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Alteration and recovery of arm usage in daily activities after rotator cuff surgery

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Background: The objective measurement of dominant/nondominant arm use proportion in daily life may provide relevant information on healthy and pathologic arm behavior. This prospective case-control study explored the potential of such measurements as indicators of upper limb functional recovery after rotator cuff surgery.
Methods: Data on dominant/nondominant arm usage were acquired with body-worn sensors for 7 hours. The postsurgical arm usage of 21 patients was collected at 3, 6, and 12 months after rotator cuff surgery in the sitting, walking, and standing postures and compared with a reference established with 41 healthy subjects. The results were calculated for the dominant and nondominant surgical side subgroups at all stages. The correlations with clinical scores were calculated.
Results: Healthy right-handed and left-handed dominant arm usage was 60.2% (±6.3%) and 53.4% (±6.6%), respectively. Differences in use of the dominant side were significant between the right- and left-handed subgroups for sitting ($P = .014$) and standing ($P = .009$) but not for walking ($P = .328$). The patient group showed a significant underuse of 10.7% (±8.9%) at 3 months after surgery ($P < .001$). The patients recovered normal arm usage within 12 months, regardless of surgical side. The arm underuse measurement was weakly related to function and pain scores.
Conclusion: This study provided new information on arm recovery after rotator cuff surgery using an innovative measurement method. It highlighted that objective arm underuse measurement is a valuable indicator of upper limb postsurgical outcome that captures a complementary feature to clinical scores.
Level of evidence: Basic Science Study, Kinesiology.

Keywords: Shoulder; outcome treatment; kinematics; inertial sensors; daily measurements

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Numerous publications address the psychological, behavioral, and neurologic aspects of lateralization in healthy and pathologic populations. However, measurements of handedness alteration have rarely been used as a treatment outcome method. More specifically, no study has evaluated the transfer of upper limb activities toward the uninvolved side in the field of orthopedic surgery. This study explored the relevance of postsurgical dominant/nondominant arm use proportion in daily life as a functional outcome after rotator cuff surgery.

With a prevalence of 20.7%, rotator cuff tear is a common upper arm condition in the general population.[30] Rotator cuff repair is a frequent surgical procedure, and 1 in every 16 visits for shoulder pain requires surgery.[11,20,21] Although this procedure generally results in reduced pain and functional improvement, it is not known when the patients objectively recover fully normal arm usage in daily life. At an early stage after surgery, the patients avoid movements on the affected side because of physical impairments such as pain, stiffness, and muscle weakness before partially or totally recovering. They very likely transfer some activities to the healthy side, which alters arm usage proportions compared with healthy people.

It is presently unknown how patients recover arm usage in daily life and if sequels or fear-avoidance prevents the return to normal usage in the long term. The presence of an incomplete usage recovery would imply an increased use of the contralateral side. This may interfere with dexterity and contribute to overuse pathologic changes. The long-term overuse of the healthy arm is of importance because degeneration is frequently bilateral and is related to microtrauma.[25,28]

Nowadays, the uncertainties about these issues can be resolved as the modifications of arm use can be easily measured with body-fixed sensors. The miniaturization and low-power consumption enable several hours of measurements in a free environment without movement hindrance.[3] The applicability and reliability of 3-dimensional body-fixed sensors (e.g., inertial sensors) for arm movement analysis have been demonstrated in healthy subjects.[9,10]

As body posture can also be analyzed with use of a sensor on the trunk, a more detailed differentiation of arm activity according to the subject's posture is possible.[23]

Accounting for the dominance of the affected side is crucial in investigating postsurgical alterations of arm usage with body-fixed sensors. Therefore, the uncertainty about the precise degree of asymmetry between upper limbs in daily life must first be resolved to obtain a correct evaluation of postsurgical arm usage alteration. An asymmetry in favor of the dominant side is found to range from 4% to 19% in healthy subjects.[1,9,29] As a consequence, the definition of more precise right-handed and left-handed norms for arm usage proportion is a prerequisite before the application of arm usage as an evaluation method for underuse studies after rotator cuff surgery. To our knowledge, only Coley et al[9] addressed this issue in daily life activities using accelerometers and gyroscopes. The study found that right-handed subjects used their dominant side 18% and 25% more on average than the nondominant side in standing and sitting postures, respectively. The left-handed subjects used their dominant side only 8% and 18% more in these postures. These norms may be used as references to compare pathologic and healthy subjects and to evaluate the influence of side dominance on arm usage recovery after surgery. However, these data were established with a limited sample (23 right-handed and 8 left-handed subjects), and the sample needs to be increased to obtain more precise estimations.

The feasibility and the value of objective measurement in the subjects' natural living environment using inertial sensors have recently been highlighted for patients scheduled to undergo shoulder surgery.[17] As a matter of fact, objectifying the extent of underuse as a function of the involved side may improve our understanding of the impact of dominance on disability and recovery. Moreover, the definition of normal and abnormal patterns of recovery of arm usage would enable identification of surgical failure and of movement fear-avoidance, which is an important determinant of recovery in shoulder conditions.[27]

Thus, the primary aim of this study was to explore the relevance of arm underuse measurement as an indicator of upper limb postsurgical function. The secondary aim was to use this new metric to investigate the impact of the rotator cuff surgery on arm usage during the first year after surgery. On the basis of the typical function recovery pattern in rotator cuff repair, we hypothesized that the affected arm usage would be significantly lower in the pathologic group than in the healthy group 3 months after surgery. Furthermore, the surgical patients would present a limited deficit after 12 months.[8] It was also hypothesized that the decreased usage would be related to pain, feeling of stiffness, and shoulder function loss.[6]

Methods

Study population

A prospective case-control study was conducted. Forty-one healthy subjects and 21 patients surgically treated for rotator cuff tear were evaluated with body-worn inertial sensors for 7 hours of daily activities. The healthy group is the same sample used in the study of Coley et al,[9] which has been increased by 10 additional subjects (6 right-handed and 4 left-handed subjects) (Table I). The patients were assessed at 3, 6, and 12 months after surgery.

Hand dominance was determined according to the patient's perception of the dominant side. The healthy participants were measured for normal usage characterization and had no history of shoulder conditions. The control population was purposefully younger than the patients to avoid bias related to the high prevalence of asymptomatic rotator cuff tears in adults older than 40 years.[26]

Table I Characteristics of participants

	Patient group	Control group	*P* value
Age, mean (SD), years	53.3 (9.0)	34.1 (8.8)	<.001
Sex (men/women)	14/7	23/18	.422
Weight, mean (SD), kg	77.0 (12.5)	68.1 (9.9)	.007
Body mass index, mean (SD), kg/m^2	26.7 (4.3)	22.9 (3.2)	.001
Size, mean (SD), m	1.70 (0.06)	1.72 (0.08)	.417
Hand dominance (right/left)	19/2	29/12	.078
Operated on dominant side (right/left-handed)	9/0	—	
Operated on nondominant side (right/left-handed)	10/2	—	

SD, standard deviation.

The patient inclusion criteria were unilateral shoulder pain with transmural supraspinatus rupture that was associated with no more than a partial upper-third subscapularis or upper-part infraspinatus tear as stated by resonance arthrography and confirmed during surgery. The patient exclusion criteria were comorbidities potentially interfering with upper arm usage of either arm and a history of shoulder conditions or trauma on the contralateral side.

Surgical technique and postoperative rehabilitation

Surgery was performed by a single surgeon (A.F.). A superolateral approach was used to detach the anterior deltoid. A tenodesis of the long head and an acromioplasty of the biceps were performed. The rotator cuff was repaired by a modified Mason-Allen suture technique. The suture ends were passed transosseously and tied over the cortical bone. All patients wore a sling for 6 weeks after surgery. Physiotherapy started with passive range of motion exercises on the first postoperative day. Active exercises were allowed after 6 weeks. Strengthening against resistance was initiated 3 months after surgery.

Arm usage and body posture

The measurement method was the same as that described by Coley et al,[9] and the data analysis was based on the same algorithms. Miniature inertial modules were fixed on the dorsal side of each distal humerus to monitor arm motion and on the sternum to detect body posture (walking, sitting, standing) (Fig. 1). Each module consisted of 3 miniature gyroscopes (ADXRS 250, ±400°/s; Analog Devices, Norwood, MA, USA) and 3 miniature accelerometers (ADXL 210, ±5 g; Analog Devices). All signals were recorded at a sampling rate of 200 Hz by data loggers (Physilog; Gait Up, Lausanne, Switzerland) carried on the subject's waist. Each subject carried the system for a minimum of 7 hours (mean measurement time [standard deviation], 7.2 hours [0.9]) and was free to perform his or her regular duties as desired during this measurement period.

Figure 1 Placement of arm sensors during measurement.

An arm was considered active when the product of acceleration and angular velocity, which indicates movement power, was above the threshold corresponding to the mean power measured for 1 hour on a motionless person. A movement was classified as dominant when the power was higher on the dominant side and as nondominant in the opposite case. The percentage of arm usage for the dominant and nondominant side was measured for both the patient and the control groups. Shoulder usage was characterized in the walking, sitting, and standing postures. The expected usage was then characterized by the mean of the group of healthy participants having the same dominant side. The outcome was considered underuse when a negative difference was found between the measured surgical side usage and the expected arm usage. For example, a 10% underuse in a right-handed patient whose right side was operated on means that the patient used the right affected arm 10% less than a typical right-handed control.

The following current clinical questionnaires were also completed: Constant and relative Constant score,[12,13] Disabilities of the Arm, Shoulder, and Hand (DASH) score,[2] Simple Shoulder Test (SST) score,[19] and visual analog scale (VAS) scores for pain and stiffness.

Statistical analysis

For the control group, the mean and standard deviation of the dominant arm usage were calculated for the left-handed and right-handed subgroups. The significance of differences between the left-handed and right-handed subgroups was calculated by a Wilcoxon rank sum test. The Friedman test with a Dunn-Bonferroni post hoc comparison was used to compare differences between postures.

The mean and standard deviation of arm underuse in the patient group were assessed at 3, 6, and 12 months after surgery. A 1-sample Wilcoxon signed rank test was used for the patient group to test if the value of underuse was significantly different from a median of 0 representing no underuse, which is equivalent to the performance of the healthy group. A Friedman test was used for the underuse difference over stages in the patient group, and a Wilcoxon signed rank test with Dunn-Bonferroni correction was used for the pairwise comparison of stages.

The results for the dominant and nondominant affected subgroups were also calculated. Because of the limited statistical power, no inferential statistics was conducted for differences between these subgroups. Spearman correlations were used to calculate the relationship between the clinical scores and arm underuse at all stages and for the evolution between stages. For all tests, the level of significance was set at $P < .05$.

Results

For the control group, considering all postures together, the measurements of arm usage showed that the healthy right-handers' dominant side use was 60.2% (±6.3%), whereas the healthy left-handers' dominant side use was 53.4% (±6.6%). Differences in use of the dominant side were significant between the right-handed and left-handed subgroups for all postures except walking (Table II). Only walking showed significant differences in use of the dominant side with other postures. Further analyses were conducted on the basis of the results of the sitting and standing postures, and the association of these postures is responsible for most of the difference between dominant and nondominant usage.

For the patient group, 1 patient was excluded from analysis at 6 months because of a surgical complication (frozen shoulder) and another did not attend the 12-month measurement session. Compared with the control group, the patient group presented a mean underuse of 10.7% (±8.9%) in the sitting and standing postures 3 months after surgery. The underuse was reduced at the following stages with an underuse of 5.1% (±7.3%) at 6 months and an underuse of 1.9% (±4.5%) at 12 months. Arm underuse in the sitting and standing postures in the patient group showed significant differences at 3 months ($P < .001$) and 6 months ($P = .006$) with the performance of the healthy group but not at 12 months ($P = .099$). The underuse at 12 months was significantly different from the underuse at 3 months ($P = .023$), but nonsignificant differences were found between the 3- and 6-month stages ($P = .072$) and the 6- and 12-month stages ($P = 1.000$).

The difference in underuse between the dominant and the nondominant affected arm subgroups was 3.2% at 3 months, 3.7% at 6 months, and 0.5% at 12 months (Table III and Fig. 2).

The correlations between underuse and the DASH, SST, and relative Constant scores were nonsignificant at all stages. The correlation with the Constant score was significant at 3 months ($r = 0.46$; $P = .034$) but not at 6 months ($r = 0.33$; $P = .152$) and 12 months ($r = 0.37$; $P = .119$). There were no significant correlations found with the VAS scores for pain and stiffness.

The correlations of evolutions between stages were significant for the relationship with the Constant scores for the 3-month to 6-month evolution only ($r = 0.47$; $P = .035$). A significant correlation was found with the DASH score for the 3-month to 6-month evolution only ($r = 0.49$; $P = .029$), and no correlations were found with the SST. There was no significant correlation found with the VAS pain score or the VAS stiffness evolution score at any stage.

Discussion

The primary aim of this study was to explore the relevance of arm underuse measurement as an indicator of upper limb postsurgical function. The secondary aim was to use this new metric to investigate the impact of the rotator cuff surgery on arm usage during the first year after surgery. The dominant/nondominant arm usage proportion in a healthy population was characterized in the first study step. We then compared the alteration and pattern of recovery during the first year after rotator cuff surgery with this reference. The long measurement time in an unconstrained environment enabled a realistic assessment of arm usage in daily life. This allowed us to examine arm usage during sitting, standing, and walking.

It appeared that the sitting and standing postures provided similar results and the mean usage difference was

Table II Mean ± standard deviation for the percentage of usage of the dominant arm according to the body posture (sitting, standing, walking, and all postures together) for the control group

Posture	All participants N = 41	Right-handed N = 29	Left-handed N = 12	Right- vs. left-handed difference
Sitting	59.2 ± 7.3	61.2 ± 6.3	54.5 ± 7.6	$P = .014$
Standing	59.1 ± 7.5	61.1 ± 7.1	54.3 ± 6.4	$P = .009$
Walking	49.8 ± 11.6**	50.8 ± 12.8**	47.4 ± 7.9**	$P = .328$
Sit and stand	59.2 ± 7.3	61.2 ± 6.6	54.3 ± 6.7	$P = .009$

Significant difference with other postures: **$P < .001$.

Table III Arm underuse in the sitting and standing postures expressed as a percentage in the dominant and nondominant affected patient subgroups with mean ± standard deviation (SD) and standard error of the mean at each stage

	Sample size	Dominant affected		Sample size	Nondominant affected	
	n	Mean ± SD	Standard error	n	Mean ± SD	Standard error
3 months	12	12.1 ± 10.0	±2.9	9	8.9 ± 7.5	±2.5
6 months	11	6.7 ± 8.6	±2.6	9	3.0 ± 4.9	±1.6
12 months	10	2.2 ± 5.1	±1.6	9	1.7 ± 3.9	±1.3

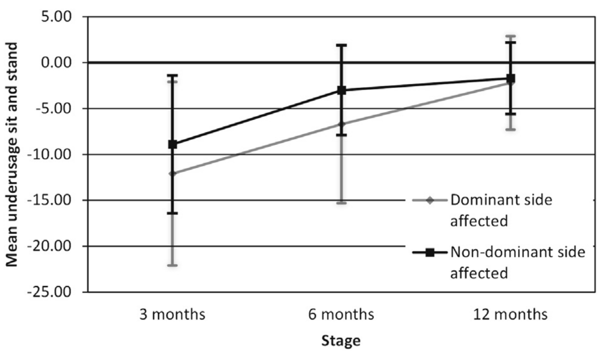

Figure 2 The *bars* indicate mean results and 95% confidence interval for patients affected on the dominant side and nondominant side.

minimal (<0.2%) and nonsignificant. These postures helped identify the subject's dominance. Thus, the subjects could be evaluated in a ''sit and stand'' posture to conduct underuse analysis. Conversely, the arm usage during walking was almost symmetric. When walking, a person generally shows either symmetric alternate arm movements or limited movement, such as having the hands in a pocket. Participants may also have been carrying various objects, but in this case, they did not substantially favor the use of either side. Thus, walking is not useful to discriminate right from left handed.

As expected, the analysis of arm usage in the healthy subjects showed a significantly more frequent usage of the dominant side compared with the nondominant side. However, the asymmetry was significantly more evident in the right-handed group than in the left-handed group. The right dominant side was 22.4% more used than the left side in the right-handed subgroup, whereas the left dominant side was 8.6% more used in the left-handed subgroup. Therefore, left-handed people do not exactly mirror the right-handed arm usage. This finding highlights that the dominance should be accounted for differently in considering right-handed or left-handed subjects. These objective results using body-worn sensors are congruent with the subjective results collected with the Edinburgh Handedness Inventory, in which respondents have to rate their hand preference on 10 manual tasks.[15] The less marked asymmetry in left-handed people may be related to their less lateralized brain organization and to their adaptation to a predominantly right-handed environment.[5,7,16]

Although the results clearly separated the right-handed from the left-handed group, the degree of handedness varied among subjects. This is in accordance with previous observations that challenged the traditional approach on the basis of the dichotomous right vs. left direction of handedness. Actually, handedness should be considered a continuous variable, and the degree of handedness rather than its direction should be accounted for in classifying participants.[4,24] Thus, the calculation of underuse with reference to a general norm is meaningful as long as groups are considered. However, it may be misleading in calculating underuse of single subjects.

The different degrees of handedness between right-handers' and left-handers' arm usages implied that 2 distinct norms were used to characterize arm underuse after surgery. The underuse was calculated to account for the natural dominance and the surgery side. The patient results showed a maximal underuse at 3 months after surgery, which decreased over time and was 1.9% at 12 months. These results were consistent with the observed progression of clinical scores during the first year after surgery.[8]

The difference between the patient group underuse and the normal use was significant at 3 and 6 months after surgery. Thus, arm underuse measurements discriminated the postsurgical from the healthy state at these stages. The significant difference between the 3-month and 12-month outcomes also indicated that this metric discriminates between postsurgical stages.

The control group was purposefully younger as it was of primary importance that the participants had healthy shoulders in the reference population. Thus, the control and the patient groups were not age matched, and as a consequence, significant differences in weight and body mass index were also observed. These differences probably had little influence on the group's results as it is not likely that arm use was more affected on one side than on the other in relation to weight or body mass index. Nevertheless, further research on the factors influencing arm use symmetry is needed to confirm this logical reasoning.

The difference between the dominant affected and the nondominant affected arm subgroups was 3.2% at 3 months, 3.7% at 6 months, and 0.5% at 12 months. A larger sample would be needed to calculate if the higher underuse measured for patients affected on the dominant arm is significant. In accordance with patients' affirmations in clinics, it is possible that this population more frequently encounters situations in which they cannot use their dominant arm as usual. Therefore, they more noticeably alter their arm usage proportion. The difference between subgroups decreased over time and became minimal at 12 months (0.5%). The 1-year prognosis of arm usage recovery was not affected by the side of surgery.

The relationships between arm underuse, the clinical questionnaires, and the pain and stiffness VAS scores were weak. The isolated correlations that were found are of limited clinical importance because of the risk of type I error in performing multiple correlations. The limited relationship with the functional scores and VAS score highlighted that the dominant/nondominant arm usage measurement captured a different aspect of shoulder activity than the clinical scores. These discrepancies may be due to the continuous measurement with embedded sensors that captures all activities during the period of measurements. These include a large variety of activities that are not necessarily demanding for the shoulder as they require a limited amount of movements or strength. Conversely, the clinical questionnaire focuses on only potentially discriminating activities and does not rely on a purely objective measurement system. The nature of the underuse measurement is different from the clinical questionnaires or VAS. Both the subjective and the objective approaches are complementary and should be used in conjunction to obtain an extensive picture of a patient's abilities.

Arm usage evaluation should be considered a representation of the functional movement performed in daily life. As such, it is able to highlight handedness and postsurgical movement alteration in a different way than classic shoulder function methods do. The alteration and progressive recovery of arm usage observed in this study indicate that this measurement was able to characterize the recovery trend over time after rotator cuff surgery.

The results that we found apply only to a population operated on according to the same rotator cuff repair surgical technique. However, the new metric may be used to evaluate in a free environment the functional impact of various shoulder disorders and treatment methods on arm use. For example, it might be of interest to investigate if arm use recovery differs from depending on the surgical approach used (e.g., arthroscopic versus mini-open). It has been stated that the surgical approach does not influence the functional outcome evaluated by clinical questionnaires[18,22] but that arthroscopy promotes better strength recovery.[31] Arm use measurement may be used to investigate whether this difference in strength modifies arm function in activities of daily living. Further research is needed to determine the physical and psychosocial factors influencing postsurgical arm usage recovery.

The limitations of this study are mainly related to the size of the patient group. Because of the limited statistical power and the conservative Dunn-Bonferroni approach used for significance adjustment,[14] the possibility of a type II error in the difference between the 3-month and the 6-month stages in the patient group should be considered. For the same reason, the significance of the difference between the right-handed and left-handed subgroups was not investigated. Further research should also consider the influence of movement fear-avoidance on affected arm underuse, as this aspect has been linked to functional status in shoulder conditions.[27] The influence of postsurgical deficiencies, including lack of strength, endurance, and motor control, should also be investigated. As the consequences of arm underuse are also presently unknown, it would also be relevant to investigate if underuse induces delays in recovery or overuse disorders of the contralateral arm.

Conclusion

This study highlighted that the arm usage proportion in healthy subjects was different as a function of arm dominance by use of body-worn sensors in daily life. However, the lateralization was more marked in right-handers. We found that arm underuse was marked at 3 months after rotator cuff surgery and almost completely recovered at 12 months, regardless of the dominant or nondominant side of the surgery. This result indicated that arm underuse measurement was able to characterize the recovery trend over time after rotator cuff surgery. The determinants of pathologic arm underuse could not be highlighted in this study. As arm underuse measurement was weakly correlated to shoulder function questionnaires, pain VAS and stiffness

VAS, it should be considered that it investigates complementary features to these clinical scores. The innovative approach applied in this study demonstrated that arm usage measurement constitutes a specific assessment of postsurgical recovery that focuses on objective arm use in daily life. Further research is needed to understand factors influencing arm underuse and consequences of altered arm usage on the pathologic and the healthy side.

Disclaimer

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