RESEARCH ARTICLE

Double Nerve Transfer Versus Triple Nerve Transfer for Elbow Flexion Restoration in C5-C6 Traumatic Brachial Plexus Injuries

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Abstract

Objectives: This preliminary study compares two nerve transfer techniques for restoring elbow function in patients with C5–C6 brachial plexus injuries. The double nerve transfer (Oberlin II) involves the transfer of fascicles from the ulnar and median nerves to the biceps and brachialis muscles. In contrast, the triple nerve transfer (Oberlin III) includes an additional transfer from the radial nerve to the brachioradialis muscle.

Methods: Nine patients with C5–C6 traumatic brachial plexus injuries were included in the study and followed for five years after nerve transfer surgery. Four patients underwent the Oberlin III technique, while five received the Oberlin II procedure. Outcomes assessed included the range of motion in the elbow and shoulder joints, hand grip strength, elbow flexion strength, elbow flexion velocity, and brachioradialis muscle bulk.

Results: All patients achieved an MRC grade of 4 for elbow flexion strength. Brachioradialis muscle bulk was recovered in the Oberlin III group, which also demonstrated a higher elbow flexion velocity (P = 0.032). Additionally, higher mean values were observed in the Oberlin III group for elbow flexion strength (in both supination and pronation) and QuickDASH scores. However, no statistically significant differences were found for these outcomes.

Conclusion: The Oberlin III technique was associated with the recovery of brachioradialis muscle bulk and improved elbow flexion velocity. These preliminary findings suggest potential functional benefits, highlighting the need for further investigation in larger cohorts.

Level of evidence: III

Keywords: Brachial plexus injury, C5-C6 avulsion, Elbow flexion, Nerve transfer, Oberlin procedure

Introduction

Traumatic accidents often cause upper brachial plexus injuries and typically affect young adults. These injuries can result in the loss of elbow and shoulder function, leading to an inability to perform daily living activities.[1] Typically, the location of a brachial plexus lesion resulting from such mechanisms is identified as preganglionic, which is considered challenging to treat with conventional nerve repair methods or nerve grafting.[2] In 1994, Oberlin *et al.* introduced the technique of transferring an ulnar nerve fascicle to the biceps branch of the musculocutaneous nerve (referred to as Oberlin I). This technique was associated with improvements in elbow flexion strength and an increased range of motion in the elbow.[3] Mackinnon *et al.* later expanded upon the Oberlin procedure by proposing a "double nerve transfer" (referred to as Oberlin II). This procedure used an expendable fascicle from the median nerve as a donor nerve for the brachialis muscle, in addition to transferring the ulnar fascicle to the biceps to enhance elbow flexion function.[4,5]

Some studies have shown that Oberlin II is more effective than single nerve transfer in restoring elbow flexion,

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particularly in achieving a functional Medical Research Council (MRC) score of ≥4 and improving the recovery of elbow flexion strength.[6,7] However, other studies suggest that both treatment groups demonstrate similar outcomes in elbow flexion, supination strength, and quality of life, as measured by postoperative Disabilities of the Arm, Shoulder, and Hand (DASH) scores.[8,9]

The brachioradialis muscle is another key muscle involved in elbow flexion. Its primary function is to act as a concentric elbow flexor, with secondary assistance in forearm pronation and supination.[10,11] In theory, reinnervating the brachioradialis muscle could enhance elbow flexion strength and improve forearm supination and pronation. This report examines the impact of integrating a fascicle from the radial nerve into the brachioradialis muscle on elbow function after the Oberlin II procedure, and whether this technique provides additional functional benefits and improvements in quality of life compared to the Oberlin II procedure alone.

Materials and Methods

Patients with traumatic upper brachial plexus injuries who, after three months, exhibited finger flexion and extension as well as elbow extension, but lacked shoulder abduction and elbow flexion, were included in the study. C5 and C6 injuries were confirmed through electrodiagnostic studies and/or MRI in both groups. A retrospective cohort study was conducted on these patients, who had undergone the Oberlin II procedure, as well as the proposed method of transferring the healthy branch of the radial nerve to the brachioradialis muscle in combination with Oberlin II (referred to as Oberlin III), with a minimum follow-up of five years. All study protocols were approved by the research council and the medical ethics committee, and all participants provided informed consent.

Medical records of the participants were collected from our hospital database, and those with a preoperative delay of more than one year were excluded from the study. Patients were divided into two groups based on the surgical procedure they underwent: Oberlin II and Oberlin III. The details of the Oberlin III procedure have been previously described.[12] We compared the results of these patients with those who underwent the Oberlin II procedure within six months before and after the period mentioned above. After five years (from April 2023), the patients were contacted for evaluation of the results in both groups.

The following variables were extracted: range of motion (ROM) for elbow flexion and shoulder external rotation and abduction, which were measured using a plastic goniometer. Elbow flexion motion was graded based on the MRC criteria. Hand grip strength was tested using the Jamar® device (Patterson Medical, Warrenville, IL, USA). Elbow strength in supination and pronation positions was measured using the Micro Manual muscle tester (North Coast Medical Inc., Morgan Hill, CA, USA). Maximum isometric elbow flexion strength at 90 degrees was measured in both pronation and supination. Strength indices (supinated and pronated) were calculated by dividing the affected-side strength by the normal-side strength to assess the strength index. Elbow flexion velocity was evaluated by measuring the time of rapid elbow flexion (in seconds) over 10 repetitions. Brachioradialis muscle bulk in superficial anatomy was assessed by observing the muscle bulk during forceful flexion against resistance in neutral forearm rotation. The QuickDASH score was also recorded for both groups.

Patients with a delay of 12 months or more before the index surgery, those with open injuries, patients scheduled for Oberlin III surgery who were unable to undergo radial nerve transfer to the brachioradialis muscle due to the presence of multiple small branches, and patients with less than five years of follow-up were excluded. Additionally, patients who were unable to participate in the final visit, as well as patients in the Oberlin II group who showed brachioradialis muscle bulk at the final visit, were also excluded.

The above data were recorded for both patient groups. Quantitative variables were summarized using means and standard deviations, while qualitative variables were summarized using frequencies and percentages. Data analysis focused on comparing the results between the groups of patients who underwent Oberlin II surgery and those who underwent surgery with the proposed method. Statistical analyses were performed using SPSS software (version 26; IBM Corp., Armonk, NY, USA). Continuous variables were compared between groups using the Mann-Whitney U-test due to the small sample size. Brachioradialis muscle bulk was compared between groups using the chi-square test and Fisher's exact test. Finally, the evaluation results of the two groups were recorded and reported, with a P-value of less than 0.05 considered statistically significant.

Results

The Oberlin II procedure was performed on 11 patients; however, two were excluded due to a treatment delay exceeding one year, two were lost to follow-up, and two others did not attend the final visit. The Oberlin III procedure involved 16 patients, but three were excluded due to the inability to identify a suitable, sufficiently large branch of the brachioradialis for nerve transfer, and nine patients did not complete the minimum follow-up period of five years. As a result, nine patients from both groups completed the minimum five-year follow-up: five patients in the Oberlin II group with a mean age of 32.2 years and four patients in the Oberlin III group with a mean age of 24.75 years. All patients had a preoperative delay of four to six months. Further details regarding the patient characteristics are provided in [Tables 1 and 2].

Discrepancies in shoulder abduction and external rotation were observed between the two groups, with a greater range of motion measured in the Oberlin II group. However, no statistically significant difference was detected (*P = 0.730 for both*).

All nine patients achieved an MRC score of 4 for elbow flexion. The Oberlin III group showed a mean flexion strength index of 0.232 ± 0.077 in the pronation position, while the Oberlin II group had a mean of 0.114 ± 0.086 (P = 0.111). The mean flexion strength index in the supination position was 0.188 ± 0.025 for the Oberlin III group, compared to 0.159 ± 0.085 for the Oberlin II group (P = 1.000).

Table 1. Characteristics of patients treated with the proposed surgical procedure

Cases (no)	Age at the time of the accident (year)	Sex	Injured Limb	Date of injury	Preoperative delay (month)	Last follow-up
1	28	Male	Dominant	February 2017	5	April 2023
2	25	Male	Non-Dominant	September 2016	4	April 2023
3	25	Male	Dominant	December 2016	6	May 2023
4	21	Male	Dominant	September 2017	4	June 2023

Table 2. Characteristics of patients treated with the Oberlin II surgical procedure

Cases (no)	Age at the time of the accident (year)	Sex	Injured Limb	Date of injury	Preoperative delay (month)	Last follow-up
5	32	Male	Dominant	March 2016	5	April 2023
6	37	Male	Dominant	October 2016	6	May 2023
7	19	Male	Dominant	June 2017	4	May 2023
8	32	Male	Non-Dominant	July 2017	6	June 2023
9	41	Male	Dominant	March 2018	5	June 2023

In patients undergoing Oberlin II surgery, the brachioradialis muscle bulk was atrophied entirely; however, this muscle was regained in all individuals in the proposed surgical group (Fisher's exact test, P = 0.008) [Figures 1 and 2].

Upon assessing the time taken for 10 consecutive elbow flexions, patients who underwent the proposed surgical intervention demonstrated superior average performance, with a time of 7.250 ± 0.957 seconds, compared to 10.000 ± 1.225 seconds in the alternative group (P = 0.032). Furthermore, the Oberlin III group exhibited greater grip strength (32.00 ± 6.68 kg compared to 26.10 ± 5.71 kg) and a better QuickDASH score (22.00 ± 7.66 compared to 24.80 ± 4.32) than the Oberlin II group. However, no statistically significant differences were found (P = 0.413 for both).

None of the patients in the Oberlin III group reported sensory irritation in the territory of the superficial radial nerve, nor did they exhibit weakness in the wrist or finger extensors. Further details regarding the patients' test results are provided in [Table 3].

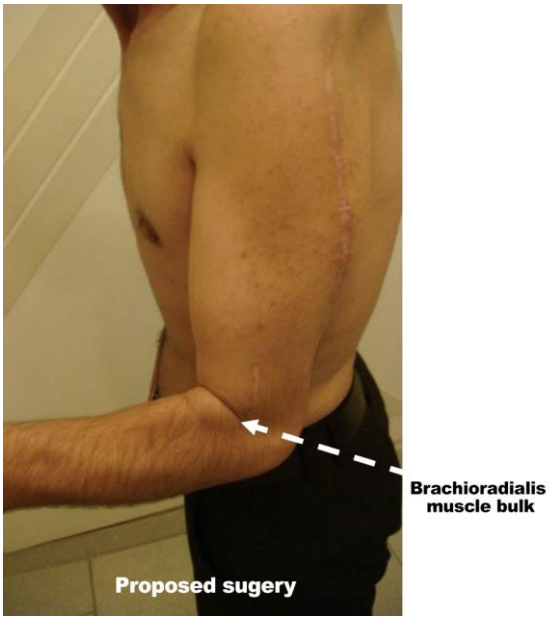

Figure 1. A single case after the proposed surgery (Oberlin III) with regained Brachioradialis muscle bulk.

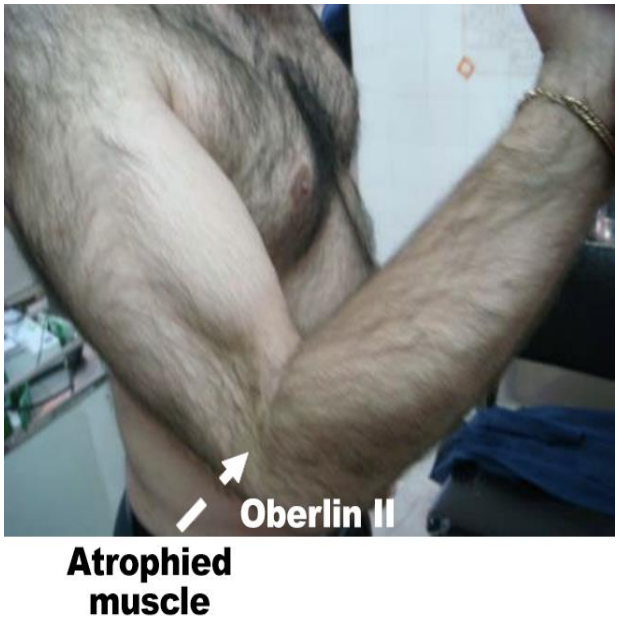

Figure 2. A single case after Oberlin II surgery with atrophied Brachioradialis muscle b

Table 3. Clinical information of patients treated with Oberlin II and the proposed surgical procedure (Oberlin III)

Cases (no)	Intervention	MRC	Grip (kg)	Elbow ROM (degree)	Shoulder abduction ROM (degree)	Shoulder external rotation ROM (degree)	Supination position index	Pronation position index	Time of 10 consecutive flexion (seconds)	Quick-DASH test	Brachioradialis muscle bulk
1	Oberlin III	4	33.0	170	110	60	0.199	0.206	8	16	normal
2	Oberlin III	4	26.0	170	70	30	0.190	0.315	7	24	normal
3	Oberlin III	4	28.0	170	80	0	0.152	0.138	8	32	normal
4	Oberlin III	4	41.0	170	110	60	0.209	0.267	6	16	normal
5	Oberlin II	4	22.5	170	170	150	0.244	0.188	10	25	atrophied
6	Oberlin II	4	29.0	130	60	10	0.041	0.029	11	30	atrophied
7	Oberlin II	4	32.0	170	100	30	0.207	0.151	8	18	atrophied
8	Oberlin II	4	18.0	170	70	0	0.098	0.015	11	25	atrophied
9	Oberlin II	4	29.0	170	90	30	0.204	0.188	10	26	atrophied

MRC: Medical Research Council; ROM: Range of motion; Quick DASH: Quick Disabilities of the Arm, Shoulder, and Hand questionnaire

Discussion

Restoring elbow flexion following upper brachial plexus injuries involves various surgical approaches, each tailored to the specific clinical scenario, including factors such as the duration since injury, the presence of passive elbow flexion, and the availability of donor muscles and nerves. Surgical options include nerve transfers (e.g., intercostal nerves, a fascicle from the ulnar or median nerves [13], long thoracic nerve, spinal accessory nerve, or thoracodorsal nerve) and tendon or muscle transfers (either non-free/pedicled or free).[14] Nerve transfers are typically prioritized as the primary treatment, though they may require sacrificing donor nerves.[15] In cases of significant fibrosis or delayed injury, where the biceps brachii muscle is irreversibly degenerated, pedicled or free muscle transfers may be necessary.[14,15]

The Oberlin-Mackinnon procedure has proven effective for restoring elbow flexion in upper brachial plexus injuries.[3-5] This technique has been widely accepted as a practical surgical approach for restoring elbow flexion following such injuries. Both techniques have demonstrated promising results without compromising donor nerve function, leading to faster recovery.[3,4] However, these transfers cannot be performed in patients with loss of elbow flexion and concomitant high median and ulnar nerve injuries.[16]

Two systematic reviews and meta-analyses have reported that additional reinnervation of the brachialis muscle did not significantly increase the proportion of patients achieving an MRC score of ≥3 for elbow flexion.[6,17] However, the double nerve transfer group showed a higher percentage of patients reaching an MRC score of ≥4 compared to the ulnar fascicular transfer group[6], particularly when the procedure was performed within six months of injury.[17] These studies suggest that double fascicular transfer is associated with superior postoperative outcomes,[6] although in some cases, single fascicular transfer may be preferred to preserve median nerve function.[17] In our study, we did not detect a statistically significant difference in MRC scores between the groups, with all patients in both the Oberlin II and Oberlin III groups achieving an MRC score of 4.

Discrepancies have also been observed regarding elbow flexion strength. While Srampickal et al. reported that the Oberlin II group had a statistically significantly better outcome in terms of elbow flexion strength compared to the Oberlin I group, with no significant morbidity,[18] Carlsen et al. found no statistically significant difference in flexion strength between the Oberlin II and Oberlin I groups.[8] Martins et al. further reported similar findings regarding the elbow flexion index[9]. In addition to these findings, we found no statistically significant difference between the Oberlin III and Oberlin II groups, although trends favored the Oberlin III group.

In studies with follow-up periods of over five years, Oberlin II transfers have shown better patient-reported outcomes compared to Oberlin I, with lower QuickDASH scores indicating reduced disability and improved recovery.[19,20] However, in a study with a shorter follow-up interval and a direct comparison between the groups, no statistically significant differences were found postoperatively.[8] In our comparison of Oberlin III and Oberlin II, no statistically significant difference in scores between the groups was detected. These results may be attributed to the limited number of patients or the significant role of shoulder abduction and external rotation function in clinical assessment outcomes.[21]

In addition to the classic Oberlin procedures, several studies have explored alternative nerve transfer techniques. Kokkalis et al. introduced a modified Oberlin procedure using two ulnar nerve fascicles transferred to the motor branches of the biceps and brachialis muscles. In the classic Oberlin I procedure, 93.75% of patients achieved MRC grade 4, while 6.25% had grade 3. In contrast, the modified procedure demonstrated better durability: 80% of patients

reached MRC grade 4+ and 20% achieved grade 4. This technique preserves the median nerve without causing motor or sensory issues in the ulnar territory.[7] Furthermore, Chepla et al. described a radial nerve branch transfer to the brachialis nerve, successfully restoring elbow flexion in a patient with combined high median, ulnar, and musculocutaneous nerve injuries, demonstrating its feasibility in complex brachial plexus cases.[15] We believe nerve transfers are highly effective for restoring elbow flexion, with Oberlin I and II being the standard approaches. When these cannot be performed, alternative transfers may be suitable and have shown excellent results. Our hypothesis regarding the additional nerve transfer in Oberlin III has demonstrated comparable outcomes, offering another reliable option for complex cases, although further study is needed.

This study has several limitations. First, the small sample size limits statistical power and the ability to detect actual differences between techniques, so the results should be interpreted with caution. Second, because a minimum five-year follow-up was required to assess long-term outcomes, several patients were lost to follow-up, introducing potential bias. Third, patients were not randomized, so observed improvements may partially reflect a surgical learning curve or evolving rehabilitation protocols rather than the technique itself. Fourth, we did not record additional operative time or collect patient-reported satisfaction regarding surgical scars, both of which could influence the overall appraisal of each method. Fifth, all outcome assessments were performed by non-blinded examiners, which introduces a risk of observer bias. On a positive note, we evaluated multiple outcome measures across motion, strength, velocity, and muscle bulk, providing a comprehensive foundation for future discussion and analysis.

Future research should build on these findings by conducting prospective studies with larger and more diverse patient populations to strengthen statistical conclusions and minimize bias. Techniques should be randomly assigned, and all outcome assessments—both functional and patient-reported—should be performed by blinded evaluators to prevent observer bias. Functional outcomes should be assessed at consistent short-, medium-, and long-term follow-up intervals to enable meaningful comparisons of recovery patterns for each procedure over time. Furthermore, future studies would benefit from including data on surgical factors such as operative time, as well as broader measures of patient quality of life, to provide a more comprehensive evaluation of each technique.

Conclusion

In conclusion, the adjunctive transfer of a radial nerve branch to the brachioradialis muscle, as part of the Oberlin III procedure, was technically successful in restoring brachioradialis muscle bulk and was associated with a statistically significant improvement in elbow flexion velocity. Additionally, the Oberlin III group showed non-significant trends toward improved flexion strength and QuickDASH scores. Due to the small sample size and other study limitations, these findings should be considered hypothesis-generating. This technique may be beneficial in patients with associated injuries that limit reinnervation of the biceps or brachialis via standard approaches, such as concomitant humeral trauma or high median and ulnar nerve injuries. Larger, prospective studies are needed to determine whether this technique offers a true clinical benefit over the standard Oberlin II procedure.

Abbreviations, Nomenclature, and Symbols:
ROM: Range of motion
MRC: Medical Research Council
DASH: Disabilities of the Arm, Shoulder, and Hand

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