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Original article

The value of preoperative examination and MRI for the diagnosis of graftable roots in total brachial plexus palsy

Évaluation clinique préopératoire couplée à l'IRM pour le diagnostic de racines greffables dans les paralysies complètes du plexus brachial

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ABSTRACT

The objective of our study was to evaluate the reliability of clinical examination paired with MRI to determine whether one or both of the superior C5 and C6 roots are graftable in cases of complete brachial plexus palsy. We conducted a retrospective study from 2013 to 2018. Twenty-seven patients who had total brachial plexus palsy and were more than 18 years of age were included. The Horner and the Tinel signs, potential phrenic nerve injury and anterior serratus muscle function were investigated. MRI with STIR 3D sequence was performed in each patient. Surgical exploration of the C5 and C6 roots confirmed if they were avulsed and, if found to be ruptured, assessed the possibility of grafting them. Serratus anterior testing had a specificity and a positive predictive value of 100% and diagnostic accuracy of 78%. The presence of the Tinel sign had a sensitivity and a negative predictive value of 100% and diagnostic accuracy of 93%. MRI had a sensitivity, specificity and diagnostic accuracy of 89%. A decision tree to determine whether or not C5 and/or C6 can be grafted has been developed. Its sensitivity and negative predictive value were 100%. This study provides initial validation of this diagnostic method for the diagnosis of graftable C5 and/or C6 roots. It could help prevent needless cervical exploration.

Mots clés :
Paralysie du plexus brachial
IRM
Exploration cervicale
Greffe

RÉSUMÉ

L'objectif de notre étude était d'évaluer la fiabilité de l'examen clinique couplé à l'IRM pour déterminer si au moins une des racines supérieures C5 et C6 sont greffables dans les paralysies complètes du plexus brachial. Nous avons mené une étude rétrospective avec un recueil de données de 2013 à 2018. Vingt-sept patients ont été inclus. Les critères d'inclusion étaient : une paralysie complète du plexus brachial et un patient de plus de 18 ans. Un signe de Claude-Bernard-Horner, un syndrome irritatif, une paralysie du muscle serratus anterior à l'examen clinique et une paralysie phrénique à la radiographie de thorax étaient cherchés. Une IRM en séquence STIR 3D était pratiquée pour chaque patient. L'exploration chirurgicale des racines C5 et C6 objectivait leur avulsion ou non et, en cas de rupture, la possibilité de les greffer. Le *testing* du serratus anterior avait une spécificité et une valeur prédictive positive de 100 % et une efficacité diagnostique de 78 %. Le syndrome irritatif avait une sensibilité et une valeur prédictive négative de 100 % et une efficacité diagnostique de 93 %. L'IRM avait une sensibilité, une spécificité et une efficacité diagnostique de 89 %. Un arbre décisionnel permettant de valider la possibilité de greffer

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C5 et/ou C6 a été élaboré avec une sensibilité et une valeur prédictive négative respectives de 100 %. Cette étude valide l'intérêt de cette méthode pour le diagnostic de la présence d'une racine greffable C5 et/ou C6. Dans les lésions complètes du plexus brachial, elle pourrait permettre d'éviter la morbidité d'une exploration cervicale.

1. Introduction

In adult cases of supraclavicular complete brachial plexus palsy, the lesions can be preganglionic (avulsion) or postganglionic (rupture). In the first case, there is no nerve stump since the root was torn off its insertion at the spinal cord. In the second case, surgical dissection can identify a distal nerve stump. Whether an avulsion or rupture, both have significant therapeutic consequences. For avulsions, the treatment mainly consists of nerve transfers, since direct microsurgical repair of the avulsed root at the spinal cord has not yet been proven effective [1]. For ruptures, the presence of a proximal nerve stump opens up the possibility of nerve grafting if a healthy area can be identified by debridement.

One of the goals of the initial work-up for complex brachial plexus injuries is to determine whether the C5 and/or C6 roots can be grafted, in order to adapt the surgical plan. Assessing patients with this type of injury requires a detailed clinical examination, electroneuromyography (ENMG) and imaging. While clinical signs and ENMG have been identified that are suggestive of an avulsion, they are not sufficiently reliable by themselves [2]. Various imaging techniques have been developed [3,4], particularly CT myelography and MRI. Pairing of the clinical examination with CT myelography has satisfactory sensitivity and specificity to differentiate between nerve root avulsion and rupture [5].

However, CT myelography is an invasive imaging modality. There is currently no way to predict satisfactorily whether a nerve root can be grafted or not, especially in cases of rupture. The aim of our study was to evaluate the reliability of clinical examination paired with MRI in diagnosing whether or not graftable C5 and/or C6 roots are present in the context of complete brachial plexus palsy in adults.

We hypothesized that a clinical examination paired with MRI is a reliable and reproducible method to determine preoperatively whether the C5 and/or C6 roots are graftable in the context of complete brachial plexus palsy in adults.

2. Patients and methods

We conducted a retrospective study of relevant cases performed between January 2013 and January 2018 at our facility. Twenty-seven patients aged 19 to 60 (mean 36 years) with complete brachial plexus palsy were included (Table 1). There were 4 women and 23 men.

A clinical and paraclinical examination was carried out in all patients to look for Horner and Tinel signs, detect phrenic nerve palsy injury and test serratus anterior function (protraction test [5]). A protraction test was considered to be positive if it reached at least 4 points on the MRC scale (Medical Research Council).

All patients had undergone a preoperative MRI (Siemens Aera 1.5 T) with Sagittal T2, Axial T1, Axial T2 Dixon, STIR 3D sequences to evaluate whether the C5 and/or C6 roots were present, thus whether they were avulsed or not (Fig. 1).

Surgical exploration of the C5 and C6 roots was performed through a supraclavicular approach. After opening the platysma and isolating the omohyoid, the phrenic nerve was identified and stimulated with 0.2 mA to verify its function. Next, the C5 and C6

Table 1
Characteristics of the 27 patients in our cohort who had complete brachial plexus palsy.

						Intact nerve roots	
Patient (No.)	Age (years)	Tinel sign	Horner sign	Protraction test	Phrenic nerve	MRI	Intraoperative
1	20	+	–	+	+	C5	C5
2	35	–	–	–	+	–	–
3	35	–	–	–	+	–	–
4	55	+	–	–	+	C5 & C6	C6
5	32	+	–	–	+	C5 & C6	C5
6	37	–	–	–	+	–	–
7	46	–	–	–	+	–	–
8	25	+	–	+	+	C5	C5
9	25	+	–	–	+	C5	C5
10	26	+	–	–	+	C5	–
11	37	+	–	–	+	C5	C5
12	50	–	–	–	+	–	–
13	19	+	–	–	+	C5 & C6	C5 & C6
14	26	–	–	–	+	–	–
15	33	–	–	–	+	C5 & C6	–
16	56	+	–	–	+	–	–
17	39	+	–	+	+	C5	C5
18	51	+	–	–	+	C5	C5
19	24	+	–	+	+	C5 & C6	C5 & C6
20	60	+	–	+	+	–	C5
21	15	+	–	+	+	C5 & C6	C5 & C6
22	38	+	–	+	+	C5	C5 & C6
23	33	+	–	+	+	C5 & C6	C5 & C6
24	31	+	–	+	+	C5	C5
25	43	+	–	+	+	C5	C5
26	43	–	–	–	+	–	–
27	21	+	–	+	+	C5	C5

+: present; –: absent.

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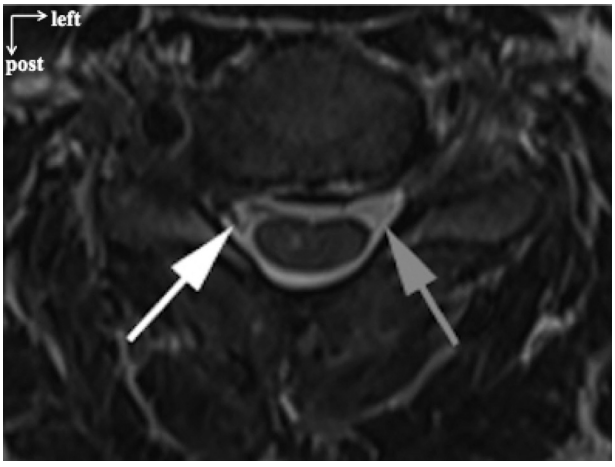

Fig. 1. Avulsion of left C6 root on MRI. The anterior and posterior rootlets are missing (grey arrow). On the right side (normal root), the anterior and posterior rootlets are clearly visible (white arrow).

Fig. 2. Cross-section of C5 and C6 roots showing several fascicles, evidence of the possibility of a nerve graft. Lat: lateral; dist: distal.

roots were identified and dissected as far as the intervertebral foramen, if needed. Once the root had been isolated, the neuroma was cut back until a healthy area was visible. A healthy area was defined as the presence of fascicles over the entire cross-section of the cut (Fig. 2). If the last cross-section of the cut was smooth, hemorrhagic and without fascicles, the nerve was considered fibrous and not graftable.

A statistical analysis was performed on the results of the clinical examination, MRI and cervical surgical exploration. Qualitative variables were described by their percentage. The sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) were calculated using the following equations: sensitivity = TP/(TP + FP), specificity = TN/(TN + FN), PPV = TP/(TP + FP), NPV = TN/(TN + FN) where TP = true positives, TN = true negatives, FP = false positives, FN = false negatives. The diagnostic accuracy corresponded to the percentage of correct preoperative diagnoses — whether a graftable nerve root was present or not — among all the results obtained for an examination, thus (TP + TN)/total number of patients. The relationship between the clinical testing and assorted variables was evaluated using the Chi-square test for trend. These tests were carried out with the software packages R version 3.5.0 and RStudio version 1.1.453 (R Foundation for Statistical Computing, Vienna, Austria). A 5% threshold was used for statistical significance.

Table 2
Sensitivity, specificity, positive and negative predictive values and diagnostic accuracy of the various examinations on the patients in our cohort.

	Sensitivity	NPV	Specificity	PPV	Diagnostic accuracy
Tinel sign, %	100	100	80	89	93
Protraction test, %	65	63	100	100	78
MRI, %	89	80	89	94	89

3. Results

No patients had Horner sign or radiographic signs of phrenic nerve injury (Table 1). Consequently, the sensitivity and specificity of these two criteria was not determined.

The serratus anterior test was positive in 11 of the 27 patients (41%) (Table 1). All of them (100%) had a graftable C5 root, while 4 patients (36%) also had a graftable C6 root. The serratus anterior muscle could be stimulated intraoperatively in 13 of the 27 patients (48%). Among the 16 patients (59%) with a negative serratus anterior test, the muscle could be stimulated electrically in 2 cases (13%) and a graftable C5 root was identified during surgical exploration in 5 cases (31%). In these same patients, MRI showed no evidence of a graftable root in 8 cases (50%). Thus serratus anterior testing had a specificity of 100% and a diagnostic accuracy of 78% (Table 2). There was a very strong relationship between a positive serratus anterior test and intraoperative electrostimulation ($P < 0.0001$). There was also a strong relationship between a positive clinical test and the presence of a graftable C5 root ($P < 0.001$). However, no relationships were identified for the C6 root.

Nineteen patients (70%) had a Tinel sign (Table 1). Among them, 17 (89%) had at least one graftable root found on MRI and 17 (89%) had at least one graftable root found during the surgical procedure. Of the 19 patients with a Tinel sign, MRI and surgical exploration found at least one graftable root in 16 cases (84%). Thus, the Tinel sign had a sensitivity of 100% and a diagnostic accuracy of 93% (Table 2).

MRI revealed no graftable roots in 9 patients (33%), which was consistent with the intraoperative exploration in 4 cases (44%) (Table 1). MRI correctly identified the graftable root(s) in 13 of 18 cases (72%). Thus its sensitivity and specificity was 89% with a diagnostic accuracy of 89% (Table 2).

Using these findings, we prepared a decision tree to help us confirm preoperatively whether or not C5 and/or C6 are graftable (Fig. 3). This decision tree had a sensitivity of 100%, specificity of 90%, PPV of 94%, NPV of 100% and diagnostic accuracy of 96%.

4. Discussion

The possibility of knowing whether a nerve root is graftable is an important piece of information that may help us to avoid needless cervical surgical exploration and to specify the proposed surgical strategy to the patient [5].

To our knowledge, our study is the first to evaluate the efficacy of a clinical examination paired with MRI results for the determining whether a graftable nerve root is present. Pairing the clinical examination with MRI allowed us to use a non-invasive, non-irradiating imaging modality without contrast product injection. By itself, MRI has not been shown to be beneficial [6–8]. Thus it was possible to determine whether or not C5 and/or C6 could be grafted with a sensitivity and negative

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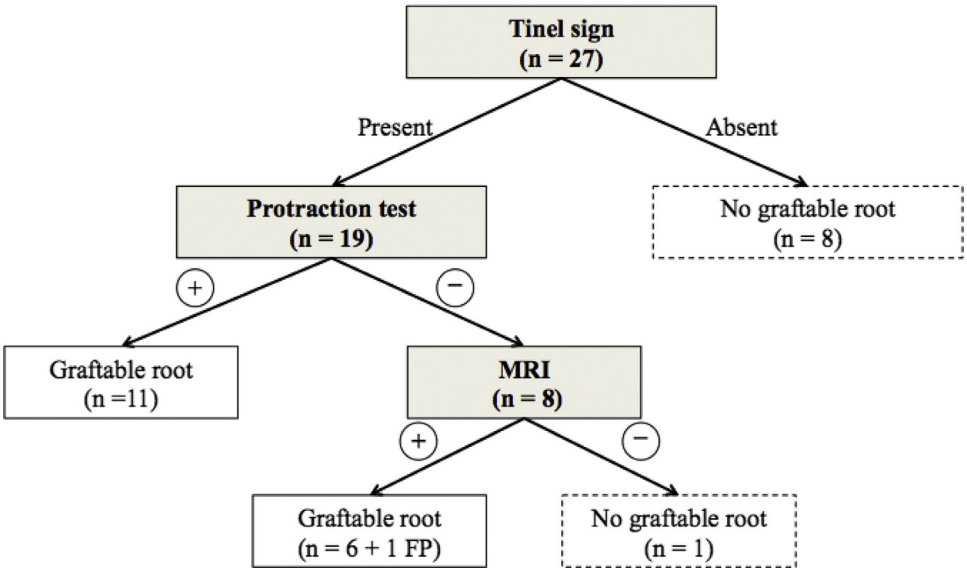

Fig. 3. Decision tree for the preoperative diagnosis of whether a graftable C5 and/or C6 nerve root is present. When applied to the 27 patients in our study cohort, only one patient would have undergone a needless cervical exploration (FP: false positive) and none would have missed a useful one (no false negative).

predictive value of 100%. In addition, our method allowed us to analyze C5 and C6 together independently of other roots. Lastly, based on our statistical analysis, we set up a decision tree (Fig. 3) to indicate when a surgical exploration is not necessary since neither C5 nor C6 are graftable. By applying the therapeutic reasoning of our decision tree to our patient cohort, the treatment decision could have been taken without MRI in 17 patients (70%). Also, thanks to the decision tree, only 1 patient out of the 10 who did not have a graftable nerve root would have undergone needless cervical exploration (one false positive). Furthermore none of the patients who had a graftable root would have missed a useful exploration (no false negative).

Other studies [5,9] have proposed diagnostic methods to evaluate whether nerve grafting is feasible (Table 3). Bertelli et al. [5] proposed an assessment method based on the results of CT myelography and clinical findings. Our new method appears to be a relevant alternative to the Bertelli one, since its diagnostic accuracy for C5 is comparable (96.8% versus 93%) and better for C6 (89% versus 84.3%). Addosooki et al. [9] proposed a score to determine whether the C5 root can be grafted based on the results of the clinical examination, ENMG, myelography and intraoperative appearance of the roots in a 36-patient case series. Contrary to our study, their cohort was heterogeneous with cases of both partial and complete palsy. The correlation between the Tinel sign and possibility of grafting the C5 root (78% sensitivity and 56% specificity) was not as strong as in our study. Unlike the decision tree proposed in our study, the score does not consider the C6 root and does not eliminate the need for surgical exploration since intraoperative observations are needed to calculate some items. Also, by not using the protraction test, the preoperative examination is missing a significant and reproducible parameter (as shown in our study), while the use of ENMG is debatable because its reliability is operator dependent. Lastly, the use of myelography, which is an invasive and irradiating modality, is a limitation for the preoperative diagnosis in our opinion.

Several studies have evaluated the benefits of CT myelography for detecting whether a nerve root is avulsed or ruptured [10–12]. Marshall et al. [10] found a correlation between the CT myelography findings and the surgical exploration in 75% of cases. They highlighted the better results for the C5 and C6 roots but without statistical support, contrary to our study. Yamazaki et al. [12] found a 100% sensitivity and 96% specificity with a diagnostic accuracy of 98%. However, contrary to the MRI used in our study, CT myelography is an invasive examination, which is not free of complications [8,13,14].

Other teams have compared the results of MRI and surgical exploration to evaluate the quality of the preoperative diagnosis of nerve root lesions. For Wade et al. [6], the MRI findings were confirmed by the surgical exploration in only 79% of cases and in 52% of cases for Carvalho et al. [7]. However, contrary to our study, no statistical validation or clinical comparison was carried out. Lastly, certain teams prefer doing MRI myelography as the results appear similar to CT myelography for the diagnosis of nerve root lesions [3,15–18]. However, the use of a contrast product makes this an invasive examination. In that case also, no clinical study was done.

While the various imaging modalities mentioned above are effective for differentiating between nerve root avulsion and rupture, contrary to our method, they do not determine whether a nerve root can be grafted, unless it is avulsed.

Our original research has some limitations. The number of patients included was small but comparable to the Bertelli et al.

Table 3
Results for the three studies evaluating a diagnostic method to determine whether or not a nerve root can be grafted.

Authors	Imaging modality	*n*	Nerve root	Se	Sp	Diag. acc.
Bertelli et al. (2006)	Clinical exam + CT myelography	32	C5	–	–	0.97
			C6	–	–	0.89
Addosooki et al. (2008)	Score based on clinical exam, myelography, EMG and intraoperative findings	36	C5	1.0	0.94	–
Our study (2019)	Clinical exam + MRI: decision tree	27	C5 and/or C6	1.0	0.90	0.96

CT: computed tomography; Diag. acc.: diagnostic accuracy; EMG: electromyography; MRI: magnetic resonance imaging; *n*: number of patients included; Se: sensitivity; Sp: specificity.

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study [5]. This may explain why none of the patients had Horner sign or phrenic nerve palsy. Note that the Horner sign is not always present even in cases of inferior nerve root avulsion and can spontaneously regress before the initial clinical examination [19]. As for phrenic nerve palsy, this nerve has variable innervation with fibers from the C3 and C4 roots [20], which explains the absence of lesions even when the C5 root is avulsed. In addition, the use of a chest X-rays helps to confirm the absence of phrenic nerve palsy with a NPV of 93%, sensitivity of 90% and specificity of 44% [21].

We limited our study to analyzing the C5 and C6 roots. The C7, C8 and T1 roots are generally not the target of nerve grafting in adults [22], thus the diagnostic interest of possible grafting has no therapeutic consequences in this case.

Lastly, for the MRI analysis, the intra-observer and inter-observer agreement were not determined.

5. Conclusion

This study validates the benefit of pairing a clinical examination with MRI for determining preoperatively whether a graftable C5 and/or C6 root is present. Additional studies on a large number of patients will be needed to confirm these findings. Moreover, given this study's findings, other studies on partial brachial plexus injuries due to isolated C5 or C6 nerve lesions need to be performed. The preoperative diagnosis of non-graftable C5 and C6 roots could allow us to eliminate cervical surgical exploration and thus its morbidity and to focus immediately on nerve transfers whenever possible.

Disclosure of interest

The authors declare that they have no competing interest.

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