Journal of Orthopedics Research and Rehabilitation

Original Article

DOI: 10.51271/JORR-0062

Age-dependent outcomes of secondary surgical and complementary rehabilitation interventions in children with brachial plexus birth injury: a one-year follow-up study

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Cite this article as: Özkan S, Evrendilek H, Berköz Ö, Akel BS. Age-dependent outcomes of secondary surgical and complementary rehabilitation interventions in children with brachial plexus birth injury: a one-year follow-up study. *J Orthop Res Rehabil.* 2026;4(1):1-7.

Received: 22.07.2025 • **Accepted**: 11.10.2025 • **Published**: 31.01.2026

ABSTRACT

Aims: To determine the one-year functional gain following secondary transfer surgery in children with BPBI and analyse the outcomes in relation to surgical timing and clinical changes over time after rehabilitation.

Methods: Forty-seven children, aged 3 to 18 years, who underwent transfer surgery and completed a 3-month rehabilitation program post-surgery, participated in this study. Active shoulder range of motion and Modified Mallet Scoring were assessed preoperatively and at 3, 6, and 12 months postoperatively. Children were grouped as having surgery younger and older than 7 years old and the results were compared. The repeated measures analysis was completed for comparison, along with post-hoc tests. Cohen's d formula is used for effect size calculation.

Results: The increase in shoulder flexion, abduction and external rotation was significant for all groups. However, the children having surgery older than 7 years demonstrated greater effect sizes for all shoulder motion ranges except internal rotation at 3-month follow-up while the younger group had higher effect sizes for flexion and abduction at 6-month follow-up. In general, only abduction, internal rotation and hand-to-mouth parameters increase were significant at 12 months follow-up. Additionally, the increase in external rotation started to decrease after 6 months.

Conclusion: The Hoffer technique increased shoulder flexion, abduction, and external rotation regardless of the onset of the surgery. However, hand-to-head function did not increase after 3 months and external rotation started to decrease after 6 months in general. It is important to develop strategies to maintain the gain after surgeries, especially in rotation angles.

Keywords: Brachial plexus, rehabilitation, tendon transfer

INTRODUCTION

Brachial plexus birth injury (BPBI) is a traction injury in the brachial plexus during birth, which causes muscle weaknesses, soft tissue contractures and progressive glenohumeral joint deformity and/or instability.[1] In BPBI, the clinical symptoms and prognosis differ according to the mechanism of injury, affected area, and applied treatment.[1] Children classified as I and II according to the Narakas System demonstrate 64% spontaneous recovery of biceps function at 3 months of age.[2] But primary care providers may overestimate recovery, residual musculoskeletal deficits may be underestimated and children who do not fully recover often face lifelong functional challenges.[3] Microsurgical exploration and reconstruction of the brachial plexus is usually undertaken at 3 to 9 months of age in children who have shown no apparent improvement.[4] The shoulder frequently remains in an internal rotation position[5] and the most limited motions that need a secondary surgical procedure are shoulder elevation and external rotation.[6,7] The reconstruction procedures might have a positive impact on shoulder functions such as reaching head or back, arm appearance and hand functions.[6]

The Modified Hoffer technique is a tendon transfer method that encompasses the transfer of the internal rotator muscles (latissimus dorsi&teres major) to the major tubercle of the humerus to increase shoulder abduction and external rotation.[8] Rehabilitation has a critical role after this surgery to prevent contractures and to improve muscle-tendon function and strength, re-education and limb awareness by including muscle strength and power training, ROM exercises and functional activities.[9,10] Increased abduction and external rotation at varying degrees after the operation and following rehabilitation have been shown.[8,11] However, the timing of the second measurement, rehabilitation results and techniques were heterogeneous with lower sample size.[12]

The main goal of the team working with BPBI is to facilitate optimal functioning avoiding developmental deficits.[13] Even

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though there are some guidelines on management, the indications and timing for secondary surgical intervention may vary among institutions.[3] There is ongoing debate regarding the optimal age for performing such surgeries.[14] Surgery age-related post-operative rehabilitation results were not assessed before. An objective knowledge on clinical change and functional gain in time after secondary surgeries following rehabilitation according to age is missing. The main purpose of our study is to state the a-year follow-up results of the physiotherapy program following surgery in children with BPBI who underwent tendon transfers to the shoulder for the management of deficits of abduction and external rotation of the shoulder according to the onset age of surgery.

METHODS

Ethics

This prospective clinical study was conducted with the approval of the İstanbul University İstanbul Faculty of Medicine Clinical Researches Ethics Committee (Date: 19.08.2019, Decision No: 1017). All procedures were carried out in accordance with the ethical rules and the principles of the Declaration of Helsinki. Participants and their parents were informed about the study, and parents signed an informed consent form.

Participants

Children aged between 3-18 years with BPBI who underwent a modified Hoffer procedure by the same 2 surgeons in a team were invited to participate in the study. Children who had any other surgery related to BPBI; other musculoskeletal, or neurologic disorder that affects hand use were not included in the study. Data excluded if children could not complete the assessment and rehabilitation protocol. All participants were recruited from the plastic and reconstructive surgery clinic of the same Medicine Hospital.

Outcome Measurements

Demographic and clinical characteristics related to BPBI were recorded. The active flexion, extension, and abduction of the shoulder were assessed with a basic goniometer while the child was standing to prevent any movements from the trunk. Meanwhile, the internal and external rotation range of the shoulder was assessed while the children were lying prone to prevent any compensatory movements. The Modified Mallet Scoring System was used to assess the outcome following the procedure. The assessments were conducted preoperatively and at the 3rd, 6th, and 12th months postoperatively. All measurements were performed by the same physiotherapist, and the total duration of the measurements was approximately 30-40 minutes.

The Modified Mallet Scoring System was used as a reliable method for evaluating the functional abilities of children with BPBI.[15] It assesses the global shoulder function with the following five criteria: active shoulder abduction and external rotation, placing the hand to the mouth, behind the neck and as high as possible on the spine. Each parameter was scored between 1 (no function) and 5 (normal function). During the assessment, children were asked to replicate the movements shown by the therapist. The test takes an average of 51 seconds when testing bilaterally.

Surgery

The surgical technique is as follows: In the lateral decubitus position, a zigzag incision is made along the posterior axillary line in order to expose the latissimus dorsi and teres major muscles. The conjoined tendon, which represents the common tendon of these muscles, is then identified. Subsequently, the conjoined tendon is detached from its insertion on the humerus and prepared for transfer. A marking is placed on the greater tubercle of the humerus at the insertion site of the rotator cuff muscles by entering through the plane between the long head of the triceps and the deltoid muscle. With the shoulder in 90 degrees of abduction and maximum external rotation, an anchor suture is placed at the marked site, and a 2/0 Ethibond polyester suture is passed through the conjoined tendon. Subsequently, the conjoined tendon is secured to the greater tubercle by tying the suture, thereby achieving the tendon transfer. Once the surgical incisions have been closed, the patient is placed in a body-supported shoulder abduction and external rotation orthosis, previously prepared for this purpose, in order to ensure that the shoulder posture is maintained. No tendon release procedure was performed for joint contractures.

Physiotherapy Intervention

Participants were taken to a standardised physiotherapy program for 12 weeks after the surgery. All individuals had face-to-face sessions 2 times a week and performed home exercises every day. The program was carried out by the same therapist different from the therapist performing the assessments.

After the surgery, initially, a circular cast was used for 6 weeks then children used full time shoulder abduction orthosis with trunk support to protect transferred muscles from elongation. During the immobilization period, active-assisted hand and wrist mobility exercises were applied. In the 6th week, active-assistive elbow flexion extension, and forearm rotation exercises started. Active assistive shoulder abduction, mobilization-based shoulder active/passive range of motion exercises, and bringing the hand back to the neck while the shoulder in 90° abduction exercises were added. At 7-9th weeks, the active shoulder abduction and external rotation, scapular adduction and inferior rotation, and pectoral stretching exercises were introduced. Electrical stimulation was applied if a child had difficulty in motor learning and/or had insufficient muscle strength. In the 10th week, controlled active shoulder abduction movements were performed with the elbow supported in extension. Active functional internal rotation exercises were tailored if the limitation was present. Resistive exercises were given with 300 gr weights for all shoulder movements. At the 12th week, stretching for transferred muscles and shoulder capsule, full resistive exercises for shoulder muscles, and functional activities were included in the physical therapy program.

Statistical Analysis

SPSS software (version 25.0, Chicago, IL) was used for analysis and data distribution was verified by the Shapiro-Wilk test. Collected data were divided into two groups for statistical analysis based on the age at which surgery was performed: "Group I (G1)" aged lower than 7 years, " Group II (G2)" aged between 7 and 16 years. The cut-off age was determined as 7, due to its recommended effective maximal age for this surgery.[16] The Friedman test to state the functional difference between groups and One-way repeated measurement was also used to state change in time for all individuals. The Wilcoxon matched-pairs signed-ranks test was used for post-hoc paired comparison with Bonferroni correction. For the group-based comparison analysis, independent t-test and Mann Whitney U test were used. The significance threshold was $p<0.05$. The effect size was calculated with Cohen's d formula, while "d=0.2 was considered a small effect, d=0.5 was a medium effect and d=0.8 was a large effect".

RESULTS

Forty-seven participants (mean age:7.01±3.27 years) with BPBI were included in this study. Surgery was performed at the mean age of 4.75±0.87 years for G1 (n=27) and 10.05±2.81 years for G2 (n=20). The demographic and clinical characteristics of the participants are in **Table 1**. The birth information for 11 children could not be documented.

Table 1. The demographic and clinical characteristics of the participants

	Group I		Group II	
	Mean (SD)	**Min-max**	**Mean (SD)**	**Min-max**
Age (year)	4.7 (SD 0.8)	3-6	10 (SD 2.8)	7-16
Follow-up (month)	35.9 (SD 17.3)	9-65	25.9 (SD 17.2)	11-84
Birth weight (g)	4396.2 (SD 825.1)	3200-6600	4334.3 (SD 849.6)	3000-5500
Gender	**n**	**%**	**n**	**%**
Girl	10	37.04	10	50.00
Boy	17	62.96	10	50.00
Effected limb	**n**	**%**	**n**	**%**
Right	15	55.56	11	55.00
Left	12	44.44	9	45.00
Narakas classification	**n**	**%**	**n**	**%**
1	6	22.22	4	20.00
2	8	29.63	5	25.00
3	11	40.74	11	55.00
4	2	7.41	0	0.00
Birth	**n**	**%**	**n**	**%**
Vaginal	16	88.89	14	77.78
Vaginal& vacuum	2	11.11	4	22.22

SD: Standart deviation, Min: Minimum, Max: Maximum g: Grams

Range of Motion

All shoulder motion ranges changed significantly for all participants 3 months after surgery ($p<0.05$) (**Table 2, Table 3**). Furthermore, there was a significant increase in shoulder flexion, abduction, and internal rotation between the 3-month and 6-month follow-ups (**Table 2, Table 3**). Only the abduction and internal rotation ranges showed a significant increase between the 6-month and 12-month follow-ups in comparison of all participants ($p<0.05$). Comparison analysis showed more shoulder flexion and abduction angle change between first and last assessments for G2 (**Table 4**) however there were no significant differences of final assessments between groups ($p>0.05$).

In group-based analysis, except for internal rotation, the G2 demonstrated greater effect sizes for all shoulder ranges of motion acquired at the 3-month follow-up. At 6-month follow-up, the G1 group had higher effect sizes for flexion and abduction, but lower effect size for internal rotation angle. Specifically, the effect sizes at 3-month follow-up were 32.4%, 47%, 47.2% higher for the G2 group in flexion, abduction and external rotation respectively while 17.9% lower for internal rotation angle (**Table 3**). During the 6 to 12-month period, groups did not show any significant change except internal rotation angle.

The Mallet Scoring System

There were significant changes in all five parameters between the pre-operative and 3-month follow-up ($p<0.05$) (**Table 5, Table 6**). There was a significant change in abduction and hand-to-mouth parameters during the 6-month follow-up period, with just the hand-to-mouth parameter being altered between 6-month and 12-month follow-up for all participants ($p<0.05$) (**Table 5**). In group-based analysis, only the hand-to-mouth parameters significantly increased between the 3-month and 6-month follow-ups in G2 (**Table 6**). The comparison analysis revealed no significant differences between the gains of the two groups. ($p>0.05$).

DISCUSSION

Our study aimed to evaluate the shoulder motion and function in children with BPBI who underwent a 12-week rehabilitation program after Modified Hoffer Technique according to the onset age of surgery. We hypothesised that the timing of surgery and the time passed from the treatment could affect the results. However, our first hypothesis was disproved as the results of children who had surgery at the age of 7 years or older had similar gains to those who had surgery earlier. After surgery followed by 12 weeks of specialised rehabilitation, we found a significant increase in all assessments. Moreover, significant changes continued in shoulder flexion, abduction, and internal rotation, as well as abduction and hand-to-mouth parameters of the Mallet score, after six months. However, only shoulder abduction and internal rotation range and hand-to-mouth parameter of Mallet score significantly increased on 12-month follow-up. One noteworthy finding was that the increase in external rotation started to decrease after 6 months.

Although the optimal age for surgery in children with BPBI has not yet been determined, there is a growing body of literature on having surgery at a younger age, around two years old, which may have a superior effect due to the prevention of fixed deformities.[17,18] One discussion is that glenohumeral remodelling may be better with balancing the shoulder by early secondary surgery. From a functional perspective, Ozben et al.[16] previously reported a higher increase in shoulder abduction and external rotation motion in children who had surgery younger than 7 years. However, their study did not present the onset values of the participants and the rehabilitation program. Covey et al.[19] reported that secondary surgery is commonly recommended for patients under the age of 7, and 3-4 years of age was the best for

Table 2. Comparison of the shoulder range assessments of all participants

	Range of motion	Flexion (°)	Extension (°)	Abduction (°)	External rotation (°)	Internal rotation (°)
	n	47	47	47	47	47
Pre-rehab	Mean (SD)	83.26 (SD 26.26)	14.04 (SD 11.26)	84.47 (SD 31.48)	27.21 (SD 19.19)	24.32 (SD 13.69)
After-rehab (3M follow-up)	Mean (SD)	118.51 (SD 18.9)	4.15 (SD 9.69)	124.04 (SD 19.69)	77.55 (SD 19.69)	-12.62 (SD 17.72)
6M follow-up	Mean (SD)	129.36 (SD 20.66)	5 (SD 9.9)	135.11 (SD 22.64)	78.72 (SD 16.47)	-0.96 (SD 19.47)
12M follow-up	Mean (SD)	134.49 (SD 24.47)	4.15 (SD 7.96)	137.77 (SD 24.36)	76.91 (SD 14.98)	2.87 (SD 16.96)
Friedman test	χ^2	99.57	49.61	92.34	83.89	75.29
	p value	<0.01*	<0.01*	<0.01*	<0.01*	<0.01*
Wilcoxon test	Assesment no (p value)	1-2 (<0.01*) 2-3 (<0.01*)	1-2 (0.00*)	1-2 (<0.01*) 2-3 (<0.01*) 3-4 (<0.01*)	1-2 (0.00*)	1-2 (<0.01*) 2-3 (<0.01*) 3-4 (0.035*)
Effect size	Assesment no (cohen's d)	1-2 (1.54) 2-3 (0.54)	1-2 (0.94)	1-2 (1.50) 2-3 (0.52) 3-4 (0.11)	1-2 (2.77)	1-2 (2.33) 2-3 (0.62) 3-4 (0.20)

Pre-rehab: Pre-rehabilitation, After-rehab: After-rehabilitation, SD: Standart deviation

Table 3. Comparison of the shoulder range assessments of each group

		Range of motion	Flexion (°)		Extension (°)		Abduction (°)		External rotation (°)		Internal rotation (°)	
		Group	Group I	Group II	Group I	Group II	Group I	Group II	Group I	Group II	Group I	Group II
		n	27	20	27	20	27	20	27	20	27	20
1	Pre-rehab	Mean (SD)	90.93 (SD 24.02)	72.9 (SD 26.15)	11.85 (SD 11.7)	17 (SD 10.18)	95.19 (SD 28.06)	70 (SD 30.65)	29.41 (SD 20.92)	24.25 (SD 16.65)	26.22 (SD 15.43)	21.75 (SD 10.79)
2	After-rehab (3M follow-up)	Mean (SD)	119.81 (SD 17.12)	116.75 (SD 21.42)	4.44 (SD 10.03)	3.75 (SD 9.44)	126.11 (SD 18.1)	121.25 (SD 21.82)	74.44 (SD 17)	81.75 (SD 16.41)	-14 (SD 16.54)	-10.75 (SD 19.49)
3	6M follow-up	Mean (SD)	131.3 (SD 19.54)	126.75 (SD 22.32)	4.07 (SD 6.94)	6.25 (SD 12.97)	139.07 (SD 21.03)	129.75 (SD 24.14)	79.63 (SD 16.05)	77.5 (SD 17.36)	-4.44 (SD 15.53)	3.75 (SD 23.39)
4	12M follow-up	Mean (SD)	136.48 (SD 24.21)	131.8 (SD 25.17)	3.15 (SD 7.36)	5.5 (SD 8.72)	137.41 (SD 25.81)	138.25 (SD 22.9)	77.41 (SD 14.5)	76.25 (SD 15.97)	3.15 (SD 17.05)	2.5 (SD 17.28)
Friedman test		χ^2	54.94	44.67	28.16	21.94	46.65	47.95	44.96	41.74	47.98	28.50
		p value	<0.01*	<0.01*	<0.01*	<0.01*	<0.01*	<0.01*	<0.01*	<0.01*	<0.01*	<0.01*
Wilcoxon test		Assesment no (p value)	1-2 (<0.01*) 2-3 (<0.01*)	1-2 (<0.01*) 2-3 (<0.01*)	1-2 (0.03*)	1-2 (<0.01*)	1-2 (<0.01*) 2-3 (<0.01*)	1-2 (<0.01*) 2-3 (<0.01*)	1-2 (<0.01*)	1-2 (<0.01*)	1-2 (<0.01*) 2-3 (<0.01*) 3-4 (0.01*)	1-2 (<0.01*) 2-3 (<0.01*)
Effect size		Assesment no (cohen's d)	1-2 (1.38) 2-3 (0.62)	1-2 (1.83) 2-3 (0.45)	1-2 (0.67)	1-2 (1.34)	1-2 (1.3) 2-3 (0.66)	1-2 (1.92) 2-3 (0.36)	1-2 (2.36)	1-2 (3.47)	1-2 (2.51) 2-3 (0.59) 3-4 (0.46)	1-2 (2.06) 2-3 (0.67)

Pre-rehab: Pre-rehabilitation, After-rehab: After-rehabilitation, SD: Standart deviation, x^2: Chi-square

Table 4. Comparison of the change of shoulder range of motions according to the groups

Range of motion	Group	n	Pre-rehab / 3M follow-up	Pre-rehab/12M follow-up
			Mean (SD)	Mean (SD)
Flexion (°)	Group I	27	28.89 (SD 20.6)	45.56 (SD 20.1)
	Group II	20	43.85 (SD 20.93)	58.9 (SD 24.25)
p value			0.019*	0.022*
Extension (°)	Group I	27	-7.41 (SD 9.84)	-8.7 (SD 9.67)
	Group II	20	-13.25 (SD 12.9)	-11.5 (SD 11.13)
p value	p value		0.042*	0.18
Abduction (°)	Group I	27	30.93 (SD 23.33)	42.22 (SD 25.66)
	Group II	20	51.25 (SD 25.22)	68.25 (SD 28.4)
p value	p value		0.003*	<0.001*
External rotation (°)	Group I	27	45.04 (SD 26.22)	48 (SD 25.27)
	Group II	20	57.5 (SD 20.16)	52 (SD 21.11)
p value	p value		0.042*	0.284
Internal rotation (°)	Group I	27	-40.22 (SD 20.32)	-31.92 (SD 22.37)
	Group II	20	-32.5 (SD 21.8)	-19.25 (SD 20.8))
p value			0.11	0.28

Pre-rehab: Pre-rehabilitation, SD: Standart deviation

Table 5. Comparison of the Mallet Scores assessments for all participants

		Mallet classification	Abduction	External rotation	Hand to head	Hand to back	Hand to mouth
		n	47	47	47	47	47
1	Pre-rehab	Mean (SD)	3.13 (SD 0.65)	2.55 (SD 0.68)	2.47 (SD 0.58)	2.68 (SD 0.78)	2.89 (SD 0.84)
2	After-rehab (3M follow-up)	Mean (SD)	3.83 (SD 0.38)	3.55 (SD 0.69)	3.57 (SD 0.58)	2.06 (SD 0.32)	3.3 (SD 0.62)
3	6M follow-up	Mean (SD)	3.91 (SD 0.28)	3.66 (SD 0.63)	3.66 (SD 0.56)	2.13 (SD 0.4)	3.53 (SD 0.62)
4	12M follow-up	Mean (SD)	3.98 (SD 0.15)	3.79 (SD 0.51)	3.77 (SD 0.48)	2.23 (SD 0.52)	3.68 (SD 0.52)
Friedman test		χ^2	88.09	86.62	103.278	40.84	56.05
		p value	<0.01*	<0.01*	<0.01*	<0.01*	<0.01*
Wilcoxon test		p value	1-2 (<0.01*) 2-3 (0.046*)	1-2 (<0.01*)	1-2 (<0.01*)	1-2 (<0.01*)	1-2 (<0.01*) 2-3 (<0.01*) 3-4 (0.02*)

Pre-rehab: Pre-rehabilitation, After-rehab: After-rehabilitation, SD: Standart deviation, x^2: Chi-square

Table 6. Comparison of the Mallet Scores assessments of each group

		Mallet classification	Abduction		External rotation		Hand to head		Hand to back		Hand to mouth	
		Group	Group I	Group II	Group I	Group II	Group I	Group II	Group I	Group II	Group I	Group II
		n	27	20	27	20	27	20	27	20	27	20
1	Pre-rehab	Mean (SD)	3.3 (SD 0.61)	2.9 (SD 0.64)	2.63 (SD 0.69)	2.45 (SD 0.69)	2.48 (SD 0.64)	2.45 (SD 0.51)	2.63 (SD 0.79)	2.75 (SD 0.79)	2.96 (SD 0.81)	2.8 (SD 0.89)
2	After-rehab (3M follow-up)	Mean (SD)	3.93 (SD 0.27)	3.7 (SD 0.47)	3.52 (SD 0.64)	3.6 (SD 0.75)	3.52 (SD 0.58)	3.65 (SD 0.59)	2.11 (SD 0.32)	2 (SD 0.32)	3.33 (SD 0.62)	3.25 (SD 0.64)
3	6M follow-up	Mean (SD)	3.96 (SD 0.19)	3.85 (SD 0.37)	3.7 (SD 0.54)	3.6 (SD 0.75)	3.63 (SD 0.56)	3.7 (SD 0.57)	2.11 (SD 0.32)	2.15 (SD 0.49)	3.48 (SD 0.7)	3.6 (SD 0.50)
4	12M follow-up	Mean (SD)	4 (SD 0)	3.95 (SD 0.22)	3.85 (SD 0.36)	3.7 (SD 0.66)	3.7 (SD 0.54)	3.85 (SD 0.37)	2.22 (SD 0.51)	2.25 (SD 0.55)	3.67 (SD 0.55)	3.7 (SD 0.47)
Friedman test		χ^2	44.76	43.69	47.10	40.84	55.81	47.56	15.60	26.31	26.07	30.48
		p value	<0.01*	<0.01*	<0.01*	<0.01*	<0.01*	<0.01*	<0.01*	<0.01*	<0.01*	<0.01*
Wilcoxon test		p value	1-2 (<0.01*)	1-2 (<0.01*)	1-2 (<0.01*)	1-2 (<0.01*)	1-2 (<0.01*)	1-2 (<0.01*)	1-2 (<0.01*)	1-2 (<0.01*)	1-2 (0.013*)	1-2 (0.013*) 2-3 (<0.01*)

Pre-rehab: Pre-rehabilitation, After-rehab: After-rehabilitation, SD: Standart deviation, x^2: Chi-square

improving function. In our study, we did not follow glenoid dysplasia but found that the mean motion gain of shoulder abduction and external rotation was similar regardless of age at surgery. Effect sizes of pre-operative and 3-month follow-up were very high for the G2 for all shoulder ranges of motions except for internal rotation. This means that children respond to intervention programs even if they have some stiffness or dysplasia.

In our study, we found that the children in G2 had more evident soft tissue stiffness as the onset shoulder movement ranges were lower. Muscle stiffness was previously found to be higher than non-affected side muscles in children with BPBI.[20] After the rehabilitation program, children older than 7 years had similar gains. However one should keep in mind that, the children who underwent a secondary surgery already have decreased myofascial tissue mobility, increased hyaluronic acid viscosity and glenohumeral deformities,[21] meaning a soft tissue problem that may decline the success of motion gain may occur after a period of surgery. The joint stiffness and deformities also affect the central nervous system as the system regulates the overall accuracy of movement based on the interpretation of hierarchical muscle activation pattern.[22,23] We may suggest that physiotherapy or exercise habits should continue until tissue maturation is completed.

One of the most remarkable results of our study is the significant gain in external rotation showed a decrease in follow-up assessments. Younger age had a significant effect in gain of external rotation till 6 months follow up. Unfortunately, even if it is a small range, external rotation started to decrease in G2 after 3 months. Safoury et al.[11] showed a significant increase in the external rotation angle of the shoulder during 6 months of rehabilitation duration in their study. A fall-off in postoperative improvement over 10 years was reported by Cohen et al.[24] Despite the short-term results of the surgery being encouraging, it is shown that the gain diminishes over time after the surgery in 7.64 years (range, 2-16.5 years).[25] Soldado et al.[26] confirmed a significant decrease especially in shoulder external rotation due to thickness and weight of denervated muscles. Clinicians should give more attention to rotation and develop strategies to maintain the gained external rotation movement, especially in children who underwent surgery late.

In the study internal rotation angles decreased after surgery, as it is expected.[27] Delioğlu et al.[28] determined that 30° of active and 41° of passive glenohumeral internal rotation motion is necessary for hand-to-back parameter. Mostly used daily living activities that required hand-to-back motion such as "tuck in shirt behind back", and "wash the middle of the back" possibly had a positive effect on the gain of internal rotation motion.[29] Therapists should focus on functional glenohumeral rotation and not disregard internal rotation motion in their treatment.[28]

Hoffer technique has a positive effect on abduction motion due to the mechanism that enables the deltoid muscle to be more active.[17,27] Despite the significant gain in the shoulder range of movement, the functional gain measured with Mallet score was only significant in the first 3 months. A long-term follow-up study reported a deterioration of shoulder abduction after 10 years in children who underwent tendon transfer surgery and explained the results with a lack of rehabilitation compliance and not using the involved arm actively.[30] Motivational rehabilitation and therapeutic options that are adapted to children's routine life to increase functional gain and prevent further soft tissue rebalancing procedures would be helpful.

A kinematics analysis study showed hand-to-neck parameter needs more external rotation and abduction motion than the hand-to-mouth parameter.[31] Limited external rotation motion affects the gain of hand-to-head function. A better hand-to-back score for Mallet Classification needs higher glenohumeral extension and internal rotation due to representing a coordinated multiplanar motion.[32] Even though there is a slight increase in internal rotation, a decrease in the glenohumeral extension might cause limited functional gain for participants in this study. It may be also because home exercises do not involve multiplanar functional movements.

Limitations

One limitation of the study is our results are limited to range of motion and Mallet Scoring results, which present data on body structures and functioning. Additionally, glenohumeral joint dysplasia screening would give valuable results; however, we could not collect the data.

CONCLUSION

As a result our results revealed that Hoffer technique increases shoulder flexion, abduction, and external rotation. The gain in external rotation started to decrease after 6 months and hand-to-head function did not increase after 3 months. Clinicians should give more attention to rotation and develop strategies to maintain the gained external rotation movement especially in children who underwent surgery late. The functional multiplanar use of the extremity should be encouraged in daily life.

ETHICAL DECLARATIONS

Ethics Committee Approval

This prospective clinical study was conducted with the approval of the İstanbul University İstanbul Faculty of Medicine Clinical Researches Ethics Committee (Date: 19.08.2019, Decision No: 1017).

Informed Consent

Informed consent was obtained from the legal guardians of the pediatric patient(s) described in this report. Where developmentally appropriate, assent was also sought from the child. The inclusion of vulnerable populations in this study adhered to national and international ethical guidelines. Extra care was taken to ensure voluntary participation, understanding, and protection of participant dignity and autonomy.

Peer Review Process

This manuscript was subject to external peer review.

Conflict of Interest

The authors declare no conflicts of interest related to this study.

Financial Disclosure

The authors received no financial support for the conduct or publication of this research.

Author Contributions

Concept: S.Ö., H.Ö.B.; Design: S.Ö., H.Ö.B.; Control: S.Ö.; Data collection and/or processing: S.Ö., H.Ö.B.; Analysis and/or interpretation: S.Ö., H.E., B.S.A.; Literature review: H.E., B.S.A.; Article writing: S.Ö., H.E., B.S.A.; Critical review: All authors.

Acknowledgments

We sincerely thank all the children and their families participating in this study. Your invaluable contribution and dedication made this research possible.

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