The Egyptian Journal of Hospital Medicine (January 2023) Vol. 90 (2), Page 2959-2966

Electrodiagnosis and Imaging Studies in Neonatal Brachial Plexus Palsy: Comparative study

[1] **Yassir Abdelhay,** [2] **Mohammad Reda Ahmad,** [1] **Amina Mohamed Hosseny**
[1] Rheumatology, Rehabilitation and Physical Medicine Department and
[2] Plastic Surgery Department, Faculty of Medicine, Zagazig University, Egypt
Corresponding author: Yassir Abdelhay, **Email:** yassir126@gmail.com**, Phone:** 01144372252

ABSTRACT

Background: Neonatal brachial plexus palsy (NBPP) is a prevalent type of newborn morbidity with a potentially devastating persistence. Neurosurgical management is indicated in NBPP patients. The selection of those infants for surgery would be made easier by early prognostic assessment.

Aim: To compare electrodiagnostics and imaging in the same patients because they have not previously been compared for precision in identifying infant brachial plexus avulsions.

Patients and methods: This study looked back at 40 infants who had surgical NBPP and were treated between 2020 and 2022 in Faculty of Medicine, Zagazig University Hospitals in Plastic Surgery, Radiology, Neuro and Rheumatology Departments. To assess the performance accuracy of ancillary tests, in comparison to surgical findings, we reported electrodiagnostic testing (EDX) and imaging sensitivity, specificity and accuracy.

Results: The mean age at surgery was 9.93±7.42 months. 45% were Narakas grade I–II, and 55% were Narakas grade III–IV. For all nerve roots, the overall accuracy of detecting avulsion was 55% for imaging and 65% for EDX. The overall accuracy of detecting rupture was 45% for imaging and 65% for EDX.

Conclusion: Imaging and EDX are not as precise as was previously asserted. Given that each test's strengths frequently compensate for its weaknesses of the others, the ideal workup for patients with NBPP is likely to include a variety of modalities.

Keywords: Neonate, Brachial plexus, Electrodiagnostic, Nerve conduction studies, Electromyography.

INTRODUCTION

Management of neonatal brachial plexus palsy (NBPP) has rapidly evolved in the last 30 years, with many contentious opinions [(1)]. Making decisions is still a hot topic, particularly when it comes to the scheduling of surgery, the selection of the procedure, and the inclusion of aiding testing [(2)]. Electrodiagnostic testing (EDX) and other modalities of imaging are two examples of preoperative contributing testing. The main aim of preoperative testing is localization of the injury and preoperative planning for nerve reconstruction. Some facilities use EDX and imaging simultaneously, whereas others never do either [(3)].

Avulsion to the lower trunk is the only surgical recommendation for early intervention that is not debatable [(4)]. According to different outcome studies, children who experienced early repair, gain more positive benefits. So, identifying avulsion injures accurately preoperational is mandatory [(5)].

Avulsion injuries can be identified with 60% to 80% accuracy with imaging, including CT and MRI myelography [(6)]. EDX has a 19% and 93%, respectively, low sensitivity and excellent specificity for avulsion injury detection [(7)]. It becomes problematic when there are both preganglionic and postganglionic injuries since this causes the injury to be incorrectly classified as a single postganglionic lesion. There are three categories of brachial plexus injuries; preganglionic lesion, postganglionic lesion, and a combination of both. Accurate and precise localization is a critical factor in determining the proper treatment strategy [(8)].

The purpose of this study was to compare electrodiagnostics and imaging in the same patients because they have not previously been compared for precision in identifying infant brachial plexus avulsions.

METHODS

Study Design

This study looked back at 40 infants who had surgical NBPP and were treated between 2020 and 2022 in Faculty of Medicine, Zagazig University Hospitals in Plastic Surgery, Radiology, Neuro and Rheumatology Departments. We took into account consecutive newborns. The current protocol called for if no signs of improvement were present after three months. Diagnostic imaging (first-line MRI) was performed after electrodiagnostics at one month or when the referral was made. The current protocol involves diagnostic imaging (first-line MRI) at 3 months if no signs of recovery exist, and electrodiagnostics at 1 month or at the time of referral. Age and gender of the patient and NBPP-specific reports factors such the affected side and the Narakas grade were evaluated. One surgeon determined the Narakas grade based on the description of the infant's hand/arm motions by the mother or obstetrician at delivery, either at the first clinical appointment, around one month of age, or both, the physical examination and neurological evaluation. The surgical results (gold standard) at the root and trunk levels confirmed the preoperative imaging and EDX accuracy of NBPP lesion detection (preganglionic and postganglionic). To assess the performance accuracy of ancillary tests, in comparison to surgical findings, we reported EDX and imaging sensitivity, specificity, and accuracy.

Received: 08/08/2022
Accepted: 11/10/2022

Imaging and EDX prior to surgery

Criteria for Electrodiagnostic

Before having surgery to rebuild their nerves, all newborns underwent electrodiagnostic testing. Studies on the implicated upper extremities in comparison to surgical findings were performed. We reported EDX and imaging sensitivity, specificity, and accuracy done for both motor and sensory purposes. The thumb, index finger, or the middle finger were used to record the median sensory responses, and the little finger was used to record the ulnar sensory nerve response (5^{th} digit). Conduction velocity, amplitude, and distal delay were among the data from the nerve conduction research that were gathered.

Electromyography (EMG) testing was done on pertinent muscle groups in the outpatient environment without anesthesia. A pediatric concentric needle was used. The EMG data gathered included morphology, the quantity of action potentials in each motor unit, as well as insertional activity and possibility of spontaneous activity (positive waves, fibrillation, and fasciculation potentials) (polyphasia, motor unit frequency, and the size and number of motor units). If the sensory nerve conduction tests resulted in results that were normal or more than 50% above or below laboratory or unaffected upper extremity norms, the lesion was classified as preganglionic (avulsion). Because of the dorsal root ganglion, a sensory nerve action potential persists, which is located far from the site of injury in root avulsions and the cell bodies of sensory axons are found here. The linked weak/flaccid muscles exhibited EMG anomalies. If the sensory conductions tests revealed abnormalities, i.e., the affected limb's nerve conduction studies showed abnormalities in the relevant muscles and less than 50% of the lab or that limb's norms; the lesions were determined to be postganglionic (rupture).

Figures 1-5 show some examples of motor and sensory studies of nerves.

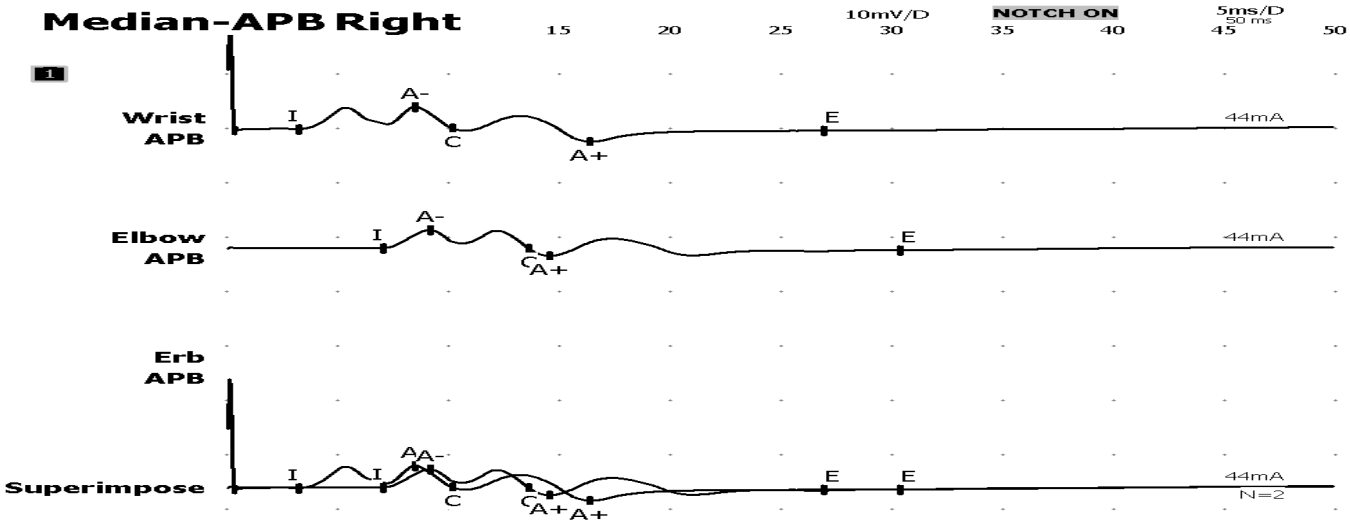

Fig (1): Motor study of right median nerve.

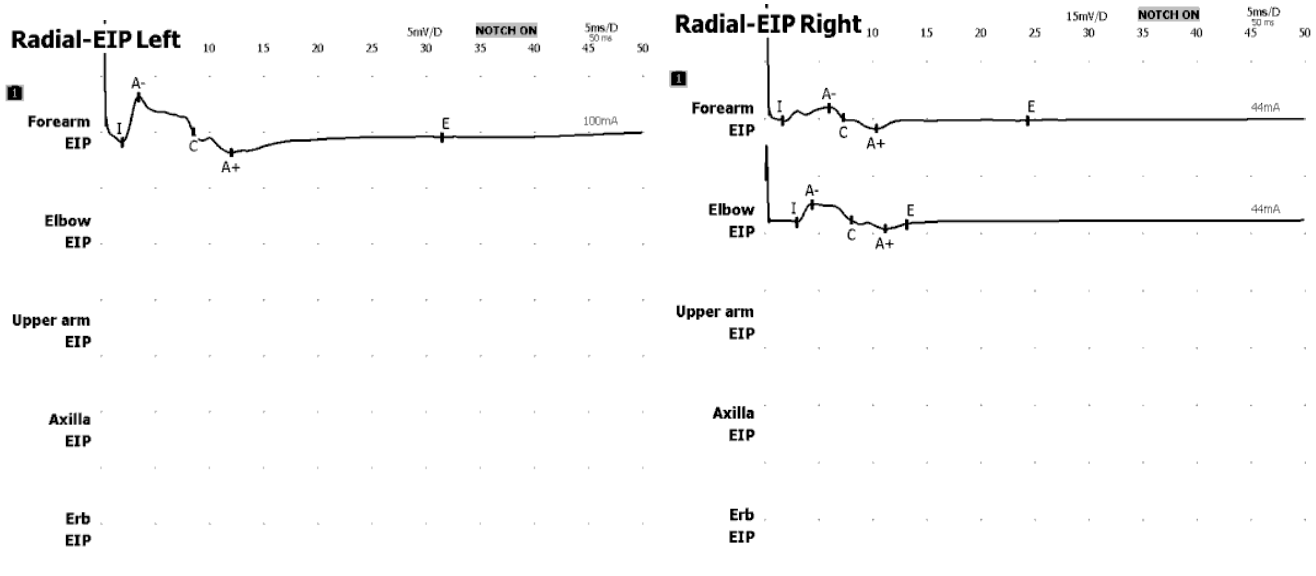

Fig (2): Motor study of both radial nerves

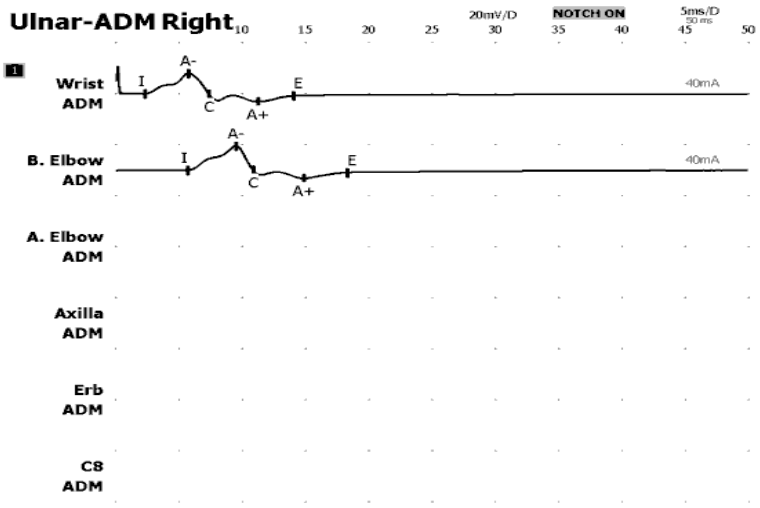

Fig (3): Motor study of right ulnar nerve

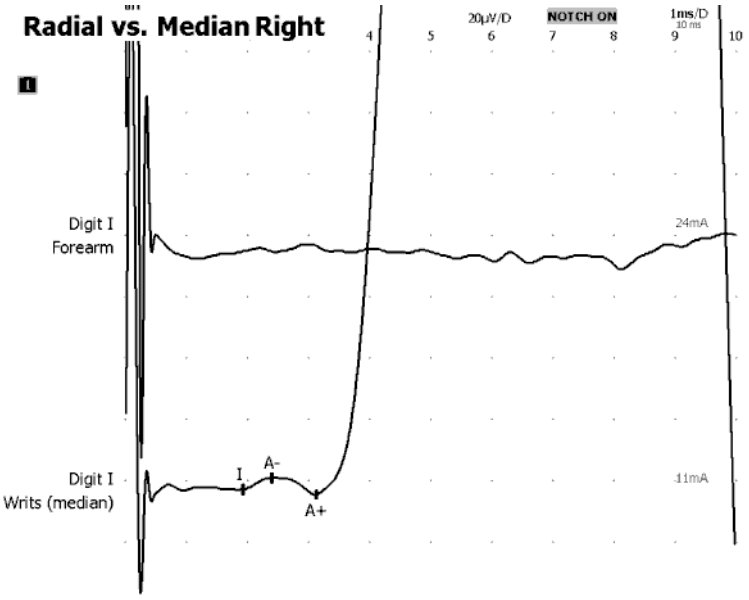

Fig (4): Sensory study of right radial vs. median nerves on digit I

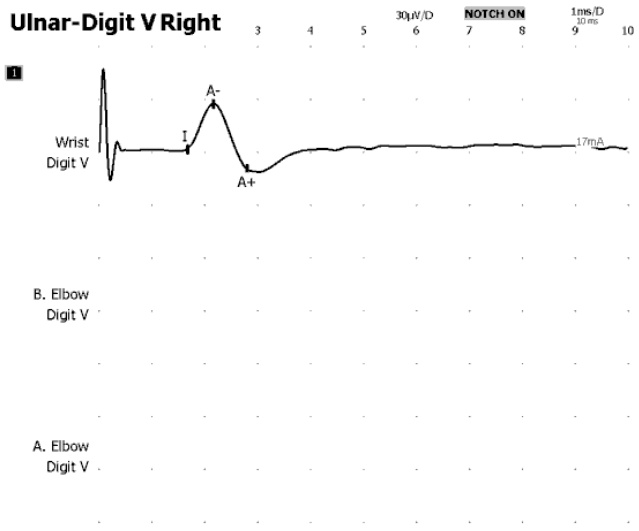

Fig (5): Sensory study of right ulnar nerve on digit V

Criteria for Imaging

Board-certified neuroradiologists protocoled and assessed the brachial plexus' imaging. There were two imaging options: CT myelography and MRI, and prior to image acquisition, a conversation with the radiologist helped to choose the imaging modality and sequencing. Before the MRI protocol was developed, CT myelography was mainly employed. MR myelography is now the procedure of choice [6]. For these imaging techniques, general anesthesia is necessary. The appearance of a pseudomeningocele was not regarded as diagnostic; instead, a direct evaluation was used to determine whether an avulsion injury had occurred or there was continuity of the ventral nerve root. The specific protocols have been detailed by **Somashekar *et al*.** [6, 9].

Ethical approval: The Institutional Review Board of Faculty of Medicine, Zagazig University gave its approval to the study protocol. This work has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for studies involving humans.

Statistical Analysis

For patient demographics and postoperative results, we used number and percentage, mean and standard deviation. We reported the sensitivity, specificity, imaging at the root (C5-T1) and trunk (upper, middle, and lower) levels for detecting preganglionic and postganglionic lesions, and accuracy. **Version 23.0 of IBM SPSS Statistics for Windows was used.**

RESULTS

Forty individuals participated in this study. The mean age at initial consultation was 63.55±54.09. More than half of cases (60%) were females. The right side was involved in 14 patients (70%). There were 22 (55%) with Narakas grades III–IV. (55%) of patients underwent MRI imaging, CT was done to (40%) and US was done to (5%) of cases (Table 1).

Table (1): Basic characteristics of the studied patients (n=40)

Characteristic	Category	Study group (n=40)	
		No.	%
Gender	**Female**	24	60
	Male	16	40
Side	**Left**	12	30
	Right	28	70
Imaging technique	**CT**	16	40
	MRI	22	55
	US	2	5
Age at diagnosis (day) Median Range	43 (4-180)		
Age at surgery (month) Median Range	6 1-24		
Narakas grade Grade I-II Grade III-IV	18 (45%) 22 (55%)		

The injuries were identified during surgery and varied by level of nerve root (Table 2)

Table 2: Summary of nerve root injuries in 40 patients

Variables	C5	C6	C7	C8	T1
Rupture	20 (50 %)	22(55 %)	16(40 %)	2(5 %)	1 (10 %)
Avulsion	20 (50 %)	16(40 %)	14(35 %)	12 (30 %)	8 (20 %)
Normal	0 (0 %)	2(5 %)	10(25 %)	26(65 %)	28 (70 %)

In table 3, root and trunk level imaging avulsion detection is described. Overall specificity was 37.5%, overall accuracy was 55%, and overall sensitivity was 66.7%.

Table (3): Validity of imaging in detection of avulsion

Variables		Imaging				
		Sensitivity	**Specificity**	**PPV**	**NPV**	**Accuracy**
Root	C5	20%	60%	33.3%	42.9%	40%
	C6	50%	75%	57.1%	69.2%	65%
	C7	57.1%	84.6%	66.7%	78.6%	75%
	C8	50%	92.9%	75%	81.3%	80%
	T1	75%	87.5%	60%	93.3%	85%
Total		66.7	37.5	61.5	42.9	55%
Trunk						
	UT	-----	100%	-----	100%	100%
	MT	-----	100%	-----	100%	100%
	LT	-----	100%	-----	100%	100%

C: cervical segment, T: thoracic segment, UT: upper trunk, MD: middle trunk, LT: lower trunk

Table 4 describes the root and trunk level avulsion detection by EDX. At C8 root levels, the overall sensitivity was greater than other roots; the overall specificity was 50%, and the overall accuracy was 65%.

Table (4): Validity of EDX in detection of avulsion

Variables		EDX				
		Sensitivity	**Specificity**	**PPV**	**NPV**	**Accuracy**
Root	C5	30%	80%	60%	55%	53.3%
	C6	37.5%	83.3%	60%	65%	66.7%
	C7	42.9%	84.6%	60%	70%	73.3%
	C8	83.3%	92.9%	83.3%	92.9%	90%
	T1	75%	81.3%	50%	92.9%	80%
Total		100%	50%	46.2%	100%	65%
Trunk	UT	-----	100%	-----	100%	100%
	MT	-----	100%	-----	100%	100%
	LT	-----	100%	-----	100%	100%

C: cervical segment, T: thoracic segment, UT: upper trunk, MD: middle trunk, LT: lower trunk

Table 5 describes the imaging detection of rupture by root and trunk level. Overall specificity was 35.7%, overall accuracy was 45%, and overall sensitivity was 66.7.

Table (5): Validity of imaging in detection of rupture

Variables		Imaging				
		Sensitivity	**Specificity**	**PPV**	**NPV**	**Accuracy**
Root	C5	20%	80%	50%	50%	50%
	C6	27.3%	77.8%	60%	46.7%	50%
	C7	25%	75%	40%	60%	55%
	C8	-----	94.7%	-----	94.7%	90%
	T1	-----	100%	-----	90%	90%
Total		66.7	35.7	30.8	71.4	45%
Trunk						
	UT	28.6%	100%	100%	72.2%	75%
	MT	-----	100%	-----	100%	100%
	LT	-----	100%	-----	100%	100%

C: cervical segment, T: thoracic segment, UT: upper trunk, MD: middle trunk, LT: lower trunk

Table 6 provides more information on EDX rupture detection at each root level. Overall specificity was 50%, overall accuracy was 65%, and overall sensitivity was 75%, with better sensitivity at the C8 root. The overall accuracy in detecting rupture using EDX in trunks was 70%, with sensitivity 54.5% and specificity 88.9%.

Table (6): Validity of EDX in detection of rupture

Variables		EDX				
		Sensitivity	**Specificity**	**PPV**	**NPV**	**Accuracy**
Root	C5	70%	60%	63.6%	66.7%	65%
	C6	81.8%	66.7%	75%	75%	75%
	C7	62.5%	75%	62.5%	75%	70%
	C8	100%	94.7%	50%	100%	95%
	T1	50%	94.4%	50%	94.4%	90%
Total		75	50	69.2	75.1	65%
Trunk	UT	85.7%	88.9%	54.5%	88.9%	70%
	MT	-----	75%	-----	100%	75%
	LT	-----	95%	-----	100%	95%
	total	54.5	88.9	85.7	61.5	70%

C: cervical segment, T: thoracic segment, UT: upper trunk, MD: middle trunk, LT: lower trunk

---

DISCUSSION

NBPP is a severe birth injury that can result in significant physical and mental impairment. Although Egyptian data on the prevalence of NBPP are unavailable, a global incidence of 0.5 to 3/1000 births is still regarded as inevitable [(10)].

Within the first few months, the majority of infants recover with conservative care, but 20–30% of patients need microsurgery because their conditions persist [(11)]. Patients with persistent neurological deficits are treated in a variety of ways, including nerve transfer and nerve grafting procedures. Despite the fact that surgical repair decision-making algorithms differ between centers, serial physical examinations are still performed at the majority of them [(12)]. By identifying the affected muscle groups, a thorough physical examination is possible pinpoint the lesion's location. However, the physical examination is insufficient to determine the injury's underlying anatomy, specifically whether a nerve rupture or root avulsion is present. A pan-plexus injury coupled with avulsion of the lower nerve root is the sole generally accepted indication for early intervention in NBPP. In patients who have brachial plexus injuries and hand weakness, it is crucial to determine whether the lower roots have sustained an avulsion injury. Any improvements in the recognition of lower trunk avulsion injuries would significantly improve the care of these patients, as this pathology cannot be easily predicted by clinical examination. The sooner surgical intervention is performed in NBPP, the better are the results. In patients with obstetric brachial plexus palsy (OBPP) with preganglionic lesions, neurotization results in faster functional recovery than nerve grafting reconstructive techniques [(13)].

Average age at first appointment in our study was 63.55±54.09; ranging from 4 to 180 days and the mean age at surgery was 9.93±7.42 months. This was near to results of **Gilbert *et al.*** in 2006 where an average age at surgery was 9.937.42 months, ranging from 1 to 24 months, despite this being an early microsurgical intervention at a relatively late age, which many authors agree that it is between 3-6 months [(14)]. This may be due to an absence of suitable health education, which causes parents to seek medical consultations late, resulting in delayed case referrals and, consequently, delayed surgical intervention.

In 28 patients (70%), the right side was involved, while the left side was involved in the other (30%). **Al Shishtawy** [(15)] discovered in a study of 24 infants with NBPP only three infants were left-sided and 21 were right-sided, indicating that the right side received more affection. **Mohasseb *et al*.** [(13)] discovered additional right-sided affection.

Intraoperative finding showed affection of all root with increased frequency of C5 avulsions and C6 rupture. Also **Mohasseb *et al*.** [(13)] study showed that love for all roots, specifically C5-T1, was the pathogenic pattern that was most frequently found intraoperatively. The C5 and C6 roots' affliction was the least prevalent pattern.

The most popular imaging technique is CT myelography used to detect avulsion and MRI as detected by **Somashekar *et al*.** [(6)] study, also our patient used MRI study in (55%) and CT myelography in (40%). The children's exposure to ionising radiation and the lumbar puncture both are issues with employing CT myelography in NBPP. In study of chow, CT myelography was 63%–72.2% sensitive in the detection of avulsion injuries in BPP [(5)]. CT myelography findings including pseudomeningoceles meaning avulsion injury and A rupture is indicated by the absence of nerve rootlets [(7)].

MR myelography is a relatively new method that eliminates the need for invasive procedures like lumber puncture and ionizing radiation [(6)]. **Somashekar *et al*.** [(6)] studies show that MR myelography has a sensitivity of 75% across the board and a specificity of 83% for detecting avulsion injuries. Our data showed that

imaging had a lower sensitivity and specificity for detecting avulsion injuries, with 66.7 and 37.5%, respectively. **Somashekar *et al*.** [6] found that imaging the sensitivity and specificity, respectively, were 70% and 66% for detecting avulsion injuries. In 2018, **Wade and colleagues** [16] published a study demonstrating the diagnostic effectiveness of MRI in patients who are adults and had sustained injuries to their brachial plexus. The overall MRI root avulsion diagnostic accuracy was 79%, while the accuracy for only 68% of cases were found to have a pseudomeningocele. While our study found that imaging had a diagnostic accuracy of 55%. **Smith *et al*.** [3] study found that while imaging had a 69% overall accuracy in detecting avulsion in NBPP, EDX had a 74% overall accuracy in detecting avulsion injuries.

According to the **Gad *et al*.,** [17] study, only 12 of the 19 avulsed nerve roots were detected by the MRI, which led to a reduction in the MRI's sensitivity, specificity, and precision in identifying preganglionic damage. The avulsion of 19 nerve roots was demonstrated by findings during surgery. During surgery, the ruptured nerve segments were found in 23 of the postganglionic (rupture) injury segments, whereas MRI detected only 14 of them. As a result, the MRI results for obstetric nerve rupture had a 60% sensitivity, a 99% specificity, and a 95% accuracy. In addition, our study found that the overall sensitivity was 66.7%, the specificity was 35.7%, and the accuracy was 45% in detecting rupture lesions at the root level.

EDX testing is safe and feasible for people of all ages [18]**.** Previous research found that EDX had a sensitivity of 19.5% and a specificity of 93.2% when it came to detecting avulsions; a subsequent study found that EDX had a sensitivity of 27.7% when it came to detecting avulsions [7, 19]**.** When it comes to the detection of nerve root avulsions using electrodiagnostics, **Smith *et al*.** [3] demonstrated not only a specificity of 90% but also an overall sensitivity of 31%. in contrast to our findings, which showed that EDX had a sensitivity of 100% overall but only a specificity of 50% for root avulsions.

There are no research done that compares overall imaging to EDX in the same patients as our study.

In the study by **Smith *et al*.** [3] when it came to detecting an avulsion, imaging had a sensitivity of 66%, which was significantly higher than EDX's detection rate of 31%. Despite this, EDX performed better than imaging in terms of overall specificity, with a score of 90% compared to 70% for imaging. The most striking differences were discovered in the lower roots, where EDX showed a specificity of 87.5% at C8 and 78.6% at T1. In comparison, the accuracy of imaging in identifying lower root avulsions at C8 was 29.4% and at T1 it was 57.1%, which demonstrates that EDX is a significantly a more focused approach to detecting avulsions in the lower roots, specifically at C8 and T1.

Our study found that EDX had a higher degree of sensitivity than imaging in the process of identifying an avulsion, 100% vs. 66.7% respectively. However, EDX outperformed imaging in terms of overall specificity, with 50% versus 37.5%, respectively. The lower roots showed the most noticeable differences, where EDX was sensitive at C8 and T1 at 83.3% and 75%, respectively. The imaging sensitivity at C8, 50% of avulsions in the lower root were detected and 75% at T1, indicating that EDX is a much more sensitive modality for detecting avulsions at the lower roots, C8 and T1.

Park *et al*. study [8] stated that clinical evidence of Horner mostly associated with preganglionic lesion of C8, T1. In our study EDX findings were consistent with clinical observation, and intra-operative findings, confirm avulsion of corresponding roots.

In conclusion, the use of EDX in the outpatient setting could aid in the detection of high sensitivity to lower plexus avulsions, possibly resulting in earlier interventions and better results.

Our finding was supported by **Hearn *et al*.** [20] study, which showed importance of EDX. Through SNC study of median nerve and EMG of deltoid in detecting upper plexus injures.

The results of **Spires *et al*.** showed that EDX assessment of nerve root lesions (pre- or post-ganglionic) has a high inter-rater reliability by two blinded, ABEM-certified electrodiagnosticians [21]**.**

According to **Vanderhave *et al*.** [7], the upper plexus, in particular, was where post-ganglionic lesions were most easily found using EDX studies. Comparative studies have shown that EDX testing in NBPP has higher diagnostic accuracy than neuroimaging techniques, particularly in terms of sensitivity and accurate preganglionic injury identification [3]**.**

Other research has demonstrated the predictive serial EDX testing's value in determining whether surgical repair is necessary or not. However, some researchers have questioned if EDX testing is accurate (and thus necessary) in NBPP [22, 23]**.**

Small sample sizes and a range of severity levels, and testing procedures for the patients included in the study are the first major limitations of this project (Lack of standardised protocol, inconsistent time between injury and assessment, a variety of technical equipment and operator skills, etc., make it more difficult to draw conclusions). However, we think that these data are helpful because of their distinctive presentation.

CONCLUSION

Imaging and EDX are not as precise as was previously asserted. Given that each test's strengths frequently compensate for its weaknesses of the others, the ideal workup for patients with NBPP is likely to include a variety of modalities. In the specific case of

locating lower nerve root avulsions, EDX outperforms imaging. Because NBPP with lower plexus avulsions is a well-established indication for early intervention, EDX can aid in identifying this pathology in the preoperative setting.

Conflict of interest: The authors declare no conflict of interest.

Sources of funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References:

1. **Gurewitsch D, Johnson E, Hamzehzadeh S *et al.* (2006):** Risk factors for brachial plexus injury with and without shoulder dystocia. American journal of obstetrics and gynecology, 194(2):486-92.
2. **Chauhan S, Rose C, Gherman R *et al.* (2005):** Brachial plexus injury: a 23-year experience from a tertiary center. American journal of obstetrics and gynecology, 192(6):1795-800.
3. **Smith W, Chang W, Yang J *et al.* (2018):** Comparative accuracies of electrodiagnostic and imaging studies in neonatal brachial plexus palsy. Journal of Neurosurgery: Pediatrics, 23(1):119-24.
4. **Pondaag W, Malessy J (2006):** Recovery of hand function following nerve grafting and transfer in obstetric brachial plexus lesions. Journal of Neurosurgery: Pediatrics, 105(1):33-40.
5. **Chow C, Blaser S, Clarke M (2000):** Predictive value of computed tomographic myelography in obstetrical brachial plexus palsy. Plastic and Reconstructive Surgery, 106(5):971-977.
6. **Somashekar D, Yang L, Ibrahim M *et al.* (2014):** High-resolution MRI evaluation of neonatal brachial plexus palsy: a promising alternative to traditional CT myelography. American Journal of Neuroradiology, 35(6):1209-1213.
7. **Vanderhave k, Bovid K, Alpert H *et al.* (2012):** Utility of electrodiagnostic testing and computed tomography myelography in the preoperative evaluation of neonatal brachial plexus palsy. Journal of Neurosurgery: Pediatrics, 9(3):283-289.
8. **Park H, Lee G, Kim I *et al.* (2017):** Brachial plexus injury in adults. The Nerve, 3(1):1-11.
9. **Somashekar K, Wilson J, DiPietro A *et al.* (2016):** The current role of diagnostic imaging in the preoperative workup for refractory neonatal brachial plexus palsy. Child's Nervous System, 32(8):1393-1397.
10. **Volpe A, Snowden M, Cheng W *et al.* (2016):** Risk factors for brachial plexus injury in a large cohort with shoulder dystocia. Archives of gynecology and obstetrics, 294(5):925-929.
11. **Abzug M, Kozin H (2010):** Current concepts: neonatal brachial plexus palsy. Orthopedics, 33(6):430-435.
12. **Wilson J, Chang W, Yang J (2018):** Prediction algorithm for surgical intervention in neonatal brachial plexus palsy. Neurosurgery, 82(3):335-342.
13. **Mohasseb F, Hassan M, Semaya E *et al.* (2019):** Evaluation of surgical outcomes of obstetric brachial plexus birth injury: clinical and electrophysiological study. Egyptian Rheumatology and Rehabilitation, 46(4):229-236.
14. **Gilbert A, Pivato G, Kheiralla T (2006):** Long-term results of primary repair of brachial plexus lesions in children. Microsurgery, 26(4):334-342.
15. **Al Shishtawy I (2003):** Prediction of functional outcome of obstetric brachial plexus palsy. Egypt Rheumatol Rehab, 30:625-632.
16. **Wade R, Itte V, Rankine J *et al.* (2018):** The diagnostic accuracy of 1.5 T magnetic resonance imaging for detecting root avulsions in traumatic adult brachial plexus injuries. Journal of Hand Surgery (European Volume), 43(3):250-258.
17. **Gad M, Hussein T, Omar M *et al.* (2020):** Role of MRI in the diagnosis of adult traumatic and obstetric brachial plexus injury compared to intraoperative findings. Egyptian Journal of Radiology and Nuclear Medicine, 51(1):1-7.
18. **Karakis I, Liew W, Darras T *et al.* (2014):** Referral and diagnostic trends in pediatric electromyography in the molecular era. Muscle & Nerve, 50(2):244-249.
19. **Terzis K, Novikov L (2005):** Radiological and electrophysiological detection of nerve roots avulsion in patients with birth-related brachial plexus paralysis. Seminars in plastic surgery, 19(1): 24-41.
20. **Hearn L, Pieper R, Yang S *et al.* (2022):** Implications of median sensory study to the thumb and deltoid/biceps motor unit recruitment on identifying C6 root avulsion in upper neonatal brachial plexus palsy. https://onlinelibrary.wiley.com/doi/full/10.1002/mus.27550
21. **Spires C, Brown M, Chang C *et al.* (2017):** Interrater reliability of electrodiagnosis in neonatal brachial plexopathy. Muscle & Nerve, 55(1):69-73.
22. **Rehm A, Thahir A (2020):** Letter regarding "Early electrodiagnosis in the management of neonatal brachial plexus palsy: A systematic review". Muscle & Nerve, 62(4):70-81.
23. **Heise O, Siqueira G, Martins S *et al.* (2007):** Clinical-electromyography correlation in infants with obstetric brachial plexopathy. The Journal of hand surgery, 32(7):999-1004.