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ORIGINAL RESEARCH ARTICLE

Outcome variability following nerve transfers for brachial plexus injuries: a cross-sectional observational study

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Abstract

Background Motor recovery after brachial plexus injury (BPI) varies depending on the type of nerve transfer procedure performed. This study aims to evaluate variability in motor recovery outcomes crucial for therapeutic planning and recovery estimation—specifically, elbow range of motion (ROM), biceps muscle activity, flexion, grip, and pinch strength—using different assessment tools.

Methods After ethical clearance, a cross-sectional observation study was conducted on 30 subjects who met the Inclusion criteria. Ethical clearance was obtained from the Institutional Ethics Committee (Approval No.: NIMS/IEC/PT/2024/03). Subjects were stratified into three groups ($n = 10$ each) based on the type of nerve transfer surgery: Oberlin 1, Oberlin 2, and intercostal nerve to musculocutaneous nerve (ICN–MCN). ROM was measured using a universal goniometer and the Pheezee device. Surface electromyography (sEMG) recorded biceps muscle activity. Elbow flexion strength was evaluated on the Medical Research Council (MRC) and Modified Medical Research Council (MMRC) scales. Grip and pinch strength were assessed using a hand-held dynamometer and a pinch gauge.

Results The Oberlin 2 group showed superior elbow flexor strength and ROM compared to the other two groups. MMRC grading provided a more detailed stratification of strength recovery than MRC. The Pheezee device enabled simultaneous recording of ROM and surface EMG. The pinch strength of i–ii and i–iii digits is better in the Oberlin 1 group than in other groups on the affected side. ICN–MCN group had minimal recovery. Significant intergroup differences were noted in elbow ROM ($p < 0.01$), MMT grades ($p = 0.0105$), and MMRC grades ($p = 0.0193$). sEMG amplitudes were highest in the Oberlin 2 group (889 ± 552 µV) and lowest in the ICN-MCN group (144 ± 142 µV).

Conclusion Study results highlight the significant variability of outcomes based on the type of surgery. MMRC grading offers a more nuanced evaluation of recovery than MRC grading alone. The Pheezee device was useful for tracking ROM and EMG concurrently. The results of this study showed that the type of nerve transfer and the choice of appropriate instrument could affect the outcome. Choosing a suitable instrument for clinical correlation and documentation might further help plan stratified rehabilitation procedures.

Keywords Brachial plexus injury, Nerve transfer, Elbow flexion, Functional recovery, Oberlin technique, SEMG, Physiotherapy, Dynamometry, MMRC

Background

The brachial plexus is formed by the ventral rami of C5-T1 spinal nerves [1, 2]. Brachial plexus injuries (BPI) often result from high-velocity trauma such as road traffic accidents, leading to varying degrees of sensorimotor and autonomic dysfunction of upper limb. Restoration of elbow flexion is crucial for the functional use of the arm.

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Brachial plexus surgery can be primary or secondary. Primary includes repair or reconstruction of nerves directly (nerve repair, grafting, transfer, and neurolysis) while secondary surgeries address residual deficits and deformities by free-functioning muscle transfer, tendon transfers, and arthrodesis. The most common donor nerves used in BPI nerve transfer procedures are the ulnar, median, and medial pectoral nerves. Extra-plexal nerve transfers are used when spinal roots are avulsed and proximal stumps are not available [3–5]. The Oberlin1 approach involves the transfer of an ulnar nerve fascicle to the biceps branch of the musculocutaneous nerve. The Oberlin 2 is a double fascicle transfer surgery aimed at transferring a median nerve fascicle to the brachialis branch of MCN and a fascicle of the ulnar nerve to the biceps branch of MCN. In the case of pan BPI or root avulsions, extra plexal nerves and intercostal nerves are transferred to MCN. Third and fourth intercostal nerves are anastomosed directly to the musculocutaneous nerve nearest to its motor point without using a nerve graft.

Recovery following BPI surgeries varies based on factors like age, time since injury, nerve availability, surgical approach type, and therapeutic adherence [6–8]. Instrument choice is seldom standardized for functional recovery measurement; variation in outcome metrics hampers the relationship between surgical strategy and recovery trajectory. Some authors employ MMT; others favor MMRC, universal goniometry, digital goniometry, dynamometry, or surface electromyography. Accurate and reproducible outcome measurements are essential for clinical monitoring of prognosis and physiotherapeutic planning. Muscle strength measurements were performed using manual muscle testing (MMT) and Modified Medical Research Council (MMRC) scales proposed by the Medical Research Council (MRC). MMRC offers 0 to 5 grades similar to the MRC scale with additional finer sub-grades (A, B, and C) within grades 2, 3, and 4. Additionally, functional tools such as a pinch gauge and a hand-held dynamometer were used for pinch and grip strength, respectively. Electrical activity of the Biceps muscle was recorded using a wearable technology, the Pheezee® system, which simultaneously measures joint angular displacement and myoelectric activity.

The timely prescriptions of neuro facilitation, biofeedback, and progressive strengthening markedly influence the function. Physiotherapists, therefore, need suitable information on reinnervation status to tailor stimulation paradigms and optimize splinting schedules and muscle loading. This study aimed at recording kinematics, strength, and sEMG with different tools to document variability in recovery following BPI nerve transfers and establishing whether assessment modality influences and guides clinicians towards evidence-based documentation and therapeutic strategy planning.

Methods

We conducted a single-center cross-sectional observational study in the Department of Physiotherapy, Nizam's Institute of Medical Sciences, Hyderabad, India. Because the study was exploratory, and there were limitations in the number of subjects available, the sample size estimation was pragmatic; power analysis using G power indicated that 10 subjects per group would detect a large between-group effect in elbow flexion ROM with 80% power at $\alpha = 0.05$. A total of 68 subjects were screened, and 30 eligible subjects were recruited who met the inclusion criteria, comprised of age 18 to 50 years, unilateral traumatic BPI treated with one of three nerve transfer procedures, a minimum of 6 months post-surgical period, no prior neurological or orthopedic impairments affecting the upper limb function. Selected subjects stratified into three groups ($n = 10$ each): Oberlin1, Oberlin2, and ICN-MCN. All subjects were evaluated with outcome measures on the affected and normal sides. The study protocol was approved by the Institutional Ethical Committee (Approval Ref. No.: NIMS/IEC/PT/2024/03) (Fig. 1).

Manual muscle testing (MMT)

Elbow strength was assessed using the MRC and MMRC grading scales. Both scales have 0–5 grades, where '0' denotes no contraction and "5" denotes normal strength [9]. MMRC scale consists of an additional three subgrades (A, B, and C) within grades 2–4 when compared to the MRC scale ([10]. The therapist palpated biceps muscle activation while the patient was performing an active elbow flexion with the forearm in a supinated position to score the strength (Tables 1 and 2).

Measurement of elbow ROM

The Pheezee is a wearable device used in physiotherapy that measures range of motion (ROM) and Electromyogram (EMG) of joints and muscles in real-time. Produced by Startoon Labs, a Hyderabad-based ISO 13485:2016 and ISO 9001:2015 Certified medical device, has received FDA (510 k Exempt) clearance for its medical use [9]. The device measures the Range of Motion (ROM) and Electromyogram (EMG) of joints and muscles in real-time [10]. It consists of wearable modules, a custom Android app, and cloud-based processing and storage. The device is battery-operated and rechargeable. The real-time data is displayed on the user's phone app, while the data is transferred to a cloud server for further analysis. Detailed reports can be generated for tracking recovery and sharing with doctors and caregivers.

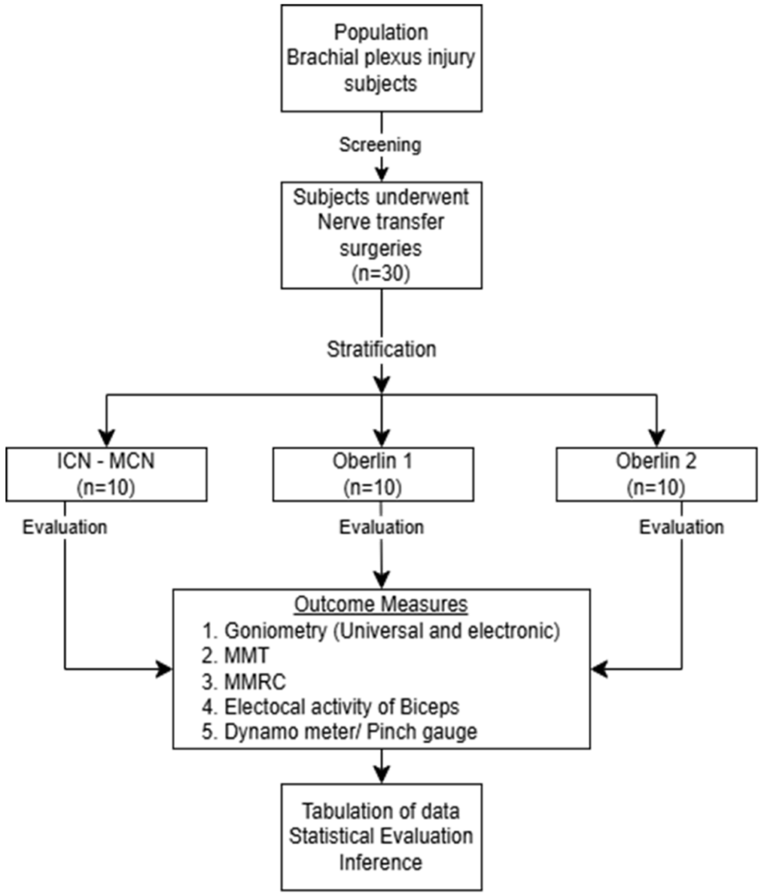

Fig. 1 Study flow chart

Table 1 MRC grades of manual muscle testing

Grades	Description
0	No visible or palpable contractions
1	Visible or palpable contractions without movement of the limb segment
2	Active full range of motion in gravity eliminated position
3	Active full range of motion against gravity
4	Active full range of motion against gravity, moderate resistance
5	Active full range of motion against gravity, maximal resistance

The elbow flexion range of motion was measured using a universal goniometer and the digital wearable Pheezee device. The therapist assessed the subject's range of motion by placing a goniometer axis at the lateral epicondyle, aligning the movable arm with the lateral aspect of the radius and the stationary arm with the longitudinal axis of the humerus (Fig. 2).

The Pheezee® (Startoon Labs Pvt. Ltd., India) is a wearable device that records joint ROM and muscle activity concurrently while the subject performs active elbow flexion (Fig. 3). This device has an upper module that consists of power management circuitry and a lower module with a movement sensor and sEMG circuitry [11, 12]. The lower module is positioned at the distal forearm, while the upper module is on the anterior part of the humerus. The biceps muscle activity was recorded by sEMG recording electrodes placed on the biceps muscle belly with the reference electrode fixed on the bony prominence (olecranon). The report was generated by the device and displayed on an Android device.

Table 2 Modified Medical Research Council system of grading for elbow flexion

Grades	Subgrades	Description
0	–	No muscle contraction
1	–	Perceptible contraction of the muscle but no movement of the joint
2		Gravity eliminated position
	A	Motion less than or equal to half the range of Full ROM
	B	Motion more than half range of full ROM
	C	Full range of motion
3		Movement against gravity
	A	Motion less than or equal to half range of full ROM
	B	Motion more than half rangeof full ROM
	C	Full range of motion
4		Motion against resistance in comparison with normal side
	A	Able to lift < 30%weight of the normal side through full range
	B	Able to lift 30–60%weight of the normal side through full range
	C	Able to lift < 60%weight of the normal side through full range
5		Normal strength

Fig. 2 ROM measurement using a Goniometer

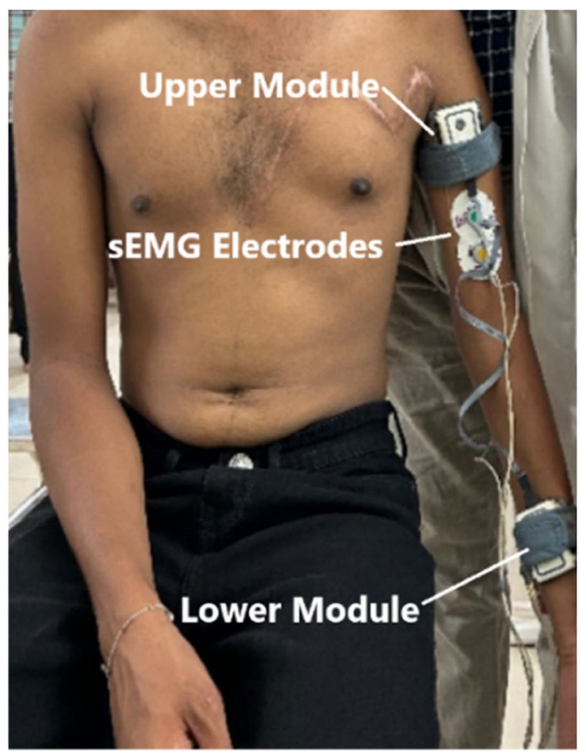

Fig. 3 Pheezee placement for ROM and electrode placement for biceps electrical activity

Grip strength

The grip strength was measured using a Hand handheld dynamometer. It measures grip strength from 0 to 200 lbs or 90 kg, accommodates small and large hand sizes, and features a dual scale readout in both pounds and kilograms. The device has an adjustable handle for different-sized objects and is scratch-resistant with a UV coating. It has a calibration certificate in compliance with ISO/IEC 17025. Subjects were asked to perform a 5-s grip contraction while the elbow was in a 90° flexion position (Fig. 4) and recorded in kilogram force. Three trials averaged with a 30-s interval between trials.

Fig. 4 Demonstration of hand held dynamometer position for grip strength

Fig. 5 Demonstration of pinch strength using pinch gauge dynamometer

Pincer grip strength

The study measured pincer grip strength using a pinch gauge Dynamometer. The Jamar Digital Pinch Gauge is a digital precision dynamometer that measures pinch force on the finger plate. The country of Origin is China. It measures 10′′×5′′×2′′ and comes with a 3-V battery and wrist strap. This tool is used to determine strength after injury or trauma and recovery progress in hand muscles during therapy or treatment. The package dimensions are 7.3×5.2×2.3 inches, and it weighs 8.78 oz. The item model number is 37219. Subjects applied pressure for 5 s on a pinch gauge with each finger against the thumb (thumb to index, middle, ring finger, and little finger) and measured in kilograms. A total of Three trials averaged with a 30-s interval between trials (Fig. 5).

Statistical analysis

The study data was analyzed using Jamovi statistical software version 2.4.8.0. Descriptive statistics of parameters expressed as mean ± SD. We employed ANOVA and Tukey's post hoc tests to compare group differences. The significance level threshold was $p < 0.05$.

Results

Demographic results

The total sample is 30; the mean age is 30.2 ± 8.9 years, height 163.1 ± 11.5 cm, weight 68.5 ± 13.43, and BMI 26.8 ± 5.9 kg/m2. No significant differences were found in age ($p = 0.065$), weight ($p = 0.632$), and BMI ($p = 0.063$). Significant between-group differences were found in height ($p < 0.001$). Further post-hoc Tukey's test revealed the Oberlin 1 group was significantly taller than both ICN-MCN ($p = 0.014$) and Oberlin2 ($p < 0.001$). No significant post hoc differences were found among groups for age, weight, or BMI ($p > 0.05$).

Table 3 displays age, height, weight, and BMI descriptive data by group.

Elbow range of motion

A one-way ANOVA test was performed to compare the active range of motion (AROM) and passive range of motion (PROM) measured on both the affected and unaffected ("normal") sides in three groups using a goniometer (G) and a Pheezee (Ph) device.

These results indicate that active range of motion (AROM) was considerably dependent on the approach of nerve transfer. ROM differences on the affected side, among the groups were significant on both the

Table 3 Descriptive statistics of age, height, weight, and BMI

Group	Age	Height	Weight	BMI
ICN-MCN	25.7 ± 4.19	161 ± 10.8	71.2 ± 14.3	28.5 ± 6.08
Oberlin 1	33.1 ± 9.73	173 ± 6.16	68.7 ± 15.6	23.6 ± 4.16
Oberlin 2	31.9 ± 10.7	155 ± 8.65	65.7 ± 10.7	28.3 ± 5.43

goniometer-measured active range of motion (G-AROM) ($p = 0.009$) and the Pheezee device-recorded active range of motion (Ph-AROM) ($p = 0.008$). Affected side Post-hoc tests further identified that the ICN-MCN group had significantly lower G-AROM (37.2°) than both Oberlin 1 (94.7°) ($p = 0.031$) and Oberlin 2 (108°) ($p = 0.007$). Similarly, in Ph-AROM, the ICN-MCN group's range of motion was significantly lower (38.5°) than Oberlin 1 (95.4°) ($p = 0.028$) and Oberlin 2 (108°) ($p = 0.006$). G-PROM ranges were complete on both sides, and the differences between the groups were insignificant ($p = 0.137$). The overall G-AROM differences on the normal side among the groups were insignificant ($p = 0.495$). These findings suggest that the Oberlin 1 and 2 procedures had a superior recovery of AROM on the affected side than the ICN-MCN group, while G-PROM on the affected as well as normal side did not differ significantly (Fig. 6).

Surface electromyography

Peak Biceps muscle amplitude was lowest in ICN-MCN group (144 ± 142 μV). Moderate in Oberlin 1 group (607 ± 486 μV), and highest in Oberlin 2 group (889 ± 552 μV) among all other groups. The normal side biceps activity was around 1213 ± 361 μV. No normalisation technique was applied; values were compared descriptively. One way ANOVA demonstrated significant intergroup difference ($p = 0.001$). Tukey post-hoc comparisons indicated a clear difference between the ICN-MCN and Oberlin 2 procedures ($\Delta = -745$ μV, $p = 0.002$), with an additional near-significant difference between ICN-MCN and Oberlin 1 ($\Delta = -463$ μV, $p = 0.060$). No significant difference emerged between Oberlin 1 and Oberlin 2 ($\Delta = -282$ μV, $p = 0.327$). Normal side showed no group differences, $p = 0.912$, and all pairwise comparisons were non-significant ($p > 0.90$).

The grip strength and pinch strength

A study comparing grip and pinch strengths across three groups (ICN-MCN, Oberlin 1, and Oberlin 2) found that the Oberlin1 group had better overall grip strength (36.4 ± 23.5) than the Oberlin2 group (25.7 ± 12.3). The differences were significant on the affected side ($p < 0.001$) and insignificant on the normal side ($p = 0.86$). Pinch strength was not similar in different fingers and decreased from digit i–ii to digit i–v on both affected and unaffected sides. The ICN-MCN group had significantly lower pinch strength than the Oberlin 1 and Oberlin 2 groups ($p < 0.001$). Clinically, the Oberlin1 group showed higher pinch strengths than the Oberlin1 group on the affected side, but statistically, no significant difference ($p > 0.75$), suggesting comparable functional outcomes. The ICN–MCN group recorded zero grip and pinch strength, as there was no reinnervation during the study (Fig. 7).

MMT and MMRC of elbow flexors

The study measured elbow flexor strength in three groups using MRC and MMRC grades. The ICN-MCN group had lower grades, while the Oberlin group had higher grades. Grade differences across groups were statistically significant on the MRC ($p = 0.0105$) and MMRC ($p = 0.0193$) scales. The MRC grades distribution was among the population: 60%–Grade 1, 40%–Grade 2. The Oberlin group had 20%–Grade 1, 50%–Grade 2, and 30%–Grade 3. The same subjects had a more dispersed distribution on MMRC Grade: The ICN-MCN group

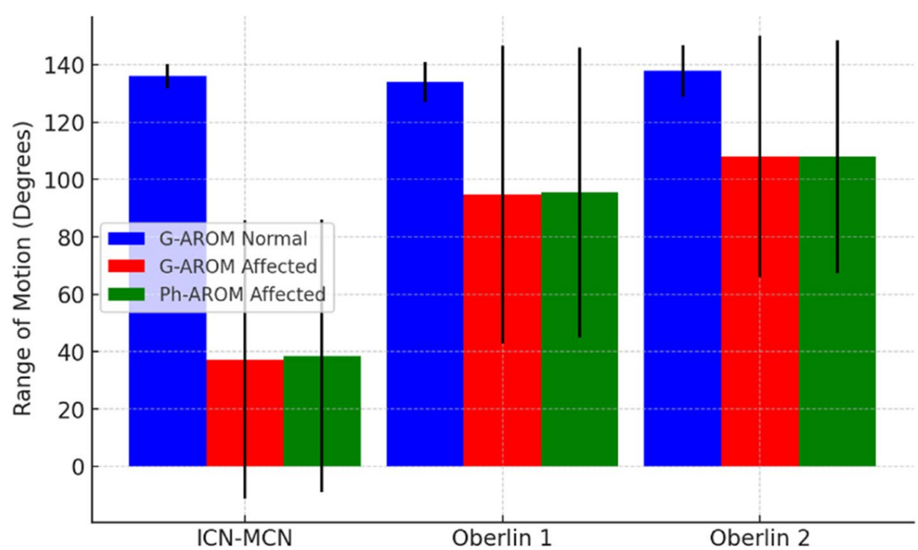

Fig. 6 Comparison of G-AROM of normal with G-AROM and Ph AROM between groups

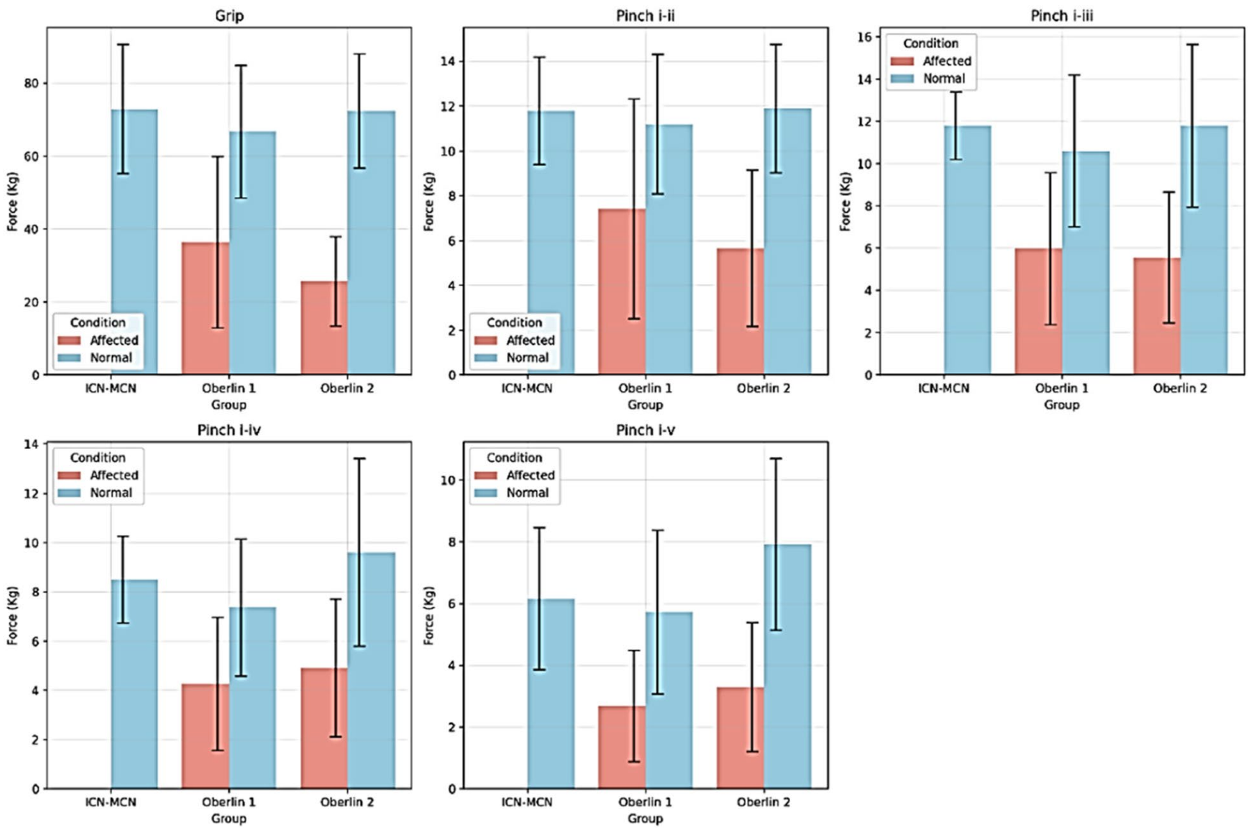

Fig. 7 Grip and pinch strength of affected and normal sides

subjects concentrated in lower grades (60%–Grade 1 and 40%–Grade 3B), Oberlin group was more dispersed (20%–Grade 1, 50%–Grade 3B, and 30%–Grade 3C). Oberlin 2: Better distributed results (10%–Grade 2A, 10%–Grade 3A, 20%–Grade 3B, and 60%–Grade 3C). The MMT and MMRC distributions differed significantly between groups ($p < 0.05$), indicating that the subject's improvement after each surgical method was different, and each scale provided a different distribution of functional grades (Fig. 8).

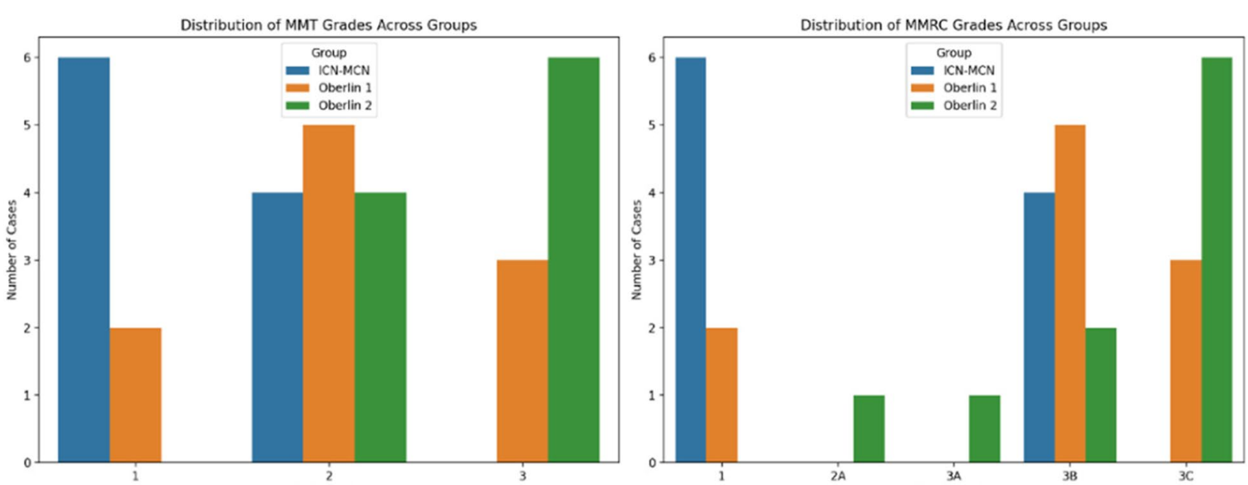

Fig. 8 Distribution of subjects' elbow flexor strength on MMT and MMRC grading

Discussion

The outcome following nerve transfer procedures in brachial plexus injuries (BPI) is influenced by multiple variables, including patient demographics, surgical technique, and timing of intervention. In the present study, although the age distribution across the groups was not statistically significant, younger individuals generally tend to show improved neuroplastic potential and regenerative capacity, as reported in prior literature. Notably, the Oberlin 2 group, involving double nerve fascicular transfer, demonstrated superior functional outcomes compared to Oberlin 1 and ICN–MCN groups. These findings align with the understanding that increased donor nerve input enhances the re-innervation potential of the target musculature [13, 14]. Variations in recovery outcomes may also relate to pre-surgical muscle and joint conditions, the presence or absence of partial innervation, and differing rehabilitation protocols postoperatively. The observed functional differences further underscore the importance of individualized surgical planning and rehabilitation strategies based on the extent and type of nerve transfer procedure utilized.

Elbow range of motion: influence of surgical approach

Restoration of elbow flexion is a primary target in BPI rehabilitation due to its role in upper limb utility. The findings of the study showed that the Oberlin 2 group, where double nerve fascicles were given to fascicles of nerves of the Biceps and Brachialis, showed a higher active range of motion than the single nerve transfer Oberlin 1 group did. The extra plexus transfer group ICN-MCN showed the lowest ROM. Active range of motion (AROM) on the affected side was significantly higher in subjects who underwent Oberlin 2 procedures compared to other groups. These results highlight that the quantity and type of donor fascicles play a crucial role in the functional re-establishment of elbow motion. While both the universal goniometer and the Pheezee device showed consistent trends in ROM outcomes. The Pheezee device's sensor's capacity to record even a slight amount of movement may be the reason for its slightly higher readings. Despite its high reproducibility and data richness, the clinical utility of the Pheezee remains limited by cost, need for training, availability, and lack of standardization limit its broader use.

Surface electromyography: insights into muscle reinnervation

Surface EMG values reflected motor unit recruitment, even in low-strength scenarios. Despite the absence of signal processing (normalization), peak amplitude comparisons offered necessary group-level insights. This study found that peak sEMG amplitudes of the biceps muscle were highest in the Oberlin 2 group and lowest in the ICN–MCN group. Even in subjects when the contraction is minimal and challenging to measure on MMT or MMRC, the electrical activity of innervated muscle was identified by sEMG. These findings are in agreement with previously reported studies. Dawn Sinn et al.'s study showed that muscle recovery was better after ulnar or median nerve transfers than intercostal nerve transfers [15]. The median and ulnar nerves control fingers, lumbricals, and interossei and are responsible for good grip and pinch strength. The ICN–MCN group had no grip and pinch strength, as there is no innervation distally. This variability may be attributed to the type of surgery and status of re-innervation [16].

Strength assessments: complementary use of MMT and MMRC

Assessment of muscle strength after nerve transfer is vital for monitoring recovery and planning rehabilitation. This study utilized both the MRC and MMRC grading systems. While both scales offer valuable clinical insights, the MMRC provides a more nuanced stratification by introducing subgrades A, B, and C within grades 2 to 4. This approach enables better discrimination of muscle recovery stages, particularly among participants transitioning between grades. The Oberlin 2 group exhibited the highest distribution across higher MMRC subgrades (3B and 3C), whereas the ICN–MCN group predominantly scored in lower MRC and MMRC categories. These findings are similar to the results of Donnelly et al., who noted that adults with partial BPIs, 84% of those who underwent double Oberlin transfer, achieved elbow flexion with an MMRC score of > 4 compared with 63% of those who underwent single (median or ulnar)s [17]. Liverneaux et al. [18] found comparable outcomes in their study on ten patients, who had the double nerve transfer, achieving grade 4 elbow flexion strength. The MMRC score enhances clinical decision-making by offering intermediate thresholds that reflect clinically relevant improvements in muscle function.

Clinical implications of instrument choice

The current study emphasizes the importance of selecting appropriate instruments for evaluating recovery in BPI. While traditional methods like the universal goniometer and MMT remain standard in many clinical settings due to their simplicity and accessibility, their limitations in sensitivity and inter-rater variability must be acknowledged. Advanced tools like the Pheezee device and sEMG provide objective and quantifiable data, enhancing precision in monitoring progress and adjusting rehabilitation strategies.

However, their adoption is dependent upon institutional resources and practitioner familiarity. Therefore, a hybrid model integrating simple tools for screening and advanced technologies for detailed evaluation could be ideal in multi-tier clinical systems. Furthermore, the choice of tool should align with the specific recovery parameter being evaluated—be it strength, range, or neuromuscular activation.

Intergroup differences: clinical and statistical significance

Statistical analysis revealed significant intergroup differences in elbow AROM, MMT and MMRC grading, and sEMG amplitude, all favoring the Oberlin 2 procedure. These findings were both statistically robust and clinically meaningful, reinforcing that surgical technique directly impacts recovery magnitude.

Conclusion

The current study provides valuable insights into the differential outcomes associated with nerve transfer procedures in BPI. The Oberlin 2 technique, involving double fascicular transfer, consistently outperformed other methods across multiple outcome domains, including ROM, sEMG amplitude, and strength grading. Instrument selection significantly influenced data sensitivity and interpretation, with tools like MMRC and Pheezee offering greater clarity.

These findings advocate for personalized surgical planning supported by appropriate outcome assessments to facilitate targeted rehabilitation. The integration of structured grading systems and technologically advanced measurement tools can enhance recovery monitoring and optimize therapeutic interventions in BPI rehabilitation.

Study limitations

As with any observational study, limitations must be acknowledged. The cross-sectional design restricts the interpretation of longitudinal progression. Additionally, the sample size, while pragmatically derived, remains small and may limit generalizability. Differences in surgical execution, rehabilitation adherence, and pre-existing muscle status may have introduced heterogeneity in outcomes. Importantly, the time from injury to surgery was not uniformly considered, which could influence reinnervation potential.

Future research should consider prospective longitudinal designs with standardized postoperative protocols and extended follow-up periods to capture the full trajectory of motor recovery. Integration of imaging techniques and intraoperative nerve stimulation may further refine selection criteria and enhance outcomes. Moreover, developing composite outcome scores that integrate strength, function, and neuromuscular activity could provide a holistic measure of recovery.

Abbreviations

Ph-AROM	Active ROM measured by Pheezee device
G-AROM	Active ROM measured by Goniometer
BPI	Brachial plexus injury
ICN to MCN	Intercostal nerve to Musculocutaneous nerve
MMT	Manual muscle testing
MMRC	Modified Medical Research Council
G-PROM	Passive ROM measured by Goniometer
ROM	Range of motion
sEMG	Surface electromyography

Authors' contributions

NKB contributed to the Research design, statistical analysis, data interpretation, and manuscript writing and served as the corresponding author. RY contributed to the Study execution, data sampling ,and statistical analysis.

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Academic research activity approved by Nizam's Institute of Medical Sciences.

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

All subjects gave informed consent for inclusion before participating in the study. The study protocol was approved by the Ethics Committee of Nizam's Institute of Medical Sciences Institutional Ethics Committee (EC/NIMS/3417/2024, 79th ESGS No. 1695/2024).

Competing interests

The authors declare that they have no competing interests.

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