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Research article

The long-term impact of rehabilitation in upper limb plexopathies

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Abstract: The main objective of the research consists in providing evidence that a long-term rehabilitation protocol is favorable for the patient. In adult brachial plexus (BP) palsies, after several surgical attempts, the lack of results in the upper limb's functionality leads to less compliance to rehabilitation therapy. The upper limb's functionality of 22 patients with posttraumatic operated chronic BP paresis (either on the right or left, regardless the dominant limb) was assessed retrospectively. The patients were evaluated regarding MRC scaling, dynamometric tests and electroneuromyographic examination. All patients have gone through at least one rehabilitation interval (10 days) after an initial evaluation, and were evaluated again, by same methods, at a second session, at least 6 months later, but no more than one year.. Mild and inconstant improvements were obtained in a total of 9 patients, especially in better dynamometric results and improved amplitudes of motor and sensory action potentials. The electrodiagnosis correlates with dynamometric parameters (muscle strength) and slight amelioration of the motor deficit. Given the small sample size as a limitation, as well as no standardized therapeutic protocol, it should be noted that the 9 patients were the only ones who either attended more than one interval or did more procedures as frequency in time (more often meaning 3 times weekly for 6 months, in 6 patients). Although the most frequent procedures were neuromuscular electrical stimulation (NMES) and proprioceptive neuromuscular facilitation (PNF), the results suggest that regardless of the techniques, the more active patients had better results. Proving the need for long-term rehabilitation, even contrary to the less visible results, can be the trigger point for future research and therapy strategies, as the results suggest central mechanisms involved, adding the cortical ongoing plasticity into the equation.

Keywords: brachial plexus, rehabilitation, dynamometry, electroneuromyography

1. Introduction

Adult brachial plexus (BP) palsies have a significant influence on people in today's fast-paced environment and are a major cause of disability. Rehabilitation from this pathology is frequently challenging. The adverse effects extend beyond the work environment to the patient's social and psychological well-being. [1,2]. The real backdrop is the ongoing rise in traffic accidents and the growing popularity of riskier, more dangerous sports. [3,4].

In a recent 2022 study, the authors explored an interdisciplinary approach to the rehabilitation of adults with brachial plexus paralysis. This condition is becoming more prevalent due to car accidents, extreme sports, and work-related injuries. The study focused on a complex surgical case, utilizing clinical and electrophysiological investigations, including Transcranial Magnetic Stimulation (TMS), to examine cortical reorganization. It highlighted that current surgical strategies, particularly those aimed at restoring elbow flexion, are guided by clinical evaluations, MRI, and electromyography (EMG). The results demonstrated that an interdisciplinary approach significantly accelerates and enhances rehabilitation outcomes. Furthermore, electrophysiological signals were found to reliably predict motor improvements when integrated into rehabilitation programs [5].

BP poses significant challenges in terms of diagnosis, treatment, and rehabilitation. Recent studies emphasize the importance of tailored surgical approaches and comprehensive rehabilitation protocols to optimize long-term functional outcomes. This paper reviews key literature on surgical procedures, electrophysiological assessments, and rehabilitation strategies in managing BP injuries.

Hill et al. (2021) stated that adult BP injuries cause significant functional deficits, severe pain, and profound mental health and economic impacts. The evaluation process involves a thorough physical exam, electrodiagnostic studies, advanced imaging, and patient counseling. Management requires a multidisciplinary team, including a peripheral nerve surgeon, physiotherapist, electro-diagnostician, mental health experts, and pain specialists. Surgical options include exploration, nerve grafting, nerve transfer, and free functional muscle transfer, with early treatment (within 6 months) generally leading to better outcomes. Despite advances, restoring hand function remains challenging, highlighting the need for continued research and innovation in treatment strategies [6]

Diagnosing BP injuries is challenging due to the variability of their causes and the similarity of symptoms to other conditions. Wiertel-Krawczuk. in a recent study. compared magnetic and electrical stimulation to evaluate their effectiveness in detecting neural conduction abnormalities in 20 BP injury patients and 20 healthy volunteers. The findings showed that magnetic stimulation amplitudes were typically higher in healthy individuals, while BP injury patients exhibited lower CMAP and magnetic stimulation amplitudes on the symptomatic side. The study also found longer latency periods in nerve responses on the asymptomatic side of BP injury patients compared to the control group, suggesting subclinical neural deficits. These results indicate that BPIs have mixed axonal and demyelination components and may affect the asymptomatic side, potentially explaining poor treatment outcomes [7].

Deodhe et al. in a recent case study highlight the severe functional limitations caused by traumatic BP injuries, particularly in upper extremity activities. BP injuries typically result from forceful events that lead to a significant loss of BP injury function. The study demonstrates that physiotherapeutic interventions, specifically Functional Electrical Stimulation (FES) and Proprioceptive Neuromuscular Facilitation (PNF), effectively improve BP injury function. Outcome measures like the Brachial assessment tool (BrAT) and upper extremity functional index (UEFI) were used to assess this improvement. PNF has been shown to aid in rehabilitation by enhancing motor control and learning, while FES promotes nerve regeneration and reduces muscle atrophy. After six weeks of intervention, combining PNF with FES was found to be a clinically effective strategy for restoring functional mobility in patients with BP injuries [8].

The primary objective of this study is to identify correlations between BP lesions, surgical procedures, electrodiagnostic findings, and different postsurgical milestones, to interpret this data in the context of long-term rehabilitation outcomes.

2. Material and Methods

The retrospective analysis involved two groups of patients who underwent brachial plexus (BP) reconstruction surgery. The first group consisted of right-handed individuals with injuries to their right upper limbs who all received the Oberlin operation, aimed at restoring elbow flexion. The second group included patients with more complex cases, characterized by varied adherence to long-term rehabilitation protocols.

Both groups were monitored over seven years at the Medical University Center Iaşi, which included the Clinical Rehabilitation Hospital, the Physical Therapy Facility at the "Grigore T. Popa" University Treatment Center, the Clinical Emergency Hospital "Sfantul Spiridon," and through an ambulatory electroneuromyography (ENMG) regimen.

Patients had extensive medical histories, with multiple surgeries evolving. While the first group followed a standardized rehabilitation protocol within six months, the second group had varied control for up to a year.

The study included 22 patients (eight women and fourteen men) with traumatic, chronic BP lesions, divided into two groups: one based on the side of the Oberlin surgery and the other based on whether the injury affected the dominant or non-dominant limb. Both groups received clinical and electrodiagnostic follow-ups after their rehabilitation procedures.

Men are usually much more predisposed to BP trauma, especially in the age category of 20-39 years [9]. In both our lots, there was a much more frequent affectation of the dominant right upper limb (64%), in patients originating from urban environments (16 cases).

We observed a dynamic of incidence of BP palsies that suggests the young adult age, usually male, with trauma related to traffic accidents (13 out of the 22 cases), followed by traumatic circumstances related to professional activities or sports.

In the early stages of the injury, the microsurgical reconstructive procedures aim towards restoring the elbow flexion of the forearm against the arm, and the function of shoulder elevation. Surgery is usually planned according to EMG findings [10,11]. Following the initial surgical interventions, other reconstructive strategies may be necessary, sometimes palliative (most of our patients having undergone 2-4 surgeries) [12].

The 22 patients with traumatic BP lesions were evaluated and monitored both clinically and from an electrophysiological perspective. Eleven patients included in the first lot had the Oberlin surgical technique in common (neurotization of the fascicular motor group from the ulnar nerve). Over six months, these individuals had clinical evaluations using the MRC scale, muscle strength testing, and ENMG (both at the start and the conclusion of the six months). They underwent three sessions a week of NMES and proprioceptive PNF as part of their rehabilitation therapy throughout this time.

The other 11 patients were only monitored by the same methods. Neither the dominant limb lesion level nor any kind of standardized protocol was associated with these patients. Every patient was evaluated at different times following various surgical operations intended to restore the functionality of the upper limbs in various rehabilitation facilities around the nation.

The patients from the first lot had a mainly C5-C6/C7 affectation of the BP, while the ones from the second lot had either C5-C6/C7 or total BP lesions.

In the first group of patients, alongside the Oberlin procedure, the medical records and history of the patients revealed an often-used procedure of neurotization of the spinal nerve to the suprascapular nerve, a technique also present among some of the patients in the second group, together with different muscle transpositions or tendon transfer procedures, or neurotization of intercostal nerves to the musculocutaneous nerve.

In all of these cases, one of the most frequent objectives of reconstructive microsurgery is to restore the elbow's function, which explains the very frequent use of the Oberlin technique.

For the statistical significance, a criterion for assembling the first lot was also the particularity that the affected upper limb to also the dominant one.

The ENMG exam itself does not consist of any absolute contraindications (not even anticoagulant therapy, which was not the case). The nervous conduction studies and the needle EMG were performed on a 2-channel EMG Neurosoft® device. The ENMG study was designed to identify neurogenic modifications according to each patient's history.

The dynamometric evaluation was performed on a hydraulic Jamar® dynamometer.

Patients were included in the study if they presented with traumatic, chronic BP injury older than 18 years of age, reflecting demographics typical for BP trauma. Eligible participants had undergone at least one BP reconstruction surgery, such as the Oberlin operation. For the first group, inclusion required adherence to a standardized rehabilitation protocol within six months after surgery. The second group included patients with complex injuries and variable adherence to rehabilitation, some for up to one year. Patients were excluded from the study if they had non-traumatic BP injuries or were under 18 years of age. Also excluded were individuals with incomplete medical records or who did not follow required rehabilitation protocols. In addition, individuals with conditions affecting the outcome of ENMG studies, such as severe systemic diseases or anticoagulant therapy, were excluded.

The statistical analysis was performed with STATISTICA 6.0 StatSoft (Europe). The comparison between the first and second evaluations was done by the t-test and ANOVA analysis. The results were analyzed according to standard variation, in which $p<0.05$ is considered significant.

3. Results

3.1 First lot

Five patients from the first lot were less compliant with the rehabilitation protocol, citing private reasons. Despite these conditions, every patient—including the five—went to rehabilitation therapy in the first two weeks and continued to attend the six-month evaluation.

The dynamometric tests showed improvements (figure 1). We considered the typical values of 14 kgF for men and 12 kgF for women. During the dynamometric examination, only the six complying patients showed a gain in muscle strength.

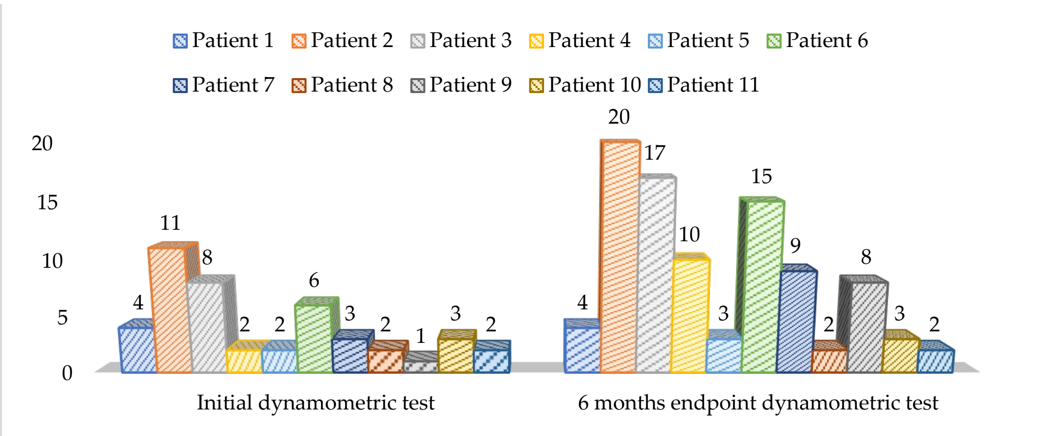

Figure 1. Dynamometric monitoring of the first lot (measured in KgF)

On the MRC scale, there were improvements from the value of 2 to 4 in the case of 2 patients, and from 3 to 4 in 2 other cases, as well as an improvement from 1 to 3 and from 3 to 4, respectively (figure 2).

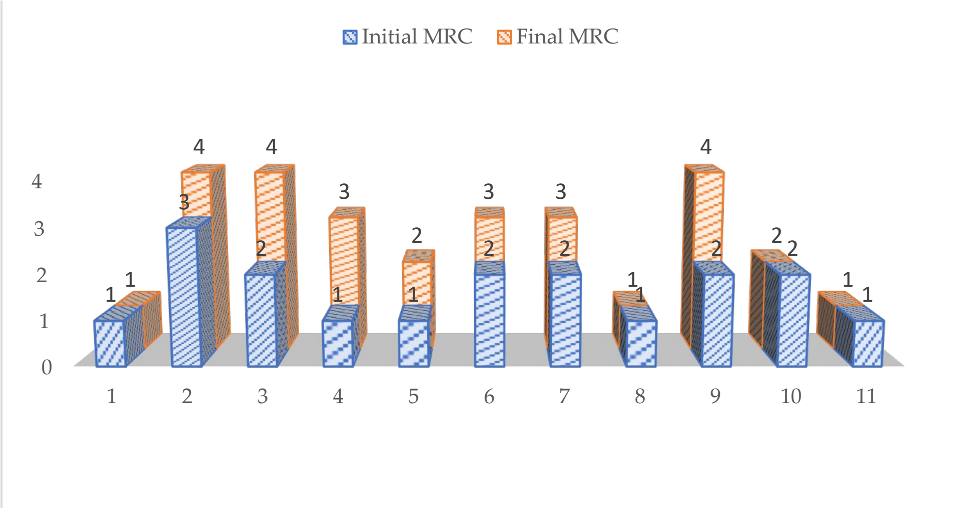

Figure 2. Evolution of MRC scaling in the first lot

In electromyographic (EMG) tests, better results (Table 1) showed evidence of an increased spontaneous activity: fibrillation potentials (Fibs) and positive sharp waves (Psws).

Table 1 EMG in *biceps brachii* (compliant patients in *italics*)

Patient	Initial EMG	Final EMG
1	No spontaneous activity, no motor unit action potential (MUAP)	stationary
2	*Chronic neurogenic pattern, high amplitude, polyphasic MUAPs*	*Fibs, Psws*
3	*Chronic neurogenic pattern, high amplitude, polyphasic MUAPs*	*Rare Fibs, Psws*
4	*No spontaneous activity, no MUAPs*	*stationary*
5	No spontaneous activity, no MUAPs	stationary
6	*Chronic neurogenic pattern, high amplitude, polyphasic MUAPs*	*Rare Fibs, Psws*
7	*Rare Fibs, Psws*	*stationary*
8	No spontaneous activity, no MUAPs	stationary
9	*Chronic neurogenic pattern, high amplitude, polyphasic MUAPs*	*Numerous Fibs and Psws*
10	No spontaneous activity, no MUAPs	stationary
11	No spontaneous activity, no MUAPs	stationary

The electroneurographic (ENG) parameters (measured during the nervous conduction examinations) also improved (figures 3 and 4). Hence, compound muscle action potential (CMAP) and sensory nerve action potential (SNAP) (especially measured in the radial nerve), showed discrete better amplitudes ($p<0.0001$), in correlation with the MRC scale ($p<0.001$), as well as with the dynamometric results ($p<0.01$) (table 2).

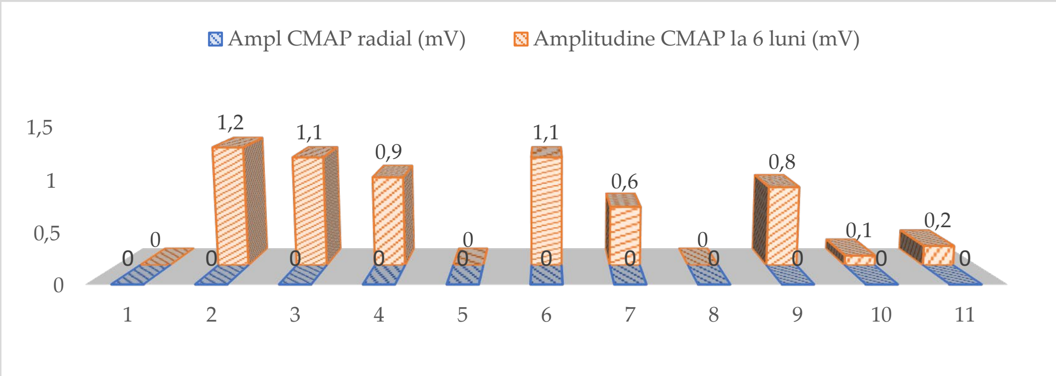

Figure 3. Evolution of CMAP amplitude (mV) in the 6 patients

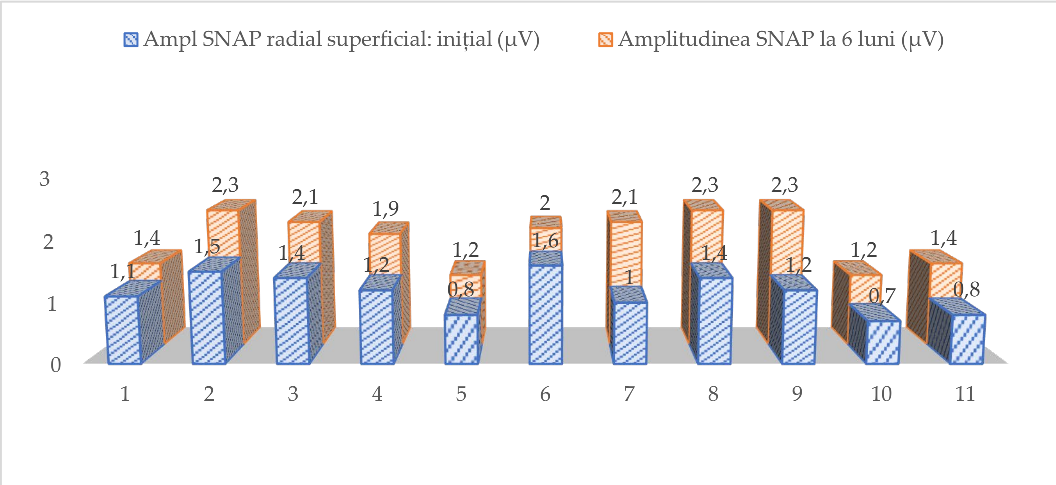

Figure 4. Evolution of SNAP amplitude (µV) in the 6 patients

Table 2. Evolution of parameters in the 6 patients with better results

Parameters	Initial evaluation *n* = 6 compliant patients	Final evaluation *n* = 6 compliant patients	*p*
CMAP amplitude in the right radial nerve (mA)	0.000 ± 0.000	0.900 ± 0.212	0.0001
SNAP amplitude in the right radial nerve (µA)	0.000 ± 0.000	0.950 ± 0.226	0.0001
MRC	2.000 ± 0.632	3.500 ± 0.548	0.0014
Dynamometric test (kgF)	5.167 ± 3.869	13.167 ± 4.875	0.0104

In the five less cooperative patients, we also noticed a slight improvement in the SNAP latency in the superficial radial nerve ($p<0.05$), however, there were no correlations or statistically significant differences (table 3).

Table 3. Evolution of parameters in the 5 patients with poor outcomes

Parameters	Initial evaluation *n* = 5 less compliant patients	Final evaluation *n* = 5 less compliant patients	*p*
CMAP amplitude in the right radial nerve (mA)	0.000 ± 0.000	0.060 ± 0.089	0.1720
SNAP amplitude in the right radial nerve (μA)	0.960 ± 0.288	1.500 ± 0.458	0.0562
MRC	1.200 ± 0.447	1.400 ± 0.548	0.5447
Dynamometric test (kgF)	2.600 ± 0.894	2.800 ± 0.837	0.7245

3.2 Second lot

The second lot of patients, who had clinical cases of either right or left BP affectation, were evaluated using the same criteria as the first lot's patients, but in a strictly retrospective fashion. For this group, the duration varied from six months to a year from their initial assessment to the final one. Every patient followed a separate rehabilitation regimen for at least ten days, or the recommended ten days every six months, either in different outpatient clinics or in a hospital.

Associations between NEMS, TENS, PNF, physical exercises, and even balneary treatment (some patients found addressability towards balneological facilities) were included in the rehabilitation regimens. In three of the patients, the needle EMG examination showed an increase in spontaneous pathological activity (table 4).

Table 4 EMG in biceps brachii (patients with better results in *italics*)

Patient	Initial EMG	Final EMG
1	no spontaneous activity, no PUMs	stationary
2	*Chronic neurogenic pattern, high amplitude, polyphasic MUAPs*	*Rare Fibs, Psws*
3	*Chronic neurogenic pattern, high amplitude, polyphasic MUAPs*	*Rare Fibs, Psws*
4	no spontaneous activity, no PUMs	stationary
5	no spontaneous activity, no PUMs	stationary
6	*Chronic neurogenic pattern, high amplitude, polyphasic MUAPs*	*Rare Fibs, Psws*
7	Chronic neurogenic pattern, high amplitude, polyphasic MUAPs	stationary
8	no spontaneous activity, no PUMs	stationary
9	Chronic neurogenic pattern	stationary
10	Chronic neurogenic pattern, high amplitude, polyphasic MUAPs	stationary
11	no spontaneous activity, no PUMs	stationary

Discrete better values were also present on the MRC scale (more likely appreciation of amelioration from the value of 0.5 to 1), which tend to correlate in these three, with mild muscle strength improvement at the dynamometric test (figures 5 and 6).

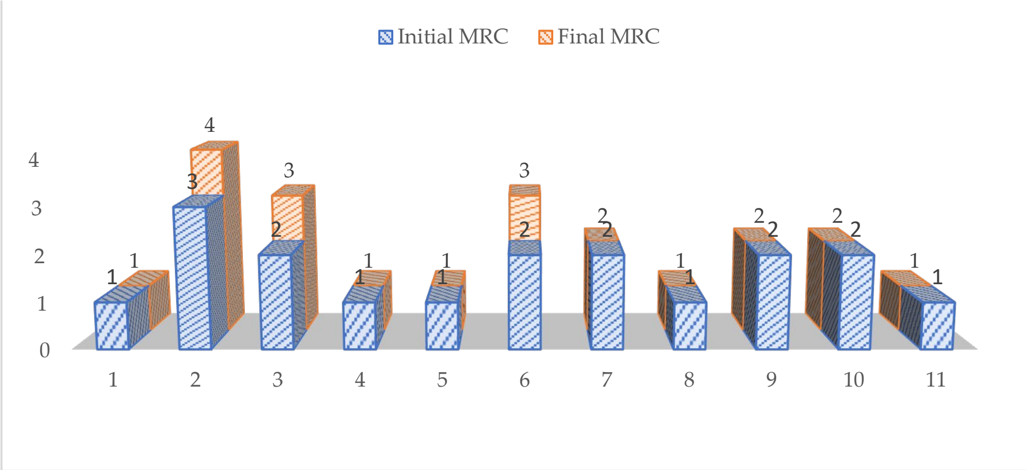

Figure 5. Evolution of MRC scaling in the second lot

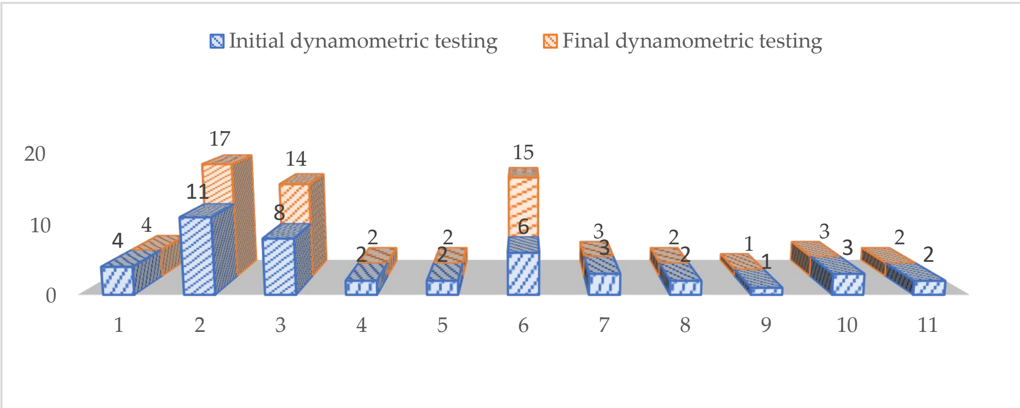

Figure 6. Dynamometric evaluation of the patients in the 2nd lot (measured in KgF)

ENG parameters mildly improved, more evident in the 3 patients (figures 7 and 8).

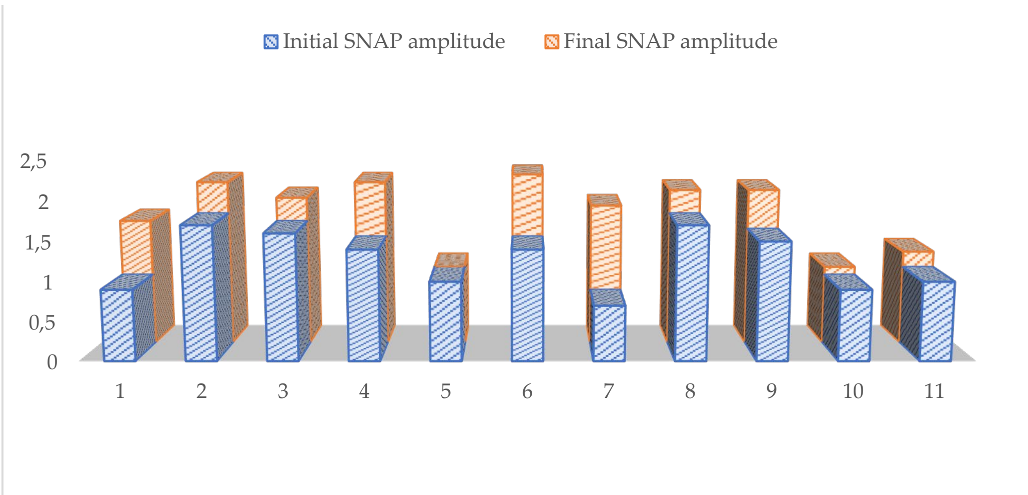

Figure 7. Evolution of SNAP amplitude (μV) in the second lot (superficial radial nerve)

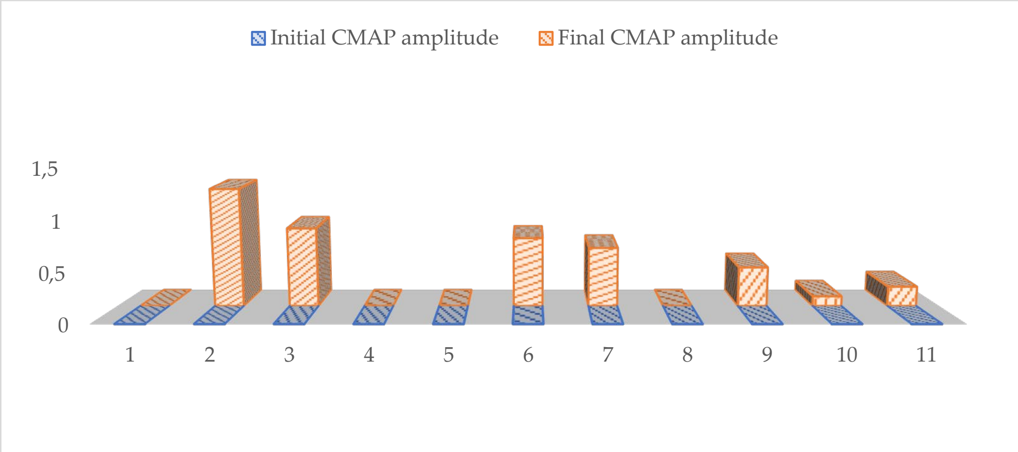

Figure 8. Evolution of CMAP amplitude (mV) in the second lot

These data do not correlate in terms of statistical significance, neither related to a whole lot of patients or right compared to left BP lesions (tables 5, 6, and 7).

Table 5. Statistical assessment of the evolution of the entire lot 2

Patients in the second lot	Initial	Final	p
CMAP radial nerve	0.000 ± 0.000	0.364 ± 0.411	0.0081
SNAP superficial radial nerve	1.155 ± 0.305	1.836 ± 0.448	0.0005
MRC	1.636 ± 0.674	1.909 ± 1.044	0.4753
Dynamometric test	4.000 ± 3.098	5.909 ± 6.139	0.3682

Table 6. Analysis of values in right-side-affected patients

Right side	Initial	Final	p
CMAP radial	0.000 ± 0.000	0.280 ± 0.335	0.0983
SNAP radial	1.060 ± 0.261	1.680 ± 0.487	0.0364
MRC	1.400 ± 0.548	1.600 ± 0.894	0.6811
Dynamometry	3.400 ± 2.793	4.600 ± 5.367	0.6691

Table 7. Analysis of values in left-side-affected patients

Left side	Initial	Final	p
CMAP radial	0.000 ± 0.000	0.433 ± 0.484	0.0532
SNAP radial	1.233 ± 0.339	1.967 ± 0.408	0.0069
MRC	1.833 ± 0.753	2.167 ± 1.169	0.5701
Dynamometry	4.500 ± 3.507	7.000 ± 7.014	0.4530

Given the patient's characteristics and unique evolution, we did not find any influence on the results from the dominant limb in the case of the three patients who showed slight improvements, particularly in muscle strength. This does not imply that a particular therapeutic procedure—surgical or restorative—caused the improvement. However, table 8 presents a comparative examination of impairment on the left and right in terms of statistical analysis.

Table 8. Comparative analysis of results from right versus left PB lesions

Right vs. Left PB lesions	Right initial results	Left initial results	p	Final results on the right	Final results on the left	p
CMAP radial	0.000 ± 0.000	0.000 ± 0.000	1	0.280 ± 0.335	0.433 ± 0.484	0.5655
SNAP radial	1.060 ± 0.261	1.233 ± 0.339	0.3747	1.680 ± 0.487	1.967 ± 0.408	0.3150
MRC	1.400 ± 0.548	1.833 ± 0.753	0.3129	1.600 ± 0.894	2.167 ± 1.169	0.3985
Dynamometry	3.400 ± 2.793	4.500 ± 3.507	0.5852	4.600 ± 5.367	7.000 ± 7.014	0.5471

4. Discussions

To evaluate the effectiveness of the rehabilitation protocol, we employed t-tests and ANOVA. The t-test was used to compare pre-and post-treatment outcomes within the same group of patients (paired t-test), allowing us to assess whether there were significant changes in muscle strength and EMG parameters over time. The ANOVA was applied to compare outcomes across multiple groups, such as different treatment regimens or patient groups, to determine if there were significant differences in improvements.

The criteria for statistical significance was set at $p<0.05$. This threshold is commonly used in clinical research to minimize the risk of Type I errors. Statistically significant results were further evaluated for clinical relevance, meaning that even if differences were statistically significant, they were assessed for practical importance in patient outcomes.

Figure 1 shows the improvement in dynamometric test results for compliant patients, indicating a significant increase in muscle strength. Similarly, Table 2 provides a detailed comparison of CMAP and SNAP amplitudes before and after treatment, with p-values demonstrating significant improvements in the compliant group.

Figures 3 and 4 illustrate the trends in CMAP and SNAP amplitudes, respectively, highlighting a clear pattern of improvement in the six compliant patients. In contrast, Figures 5 and 6 depict the less pronounced changes observed in the second lot, suggesting that additional factors may influence the efficacy of treatment.

A consistent trend observed was that compliant patients showed more substantial improvements in muscle strength and EMG parameters compared to less compliant patients. This suggests that adherence to the rehabilitation protocol plays a crucial role in treatment efficacy.

Tables 5 through 8 provide detailed statistical assessments of different patient groups, including those with right vs. left BP lesions. The comparative analysis indicated no significant differences between the two sides, suggesting that the rehabilitation protocol's effectiveness was consistent across both sides.

We focused mainly on the radial nerve, which can occasionally be spared but can also be impacted in a variety of injuries, including C5-C6, C5-C6/C7, C7, or C7-C8/T1. When utilizing the MRC scale, the forearm's flexion against the arm is determined by the median and ulnar nerves [13,14].

In our chronic patients, with a long history of elbow flexion and severe MRC affectation, motor evaluation of these nerves doesn’t provide useful information. The radial nerve (having more roots) is preferred since patients with severely impacted MRC typically attempt to elevate their forearms using the muscles that remain with satisfactory nervous input.

Most exploratory protocols based on the study of motor nerve conduction in BP lesions mainly recommend the evaluation of the median and ulnar nerves, which are also the most often chosen in various neurotization leads. But the radial nerve is important due to its frequent damage in injuries of the shoulder, but also of the humerus, associated with the traumatic pathology underlying plexus injuries [15].

Within the complex involvement of PB pathology, the radial nerve is very useful to explore when a posterior cord injury is suspected [16].

In electromyographic practice, all 3 nerves are frequently evaluated. Although all 3 nerves (median, ulnar, radial) were routinely investigated in the ENMG evaluation of the present study, we chose to refer to the motor parameters of the radial nerve for the two groups of patients, for several reasons.

The first reason is that the median and ulnar nerves are particularly useful for elbow flexion when following the progression of a BP injury in the early stages of its occurrence. In the present study, all patients have chronic lesions of the PB, none of them having recent surgery.

The second reason is the location of the origin of the radial nerve, which originates from the posterior cord originating from all three trunks (upper, middle, and lower). Being located in the middle, it can be affected both in C5-C6, C5-C6/C7, C7, and C7-C8/T1 lesions, respectively alternatively spared or only partially affected, or it can be significantly affected even in the situation of a complete BP palsy.

This last aspect is the basis of the third reason why we preferred it. Median nerve and ulnar nerve injuries being directly related to the assessment of forearm flexion on the arm on the MRC scale, in our chronic patients, with severely affected MRC, highlighting these two nerves (from a motor point of view) would not have brought enough information of relevance.

Multiple surgical methods are typically needed to treat BP lesions resulting from trauma. Elbow flexion produces the best benefits when applied to C5-C6 lesions [16]. However, in certain cases—such as when restoring the opposition of the first finger—patients may also require further therapies to address related impairments [9,17].

Physiotherapy-assisted neurorehabilitation is crucial to the patient's functional rehabilitation [4,18]. By increasing elbow flexion, NEMS and PNF are beneficial not only at the peripheral level but also at maintaining neuroplasticity [4,18]. The assumption that EMG can offer effective monitoring of the rehabilitation process is supported by this research and real data from rehabilitation [19].

Patients with bilateral BP traumatic lesions who participate in a rigorous rehabilitation program that includes finger motility exercises and electrostimulation experience satisfactory, repeatable outcomes. In certain circumstances, the initial MRC can expand to unrestricted motility after three months of resistance-free movement against gravity [20].

Electrostimulation has the potential to be used in a variety of rehabilitation settings, such as modifying motor performance or lessening the intensity of symptoms [21]. Although NEMS currents can strengthen certain muscles, the strength gain in the muscles on the other side exhibits the most remarkable outcomes [21]. The improvement in muscular strength in some of our patients who underwent periodic rehabilitation sessions but did not undergo recent surgery can also be explained by the rise in contralateral strength.

The basic idea behind the NEMS process is to create a strong electrical field close to the peripheral nerves' motor axons. This causes the axonal membrane to depolarize, which in turn produces an action potential that will cause a muscle contraction. In addition, the muscle's vascularization needs to be competent for NEMS to be effective, and the peripheral nerve that supplies the targeted muscle needs to be intact [22]. This mechanism explains why some of the findings are stationary for our patients who have severe chronic nerve damage.

PNF is a rehabilitation method centered on contractile strength facilitation and mechanical resistance applied to muscular contraction. Its goal is to assist build muscle strength. Patients with severe loss of muscle strength and peripheral affectation can benefit from the use of PNF [23, 24].

In the six patients from the first lot in our investigation, the combination of NEMS + PNF led to an increase in MRC, which was correlated with improvements in electrophysiological parameters and dynamometric testing strength. This also applies to the three patients from the second lot who showed improvements on the dynamometric testing as well as the MRC scale.

The primary finding from the analysis of the two patient lots is that a prolonged rehabilitation regimen can be connected to maintaining long-term clinical favorable correspondence.

The small sample size and lack of a standardized rehabilitation protocol are notable limitations. Future research should aim to include larger cohorts and establish standardized rehabilitation protocols to further validate and refine the findings. Additionally, exploring the role of central mechanisms and cortical plasticity in rehabilitation outcomes could provide deeper insights into the rehabilitation process. The retrospective nature of the study, which depends on existing medical records, may result in incomplete or inaccurate data, potentially impacting the findings.

Anghelescu et al. demonstrate the importance of long-term rehabilitation in managing severe neurological injuries, including BP palsies and complex neuraxial injuries like tetraplegia and blindness. They highlight that patient compliance and consistent engagement in rehabilitation are crucial for achieving better outcomes, even if initial improvements are modest. The potential for central mechanisms and cortical plasticity to aid in recovery is pertinent in both cases. Despite the severity of the injuries, sustained rehabilitation efforts are vital for optimizing functional recovery. Ultimately, persistent rehabilitation can lead to significant, albeit gradual, improvements in the quality of life [25].

The research on long-term rehabilitation for BP palsies highlights that consistent, extended therapy is crucial for significant functional improvement. Similarly, the home-based active orthosis is designed to enhance patient adherence and support sustained upper limb training at home. Both approaches leverage modern technology and task-specific training to stimulate neuroplasticity and improve recovery outcomes. The orthosis addresses practical barriers such as high costs and accessibility, aligning with the research's emphasis on optimizing rehabilitation methods. Overall, both the study and the orthosis underscore the importance of ongoing, effective rehabilitation for achieving meaningful recovery [26].

Stoica et al.'s recent study highlights the importance of long-term rehabilitation for improving outcomes in cervical spinal cord injury, noting that consistent therapy leads to significant gains despite initial minimal results. Patient compliance and frequent participation are crucial, as they enhance rehabilitation effectiveness. Technological and practical solutions, such as home-based orthoses, address cost and accessibility barriers, supporting more effective rehabilitation [27].

5. Conclusions

This study underscores the importance of long-term rehabilitation in improving outcomes for patients with posttraumatic chronic BP lesions. Our findings reveal that while improvements may be modest and variable, consistent engagement in rehabilitation therapies can lead to meaningful gains in muscle strength and electrodiagnostic parameters.

The results from the compliant patients in the first group show that adhering to a structured rehabilitation program, including NMES and PNF, significantly improves muscle strength and electrodiagnostic parameters. These improvements align with increased amplitudes in CMAP and SNAP, highlighting the positive impact of sustained rehabilitation efforts.

The study reveals a clear correlation between patient compliance and rehabilitation outcomes. The more active patients, who adhered to frequent rehabilitation sessions, exhibited greater improvements compared to those with less consistent attendance. This emphasizes the need for patient motivation and adherence to prescribed rehabilitation protocols to achieve optimal results.

The study's results support the continued use of long-term rehabilitation for patients with chronic BP lesions, even when immediate results are not evident. Emphasizing the importance of ongoing therapy and patient engagement can enhance functional rehabilitation and quality of life for individuals affected by BP injuries.

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