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Original article

Comparison of spinal accessory nerve transfer to supra-scapular nerve vs. shoulder arthrodesis in adults with brachial plexus injury

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ABSTRACT

Background: Restoring shoulder mobility, stability, and strength is a key goal in patients with brachial plexus injuries. Shoulder arthrodesis is chiefly used as an adjunct to, or after failure of, initial direct nerve surgery. The objective of this study was to compare clinical and functional shoulder outcomes after direct nerve transfer vs. shoulder arthrodesis in adults with supra-clavicular brachial plexus injuries.
Hypothesis: Shoulder arthrodesis, currently used as a salvage procedure in brachial palsy injuries, deserves to be viewed to a valid alternative to direct nerve transfer.
Material and methods: A retrospective study was conducted in 58 patients with a follow-up of at least 2 years. Among them, 20 were managed by transfer of a spinal accessory nerve fascicle to the supra-scapular nerve and 38 by shoulder arthrodesis. Outcome measures were shoulder range-of-motion, isometric shoulder strength, and the Disabilities of the Arm, Shoulder, and Hand (DASH) score.
Results: Mean age at surgery was 24 years and mean follow-up was 46 months (range, 24–156 months). Motion ranges of the shoulder were not significantly different between the two treatment groups. Data variance was significantly greater in the nerve transfer group than in the shoulder arthrodesis group for scapular antepulsion ($p = 0.0011$), abduction ($p < 0.001$), and external rotation ($p = 0.0066$). Strength was significantly greater in the arthrodesis group in all directions of motion. The DASH scores showed no significant between-group differences.
Conclusions: The results of this study conflict with the widely help opinion that nerve transfer to the supra-scapularis nerve produces better clinical outcomes compared to shoulder arthrodesis. Nerve transfer was not better than shoulder arthrodesis in our patients. The data variance heterogeneity suggests poor predictability and reliability of nerve transfer, in contrast to the modest but predictable and uniform results of shoulder arthrodesis.
Level of evidence: IV, retrospective observational comparative study.

1. Introduction

Brachial plexus injuries in adults remain challenging to treat [1–3]. The two main clinical presentations are upper-trunk palsy involving C5 and C6, and in some cases C7, which does not affect hand function, and pan-plexus palsy, with loss of function of the entire upper limb [2,3]. Although these two types of injury have different functional prognoses, loss of shoulder function in both produces severe upper limb impairments [4]. Restoring shoulder stability, mobility, and strength is therefore key to the recovery of upper limb function, and restoring active elbow function is the top priority [5–8].

The main options for restoring the function of the paralysed shoulder are direct nerve surgery involving grafting of nerve fascicles from non-avulsed roots or nerve transfers [1,3,9–12] and palliative treatments such as shoulder arthrodesis [13,14], muscle transfers [1,12], and humeral derotation osteotomy [8].

To our knowledge, no published studies have compared outcomes after direct nerve surgery and shoulder arthrodesis. Shoulder arthrodesis is often viewed as a palliative treatment for use as an adjunct to, or after failure of, direct nerve surgery. The results of several clinical studies [13–15] led us to challenge this view.

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The primary objective of this study was to compare clinical and functional shoulder outcomes after direct nerve transfer vs. shoulder arthrodesis in adults with supra-clavicular brachial plexus injury. The secondary objectives were to assess the effects on clinical outcomes of spinal accessory nerve transfer to the supra-scapular nerve in patients who underwent shoulder arthrodesis after direct nerve surgery for the same indications. The working hypothesis was that shoulder arthrodesis, currently used as a salvage procedure in brachial palsy injuries, deserves to be viewed to a valid alternative to direct nerve transfer.

2. Material and methods

A retrospective single-centre study was conducted in patients who underwent surgery for brachial plexus injuries between 1994 and 2000. All patients underwent a clinical evaluation by an independent observer. Written informed consent was obtained from each patient before study inclusion.

2.1. Inclusion criteria

Patients older than 15 years were included if they had clinical shoulder palsy due to supra-clavicular brachial palsy injury. All patients underwent either direct nerve surgery or shoulder arthrodesis to restore shoulder function. Only patients with a follow-up of at least 2 years were included.

2.2. Exclusion criteria

Patients with infra-clavicular or retro-clavicular brachial plexus injuries were excluded. We also excluded patients whose brachial plexus palsy was caused by a tumour, radiotherapy, gunshot wound, or blunt weapon injury.

2.3. Patients

The study included 58 patients with a mean age at surgery of 24 years (range, 15–52 years). The patients were divided into two groups based on whether they had upper-trunk palsy or pan-plexus palsy. Active elbow flexion was restored by transfer of an ulnar nerve fascicle [16] in 5 patients and by transfer of the T3, T4, and T5 intercostal nerves [3,8] in the remaining patients.

Nerve transfer was performed initially in 33 patients. Among them, 13 subsequently underwent shoulder arthrodesis due to failure of the direct nerve procedure. No clinical data collected before arthrodesis was available for these 13 patients, who were therefore excluded from the nerve transfer group. Of the 20 patients left in the nerve transfer group, 12 had upper-trunk palsy and 8 pan-plexus palsy. In all these patients, the objective was to restore supra-scapular nerve function via partial spinal accessory nerve transfer preserving the supply to the upper trapezius muscle [9]. The elbow was immobilised by the side for 1 month after the nerve transfer procedure. A rehabilitation programme was then followed to preserve joint range-of-motion.

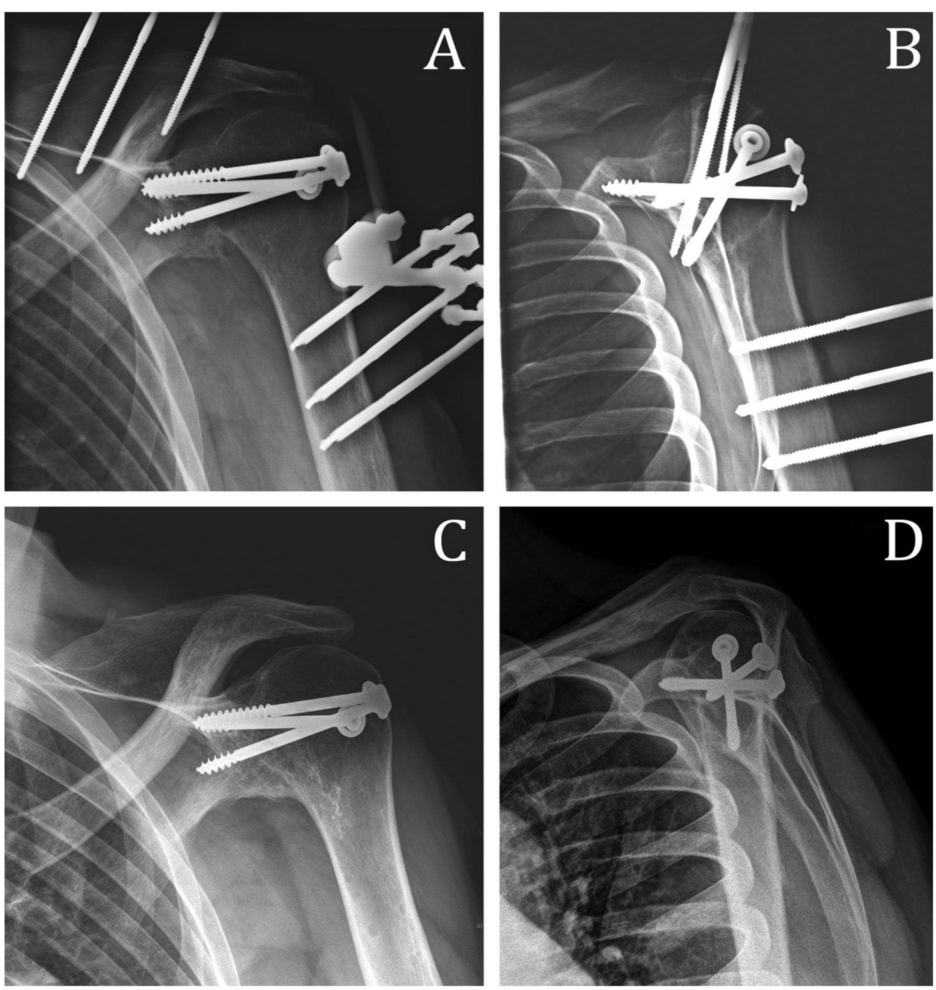

Fig. 1. Shoulder arthrodesis by humero-scapular compression-screw fixation combined with external fixation (Hoffmann®, Stryker, Kalamazoo, MI, USA). A and B. Antero-posterior and lateral radiographs 2 months after surgery. C and D. Antero-posterior and lateral radiographs at last follow-up 74 months after surgery.

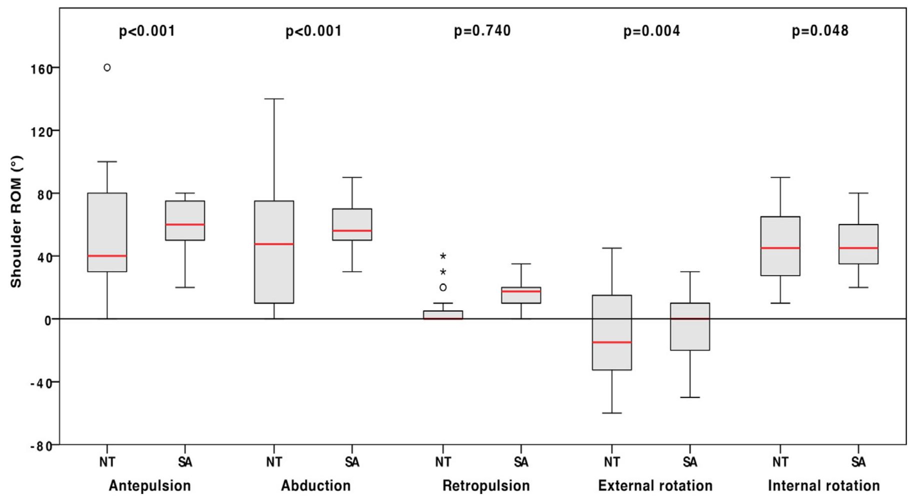

Fig. 2. Comparison of dispersion of shoulder range-of-motion (ROM) data in the groups managed by nerve transfer (NT) and shoulder arthrodesis (SA) within the overall study population. *, °: outliers.

Of the 38 patients managed by shoulder arthrodesis, 12 had upper-trunk palsy and 26 pan-plexus palsy. The arthrodesis was the primary procedure in 25 patients and was performed after failure of nerve transfer in the remaining 13 patients. Pre-operative serratus anterior muscle function was M4+ or higher. Open arthrodesis was performed via the posterior approach (Fig. 1). Humero-scapular compression-screw fixation was combined with external fixation (Hoffmann®, Stryker, Kalamazoo, MI, USA) [13]. In addition, a thoraco-brachial splint was worn for 2 months. Rehabilitation of the scapulohumeral joint was started immediately with protection by the external fixator. The fixator was removed 2 months after surgery provided bone fusion was confirmed by the radiographs and, if needed, a computed tomography scan.

2.4. Clinical and functional assessments

A goniometer was used to measure the ranges of antepulsion, retropulsion, abduction, external rotation, and internal rotation. Antepulsion and retropulsion were measured between the plane of the scapula and the axis of the arm, abduction between the vertebral border of the scapula and the axis of the arm, and rotations with the elbow flexed at 90° and by the side, as the angles between the sagittal plane and the forearm. Isometric shoulder strength (KgF) was determined using a hydraulic dynamometer at 30° of antepulsion, 30° of abduction, 0° of adduction, and in the spontaneous neutral position for external and internal rotations. Shoulder function was assessed based on the 100-point Disabilities of the Arm, Shoulder, and Hand (DASH) scale.

In the group with shoulder arthrodesis, the position of the fusion was determined in antepulsion, abduction, and internal rotation, using a goniometer.

2.5. Statistical analysis

SPSS® software (IBM, Armonk, NY, USA) was used for the statistical analysis. Qualitative variables were described as number and percentage and compared between groups by applying the Chi^2 test. Continuous quantitative variables were described as mean and standard deviation (SD) and compared using the Mann-Whitney test. Levene's test was applied to evaluate homoscedasticity of the clinical data [17]. Values of p smaller than 0.005 were deemed significant.

3. Results

Mean follow-up was 46 months (range, 24–156 months) overall, 58.1 months (range, 24–188 months) in the arthrodesis group, and 40.8 months (range, 24–73 months) in the nerve transfer group ($p = 0.961$). Mean age at surgery was significantly older in the arthrodesis group (30 years; range, 18–60 years) than in the nerve transfer group (24 years; range, 17–34 years) ($p = 0.001$); of the 20 patients in the nerve transfer group, 14 (70%) were younger than 25 years. Mean time from injury to nerve transfer was 5.6 months (range, 2–9 months).

Mean gleno-humeral position in the arthrodesis group was in 26 ± 8° of antepulsion, 28 ± 10° of abduction, and 27 ± 11° of internal rotation.

3.1. Overall population

The mean range-of-scapular retraction was significantly greater in the arthrodesis group than in the nerve transfer group (16° vs. 6°, $p = 0.002$). No other significant differences were found. Variance of the range-of-motion data was significantly greater in the nerve transfer group than in the arthrodesis group in all directions except scapular retropulsion (Fig. 2). Strength was significantly greater in the arthrodesis group than in the nerve transfer group in all directions of motion (Table 1). The DASH scores were not significantly different between the two groups, although a trend toward better results was noted in the arthrodesis group (38.1 with arthrodesis vs. 44 with nerve transfer, $p = 0.190$).

3.2. Upper-trunk plexus palsy

No significant between-group differences were found for range-of-motion of the shoulder ($p > 0.05$). Data variance was significantly

Table 1
Isometric shoulder strength (mean ± SD) in the nerve transfer and shoulder arthrodesis groups within the overall population.

	Nerve transfer ($n = 20$)	Arthrodesis ($n = 38$)	p-value
Strength, (FgF)			
Antepulsion	1.4 ± 1.9	7.8 ± 4.8	<0.001
Abduction	1.3 ± 1.9	7.7 ± 4.9	<0.001
Adduction	2.1 ± 3.7	6.9 ± 5.9	<0.001
External rotation	0.4 ± 0.9	3.1 ± 2.5	<0.001
Internal rotation	1.1 ± 1.8	5.4 ± 5.2	<0.001

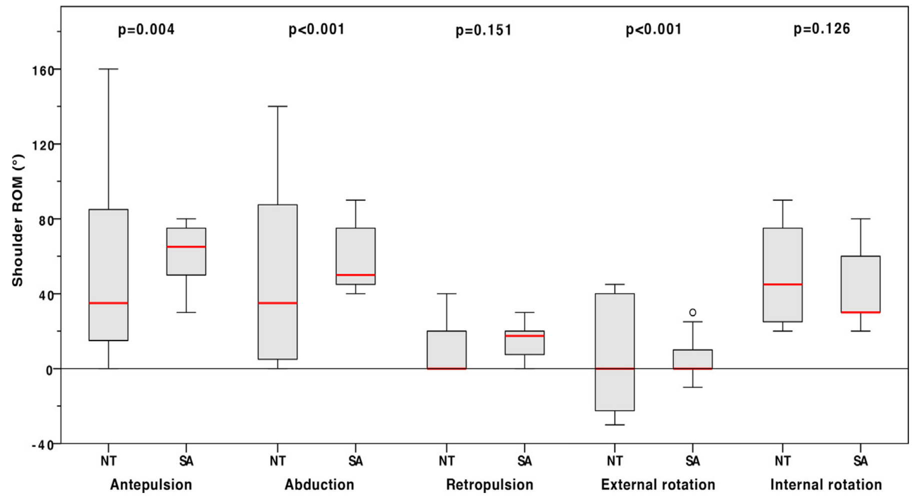

Fig. 3. Comparison of dispersion of shoulder range-of-motion (ROM) data in the groups managed by nerve transfer (NT) and shoulder arthrodesis (SA) within the population with upper-trunk palsy. °: outliers.

Table 2
Isometric muscle strength (mean ± SD) in the nerve transfer and shoulder arthrodesis groups within the population with upper-trunk palsy.

	Nerve transfer (n = 12)	Arthrodesis (n = 12)	p-value
Strength, (KgF)			
Antepulsion	1.8 ± 2.1	11.3 ± 5.0	<0.001
Abduction	1.9 ± 2.3	11.3 ± 5.3	<0.001
Adduction	3.1 ± 4.5	13.0 ± 6.4	<0.001
External rotation	0.6 ± 1.1	6.1 ± 2.0	<0.001
Internal rotation	1.7 ± 2.0	10.6 ± 5.3	<0.001

greater in the nerve transfer group than in the arthrodesis group in antepulsion and external rotation (Fig. 3). Strength was significantly better in all directions of motion in the arthrodesis group than in the nerve transfer group (Table 2). The DASH scores were not significantly different between the two groups.

3.3. Pan-plexus palsy

Compared to the nerve transfer group, the arthrodesis group had significantly greater motion ranges in abduction (59° vs. 44°, p = 0.035), external rotation (−6 vs. −32, p = 0.005), and retropulsion (16 vs. 0, p < 0.001). Data variance differed significantly between the two groups only for retropulsion (Fig. 4). Isometric shoulder strength was significantly greater in the arthrodesis group than in the nerve transfer group in all directions of motion (Table 3). The DASH scores were not significantly different between the two groups.

3.4. Influence of partial spinal accessory nerve transfer on shoulder arthrodesis outcomes

Within the arthrodesis group, no significant differences were found between the subgroups with primary arthrodesis and with secondary arthrodesis after nerve transfer failure regarding range-of-motion, isometric shoulder strength, or DASH scores (Table 4). In the subgroup with primary arthrodesis, trends were found towards greater ranges of antepulsion (67° vs. 58°, p = 0.073) and abduction (66° vs. 56°, p = 0.064) compared to the secondary arthrodesis subgroup.

3.5. Complications

Complications occurred in 7 (18%) of the 38 patients in the arthrodesis group. In 3 patients, non-union of the arthrodesis required revision surgery consisting in new internal fixation and autologous iliac bone grafting. Proximal humerus fractures occurred within 6 months after the arthrodesis procedure in 3 other patients, requiring plate fixation. Finally, a superficial surgical-site infection at the external fixator pin sites developed in 1 patient but did not require revision surgery. No complications were recorded in the nerve transfer group (p = 0.0407).

4. Discussion

The management of shoulder palsy due to supra-clavicular brachial plexus injury remains controversial. The prevailing opinion is that direct nerve lesion repair should be performed to restore the highest possible level of function. Palliative procedures are thus reserved for patients in whom this initial treatment fails or produces insufficient improvements [1,3,12,18–20].

This study reports outcomes in a retrospective cohort of patients with brachial plexus injuries. Spinal accessory nerve transfer to the supra-scapular nerve was combined with ulnar nerve transfer to restore active elbow flexion. The standard treatment of C5-C6 palsy involves transferring the long head of triceps nerve to the axillary nerve – a method described in 2003 [21] after our patients received their treatment – and transferring the spinal accessory nerve to the supra-scapular nerve. This dual nerve transfer technique is feasible only in patients with upper-trunk palsy involving C5 and C6 but not C7. It may produce better shoulder stability and greater ranges of abduction and external rotation compared to single-transfer procedures [3,8,22]. For the treatment of upper-trunk palsy involving C5, C6, and C7, we elected to transfer intercostal nerves to the musculo-cutaneous nerve in order to spare the ulnar nerve [3,8], thus limiting the ability to restore a nerve supply to the shoulder. In pan-plexus palsy, the most widely used strategy is similar to the treatment used in our study for patients with upper-trunk palsy involving C5, C6, and C7. Options for restoring function to the paralysed shoulder include direct nerve surgery with partial transfer of the spinal accessory nerve to the supra-scapular nerve, which is usually available [9], and palliative treatments. Thus, our findings have major implications for the management of pan-plexus palsy and of upper-trunk palsy involving C5, C6, and C7.

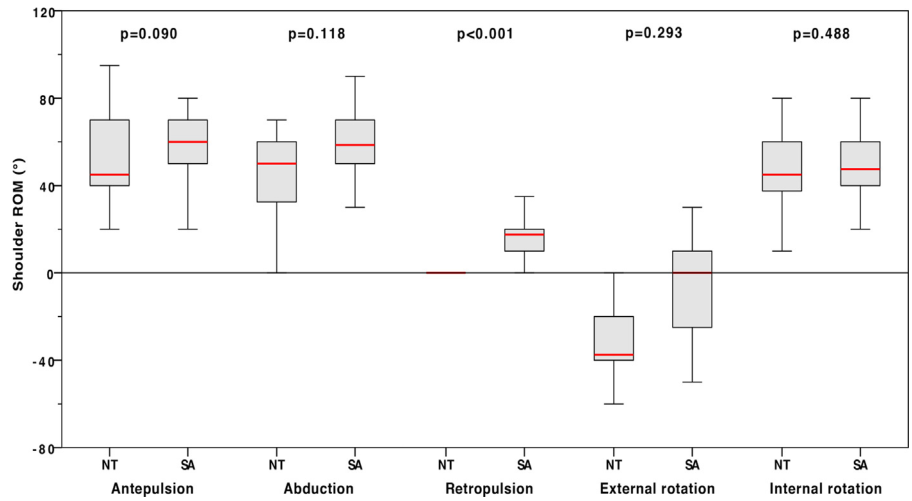

Fig. 4. Comparison of dispersion of shoulder range-of-motion (ROM) data in the groups managed by nerve transfer (NT) and shoulder arthrodesis (SA) within the population with pan-plexus palsy.

Table 3
Isometric muscle strength (mean ± SD) in the nerve transfer and shoulder arthrodesis groups within the population with pan-plexus palsy.

	Nerve transfer ($n = 8$)	Arthrodesis ($n = 26$)	p-value
Strength, (KgF)			
Antepulsion	0.9 ± 1.3	6.2 ± 3.9	<0.001
Abduction	0.5 ± 0.8	6.0 ± 3.8	<0.001
Adduction	0.6 ± 0.2	4.1 ± 2.9	0.002
External rotation	0.1 ± 0.1	2.1 ± 2.9	<0.001
Internal rotation	0.2 ± 0.5	3.1 ± 3.0	<0.001

Table 4
Comparison of clinical and functional outcomes (mean ± SD) after primary shoulder arthrodesis vs. secondary shoulder arthrodesis after failed nerve transfer.

	Arthrodesis after nerve transfer ($n = 13$)	Primary arthrodesis ($n = 25$)	p-value
Range-of-motion, (°)			
Antepulsion	58 ± 15	67 ± 14	0.073
Retropulsion	16 ± 14	15 ± 15	0.697
Abduction	56 ± 14	66 ± 15	0.064
External rotation	−6.2 ± 19	0.2 ± 20	0.389
Internal rotation	46 ± 17	51 ± 17	0.406
Force, (KgF)			
Antepulsion	7.4 ± 4.1	8.6 ± 6.1	0.464
Abduction	7.0 ± 4.0	8.9 ± 6.3	0.266
Adduction	6.0 ± 4.9	8.7 ± 7.5	0.259
External rotation	2.7 ± 2.0	4.0 ± 3.4	0.264
Internal rotation	4.5 ± 3.7	7.1 ± 7.2	0.244
DASH score	32.2 ± 13.2	41.1 ± 16.4	0.104

DASH: Disability of Arm, Shoulder, and Hand scale, maximum 100 points.

The range-of-motion outcomes in our study are consistent with previous studies of shoulder arthrodesis [13,15,23–25] and direct nerve surgery [10,26–31]. No significant between-group differences were found for the overall population or the subgroup with upper-trunk palsy. However, patients with failure of nerve transfer were excluded from the nerve transfer group, leading to marked overestimation of the outcomes of this procedure. In the subgroup with pan-plexus palsy, arthrodesis produced significantly better ranges of external rotation and retropulsion compared to nerve transfer. This finding probably reflects the difficulty in restoring an effective nerve supply to the shoulder in patients with pan-plexus palsy.

Direct nerve surgery must overcome two obstacles, namely, the possibility of injuries at two distinct levels and the usually partial recovery of supra-scapular nerve activity, with a predominance of abduction and very little external rotation [7]. This imbalance may be due to the greater neurotropism of the supra-spinatus muscle, which is the first muscle to undergo re-innervation [32]. External rotation is related to movement of the scapula on the rib-cage as seen after arthrodesis rather than to true external rotation within the gleno-humeral joint [7,9]. Thus, the re-innervated muscles simulate an active tenodesis that stabilises the humeral head, as opposed to producing forces capable of generating movement. External rotation is as good or better after shoulder arthrodesis than after direct nerve surgery, resulting in improved upper limb function [14]. Nerve transfer to both the supra-spinatus and the infra-spinatus muscles to improve external rotation has been assessed in a cadaver study [33]. Selective innervation of the infra-spinatus muscle was achieved using the medial branch to the triceps muscle anastomosed to the supra-scapular nerve, cut immediately distal to the emergence of its branch for the supra-spinatus muscle, just proximal to the spino-glenoid notch [33]. No clinical evaluation of this technique has been reported.

Our findings challenge the widely held belief that direct nerve surgery produces better clinical outcomes compared to shoulder arthrodesis, which was therefore initially reserved for patients in whom direct nerve surgery failed [8,13]. Thus, we found no evidence that spinal accessory nerve transfer to the supra-scapular nerve was superior over arthrodesis. Our findings are particularly compelling, as the 13 patients with failed direct nerve surgery requiring secondary shoulder arthrodesis were excluded from the nerve transfer group. In addition, the wide variability in outcomes in the nerve transfer group contrasted with the relative predictability of the results after shoulder arthrodesis in both the overall population and the subgroup with upper-trunk palsy (Figs. 2–4). In these indications, direct nerve surgery may therefore produce unpredictable and variable outcomes contrasting with the modest but uniform and predictable results of shoulder arthrodesis. Furthermore, isometric shoulder strength was greater in the arthrodesis group in all directions of motion and types of palsy, compared to the nerve transfer group. Restoring shoulder mobility and stability has been defined as the objective of direct nerve surgery [2,6,11]. Arthrodesis may produce good shoulder stability and strength, with reproducible motion ranges that improve the final outcome [2,6,14,15]. Chammas et al. pointed out that good shoulder stability benefits elbow muscle strength, thereby optimising the final clinical result [14].

The reliability of the surgical procedure, notably the risk of complications, is a major consideration. Complications occurred in 18% of patients after arthrodesis compared to none of the patients after nerve transfer. Atlan et al. recommended the implantation of a massive cortico-cancellous autograft in a non-anatomical subacromial position to improve bone healing [34]. The best fixation method is not agreed on [14,24,25,34]. We elected to combine a humero-scapular compression-screw with external fixation. External fixation carries an additional risk of infection and requires further surgery for pin removal but allows the immediate initiation of scapulo-thoracic and elbow rehabilitation.

Whether harvesting part of the spinal accessory nerve affects shoulder function is debated. No cases of trapezius muscle function impairment have been reported when the transfer was sufficiently distal to spare the supply to the superior trapezius muscle [9,11,31]. In our study, trends toward poorer motion ranges, shoulder strength, and DASH scores were found in the subgroup with arthrodesis after nerve transfer, but the differences were not statistically significant (Table 4). Thus, provided spinal accessory nerve harvesting is properly performed, partial denervation of the trapezius muscle seems to have little influence on the outcomes of secondary shoulder arthrodesis. Nevertheless, to optimise shoulder function, primary direct nerve surgery should not be performed routinely but should instead be reserved for patients who are likely to achieve good clinical outcomes. Age younger than 35 years and a time since injury of less than 6 months are optimal criteria for selecting patients to direct nerve surgery [4,8]. In this situation, direct nerve surgery should in theory produce optimal motion ranges and shoulder strength. Nevertheless, the patients should be informed in detail of the goals of surgery, time to final clinical results, and variability in clinical outcomes even when the initial indication is optimal. In other clinical situations, notably in patients older than 35 years and/or with a time since injury of 6 to 9 months, the outcomes of direct nerve surgery should be viewed as unpredictable and shoulder arthrodesis may therefore be the best primary procedure given the uniformity and predictability of its clinical outcomes.

The main limitation of our study is the retrospective design. However, data collection was standardised and performed by an independent examiner. The small sample size invites caution in interpreting the findings. Major selection bias was introduced by excluding 13 patients from the nerve transfer group due to failure of this procedure requiring secondary arthrodesis. Thus, outcomes in the nerve transfer group were markedly overestimated, as the patients were either good responders or declined secondary arthrodesis. The inclusion in the nerve transfer group of 4 patients with a time since injury longer than 6 months (7, 8, 8 and 9 months, respectively) may have artificially minimised the benefits of nerve transfer. However, these patients had to be kept in the study to allow an assessment of the influence of spinal accessory nerve harvesting on the outcomes of shoulder arthrodesis.

5. Conclusion

The results of this study suggest that nerve transfer and shoulder arthrodesis may produce similar clinical outcomes. Nevertheless, the uniformity and predictability of outcomes after shoulder arthrodesis are in contrast to the heterogeneity and unpredictability of the results of nerve transfer.

Our finding that spinal accessory nerve harvesting had little clinical effect on scapulo-thoracic mobility suggests that primary nerve transfer should be performed in young patients with a short time since injury. When this procedure fails and in older patients with longer times since injury, shoulder arthrodesis seems to be a reliable surgical option for producing a strong and stable shoulder, as opposed to a mere palliative procedure.

Disclosure of interest

The authors declare that they have no competing interest.

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None.

Contribution

All authors contributed equally to this study.

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