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Review Article

Diagnostic accuracy of magnetic resonance imaging in post-traumatic brachial plexus injuries: A systematic review

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ABSTRACT

Computed Tomographic Myelography (CTM) is a gold-standard imaging test for evaluating the brachial plexus and has been used for a long time. Another imaging test more recently used is Magnetic Resonance imaging (MRI), which is also part of the plexus evaluation. The purpose of this study was to determine the accuracy of MRI in diagnosing post-traumatic injuries of the brachial plexus. We conducted a Systematic Review with cross-sectional studies of diagnostic accuracy. Studies with populations presenting post-traumatic brachial plexus injury, over 16 years old, both genders, and examined by CT Myelography and MRI were evaluated. The trial resulted in three studies that covered the inclusion criteria. The sample consisted of 46 participants. The tool Quality Assessment of Diagnostic Accuracy Studies (QUADAS-2) was used to evaluate the quality of the studies, and the software RevMan was used to identify the homogeneity of the studies that entered the analysis. The study was registered in PROSPERO under the number CRD42016041720. Studies showed moderate to high risk of bias, with low or very low quality of evidence due to the limitations of studies and differences in comparing the assessment groups. The heterogeneity of the studies made it impossible to create *meta*-analyzes. MRI has been an excellent test for assessing traumatic brachial plexus injuries in clinical practice; however, the quantitative analysis of studies identified a lack in methodological rigor. Future studies should focus on methodological rigor, providing more accurate assessments of modalities and their benefits.

1. Introduction

The brachial plexus is composed of the C5, C6, C7, C8 and T1 spinal nerves, being responsible for sensitive and motor innervation of the upper limbs [1]. Because of its anatomical relations with mobile structures such as the neck and upper limbs, it has a great propensity to be affected during high impact accidents [2,3]. Brachial plexus injuries related to car accidents are a major public health problem, such as in Brazil where the costs come to be the equivalent of 1.2% of gross domestic product (GDP) [4], and they mainly affect economically productive people as they particularly involve motorcyclists [5–9].

The occurrence of avulsion injuries or stretching of the brachial plexus is frequent in car accidents [2,6]. Such injuries can be preganglionic located closely to the dorsal root ganglion or postganglionic located distal to the dorsal root ganglion. They can lead to motor and/or sensitivity, temporary or permanent dysfunction, which can be either recovered spontaneously or by means of various microsurgical procedures [10].

The brachial plexus presents great anatomical complexity. Thus, in addition to clinical evaluation, imaging methods are of utmost importance to complement the diagnosis, both in location and in characterizing the injury type that affects this region [11]. The distinction between proximal injuries or preganglionic and distal or postganglionic is one of the most important prognostic factors, directly determining the best treatment to be indicated [12].

Computed tomographic myelography (CTM) is an imaging test which has been used for a long time in diagnosing post-traumatic injuries, and has many advantages such as greater ease in evaluating adjacent fractures and detecting preganglionic injuries. Its limitations include its invasive nature, the use of ionic contrast agents, and the use of ionizing radiation [13].

Another more recent imaging test is Magnetic Resonance Imaging (MRI). It is a non-invasive test without ionizing radiation and provides good assessment of postganglionic injuries [13]. A detailed evaluation

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of the brachial plexus is possible using MRI and shows multiplanar and high resolution ability, providing better anatomical definition [14]. The nerves and perineural fat are easily identified by their differences in signal intensity, which provides an intrinsic contrast between these structures [14]. In addition, MRI has the additional advantage of visualizing the distal nerves of the vertebral foramina [14,15].

MRI can also identify: hematomas, edemas, fibrosis, disruption of scalene muscles, pseudomeningoceles, brachial plexus thickening and distortion with the presence of masses indicating the formation of post-traumatic neuroma. Nerves without injuries appear as linear structures with a hypo intense signal, surrounded by fat in all sequences. The injury is classified as radicular avulsion in the absence of the hypo intense signal of the root surrounded by fat within the neural foramina, or when the anterior and posterior roots are clearly identified as being detached from the medulla. Radicular avulsions occur more frequently in the C7 and C8 roots, and may be related to dura ruptures with pseudomeningoceles formation that are cystic dilations of the thecal sac [12,14,15].

Given what has been exposed and the lack of studies confirming the accuracy of MRI in this population, a systematic review was developed in order to help fill the gap left in the literature through evidence-based health.

The hypothesis of this research is that magnetic resonance imaging is as accurate as computed tomographic myelography (CT myelography) in evaluating post-traumatic brachial plexus nerve injuries. Thus, the goal was to conduct a systematic review with possible *meta*-analysis to verify the accuracy of magnetic resonance in diagnosing post-traumatic nerve injuries in the brachial plexus.

1.1. Question based on P.I.C.O

Is MRI accurate in diagnosing post-traumatic brachial plexus nerve injuries when compared to computed tomographic myelography (CT myelography)?

2. Materials and methods

A systematic review with cross-sectional studies of diagnostic accuracy was conducted. The research was developed in the Motor Control Laboratory (Laboratório de Controle Motor – LACOM) and the Cardiopulmonary Laboratory (Laboratório Cardiopulmonar – LACAP) of the Universidade Federal de Pernambuco (UFPE). Inclusion criteria for the study were: studies whose population consisted of patients with suspected post-traumatic brachial plexus nerve injury (pseudomeningoceles, pre and postganglionic injuries and root injury), over 16 years old, of both genders and who have had both imaging tests (CT myelography and MRI); and as exclusion criteria: studies with patients who underwent surgical treatment with hemodynamic instability and/or were hospitalized, and literature reviews.

2.1. Database search

The study searches were conducted in the following electronic databases: Cochrane Central Register of Controlled Trials (CENTRAL), MEDLINE (via PubMed), Latin American and Caribbean Health Sciences Literature (LILACS) (via BIREME), Scielo, PEDro, CINAHL (via CAPES), Web of Science, Scopus and the IBICT database of theses and dissertations. Potentially relevant titles and abstracts found in the database search were stored, and a further detailed analysis of the full text was performed. There were no linguistic restrictions or year of publication restriction to minimize possible publication bias. Combined descriptors and keywords were used for search strategy to capture relevant articles related to the topic; such as: "Brachial plexus"; "Neuroimaging"; "Magnetic Resonance Imaging"; "Tomography; X-Ray computed"; "Nerve injuries"; "Accuracy"; "Diagnostic imaging"; "Techniques and procedure"; "Diagnosis"; "Sensitivity"; "Specificity"; "predictive value of tests" and "ROC curve".

2.2. Study selection

Selected studies were included according to the inclusion and exclusion criteria of this research and which are described in the flowchart according to PRISMA. Concerning the analysis, article selection was conducted by two independent evaluators, with a third evaluator for deciding possible contradictions in selecting the articles. The results were then described in a specific form for registering the studies and an Excel table.

2.3. Outcomes

Regarding the study outcomes, the following were selected: sensitivity, specificity, positive predictive value, negative predictive value, positive likelihood ratio, negative likelihood ratio and ROC curve of the exams mentioned for diagnosis of post-traumatic brachial plexus nerve injuries.

2.4. Qualitative and quantitative analysis

The Quality Assessment of Diagnostic Accuracy Studies (QUADAS 2) [16] tool was used for analyzing the evidence level of studies, the Cochrane Handbook tool for analyzing the risk of bias and RevMan program [17] for heterogeneity analysis. The qualitative data for characterizing the studies was statistically standardized and described in Tables 1 and 2, and then a heterogeneity analysis was performed in RevMan software. The systematic review was recorded in PROSPERO under number CRD42016041720.

3. Results

In total 1330 studies were found through the databases: Pubmed (n = 654), Cinahl (n = 436), Lilacs (n = 14), Scielo (n = 24), Pedro (n = 12), Scopus (n = 6) and Web of Science (n = 184). Duplicate studies were excluded (n = 19), and 1286 were subsequently excluded by title and abstract, with 25 selected articles remaining for full reading. From these, 22 articles were excluded due to being different studies using other imaging types or studies only reporting surgical procedures. Thus, three articles [18–20] were included in the quality synthesis. From these selected articles, 2 had been found in Pubmed [18,19] and one article [20] in Scielo. The study characteristics are presented in the flowchart (Fig. 1). The included studies were conducted in Italy [18], Japan [19] and South Africa [20]. All were cross-sectional using magnetic resonance (MRI) and computed tomography myelography (CT myelography) imaging techniques in post-traumatic brachial plexus injury patients. The participants' ages ranged from 16 to 60. Calibration of the MRI and CT myelography devices were reported in the studies (Table 1). The total study sample was 46 patients. The most frequently found inclusion criteria were: patients with traumatic brachial plexus injury, who had been submitted to MRI and CT myelography and were followed for a certain period. The three selected articles had the objective of determining the diagnosis accuracy (sensitivity, specificity) through resonance by evaluating brachial plexus injuries (Table 2).

3.1. Sensitivity outcome

Regarding the sensitivity of imaging tests, one of the articles [18] described MRI as sensitive in detecting nerve root integrity in 89%, while another article [19] showed that sensitivity in detection of pseudomeningoceles was 88%, in addition to the sensitivity in detecting root injury being 91%. The third article [20] concluded that the sensitivity for detecting pseudomeningoceles and preganglionic injuries was also high, about 82% in MRI (Table 2).

Table 1
Characteristics of selected studies.

First Author/ Year/Country	Inclusion Criteria	Age	Total of sample (Gender)	Study design	Objective of the study	Tests Images used in the study	MRI Parameters	CT Parameters
Gasparotti et al. [18] Italy	Brachial plexus traumatic injury January 1993 and December 1994	17 to 46 years old	20 patients (18♂ and 2♀)	Cross-sectional	Determining the accuracy of the diagnosis through MRI myelography	- MRI myelography; -Conventional myelography; - CT myelography (Between 1–9 months after injury).	- MRI myelography: 1.5-T with constructive interference in technical steady state (CISS) 1 mm in axial	- CT myelography. Contiguous axial scans of 2 mm thickness were obtained with a high reconstruction algorithm.
Nakamura et al. [19] Japan	Brachial plexus injury 1993 and 1996.	16 to 38 years old	10 patients (9♂ and 1♀)	Cross-sectional	Compare the three techniques	- MRI myelography; -Conventional myelography; -CT	- MRI myelography (1.5 T Sigma (GE Medical, Milwaukee, Wisconsin) and a cervical surface coil, T2 wted	-CT held 2 h after myelography. The CT images were obtained in each nerve root C4 to T1 with three slices and slice gap of 3 mm.
Linde et al. [20] South Africa	Brachial plexus traumatic injury. From May 2012 to June 2014.	19–43 years old	16 patients (15♂and 1♀)	Cross-sectional	Compare the sensitivity and specificity of the MRI with CT myelography	-MRI; -CT myelography.	- MRI using Siemens MAGNETOM Symphony 1.5Tesla eco scanner. Use the coil spinal cord, 256 × 256 matrix, and 260 mm field of view. T2-weighted images(TR = 1500, TE = 126) slices with a thickness of 1 mm were obtained in three orthogonal planes.	- CT myelography. Siemens Somatom definition AS 128 − slices (CT) of scanner with: 1 mm reconstructions × 1 mm.

Table 2
Outcomes.

Author/Year	Total of sample	Accuracy/Precision True value being measured	Sensitivity (IC 95%) Truly Positive Individuals (patients)	Specificity (IC 95%) Truly Negative Individuals (healthy)	PPV Patients among the positives of the test	NPV Healthy among the negatives of the test	PLR Likelihood of patients	NLR Likelihood of healthy	RC	Conclusion
Gasparotti et al. [18]	20	Diagnostic accuracy in the nerve root evaluation: MRI myelography 92%	Nerve Root Integrity: MRI myelography showed Sensitivity of 89%	Nerve Root Integrity: MRI myelography showed Specificity of 95%	33 true-positive results in MRI myelography	58 true-negative results in MRI myelography	3 false-positive results With weak nerve visibility by MRI myelography	4 False-negative results in MRI myelography	–	MRI myelography shows the traumatic injuries of the proximal portion of the brachial plexus
Nakamura et al. [19]	10	Nerve root injury: - MRI myelography 92%; - Conventional myelography 81%; - CT 92% Detecting pseudomeningoceles: - MRI myelography 98%; - Conventional myelography 93%; - CT 99%.	Nerve root injury: - MRI myelography 91%; - Conventional myelography 54%; - CT 94%. Detecting pseudomeningoceles: - MRI myelography 88%; - Conventional myelography 56%; - CT 100%.	Nerve root injury: -MRI myelography 92%; -Conventional myelography 94%; -CT 91%. Detecting pseudomeningoceles: - MRI myelography 100%; - Conventional myelography 100%; - CT 98%	–	–	–	–	–	MRI myelography showed many advantages over conventional CT and myelography
Linde et al. [20]	16	–	Detecting preganglionic and pseudomeningoceles injuries: - MRI showed 82% compared to CT myelography.	Detecting preganglionic and pseudomeningoceles injuries - MRI showed 100% compared to CT myelography.	Detecting pseudomeningoceles injuries: - MRI showed 100% (PPV) compared to CT myelography.	Detecting preganglionic and pseudomeningoceles injuries: - MRI showed 71% (NPV) compared to CT myelography.	–	There were no false positive	–	MRI was equally sensitive when compared to CT myelography in detecting pre ganglionic injuries due to avulsion of nerve roots

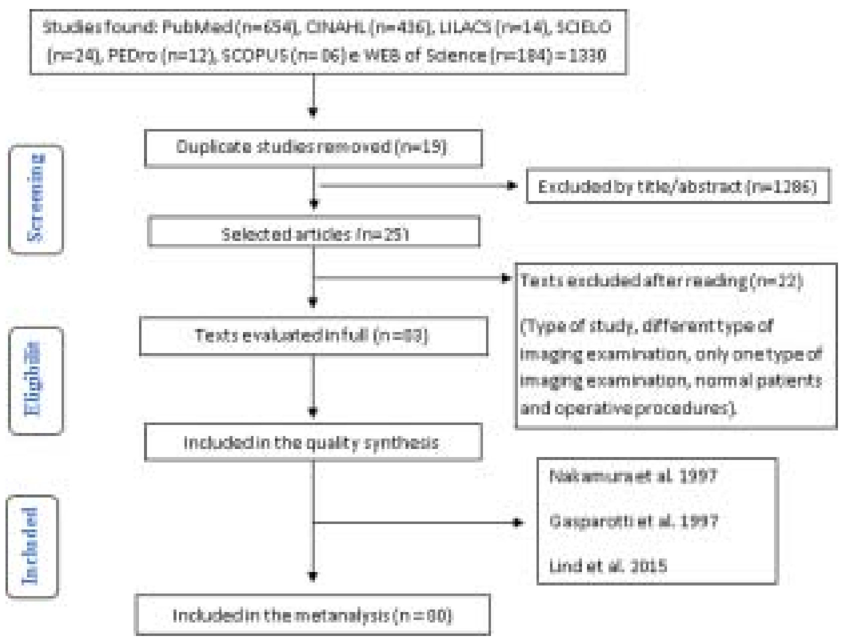

Fig. 1. Search and selection of studies for systematic review in accordance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

3.2. Specificity outcome

MRI showed 95% specificity when the nerve root integrity was observed in one study [18], and specificity in another study [19] was 92% for nerve root injury detection and 100% in detecting pseudomeningoceles. The third study [20] showed 100% specificity in detecting pseudomeningoceles and preganglionic injuries (Table 2).

3.3. Methodological quality of the selected articles

Inclusion criteria were poorly defined in all selected articles [18–20] since there was no proportionality of gender and there was an age disparity (16–61 years old). All studies [18–20] were classified as having high risk of bias for not reporting the sample size calculation and allocating individuals between examinations.

There was masking during the evaluation of radiological examinations in two studies. All measurements of the evaluation test and the gold-standard were held among the participants in the three studies and by the same examiner [18–20] (Fig. 2). All studies [18–20] held their samples throughout the analysis, however, there were no reports of loss and/or analysis by intention to treat (Table 3).

Based on the quality of evidence from the studies (Quadas) (Table 3), there is risk bias diversity from below, and obscure to high risk in the studies found. One of the three articles [19] presented more methodological flaws, which further compromised the sample effect size of this review. Another recently published study [20] with only three bias obscure items showed far superior quality in study design to the other two (Fig. 2).

4. Discussion

This is the first systematic review attempting to approach the accuracy of MRI in patients with traumatic injuries of the brachial plexus compared to CT myelography. Moreover, despite the low methodological rigor found in the studies, MRI has been considered a fairly accurate imaging technique by radiologists in their clinical practices.

In all three studies [18–20] of this systematic review, the gold-standard test evaluators were the same who evaluated the comparison test, and this can lead to an inspection bias. In order to avoid this type of bias, it is required that the study should be masked and that both tests be interpreted without knowledge of the patient's clinical

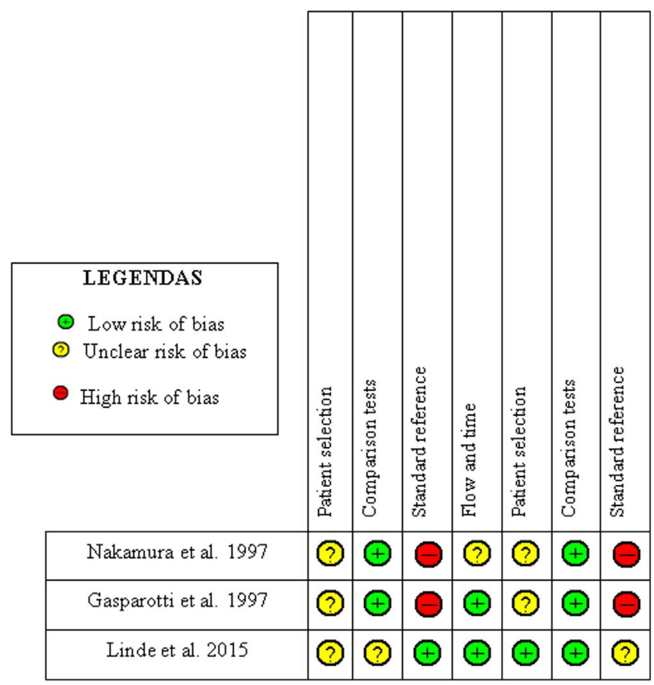

Fig. 2. Analysis of the risk of bias of the studies.

characteristics or the result of another test to ensure that only the test's diagnostic contribution is being assessed. The evaluators had no knowledge of the clinical and intraoperative findings in two of the studies [18,20], and the third article [19] was not well explained.

None of the articles [18–20] clearly showed the time between applying the gold standard and the test under evaluation. The time between test application may not extend to the point of changing the degree of disease severity. There was also a very wide range between the date of the injury and the imaging test. For example, in one study [19] this time ranged from 1 to 30 months.

Well-defined inclusion criteria were not established in order to homogenize the sample in the studies [18–20]. The selection criteria were very limited, as well as the study design and comparison of clinical characteristics of patients included in each study. Studies with very

Table 3
Quadas Tool.

N° Items	Yes	No	Unclear
1 Was the spectrum of patient's representative of the patients who will receive the test in practice?			
2 Were selection criteria clearly described?			
3 Is the reference standard likely to correctly classify the target condition?			
4 Is the time period between reference standard and index test short enough to be reasonably sure that the target condition did not change between the who test?			
5 Did the whole sample or a random selection of the sample, receive verification using a reference standard of diagnosis?			
6 Did patients receive the same reference standard regardless of the index test result?			
7 Was the reference standard independent of the index test (i.e., the index test did not form part of the reference standard)?			
8 Was the execution of the index test described in sufficient detail to permit replication of the test?			
9 Was the execution of the reference standard described in sufficient detail to permit its replication?			
10 Were the index test results interpreted without knowledge of the results of the reference standard?			
11 Were the reference standard results interpreted without knowledge of the results of the index test?			
12 Were the same clinical data available when test results were interpreted as would be available when the test is used in practice?			
13 Were uninterpretable/intermediate test results reported?			
14 Were withfrawals from the study explained?			

Source: Oliveira MRF, Gomes AC, Toscano CM − 2011.
Fonte: Oliveira MRF, Gomes AC, Toscano CM − 2011.

small samples are considered to have publication bias, which was found in all three studies [18–20] included in our systematic review. Evidence from the presented studies should be analyzed with caution, since only three studies were found, and these totaled 46 patients, but was the only evidence found. Another bias found was the fact that two [18,19] of the three studies did not use the Kappa index to evaluate the agreement between evaluators on a test.

Another point was the difference in the parameters of radiological examinations, also known as measurement bias. Selection bias was also present, since all included studies [18–20] had retrospective tests. Statistical analysis of any of the included cross-sectional studies presented the confidence interval odds ratio and/or roc curve, which leads to further challenge the results.

Despite the high sensitivity and specificity found in these studies, it is important to note that all the articles included in this systematic review showed a high or uncertain risk of bias to methodological criteria, as mentioned above. These criteria must be met by the researchers to ensure the reliability and reproducibility of results obtained in diagnostic accuracy studies. Therefore, future studies with appropriate methodological quality based on QUADAS (Quality Assessment of Diagnostic Accuracy Studies) [19] should be developed to show the accuracy of magnetic resonance in the diagnosis of post-traumatic brachial plexus injury when compared to computed tomography myelography.

5. Conclusion

There is no evidence in the studies found regarding the accuracy of nuclear magnetic resonance in relation to myelotomography, which makes the study inconclusive. Its use is simple and has positive results, and the recommendation is to conduct more robust studies to prove the accuracy in the literature.

Conflict of interest

There was no conflict of interest or financing.

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