnostic modality to evaluate the severity of BPI in determining the diagnosis, treatment as well as the prognosis, the hunt for an alternative still persists due to its shortcomings.

Ultrasonography has gained popularity as an efficacious diagnostic imaging modality, which has been substantiated in studies conducted by Caldana *et al*. [4]**,** Griffith *et al*. [6], Gunes *et al*. [7], *et al*., who have studied the role of USG in evaluation of cervical nerve roots, as well as the upper and middle trunks, in the post ganglionic brachial plexus injuries and concluded USG that it can be used as an adjunct to MRI.

We conducted our study in 23 upper limb trauma and brachial plexus injury patients and all of them were selected based on the inclusion criteria. Therefore, as expected, all patients had abnormal findings on the affected side on USG, MRI and Intraoperatively.

The majority of the subjects in our study were male, accounting for 91%., which was in agreement with the study conducted by Midha *et al*. [8], Out of the 23 patients, 52.2% had left sided injury while 47.8% of them had right sided injury.

The most common abnormality detected by ultrasound in our study was neuroma in 11 out of 23 patients (47.8%), which when assessed by MRI & intra-operatively amongst the same group of patients recorded 10 out of 23 (43.4%). Thus, the Sensitivity of ultrasound to detect neuroma was found to be 100% and the specificity was 92.3%, whereas MRI showed a sensitivity of 100% and specificity of 100% for neuroma.

Rupture was observed in 9 out of 23 (39%) by ultrasound, while MRI & intra-operative findings recorded 11 out of 23 patients (47.8%). We found that the sensitivity of ultrasound to detect rupture was 81.8% and specificity was 100%, while MRI showed a 100% sensitivity and specificity in detection of ruptures. Our study results were similar to that observed by Vaishali Upadhyaya *et al*. [9] in which USG and MRI can effectively demonstrate complete rupture and MRI will be superior in incomplete rupture/nerve transection, this may be the reason for more ruptures on MRI in our study.

In an intraoperatively confirmed case of rupture which was correctly diagnosed on MRI was diagnosed as neuroma on USG at root level. This finding may be due to vertebral artifact obscuring root injury.

Overall, we had recorded that USG has an 81.8% sensitivity, 100% specificity, 100% positive predictive value, 85.7% negative predictive value and 91% diagnostic accuracy in detection of rupture cases; 100% sensitivity, 92.3% specificity, 91% positive predictive value, 100% negative predictive value and 96% diagnostic accuracy for neuroma, while MRI shows a 100% sensitivity, specificity, positive predictive value, negative predictive value and diagnostic accuracy for rupture & neuroma.

These findings were similar to the study done by Gunes *et al*. [7] with 43 patients of post ganglionic brachial plexus injury which showed 84% sensitivity, 100% specificity, 100% PPV, 81% NPV and 90% diagnostic accuracy for USG and 100% sensitivity, specificity, PPV, NPV, diagnostic accuracy for MRI.

We also found that Root level injuries (43.4% in USG and 47.8% in MRI) were the most often affected region followed by the trunk (26%) and division level injuries (26%) in both ultrasound and MRI.

On further assessing the root level injuries, C5 root was most commonly affected (17.4%) followed by C6 (13%) and C7 (8.7%).

As per our study, predictive validity of nerve thickening is 100% for MRI and 50% for USG. This can be substantiated from the data put forward by Chen *et al*.,**(10)** that this discrepancy is due to in post-ganglionic lesions & that it is actually the technician's skill which helps to determines the lesions during the imaging.

Despite the fact that almost all post-ganglionic lesions at the C4–C8 levels in US were identified in our study (i.e. 96% 20/21), USG failed to detect the same at the T1 nerve roots as well as the lower trunk in 2/2 individuals (8.7% of total cases). However, these were successfully identified by MRI and intraoperatively. The inability of USG to identify the changes can be attributed to poor acoustic window on USG or could be due to fact that levels of injuries were deep in location. As a result, in roughly 8.7% of patients, the lower nerve roots and trunks were not assessed properly in USG.

Previously, the study carried out by Gunes *et al*., [7] also reported analogous technical snags during the use of USG for assessment of brachial plexus injury. It is postulated that it is not easy to assess the C8 and T1 nerve roots since they are extremely deep and caudal. We also found that USG could not record isolated intra-dural injury which can be attributed to the fact that the roots originate within the vertebral column and bone obscures sonographic vision [11].

Our study found ultrasonography as an efficient imaging diagnostic modality owing to its characteristics such as high-resolution images, dynamic imaging, ease of access, ease of interpretation by the diagnostician as well as being cost-effective.

However, there is requirement for more studies which can substantiate the use of ultrasonography as a reliable standalone imaging diagnostic modality in the detection & assessment of brachial plexus injury. Therefore, we recommend the use of ultrasonography as an adjunct to MRI in the current scenario until there is addition of more concrete evidence in support of ultrasonography. In case of non-availability of MRI, we recommend the use of ultrasonography as an alternative.

The strengths of our study are the presence of USG, MRI and intraoperative findings for comparison for all cases. Limitations in our study, though USG is a good modality due to its higher resolution, because of operator variation the results could vary between different persons/equipment and sample size in this study is small thus, may influence statistical significance.

5. Conclusion

Ultrasonography recorded a high degree of accuracy in identifying the postganglionic brachial plexus injury associated with proximal roots, divisions, upper and middle trunks in the lateral region of the neck while the imaging in lower trunk was limited. Therefore, we conclude that ultrasonography supersedes the limitations of MRI such as static imaging, expensive & technique sensitivity, which makes it a more lucrative diagnostic modality for studying the brachial plexus in adjunct or in absence of MRI.

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7. Conflict of Interest

Not available

8. Financial Support

Not available

9. References

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