Original article

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Spinal accessory to suprascapular nerve transfer in brachial plexus injury: outcomes of anterior vs. posterior approach to the suprascapular nerve at associated ipsilateral spinal accessory nerve injury

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Objective: the spinal accessory nerve (Acc) is susceptible to trauma in at least 6% of cases of brachial plexus injury (BPI). The impaired Acc function disables its utilization for transfer to the suprascapular nerve (SS). The selection of approach to SS is highly dependant on the anatomy of BPI. The purpose of this study was to determine the incidence of the anterior-posterior approach of Acc to SS transfer in BPI and associated functional outcomes.

Methods. Twenty nine patients with BP/Acc associated injury were included. Ten patients underwent the transfer of Acc to SS by the anterior approach (AA), 19 patients – by the posterior approach (PA). Nine nerve transfers through AA and one nerve transfer through PA required the interposition of an autologous nerve graft. The functioning of the supra-/infraspinatus muscle was evaluated at 9 and 15mos. on the basis of the MRC and the external rotation (ER) range. ER more than +40^0 beyond the sagittal plane was regarded as effective recovery of function.

Results. Impaired function (M3 or lower on MRC) of the lower trapezius muscle was associated with preserved anatomy of the SS in the supraclavicular region in 9 out of 10 cases. Eighteen patients (62%) recovered to M3 and higher (shoulder stability), 11of these (38%) showed recovery to M4-M5. Five of all patients recovered to M4-M5 and were able to produce ER within the effective ROM (+40^0-60^0 of ER). After the AA to the SS, shoulder stability was restored in 60% of cases (M4-M5 in 30%). After the PA to the SS, shoulder stability was restored in 74% of cases (M4-M5 in 42%). Only non-complete BPI showed effective recovery of power and function in terms of less than 6 mos. after injury. PA to SS with no graft provided shoulder stability in 72% of cases, AA to the SS and the graft interposition ensured shoulder stability in 50% of cases.

Conclusions. The incidence of AA to the SS was 35%, PA – 65%; preserved anatomy of the SS in supraclavicular region was associated with an increased risk of trapezius muscle dysfunction; the PA to SS and consecutive direct end-to-end transfer of Acc showed better results compared to other combinations of nerve transfers in providing shoulder stability.

Key Words: *brachial plexus injury; suprascapular nerve; spinal accessory nerve; nerve transfer*

Introduction. Reconstruction of active abduction and external rotation of the shoulder in brachial plexus (BP) injury with nerve transfers has become a routine procedure in the last decade [1,2]. Since the availability of expendable donor nerves is severely dependant on the anatomy of the injured BP, both abduction and external rotation of the shoulder can be achieved by reinnervation of the suprascapular nerve alone [3]. Several techniques became an instant classic with predictable results within a predictable timeframe [4]. And if the exposure of the suprascapular nerve through the anterior or posterior approach is still variable, then the utilization of branches of the spinal accessory nerve has become the "gold standard" [5].

Most injuries to the BP occur due to the application of traction force in a period of time limited to milliseconds [6]. Traction-type injuries to other neural structures that provide motor functions to superficial and deep muscles within the boundaries of the lateral triangle of the neck (TLC), posterior triangle of the neck (TPC) or far beyond them are extremely rare [7,8,9]. Only a small number of publications are devoted to the associated injury to the BP/cervical plexus [7].

It is known that the most valuable derivate of the cervical plexus, the phrenic nerve, can be utilized to substitute a non-functioning musculocutaneous nerve [10] in the surgically induced reanimation of the function of the upper extremity of the highest priority [11] – elbow flexion. The association between the injury to BP and the phrenic nerve has been defined [12]. The likelihood of sustaining a concomitant to BP injury an irreversible phrenic nerve injury is up to 20% [12]. Despite the fact that the loss of the function of the phrenic nerve narrows the pool of extraplexal donors, especially in cases of complete BP lesions, other donors, both of ipsi- and contralateral origin, are still available for transfer [13,14].

Even less is known about the incidence of the associated injury to the spinal accessory nerve, the second biggest provider of motor function within the boundaries of the TLC and TPC. Bertelli J.A. [7] showed that the spinal accessory nerve was susceptible to trauma in at least 6% of cases of BP injury. The loss of spinal accessory nerve function resulted in paralysis of the trapezius muscle, further destabilizing the scapula [7], and attempts to restore it were described [7]. Compared to loss of function of the phrenic nerve, injury-associated exclusion of either branch of the spinal accessory nerve, especially the branch to pars ascendens of the trapezius muscle, from the pool of donors utilized to substitute the non-functioning suprascapular nerve in surgically induced reanimation of function of the upper extremity of the second highest priority 11] – external rotation/abduction of the shoulder, could barely be compensated.

Thus, the selection of either approach to the acceptor or donor nerve when trying to reinnervate the suprascapular nerve largely depends on the anatomy of the injury to the neural structures within the boundaries of the TLC and TPC. Since multiple combinations are possible, it is necessary to be able to perform each of them in a stepwise manner on the basis of pre-operative clinical/electrophysiological and surgical findings.

The purpose of this study was 1) to define determine incidence of anterior-posterior approach combinations in BP injury; 2) to define and compare associated functional outcomes; 3) the possibility of using an alternative technique at complete Acc injury.

Materials and methods

Study type. This was a retrospective, single-center study of a consecutive case series from 2013 to 2019. Level of evidence IV.

Patient population. Twenty nine patients with closed traction-type injury to BP were included (Table 1): one patient (3%) with C5 BP injury, seven patients (24%) with C5-C6 injury, twelve patients (41%) with C5-C6-C7 injury, nine patients (32%) with complete BP injury according to pre-operative clinical neurological findings (including two patients with gunshot mechanism of trauma). All included cases of BP injury were classified as Level 1-2 according to Chuang [15]. The mean age of the included patients was 29.4 years (range 6-59 years). The mean terms from injury to surgery were 9.1 mos. (range 1-72 mos.). Eight patients (27%) received nerve transfer within 0-3 mos., eleven patients (38%) – in terms of 3-6 mos., six patients (21%) in terms of 6-9 mos., one patient (3%) – in terms of 9-12 mos., four patients (11%) – in terms of more than 12 mos. after injury. The surgery was preceded by standard neurological, electrophysiological examinations and MRI of the cervical spine. The function of specific branches of the spinal accessory nerve was determined by the power of the corresponding muscles [7] according to the British Medical Research Council scale [16].

In 17 out of 29 cases, the injury to the BP was accompanied by fractures of the bony structures of the shoulder girdle in 8 cases (in 6 cases – the clavicle, in 2 cases – the scapula), the transverse processes of the lower cervical spine in 2 cases, the upper arm in 5 cases, the forearm in 2 cases (Table 1). In 2 cases, we observed a combination of shoulder girdle/upper arm or upper arm/forearm fractures ***(Table)***. All fractures of the clavicle, humerus, radius and ulna were repaired with plates or intramedullary synthesis devices on earlier terms, neither of the fractures required secondary synthesis in the long term.

Surgical procedure. All included patients were retrospectively divided into two groups according to availability of the suprascapular nerve (SS) for transfer during the exploration of the BP in the supraclavicular region: A – ten patients (35%), B – nineteen patients (65%) ***(Fig.1)***.

A. Anterior approach. The anterior approach to the suprascapular nerve and the precise technique of transfer of the spinal accessory nerve to the SS are well described [17]. Ten patients were selected for anterior reinnervation of the SS – the supraclavicular exposure of the BP revealed a distal stump of the SS ***(Fig.1)***, suitable for transfer [3]. Nine out of 10 patients (90%) selected for the anterior approach showed pre-operative clinical and electrophysiological signs of impaired function (M3 or lower on the MRC scale) of both the pars descendens (upper trapezius – UT) and the pars ascendens (lower trapezius – LT) of the trapezius muscle. These patients were selected for transfer of the pars sternocleidomastoideus of the spinal accesory nerve (Acc(SCM)) to the SS via an anterior approach, which required interposition of a sural nerve graft with approx. length 13-15cm. – A+1 combination ***(Fig.1)***. Only one patient was selected for the "classic" transfer [5,17] of the LT branches of the spinal accessory nerve to the SS via the anterior approach – A+3 combination ***(Fig.1)***. The anatomy of BP injury among patients selected for the anterior approach was as follows: two cases of C5-C6 injury, four cases of C5-C6-C7 injury and four cases of complete BP injury ***(Fig.1)***.

B. Posterior approach. The posterior approach to the SS and the precise technique for transferring the spinal accessory nerve to the SS are well described [4]. Nineteen patients were selected for posterior reinnervation of the SS, since supraclavicular exposure of the BP revealed either absence of the distal stump of C5-C6/SS or severely scarred structures of the BP/SS ***(Fig.1)*** that were not suitable for the transfer [3]. Eighteen of 19 patients who were selected for the posterior approach and showed pre-operative clinical and electrophysiological signs of preserved function (M4 and higher on the MRC scale) of both UT and LT received a "classic" transfer of the branch of the spinal accessory nerve to the pars ascendens of the trapezius muscle (Acc(LT)) to the SS via posterior approach – B+3 combination **(Fig.1)**. One patient was selected for Acc(SCM) to SS transfer via a posterior approach, which required the interposition of a sural nerve graft with approx. length 17cm. – B+1 combination ***(Fig.1)***. The anatomy of BP injury among patients selected for the posterior approach was as follows: one case of C5 injury, five cases of C5-C6 injury, seven cases of C5-C6-C7 injury, and five cases of complete BP injury ***(Fig.1)***.

Follow-up and outcome evaluation. All patients were instructed to limit passive motion in glenohumeral joint for at least 3 weeks after surgery. Active rehabilitation was

This article contains some figures that are displayed in color online but in black and white in the print edition.

Table. Characteristics of the patient population in the study: age, anatomy of injury, time from injury to surgery, utilized nerve transfer technique

#	BP injury/ anatomy	Age	Time to surgery (mos.)	Bone injury (fracture)	Anterior approach to SS		Posterior approach to SS	
					Acc(LT) ant	Acc(SCM)	Acc(LT) post	Acc(SCM)
1	C5-6	46	0-3				+	
2	C5-6	43		humerus		+		
3	C5-6	30		clavicle			+	
4	C5-6-7	27		clavicle			+	
5	Complete	16		radius/ulna	+			
6	Complete	38					+	
7	Complete	32		C7 TP		+		
8	Complete	23		clavicle			+	
9	C5	22	3-6				+	
10	C5-6	18		scapula/coracoid		+		
11	C5-6	22					+	
12	C5-6-7	32		clavicle		+		
13	C5-6-7	45		clavicle			+	
14	C5-6-7	20				+		
15	C5-6-7	26		C6-C7 TP		+		
16	Complete	30				+		
17	Complete	19		humerus			+	
18	Complete	27		humerus/clavicle			+	
19	Complete	37		humerus/radius			+	
20	C5-6-7	21	6-9	scapula/spine				+
21	C5-6-7	33				+		
22	C5-6-7	39					+	
23	C5-6-7	23		clavicle			+	
24	Complete	18		radius/ulna		+		
25	C5-6-7	24	9-12				+	
26	C5-6	6	>12				+	
27	C5-6	45					+	
28	C5-6-7	31		humerus			+	
29	C5-6-7	59					+	

Note: BP – brachial plexus; TP – transverse process of the vertebra; Acc(LT) – branches to the lower trapezius of the spinal accessory nerve; Acc (SCM) – branches to sternocleidomastoid muscke of the spinal accessory nerve; SS – suprascapular nerve, ant – anterior approach to the donor nerve; post – posterior approach to the donor nerve.

initiated no earlier than 1.5mos. post-op. The evaluation of the functions provided by the reinnervated SS was conducted on 9 and 15mos. post-op. The functional outcome was assessed on the basis of 2 main parameters: the power of external rotation of the shoulder (supra-/infraspinatus muscle) based on the MRC scale and the range of motion (ROM) provided by the recovered external rotators of the shoulder [18]. Recovery to M4-5 on the MRC scale was considered as an effective recovery of muscular power. External rotation (ER) of more than $+40^0$ beyond the saggittal plane was considered as an effective recovery that produced an effective ROM (eROM), in accordance with the maximum requirements for ER during basic activities of daily living (ADL) [18].

The function of the upper extremity of the second highest priority implies not only active motions within the ROM in the sagittal and frontal planes (forward flexion, abduction and external rotation, respectively), but also the overall stability of the glenohumeral joint [11]. The glenohumeral joint stability could be provided even by

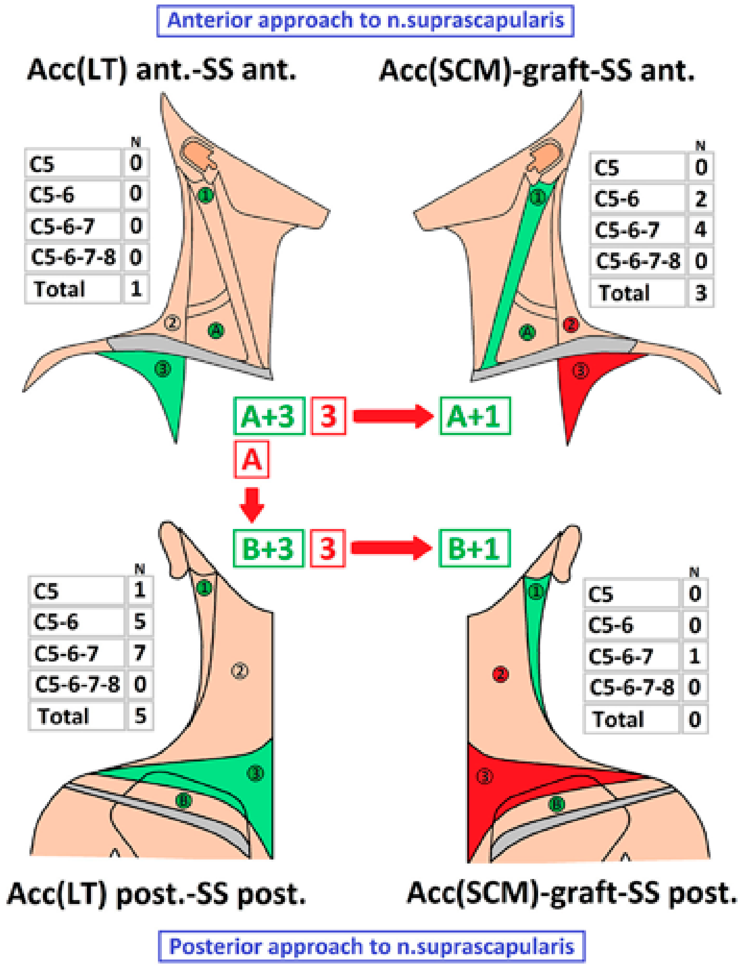

Fig.1. Characteristics of patients selected for anterior or posterior approach to the suprascapular nerve: anatomy of BP injury, selection of donor nerves.

Acc(LT) – branches to the lower trapezius of the spinal accessory nerve; Acc(SCM) – branches to the sternocleidomastoid muscle of the spinal accessory nerve; SS – suprascapular nerve, ant – anterior approach to either the acceptor or donor nerve; post – posterior approach to either the acceptor or donor nerve; graft – transfer required a sural nerve graft interposition; A – SS is suitable for transfer through the anterior approach; B – SS is suitable for transfer through the posterior approach; 1 – sternocleidomastoidmuscle/Acc(SCM); 2 – upper trapezius/Acc(UT); 3 – lower trapezius/Acc(LT); green circle – acceptor nerve is suitable for transfer/donor nerve is functioning; red circle – acceptor nerve is not suitable for transfer/donor nerve is not functioning; Total – a complete BP injury.

partially recovered external rotators. In this study, any case of recovery of supra-/infraspinatus muscles to M3 was considered effective in terms of stability of the glenohumeral joint.

Statystical analysis. The small number of patients did not allow for any meaningful statistical analysis.

Results

In 19 cases, Acc(LT) was suitable for transfer. Throughout 10 cases of anterior approach to the SS, when the exploration of the BP revealed no severe scarring in the supraclavicular region or, in other words, the SS was suitable for transfer via the anterior approach, the malfunction of Acc(LT), reflected in an impaired function (M3 or lower on the MRC scale) of the pars ascendens (lower trapezius – LT) of the trapezius muscle, was observed in 9 out of 10 cases. On the contrary, when the exploration of BP in the supraclavicular region revealed severe scarring or the absence of neural structures of the BP/SS and a posterior approach to the SS was chosen, an impaired function (M3 or lower on the MRC scale) of the pars ascendens (lower trapezius – LT) of the trapezius muscle was observed in 1 of 19 cases.

Overall, in 18 patients (62%), we observed the recovery of the supra- and infraspinatus muscles to M3 and higher. Eleven of these patients (38%) showed an effective recovery of the power (M4-M5) of the external rotators of the shoulder ***(Fig.2B)***.

Overall, 5 patients (17% of all participants; 45% of all recovered to M4-M5) were able to utilize recovered to M4-M5 external rotators of the shoulder within the eROM (+40⁰-60⁰ of ER) ***(Fig.2B)***, none of which were able to produce ER within the maximal ROM (mROM) ***(Fig.3)***. Another 5 patients (17% of all participants; 45% of all recovered to M4-M5) were able to produce an ER beyond the sagittal plane but not within the eROM ***(Fig.2B)***.

After reinnervation of the SS through the anterior approach, we observed the recovery of the supra- and infraspinatus muscles to M3 and higher in 60% of cases. Effective power of the supra- and infraspinatus muscles was restored in 30% of cases (3 out of 10) ***(Fig 2A)***, while the A+1 combination was effective in 33% of cases ***(Fig.2A)***. After reinnervation of the SS through the posterior approach, we observed the recovery of the supra- and infraspinatus muscles to M3 and higher in 74% of cases. Effective power of the supra- and infraspinatus muscles was restored in 42% of cases (8 out of 19) ***(Fig. 2A)***, while the B+3 combination was effective in 39% of cases ***(Fig.2A)***.

The utilization of the A+1 combination allowed 1 patient (11%) to utilize the recovered to M4-M5 external rotators of the shoulder within the eROM (+40⁰-60⁰ of ER) ***(Fig.2C)***, while the utilization of the B+3 combination allowed 4 patients (22%) to utilize the recovered to M4-M5 external rotators of the shoulder within the eROM (+40⁰-60⁰ of ER) and another 7 patients (39%) to produce the ER beyond the sagittal plane ***(Fig.2C)***.

Considering that 7 out of 9 A+1 combinations and 11 out of 18 B+3 combinations were performed less than 6 mos. after BP injury (within less than 6 mos. are considered the most suitable time-frame for nerve transfers according to Martin et al. [19]), the overall M4-M5 efficacy of A+1 and B+3 was 43% and 55%, respectively.

Five out of 7 patients (71%) with C5-C6 injury to BP received surgery within less than 6 mos. with an overall recovery of the effective power of external rotators (M4-M5) in 3 cases – 60% ***(Fig.2B)***. The B+3 combination brought effective recovery in 2 cases, A+1 combination – in 1 case ***(Fig.2B)***.

Five out of 12 patients (42%) with C5-C6-C7 injury to BP received surgery within less than 6 mos. with an overall recovery of the effective power of external rotators (M4-M5) in 2 cases – 40% ***(Fig.2B)***. It was only the B+3 combination that brought an effective recovery ***(Fig.2B)***.

Seven out of 8 patients (87,5%) with total BP injury received surgery within less than 6 mos. with an overall recovery of the effective power of external rotators (M4-M5) in 2 cases – 29% ***(Fig.2B)***. B+3 combination brought an effective recovery in 1 case, A+1 combination – in 1 case ***(Fig.2B)***.

Overall, these were only non-complete injuries to the BP (C5 in 1 case, C5-C6 in 2 cases, C5-C6-C7 in 2 cases) with effective recovery of both the power of the external rotators and the function (ER) they provided ***(Fig.3)***. Regardless of the combination of surgery that was performed (B+3 combination in 4 cases, A+1

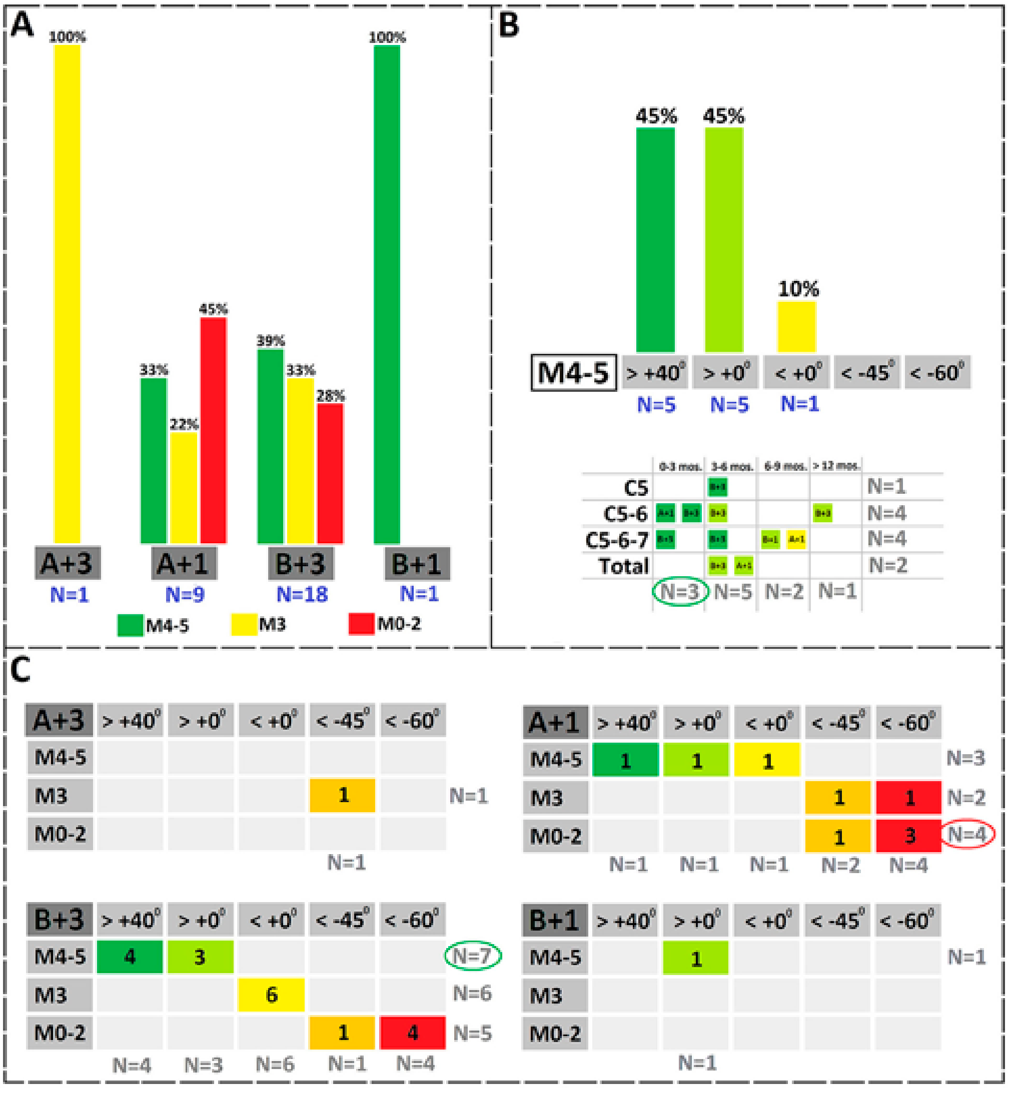

Fig.2. Recovery of supra-/infraspinatus muscles: combinations of nerve transfer, MRC score, ER range
MRC-based efficacy of different combinations of nerve transfer. *A.* A+3 – Acc(LT) ant.-SS ant.; A+1 – Acc(SCM)-SS ant., B+3 – Acc(LT) post.-SS post.; B+1 – Acc(SCM)-SS post.

B. Effectiveness of external rotation provided by M4-M5 recovered external rotators. Green – ER within eROM (+40⁰-60⁰); light green – ER below eROM (+0⁰-40⁰), beyond the sagittal plane; yellow – unable to sagittalize the shoulder, (-45⁰-0⁰); Total – a complete BP injury.

C. MRC-based efficacy of different combinations of nerve transfer vs. effectivenes of ER. Orange – ER -60⁰-45⁰; red – ER (-90⁰-60⁰).

combination in 1 case), they were all conducted within less than 6 mos. after injury ***(Fig.3)***.

Overall recovery of the external rotators to M3 after the B+3 combination of nerve transfer was observed in 6 cases ***(Fig.2C)***, and in 2 cases after the A+1 combination of nerve transfer ***(Fig.2C)***.

The B+3 combination of nerve transfer allowed to provide the stability of the glenohumeral joint in 13 cases (72%) –7 recovered to M4-M5, 6 recovered to M3 ***(Fig.2C)***. The A+1 combination of nerve transfer allowed to provide the stability of the glenohumeral joint in 5 cases (50%) – 3 recovered to M4-M5, 2 recovered to M3 ***(Fig.2C)***.

Discussion

Brachial plexus injury is known as a severe disabling neurological condition [15]. Since the potential to regenerate spontaneously is unpredictable [20] and the majority of methods, radiological or electrophysiological, to objectify this condition are reliable only to a certain extent [20,21], only surgical reconstruction within an adequate timeframe [19] can return valuable functions of the upper extremity with a predictable probability [19].

Surgical techniques of nerve transfers, which have emerged in the last two decades, allow substituting any function of any segment of the upper extremity. Elbow flexion, shoulder stability as well as active motions in the glenohumeral joint are prioritized among others and are known as functions of the highest (Priority 1) and second highest priority (Priority 2) [11].

If recovery of elbow flexion can be achieved with nerve transfers in almost any type (anatomy) of BP injury, the pool of intra- and extraplexal nerve donors that are utilized for reconstruction of abduction and external rotation of the shoulder is strongly dependent on the anatomy of the BP injury. Double nerve transfers [5] can be utilized only for non-complete BP injuries, while reinnervation of only the suprascapular nerve is possible in the majority of cases of complete BP injury. Under both conditions reinnervation of the suprascapular nerve with either branch of the spinal accessory nerve is considered the "gold standard" [4,5,17], and both anterior and posterior approaches to the suprascapular nerve are utilized [4,5,17].

Less information can be found regarding loss of spinal accessory nerve function associated with BP injury. In recently published large series by Bertelli et al. [7], the incidence of combined injury to the BP and the spinal accessory nerve was 6%, wherein the spinal accessory nerve injury associated with complete paralysis of the trapezius and sternocleidomastoid muscles was extremely rare. Rather, incomplete paralysis or a minor decrease in power were described [7]. No reliable association between the injury to bony structures and the direction of traction during the injury of BP was found, as well as no reliable association with the anatomy of BP injury was described [7].

The potential to utilize partially injured motor nerves as a donor in nerve transfer procedures is debatable [22,23]. A number of publications [22,23], of both experimental and clinical applications of partially injured nerves, have appeared. As of now, this methodology serves rather as a salvage procedure, and the outcomes have yet to be proven.

In this study, branches of the spinal accessory nerve were utilized to reinnervate the suprascapular nerve, the recovery of external rotation of the shoulder, which should provide sagittalization of the forearm and shoulder was assessed.

Overall, 35% of BP injuries were associated with decreased function (M3 or lower) of the trapezius muscle (both upper and lower trapezius), which was a much higher rate than it was reported by Bertelli et al. [7]. No association between the anatomy of the BP injury and the spinal accessory nerve injury was found. The distribution of the anatomy of the BP injury in groups with injured and uninjured spinal accessory nerve was uniform – C5-C6 (22% vs. 27%), C5-C6-C7 (44% vs. 39%) and a complete BP injury (34% vs. 34%).

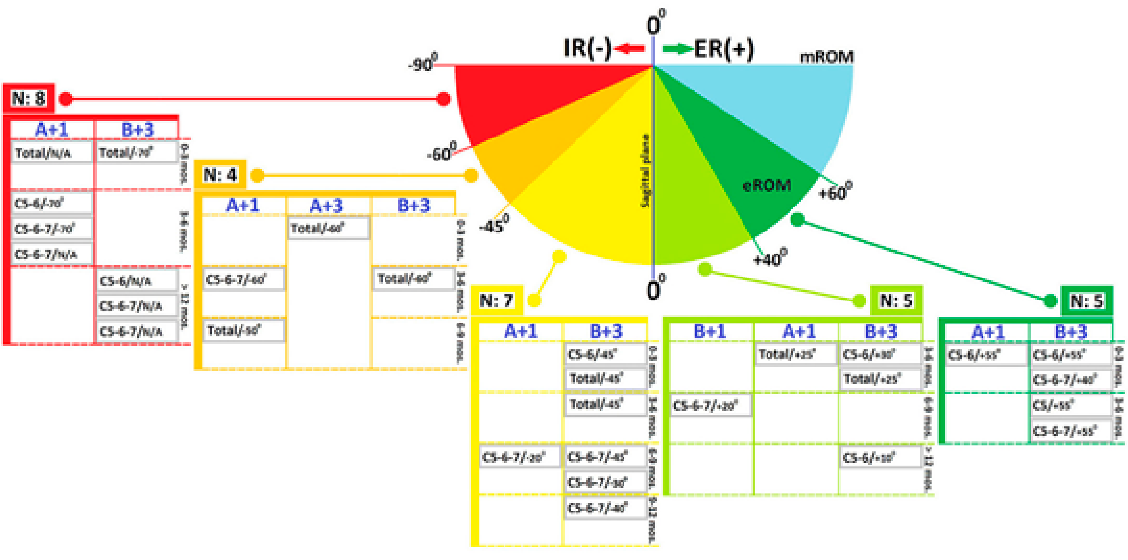

Fig.3. Dependence of ER provided by reinnervated external rotators of the shoulder on the anatomy of the BP injury, terms of surgery, nerve transfer combination

IR – internal rotation; ER – external rotation; mROM – maximal range of motion; eROM – effective range of motion (see text); A+3 – Acc(LT) ant.-SS ant.; A+1 – Acc(SCM)-SS ant., B+3 – Acc(LT) post.-SS post.; B+1 – Acc(SCM)-SS post; Total – a complete BP injury

We found an association between the preserved function of the lower trapezius and the preserved anatomy of the suprascapular nerve in the supraclavicular region: in 90% of cases of the paralyzed lower trapezius, we found a suprascapular nerve in the supraclavicular region that was suitable for transfer, and vice versa – in almost all cases (95%) of the absence, retraction of the BP trunks into the subclavicular region, severe scarring of the BP upper trunk/suprascapular nerve (or all combined),we observed the preserved function of both the upper and lower trapezius (M4-M5). Accordingly, the mechanism of potential BP and spinal accessory nerve injury proposed by Bertelli et al. [7] can hardly be true. Depression of the shoulder as a mechanism of combined injury described by Bertelli et al. [7] should be associated with the macroscopic changes of structures of the BP seen in this study in the group of patients with preserved function of the trapezius muscle – absence, retraction in the subclavicular region, severe scarring of the BP upper trunk/suprascapular nerve. No association between the injury of the bony structures of the shoulder girdle or upper arm and the spinal accessory nerve injury was found in this study.

Overall, we observed almost equal recovery of shoulder stability provided by the recovered external rotators (M3 and higher), regardless of the approach to the suprascapular nerve – 60% vs. 74% with the anterior vs. posterior approaches. These long-term outcomes were similar to those reported by Maurya et al. [3]. We observed a change in the power recovery efficacy with the expansion of the anatomy of the BP injury: nerve transfers performed in less than 6 mos. at C5-C6 BP injury, showed effective recovery in 60% of cases; nerve transfers performed in less than 6 mos. at C5-C6-C7, showed effective recovery in 40% of cases; nerve transfers at complete BP injury showed effective recovery in 29% of cases. Long-term outcomes were similar to those reported by Maurya et al. [3]. Partial BP injuries that recovered to M4-M5 had superior eROM outcomes of external rotation compared to complete BP injuries, none of which were able to produce an ER within the eROM – 5 vs. 0 ***(Fig.3)***, while both cases of complete BP injury showed recovery of the ER to $+25^0$ ***(Fig.3)***.

In this study, we opted not to utilize partially injured branches of the spinal accessory nerve, which, accordingly, led to the utilization of an undesired maneuver [24] in the nerve transfer procedure – the elongation of the donor nerve through an autologous nerve graft. Accordingly, the overall recovery of the power of the external rotators, which provided shoulder stability (M3 and higher) for the nerve transfer through an autologous graft, was 55%, while direct coaptation brought the recovery of the power of the external rotators, which provided at least shoulder stability, in 74% of cases.

Throughout the years of the study (2013-2019), we did not encounter associated BP injuries accompanied by global palsy of the muscles innervated by the spinal accessory nerve – both sternocleidomastoid and trapezius muscles. Nevertheless, in early 2020, a patient with a complete BP injury associated with global spinal accessory nerve palsy that required the utilization of the technique presented by Bhandari et al. in 2016 [25], was treated in our department ***(Fig.4)***.

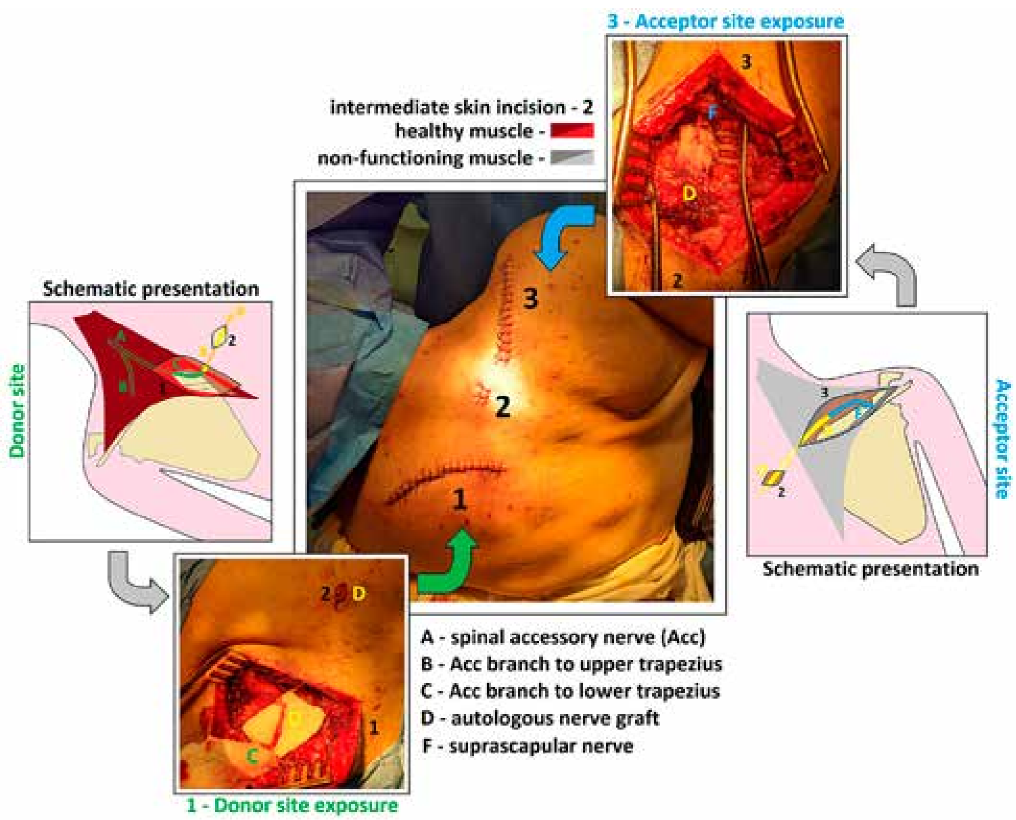

Fig.4. Schematic and intraoperative representation of the transfer of the contralateral branch of the spinal accessory nerve to the lower trapezius to the suprascapular nerve of the injured site (Bhandari transfer)

As described by Bhandari et al. [25], the procedure of the contralateral (left) branch of the spinal accessory nerve to the lower trapezius was transferred to the suprascapular nerve of the injured site (right) through a sural nerve graft approx. 10cm. long 3 mos. after BP injury. Follow-up was similar to patients in the study cohort. Long-term outcomes showed the recovery of supra-/infraspinatus muscles to M4 with external rotation achieving $+30^0$. It is quite obvious that using the technique of Bhandari et al. [25] made it possible to reduce the distance between the donor and acceptor nerves (by 3-5cm. less than with Acc(SCM) transfer via the anterior approach to the SS; by 7cm less than with Acc(SCM) transfer via the posterior approach to the SS). We observed no development of even minor shoulder or scapular instability in a healthy area with transfer associated denervation of the lower trapezius – there was no decrease in ROM in the glenohumeral joint in the sagittal/frontal plane, no scapular winging was seen. We believe that this technique allows not only to reduce the length of the autologous graft, but also to avoid the utilization of partially damaged nerves (a potentially positive, but yet unproven technique) in similar cases.

Study limitations. Due to the small series size and small number of groups, no significant statistical analysis was performed. Not all included patients had electrophysiologically proven partial or complete paralysis of the trapezius muscle before surgery, in these cases the diagnosis was based purely on clinical findings. Patients with poor recovery (M0-M2) were not examined electrophysiologically at later stages due to logistic and financial reasons.

Conclusions

The incidence of anterior approach to the suprascapular nerve was 35%, posterior approach – 65%; preserved anatomy of the suprascapular nerve in the supraclavicular region was associated with an increased risk of trapezius muscle dysfunction; posterior approach to the suprascapular nerve and consecutive direct end-to-end transfer of a branch of the spinal accessory nerve to the lower trapezius showed better results compared to other combinations of nerve transfers in providing stability in the glenohumeral joint (74% of cases); better results in recovery of effective external rotation were associated with incomplete BP injury (5 to 0 for incomplete vs. complete BP injury); an alternative technique for the transfer of the contralateral spinal accessory nerve helped decreasing the graft length and avoiding the transfer of a partially injured spinal accessory nerve, its efficacy needs further investigation.

Disclosures

Conflict of interests

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee, as well as the Declaration of Helsinki (1964) and its later amendments, or comparable ethical standards. The study was approved by the Bioethics Committee of Romodanov Neurosurgery Institute of the NAMS of Ukraine.

Informed consent

Conscious and voluntary written consent to participate in the study was obtained from each patient.

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