Normalization of Shoulder Complex Kinematics Following Rotator Cuff Repair Surgery

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INTRODUCTION: Nearly 300,000 rotator cuff repair surgeries are performed each year in the U.S.A. [1]. Post-op rehabilitation must allow the repaired cuff to heal while restoring function and range of motion [2]. Normalization of the affected shoulder is defined as "changed kinematics toward symmetrical bilateral motion," as compared to the contralateral asymptomatic shoulder [3]. Normalization of shoulder motion has been observed by one to two years after surgery [3], but the process for how normalization occurs and its impact on function is unknown. This study evaluated functional outcomes and shoulder complex joint kinematics of patients with rotator cuff tears to quantify the changes occurring within the first year of repair, during rehabilitation.

METHODS: The IRB approved this study and informed consent was obtained prior to data collection. Ten adults (mean age 62.1 ± 6.6 years; 5 females) with a unilateral full-thickness single- or multi-tendon tear involving the supraspinatus tendon (mean tear size 1.2 ± 0.36 cm, 5 single- /5 multi-tendon tears) attended three test sessions: pre-op, and 3- and 6- months after surgery. Participants completed three functional outcomes: the Simple Shoulder Test (SST), the UCLA Shoulder Score, and the American Shoulder and Elbow Surgeons (ASES) Shoulder Score. Then they performed multiple trials each of maximal abduction and maximal external rotation from an adducted posture, challenging tasks with a rotator cuff tear, using their surgical and contralateral, asymptomatic arms. The trajectories of 27 markers adhered to the upper body were captured by a 15-camera Vicon motion analysis system. Thoracohumeral (TH), sternoclavicular (SC), acromioclavicular (AC), and glenohumeral (GH) joint kinematics were calculated using a modified version of our established inverse kinematics model [4]. For each visit, group averages were computed for the outcomes scores, and the peak elevation angles (abduction task) and peak external rotation angles (external rotation task) for each joint of both arms. Wilcoxon signed rank tests were used for comparisons between arms and between evaluations ($p<0.05$). The Benjamini-Yekutieli (BY) method adjusted the p-value to account for the multiple peak angle comparisons ($p<0.0029$).

RESULTS SECTION: Significant differences in peak joint angles between arms and between visits were observed in the TH and GH joints during both tasks and the AC joint during abduction (Figure 1A & 1B). The average bilateral difference (surgical arm angle minus contralateral arm angle) as well as the number of participants with a difference greater than 10 degrees, considered clinically relevant, are also reported (Figure 1A & 1B). For each functional outcome, the score at 6-months post-op was significantly higher (i.e., better shoulder function) than both the pre-op and the 3-month post-op scores, while no significant differences were observed between the pre-op and the 3-month post-op scores (Figure 1C).

DISCUSSION: Proper rehabilitation, particularly within three months post-op, is key to good functional outcomes [2]; however, the optimal rehabilitation protocol is still being deliberated [2,5]. Although most protocols aim to restore active range of motion (ROM) by three to four months [5], this was not observed in this study. The lack of significant differences in the peak angle at every joint between the pre-op and 3-month post-op visits suggests a particular absence of the expected progress toward normalization by 3-months after surgical repair, and in the case of external rotation a reduction in ROM. Normalization of all joints during both tasks was only achieved by one participant at 6-months post-op. Bilateral differences >10 degrees and compensation patterns, such as increased AC upward rotation to account for reduced GH elevation during abduction, persisted in nine participants. For many participants the bilateral difference was so large it made activities of daily living (ADLs) challenging or impossible to perform, particularly pre-op and at 3-months post-op. These results are also reflected in the functional outcomes, with minimal, non-significant changes in scores by 3-months post-op, and 20-40% of participants still not achieving scores indicating good function by 6-months post-op. Overall, this work suggests that joint normalization and functional outcomes scores experience the most improvement between 3- and 6-months post-op. Critically, the results suggest that current rehabilitation protocols may have unrealistic 3-month post-op goals, which can directly affect ADLs and return to work. This study also continues to show that thoracohumeral motion alone does not provide a comprehensive picture since compensation strategies among SC, AC, and GH joints were observed and changed between visits.

SIGNIFICANCE/CLINICAL RELEVANCE: Knowledge of pre-op shoulder complex dysfunction and post-op normalization is critical to understanding the rehabilitation process and recovery. This work helps identify the extent of recovery and potential timing for interventions, and ultimately may be used to set realistic patient expectations, improve outcomes, and reduce recovery time.

REFERENCES: [1] M. Crawford, AAOS Now, 34, 2014; [2] H. Tonotsuka, et al., J Orthop Surgery, 25(3):1-8, 2017; [3] A. Kolk, et al., J Shoulder Elbow Surg, 25:881-889, 2016.; [4] A. J. Schnorenberg, et al., J Biomech, 47:269-276, 2014; [5] C. Jung, et al., Obere Extrem, 13:45-61, 2018.

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A

	Peak TH Elevation			Peak SC Elevation			Peak AC Upward			Peak GH Elevation		
	Angle (°)	Bilateral Diff.		Angle (°)	Bilateral Diff.		Angle (°)	Bilateral Diff.		Angle (°)	Bilateral Diff.	
		Avg (°)	n>10°		Avg (°)	n>10°		Avg (°)	n>10°		Avg (°)	n>10°
Con.	128 (14)			37 (8)			54 (17)			84 (14)		
Pre-Op	70 (20)* ł	-60 (23)	10	30 (9)	-18 (9)	4	6 (18)* ł	-49 (19)	10	43 (18)* ł	-43 (21)	10
3M Post	81 (36) ł	-63 (23)	7	30 (10)	-17 (6)	4	35 (32)	-34 (20)	6	43 (28)	-57 (10)	7
6M Post	130 (12)	N/A	0	40 (6)	N/A	0	63 (13)	-18 (1)	2	81 (20)	-15 (5)	4

B

	Peak TH External Rot.			Peak SC Retraction			Peak AC External Rot.			Peak GH External Rot.		
	Angle (°)	Bilateral Diff.		Angle (°)	Bilateral Diff.		Angle (°)	Bilateral Diff.		Angle (°)	Bilateral Diff.	
		Avg (°)	n>10°		Avg (°)	n>10°		Avg (°)	n>10°		Avg (°)	n>10°
Con.	56 (9)			23 (7)			55 (6)			86 (11)		
Pre-Op	42 (10)	-20 (8)	5	23 (6)	-14 (1)	2	53 (5)	N/A	0	72 (11)	-25 (11)	4
3M Post	32 (12)* ł	-26 (6)	9	24 (7)	N/A	1	53 (6)	N/A	0	63 (11)* ł	-25 (6)	9
6M Post	51 (14)	-15 (3)	6	26 (6)	N/A	1	55 (8)	N/A	1	80 (15)	-22 (13)	3

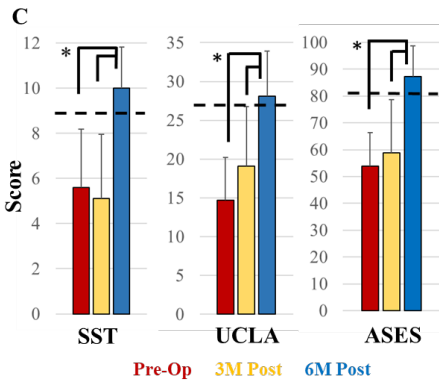

Figure 1. **(A)** peak elevation and **(B)** peak external rotation angles (degrees) for each joint of the contralateral arm (Con.) and the surgical arm at each visit: Pre-op, 3-months post-op, and 6-months post-op. * Indicates peak angles that are significantly different than the contralateral arm. ł indicates peak angles that are significantly different than the surgical arm at 6-months post-op (adjusted $p<0.0029$). The average bilateral differences in peak angle between arms (surgical– contralateral) at each visit and the number of participants (n) with an absolute bilateral difference of more than 10 degrees are presented. (TH: thoracohumeral, SC: sternoclavicular, AC: acromioclavicular, GH: glenohumeral). **(C)** Group average scores (+1 SD) of the SST, UCLA, and ASES at each visit: Pre-Op (red), 3-months (yellow) and 6-months (blue) post-op. The y-axis represents the range of scores achievable. The dashed lines indicate the score at which either "good" shoulder function, or the Patient Acceptable Symptom State is achieved. * Indicates significant differences between visits ($p<0.05$).