



Age correlation in upper brachial plexus injury patients undergoing nerve transfer surgeries



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1. Introduction

Brachial plexus injury (BPI) has a variable spectrum. There can be a partial injury involving fewer roots or entire plexus can be involved (Narakas, 1991; Brunelli et al., 1990). 20–25% of traumatic BPI are due to C5,6 root injuries (Dubuisson and Kline, 2002). BPI mostly affects young men from 20 to 30 years of age, who have just entered into the most productive years of life (Jain et al., 2012). BPI themselves are not fatal. It can lead to loss of functionality in the upper limb, making it difficult and frustrating to perform the task of daily living and performing in his or her workplace, ultimately resulting in economic losses and unemployment (Jain et al., 2012; Kitajima et al., 2006). A considerable socioeconomic consequence accompanies BPI in the form of financial damage, productivity loss and as well as a marked decrease in quality of life (QOL) (Jain et al., 2012; Shin et al., 2005). Various surgical modalities have been described in the literature, including neurolysis and neurotisation (with or without nerve transfer). In the current era of microsurgery, results are more favorable and better compared to earlier studies (Brunelli et al., 1990; Ricardo, 2005a).

Various factors influence the outcome in patients undergoing brachial plexus reconstruction surgeries. The nature and extent of the injury, time from injury to surgical intervention, number of avulsed roots and number of axons reaching the target muscle are the critical determinant of a successful outcome (Socolovsky et al., 2011). Age can also impact the final results following a successful surgical repair.

The current literature has conflicting evidence regarding age and outcomes following brachial plexus reconstruction. Some authors suggest good recovery and others refute it in the older age group. The patient's age can be a critical determining factor in the outcome of brachial plexus reconstruction. Currently, there is a paucity of literature on the age correlation with the outcome of brachial plexus reconstruction in upper BPI (Sungpet et al., 2000; Gillis et al., 2019). The surgical results were assessed using sensory and motor recovery in most of the literature. However, functional status does not always correlate with sensory and motor recovery. Very few studies have evaluated the functional outcome and QOL. With the recent advent of statistically validated assessment tools and validated QOL functional score, it has become easier to quantify, measure, assess and compare these outcomes (Dubuisson and Kline, 2002; Choi et al., 1997; Kretschmer et al., 2009).

Considering the conflicting literature, we conducted this prospective observational study. We analysed 17 upper BPI patients undergoing nerve transfer. The clinical, patient-reported outcome and neurophysiological outcomes were correlated with age at various time intervals.

1.1. Material and methods

This prospective observational study was conducted from January 2017 to March 2019. A total of 17 patients of traumatic BPI with or without associated injuries were included in the study. Patients of ≥ 18 years of age and both sexes were recruited. Acute traumatic, upper limb

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amputation, penetrating BPI and unwilling and unconscious patients were excluded from the study. Institutional ethical clearance for the study was obtained. The patients were divided into two groups. Group A included patients from 18 to 40 years of age and group B included patients >40 years of age. A detailed history was taken and relevant clinical examination and motor examination based on the British Medical Research Council (MRC) to estimate limb and axial muscle strength. MRC scale (M0-M5) was used for the primary outcome measure of elbow flexion and shoulder abduction strength. The visual analogue scale (VAS) was used to assess the severity of pain. It is made up of a 10-cm line with two extremes of pain, with zero denoting "no pain" and 10 representing "worst imaginable pain". To evaluate the global function of the upper limb, the Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire was used. The DASH consists of 30-items surveys. It measures the degree and amount of difficulty faced by a patient in doing daily activities, including the severity of pain symptoms, weakness, tingling, activity-related pain and stiffness (five items), and the effect of the condition on social activities (one item), work (one item), sleep (one item), and self-image (one item), measured on a 5-point Likert scale (1–5). The scores of all items are added to calculate a DASH score ranging from 0 to 100. Higher DASH scores reflect more significant disability. Patients were also subjected to an electrodiagnosis study. Electromyography (EMG) was attempted in the following muscles: deltoid, biceps, triceps, infraspinatus, supraspinatus and trapezius. After needle insertion, pathologic spontaneous activity, shown as fibrillation potentials and positive sharp waves were determined. The patient was then asked to contract the muscle of interest to assess the presence of motor unit action potentials (MUAPs) under voluntary control and if present these were recorded.

1.2. Statistical analysis

The data was analysed using SPSS version 22 (IBM Corp., Armonk, N.Y.). The continuous variables were expressed as means with standard deviations and categorical variables were expressed as percentages. Non paired student's t-test was used for intergroup comparisons. Continuous outcome variables such as DASH and VAS scores were compared between groups using Wilcoxon signed ranked test. In contrast, categorical variables such as MRC scores were evaluated using the chi-square test. Pearson correlation coefficient was used for the variable pairs, e.g., elbow flexion strength/age of the patient, shoulder abduction strength/patient's age). A correlation coefficient (r) of 0.00–0.30 indicative of negligible correlation, 0.30–0.50 a low correlation, 0.50–0.70 a moderate correlation, 0.70–0.90 a high correlation and 0.90–1.00 a very high correlation. For all the analysis, a p -value less than 0.05 was considered significant.

1.3. Surgical technique

Under general anaesthesia, the patient was positioned supine with their neck extended and turned in the opposite direction. The supraclavicular incision was made. The incision was continued superiorly along the posterior border of the lower part of the sternocleidomastoid muscle. Usually, the space between the anterior and middle scalene muscles is occupied by the upper brachial plexus spinal nerves. Erb's point and suprascapular nerve (SSN) were identified. For the donor, the spinal accessory nerve (SAN) was used. SAN was exposed by opening the deep cervical fascia and its branches were traced as distally as possible to gain the maximum length. SAN was sectioned from the distal most part. A proximal branch from the SAN was preserved to supply the trapezius muscle. The Coaptation of SAN to SSN was done at a depth in the neck. Doing a tension-free coaptation in such a bottom is a difficult task. Most of the time micro instruments reach the coaptation site with difficulty. Moreover, it is tough to manoeuvre these instruments at such depth. We used an innovative method of achieving tension-free coaptation done at depth. Firstly, we fill the depth with an absorbable hemostatic gel sponge. Then both the nerve ends are rested over it. This sponge gel will

reduce the depth and help in lifting the nerves. Then a tension-free neurotization was done between SAN and SSN with nonabsorbable monofilament 10–0. The fibrin glue was applied over the coaptation site for reinforcement [Fig. 1 a, b].

For elbow flexion restoration, Oberlin transfer was done. A longitudinal incision was made in the anteromedial aspect of the upper arm. The ulnar nerve was identified as posteromedial to the brachial artery. After a longitudinal aponeurotomy was made, Intrafascicular dissection was done. The nerve stimulator was used to determine the fascicle supplying the flexor carpi ulnaris (FCU) muscle. The musculocutaneous nerve was traced after it crossed the coracobrachialis muscle. The motor branch to the biceps muscle was identified and dissected. Nerve fascicles carrying motor fiber to the FCU muscle were sectioned. The FCU fascicle was coapted with the motor branch to the biceps. The coaptation was done with nonabsorbable monofilament 10–0 and fibrin glue [Fig. 1 c].

For the Somsak technique, the patient was positioned in the semi-lateral position with the affected arm over the thorax. An oblique incision was made along the posterior border of the deltoid in the upper arm and the deltoid muscle was retracted laterally. Quadrilateral space was identified. It is bounded medially by the long head of the triceps muscle and lateral boundary by the humerus. The teres minor and teres major muscles form the superior and inferior border respectively. The axillary nerve was identified in this space. The axillary nerve gives a branch to teres minor muscle and then divides into an anterior and posterior branch. The anterior branch provides motor supply to the deltoid muscle. The anterior branch was dissected as proximally as possible for the maximum length and transected. The motor branch to the long head of the triceps muscle was dissected as distally as possible and then sectioned from the distal most part and flipped 180°. It was coapted with the anterior branch of the axillary nerve with nonabsorbable monofilament 10–0 and fibrin glue [Fig. 1 d].

The skin was closed with the nonabsorbable monofilament 3-0 suture. The arm was flexed, immobilized and strapped to the chest. Post-operatively the immobilization was maintained strictly for three weeks. It was followed by the gradual passive physiotherapy of the elbow and the shoulder joints. Electrical stimulation of the paralyzed muscle was done until adequate power was achieved. At every three-month interval, all the patients were evaluated and followed up to eighteen months.

2. Results

A total of 17 patients diagnosed with upper BPI were recruited sequentially in the study [Table 1]. The maximum number of cases were between 25 and 30 years of age (41%). Sixteen were men and one was a woman. 16 (94%) patients had a roadside accident (RSA) and were mostly associated with two-wheelers. Ten patients in group A had a mean age of 26.6 ± 2.95 . In comparison, seven patients in group B had a mean age of 44.7 ± 13.25 years. In group A, six (60%) patients had right-sided upper BPI and four (40%) patients had left-sided upper BPI as compared to five (71%) patients who had right-sided and two (29%) patients had left-sided upper BPI in group B. C5,6 paralysis was seen in eight (80%) patients in group A and five (71%) patients in group B. In group A two (20%) patients had C5,6,7 paralysis as compared to two (29%) patients in group B. The mean time interval from injury to exploration was 6.27 ± 1.66 months in group A and 7.59 ± 1.62 months in group B. The minimum follow-up period was twelve months. Various nerve donors were used for the nerve transfer surgery, as shown in Table 2. Among the overall 17 patients, seven (41%) patients achieved M4, six (35%) M3, three (18%) M2 and one (6%) M1 elbow flexion strength. Attainment of shoulder abduction strength was lower than elbow strength. Only two (12%) patients achieved M4, eleven (65%) had M3, and two (12%) patients each made to M2 and M1 shoulder abduction strength. The mean shoulder abduction range of motion (ROM) for group A was $34 \pm 12^\circ$ compared to $12 \pm 17^\circ$ for group B.



Fig. 1. a) We used an innovative method of achieving tension-free SAN-SSN coaptation done at depth. Firstly, we fill the depth with an absorbable hemostatic gel sponge. b) Both the nerves are rested over the gel foam and tension free coaptation was done between SAN and SSN. c) Oberlin 1 nerve transfer. The FCU fascicle was coapted with the motor branch to the biceps. d) Somsak nerve transfer. The motor branch to the long head of triceps muscle coapted with the anterior branch of the axillary nerve.

Table 1
Description of patient's clinical data.

Group A (age < 40 years)						
Age (years)	Side of limb	Paralysis type	Surgical technique	Final Outcome		
				Elbow flexion strength	Shoulder abduction strength	Shoulder ROM (Degree)
28	Rt	C5,6,7	san-ssn,oberlin1	M4	M3	30
23	Rt	C5,6	san-ssn,oberlin1, somsak	M4	M3	50
26	Rt	C5,6	External neurolysis	M4	M4	30
28	Lt	C5,6	san-ssn,oberlin1, somsak	M4	M3	20
30	Lt	C5,6	san-ssn,oberlin2, somsak	M3	M3	30
23	Lt	C5,6,7	san-ssn,oberlin1	M4	M3	60
22	Rt	C5,6	san-ssn,oberlin1, somsak	M3	M3	30
28	Lt	C5,6	san-ssn,oberlin1, somsak	M4	M3	20
28	Rt	C5,6	san-ssn,oberlin1, somsak	M3	M3	50
30	Rt	C5,6	san-ssn,oberlin1, somsak	M4	M4	40
Group B (age > 40 years)						
Age (years)	Side of limb	Paralysis type	Surgical technique	Final Outcome		
				Elbow flexion strength	Shoulder abduction strength	Shoulder ROM (Degree)
42	Rt	C5,6	san-ssn,oberlin1	M3	M3	30
45	Lt	C5,6	san-ssn,oberlin1	M2	M3	20
41	Lt	C5,6,7	External neurolysis	M2	M2	0
46	Rt	C5,6	san-ssn,oberlin1, somsak	M3	M1	0
50	Rt	C5,6	san-ssn,oberlin1, somsak	M1	M1	0
42	Rt	C5,6,7	san-ssn,oberlin1	M3	M3	40
47	Rt	C5,6	san-ssn,oberlin1, somsak	M2	M2	0

Rt, Right; Lt, Left; san, spinal accessory nerve; ssn, suprascapular nerve.

2.1. Comparing the groups

No statistically significant difference between the groups was observed as per paralysis type, site of limb involvement and mean time interval from injury to exploration. Functions achieved were assessed as poor to excellent as per the assessment scale by Terzis et al. (1999). At the end of twelve month follow-up period, seven patients (70%) in group A scored M4 (good) elbow flexion strength and none in group B. Three patients (30%) in group A and three patients (43%) in group B achieved M3 (fair) elbow flexion strength. A statistically significant difference in elbow flexion was seen between the two groups ($p < 0.01$). Group A tends to have greater elbow flexion strength at the end of the follow-up period. The majority of study subjects achieved M3 shoulder abduction strength. In group A, two (20%) patients achieved M4 power but none in

group B. M3 abduction strength was present in eight (80%) patients in group A and three (43%) cases in group B. Two (29%) patients achieved M2 and M1 abduction strength in group B respectively whereas none in group A. At the end of the follow-up period a statistically significant difference was observed between the groups ($p = 0.02$) [Fig. 2]. Even for a shoulder ROM, a statistically significant difference was present ($p = 0.01$) [Figs. 3 and 4].

In both groups, it was found that the VAS decreased at all the post-operative stages considerably. A statistically significant difference was found in VAS ($p = 0.02$). Like VAS, the DASH score also decreases at all the postoperative stages and a statistically significant difference was found ($p = 0.01$) [Fig. 5].

A statistically significant difference of MUAPs in the bicep brachia muscle ($p = 0.04$) was present between the groups. However, there was

Table 2
Demographic profile and perioperative data of patients.

	Group A (age<40)	Group B (age>40)	
Mean age ±standard deviation (years)	26.60 ± 2.95	44.71 ± 3.25	
Age range (years)	22–30	41–50	
Side affected	Rt Lt	6 (60%) 4(40%)	5 (71%) 2 (29%)
Dominant arm involved	Yes No	7 (70%) 3(30%)	4 (57%) 3 (43%)
Distribution of paralysis	C5,6 C5,6,7	8 (80%) 2 (20%)	5 (71%) 2 (29%)
Time interval from injury to exploration (months)	6.27 ± 1.66	7.59 ± 1.62	
Surgical procedure	SAN-SSN Oberlin 1 Oberlin 2 Somsak External neurolysis	9 (90%) 8(80%) 1(10%) 7 (70%) 1(10%)	6 (86%) 6 (86%) 0(0%) 5 (71%) 1(14%)
Preoperative	VAS DASH	8.8 ± 0.42 68.49 ± 9.36	8.57 ± 0.97 71.81 ± 4.85

Rt, Right; Lt, Left; SAN, Spinal accessory nerve; SSN, Suprascapular nerve; VAS, Visual analogue score; DASH, Disabilities of the Arm, Shoulder and Hand score.

no statistically significant difference in the neurophysiological evidence of supraspinatus and deltoid muscle.

2.2. Correlation analysis

Pearson correlation revealed a high negative correlation between age and elbow flexion strength and shoulder abduction strength. A moderate negative correlation between age and shoulder ROM. A very high positive correlation between age and DASH. A moderate positive correlation between age and VAS [Table 3].

3. Discussion

BPI most often afflicts young men around 25 years old, embarking on their most productive years of life. The present study's mean age was higher than the published studies (Dubuisson and Kline, 2002; Jain et al., 2012; Kitajima et al., 2006). It may be due to two distinctive groups with different age profiles. In the current study, 94% of patients had RSA. The

frequency of RSA as a predominant cause of traumatic BPI varies in most studies. A study conducted in Thailand by Songcharoen et al. reported that 91% of BPI were due to RSA (Songcharoen, 1995). Whereas Dubuisson from Belgium and Kandenwein from Germany reported that 60% and 80% of traumatic BPI were due to RSA respectively (Dubuisson and Kline, 2002; Kandenwein et al., 2005).

Age can affect the outcome in patients undergoing nerve transfer surgery for BPI. Multiple case series have supported a correlation between age and elbow flexion. Nagano et al. found that the best results of intercostal nerve transfer for elbow function were present in patients <30 years of age and operated within six months (Nagano, 1998). Terzis et al. in their study of 162 BPI patients who underwent radial nerve reconstruction for triceps restoration found that outcome was better in patients less than 16 years of age (Terzis and Barmptsioti, 2012). Socolovsky et al. conducted a study in which sixty patients were divided into three age groups (<20, 20–29 and > 30). Their data suggested that the outcome of the surgery was linked to age. Increased age was associated with poor elbow outcomes. However, shoulder abduction strength was unrelated to age (Socolovsky et al., 2017). El-Gammal and Fathi performed 71 extraplexal neurotization and 18 interfascicular grafting procedures separately or in combination in 32 male patients with BPI. Patients operated after six months and over 40 years of age had weak elbow flexion (<M2) and shoulder abduction of 25°. Whereas those under 40 years of age and operated within six months had fair or good elbow flexion (>M3) and shoulder abduction of 45°. However, these results were not statistically significant (El-Gammal and Fathi, 2002). Lee et al. retrospectively studied 21 patients and found that deltoid muscle strength following triceps to axillary nerve transfer correlated with age. Eleven patients out of twelve aged <39 years had an excellent outcome. Whereas five patients had muscle strength of ≤ M3 (Lee et al., 2012). In the Sungpet series, 34 out of 36 upper BPI patients achieved bicep strength of M3+. They all underwent transfer of a single ulnar nerve fascicle to the motor branch of the bicep brachi (Sungpet et al., 2000). Leechavengvongs et al. in their study of 32 BPI patients, reported bicep strength of M4 in 30 patients. The patient's ages ranged from 19 to 46 years, with a mean age of 28. Twenty-six patients had C5,6 root avulsion, 4 had C5,6,7 root avulsion, and the other two had lateral and posterior cord injury (Leechavengvongs et al., 1998). In another study by Leechavengvongs et al. on seven patients with a mean age of 25 years of upper BPI, they reported the outcome of nerve transfer using the nerve to the long head of the triceps to the anterior branch of the axillary nerve. All the patients had deltoid muscle strength of M4 with an average shoulder abduction of 124° (Leechavengvongs et al., 2003).

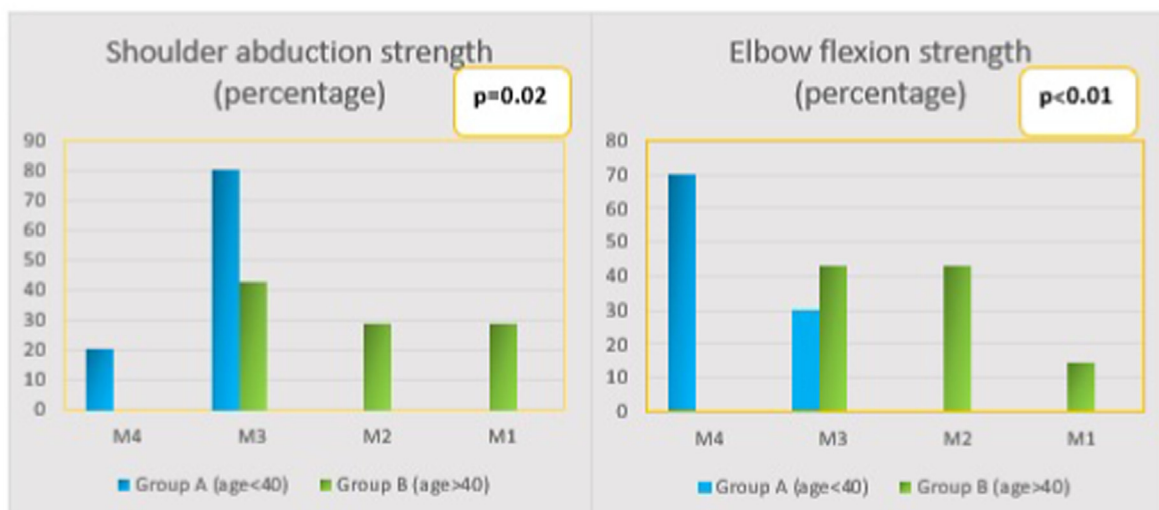


Fig. 2. Comparison of shoulder abduction strength and elbow flexion strength after follow-up period in both the groups. A statistically significant difference was present between the groups.

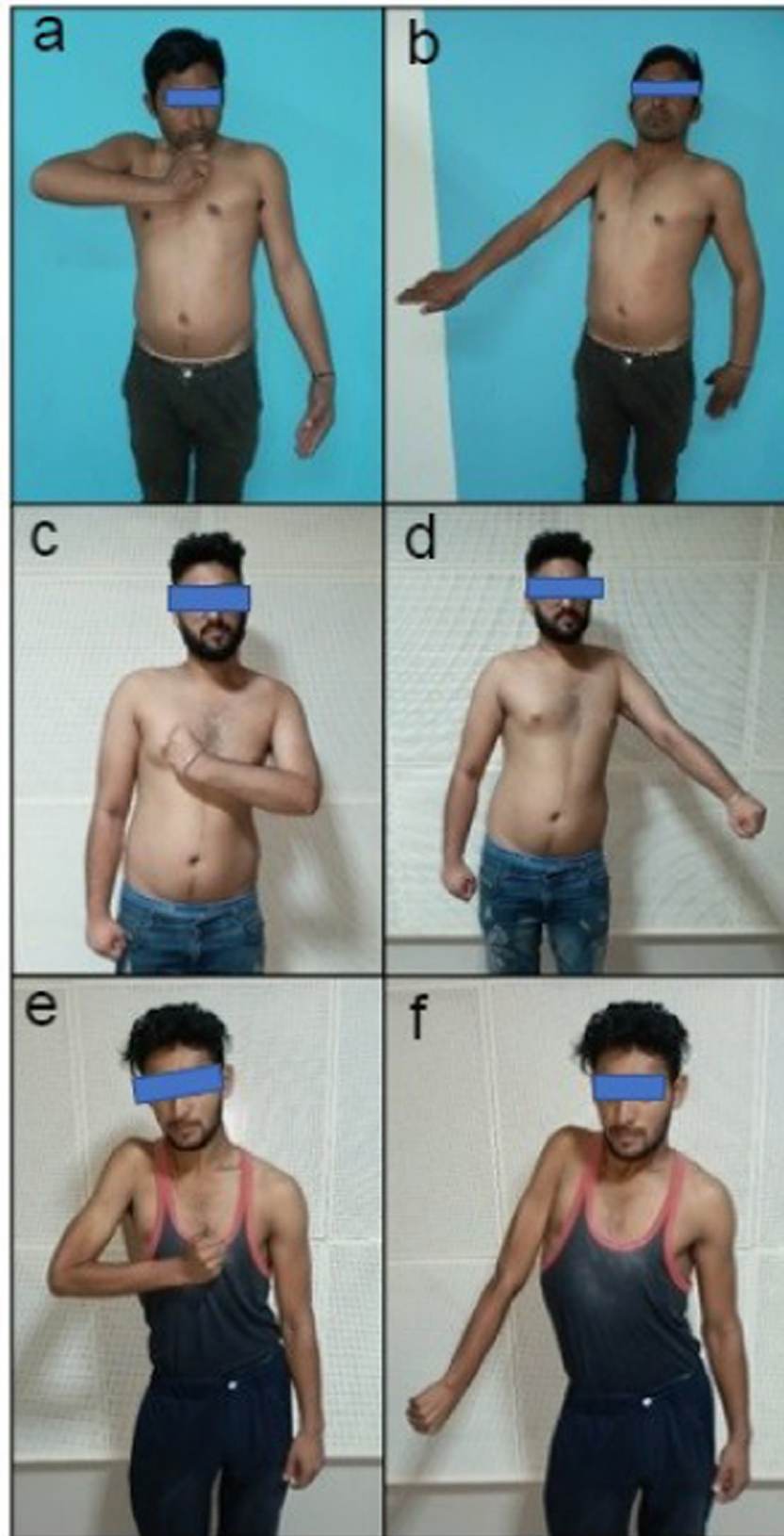


Fig. 3. Outcome in the group A (<40 years) at the twelve months follow up. (a, b) Patient with right C5,6 paralysis underwent nerve transfer. The patient had M4 elbow flexion strength and 50 degrees of abduction. (c, d) Patient with left C5,6,7 paralysis, he had M4 elbow flexion strength and 60 degrees of abduction after nerve transfer. (e, f) Patient had right C5,6 paralysis and after nerve transfer, he achieved M3 elbow flexion strength and 30 degrees of abduction.



Fig. 4. Outcome in the group B (>40 years) at the twelve months follow up. (a,b) Patient with right C5,6,7 paralysis underwent nerve transfer. The patient had M3 elbow flexion strength and 40 degrees of abduction. (c, d) Patient with left C5,6 paralysis, he had M2 elbow flexion strength and 20 degrees of abduction after nerve transfer.

Multiple studies also reported contradictory evidence and refuted any correlation between age and brachial plexus reconstruction outcome. Samardzic's et al. evaluated 44 patients of upper BPI. the nerve transfer was performed by using the collateral branches of the brachial plexus i.e. thoracodorsal and medial pectoral nerve. 68% of cases in this series were less than thirty years old. Functional elbow recovery was present in 94%. They did not find any correlation between age and the outcome following nerve transfer with the collateral branches of the brachial plexus (Samardzic et al., 2011). A study on 58 patients older than 50 years by Joshua et al. suggested that good elbow flexion can be achieved after surgery in traumatic BPI. 60% of patients achieved elbow flexion \geq M3. 38% had pan bpi, 29% had C5,6 and 20% had C5,6,7 injury pattern. The nerve grafting and nerve transfer group had better outcomes than the free functional muscle transfer group (Gillis et al., 2019). Similarly, Ricardo M et al. and Thatte MR et al. found no correlation of age with outcomes following brachial plexus reconstruction either with nerve transfer (intraplexus and extraplexus) or grafting (Ricardo, 2005b; Thatte et al., 2013).

In the current study, at the end of the follow-up period, a statistically significant difference was present in the elbow flexion strength, shoulder

abduction strength and shoulder ROM when compared between the groups. A strong negative correlation was present between the age and elbow flexion strength, shoulder abduction strength and shoulder ROM.

Beaton et al. in their study showed that with the mean DASH score change of 17, the patient reported their problem as better. Whereas, with a mean difference of 20, the patient reported their function as better (Beaton et al., 2001). In The study by Husted JA et al., a mean score change of 19 indicated a change in disability rated as "much better/worse" and a mean score change of 10 as "somewhat better/worse" (Husted et al., 2000). In the present study, the DASH score decreases considerably at all the postoperative stages in both groups. The mean change after the follow-up period in the DASH score was 26 for group A and 12 for group B. The mean change in score for group A was in concordance with the study by Beaton et al. (2001). We found a statistically significant difference in the DASH outcome between the groups and a high positive correlation with age.

In the present study, on comparing the groups, a statistically significant difference was found in the VAS at the end of the follow-up period. A moderate positive correlation was seen between age and VAS. These results were comparable to the study by Kretschmer et al. (2009).

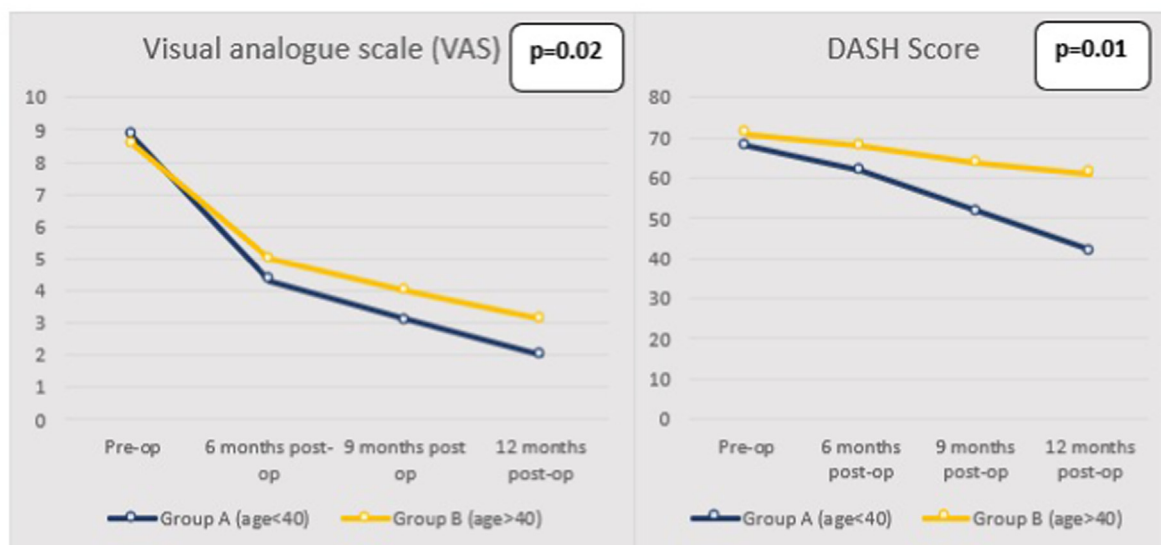


Fig. 5. Comparison of VAS and DASH after follow-up period in both the groups. A statistically significant difference was present between the groups.

Table 3

Correlation of age with various variables.

Variable tested	Degree of correlation	Statistical significance	Degree of correlation
Age and elbow flexion strength	$r = -0.73$	$P < 0.01$	High negative
Age and shoulder abduction strength	$r = -0.72$	$p < 0.01$	High negative
Age and shoulder ROM	$r = -0.63$	$p < 0.01$	Moderate negative
Age and DASH	$r = 0.87$	$p < 0.01$	High positive
Age and VAS	$r = 0.53$	$p = 0.02$	Moderate positive

ROM, Range of motion; DASH, Disabilities of the Arm, Shoulder and Hand score; VAS, Visual analogue score.

Early signs of muscle recovery may be detected on EMG. EMG recovery does not always ensure relevant clinical recovery. When the target end organs are more distal, then ongoing reinnervation may not be detected on EMG (Thatte et al., 2013). Several studies have found that despite surgery yielding measurable improvements, but still patient may not be happy with the arm function (Novak et al., 2011). In the present study, at the end of 12 months, neurophysiological evidence of reinnervation of various muscles was observed. A statistically significant difference in MUAPs in bicep brachii muscle was found between the groups.

Certain limitations come in the forefront at the end of the present study. The main limitation of our study is the small sample size. Another limitation was the late presentation of the patients to our center, which has a bearing on the time from injury to the surgical exploration and ultimately on the results. However, all the patients were operated in the stipulated period of nerve recovery. One patient in both the groups underwent external neurolysis. Multiple factors contribute to global shoulder motion. Thus, making reliable and objective assessments of shoulder joint function a challenge. Arm-abduction should be assessed as gleno-humeral abduction by immobilising the shoulder blade. Scapula movement contributes to arm abduction. This movement do not essentially is a consequence of brachial plexus injury recovery. Clinical shoulder range of motion measurements is imprecise, limiting the current study. Currently, there is an ambiguity regarding the best evaluation method for the assessment of brachial plexus reconstruction. The MRC grading should be complemented with the newer method of evaluation like a computerized assessment of movements and dynamometer-based assessment to substantiate the outcome findings.

4. Conclusion

As per the current study, Post-surgical results may vary depending on multiple factors and age is one of the critical factors. This study supports the various correlation of age with the outcomes of upper brachial plexus reconstruction surgery, especially for elbow flexion and shoulder abduction. Nerve transfer surgeries for upper BPI bring about great recuperation of elbow and shoulder functions. The main finding of the current study was the inverse relationship we distinguished between age and elbow flexion and shoulder abduction strength. In managing upper BPI, the favorable factors are younger patients with short denervation periods.

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Declaration of competing interest

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