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## NOVEL APPROACHES TO OBJECTIVELY ASSESS SHOULDER FUNCTION

Wendy J. Hurd, PhD<sup>a,\*</sup>, Melissa M. Morrow, PhD<sup>a</sup>, Emily J. Miller, MS<sup>a</sup>, Robert A. Adams, OPA-C<sup>a</sup>, John W. Sperling, MD, MBA<sup>a</sup>, and Kenton R. Kaufman, PhD<sup>a</sup>

<sup>a</sup>Department of Orthopedic Surgery, Mayo Clinic, Rochester, MN, USA

### Abstract

**Background**—The purpose of this study was to evaluate the effectiveness of existing technologies implemented in a novel manner to objectively capture upper extremity function.

**Materials and methods**—Patients scheduled to undergo reverse shoulder arthroplasty (RSA) were recruited for the study. Functional limb use was measured using triaxial accelerometers worn in the subjects' natural living environment. Functional reach area was captured using three-dimensional motion analysis testing as subjects were asked to circumduct their limb reaching as far as possible in a circular manner. Statistical testing ( $\alpha$  0.05) was performed using paired t-tests to identify differences between limbs.

**Results**—There was no difference in functional limb activity between sides for the lower ( $p=0.497$ ) or upper arm ( $p=0.918$ ) for inactivity time. Mean activity was greater for the uninvolved limb compared to the involved limb (lower arm,  $p=0.045$ ; upper arm,  $p=0.005$ ). Low intensity activity was greater for the involved arm compared to the uninvolved arm (lower arm,  $p=0.007$ ; upper arm,  $p=0.015$ ), while high intensity activity was greater for the uninvolved arm (lower arm,  $p=0.013$ ; upper arm,  $p=0.005$ ). Radius of the functional reach area was greater for the uninvolved limb compared to the involved limb ( $p=0.006$ ).

**Conclusions**—Novel methods of capturing function were effective in discerning differences in side-to-side abilities among patients scheduled to undergo RSA. These testing procedures may be utilized to capture function across a spectrum of shoulder pathologies. These objective data are invaluable in assessing the impact of pathology, recovery after intervention, and obtaining reimbursement from third-party payers.

### Keywords

Shoulder; Arthroplasty; Function

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\*Corresponding Author, Wendy J. Hurd, PhD, Charlton North Bldg, L110, Rochester, MN 197116, USA, [hurd.wendy@mayo.edu](mailto:hurd.wendy@mayo.edu).

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## INTRODUCTION

The number of reverse shoulder arthroplasty (RSA) procedures performed annually is increasing dramatically.<sup>9</sup> Market analysis reports indicate approximately 10,000 RSA procedures were performed in the US in 2007, a five-fold increase compared to the number of procedures performed in 2004.<sup>9</sup> Surgical goals include a reduction in pain and enhanced function. Although originally intended for treatment of glenohumeral osteoarthritis with rotator cuff deficiency, indications for RSA are expanding.<sup>4</sup> Functional improvements after surgery are significant. Castricini et al<sup>1</sup> prospectively evaluated 80 patients undergoing RSA for primary osteoarthritis, massive rotator cuff tear, or cuff tear arthropathy. Outcome measures included the Constant-Murley score, shoulder range of motion, the Short Form Health Survey, and radiologic assessment. Castricini et al<sup>1</sup> reported 5 years after undergoing RSA, patients exhibited similar functionality as healthy controls. It is questionable, however, whether the measures utilized by Castricini et al<sup>1</sup> are the most effective means by which to objectively assess function.

A multitude of metrics are available to assess patient function after RSA. Disease specific questionnaires define function based on patient reporting. Clinical measures are utilized to infer function and may include goniometric range of motion, strength testing, and radiographic assessment of prosthesis positioning and bone healing. Both patient self-report and clinical measures, however, have limitations. Patient-reported function must be interpreted with caution as they are dependent on patient recall and perception of activity performance.<sup>11; 15</sup> Clinical measures do not inherently capture function. Novel approaches to objectively capture upper extremity function are critical for continued advancement of patient care and accurately assessing treatment effectiveness.

Limb activity in an individual's natural living environment and reaching area are two components of upper extremity function. Few investigators have objectively captured these metrics in patients with shoulder pathology.<sup>2; 5</sup> Triaxial accelerometer based activity monitors have been implemented on a broad scale among researchers who are interested in measuring physical activity. In these instances the activity monitor is worn at the waist, or around an ankle to capture step counts. Their application for capturing upper extremity limb use has been limited. Three dimensional motion analysis testing is used extensively to assess upper extremity movement kinematics. Typically movement is assessed as the subject performs cardinal plane motions or discrete activities. These kinematic data provide meaningful information yet fail to comprehensively capture the dynamic mobility of the glenohumeral joint. Fundamentally the primary purpose of the shoulder is to aid in the positioning of the hand for interaction with the environment.<sup>8</sup> Therefore a simplistic yet relevant question regarding functional shoulder mobility is *how far can I reach?*

The purpose of this study was to evaluate the effectiveness of existing technologies implemented in a novel manner to objectively capture upper extremity function. We hypothesized functional reaching area measured using three-dimensional motion analysis testing would be greater for the uninvolved limb compared to the involved limb. We also hypothesized the functional limb use measured using triaxial accelerometers would be greater for the uninvolved limb compared to the involved limb.

## METHODS

### Participants

The study implemented a prospective, case series with a single testing session. Fifteen subjects (seven females, eight males) with glenohumeral OA and rotator cuff insufficiency scheduled to undergo RSA were recruited for study participation. Study participants were required to be between 50–85 years of age (Mean, 74 years; SD, 6), independent ambulators, no neurological disease, and have minimum to no symptomatic pathology in the contralateral glenohumeral joint. All patients were recruited from the practice of a single orthopedic surgeon and had no other symptomatic injury to the involved upper extremity other than the shoulder of interest. Prior to initiating study procedures all participants provided written informed consent approved by Mayo Clinic Institutional Review Board, IRB #12-003780

### Functional Limb Activity

Functional limb activity was measured using triaxial accelerometry based activity monitors (ActiGraph, Pensacola, FL, USA). Monitors were worn for three days in the subjects' natural living environment including work and non-work activities. Sleep was not included in the data collection period of interest. The monitors were worn inside a pocket attached to Velcro straps and secured bilaterally to the upper arms at the mid-biceps, and the lower arms at the wrist.

Each activity monitor contained a triaxial accelerometer and captured data at  $\pm 6g$  at a rate of 100 Hz. Analyses were performed independently for each segment using custom Matlab programs (MathWorks, Natick, MA, USA). Filtered signals were parsed into 60-s (1 min) epochs. For each epoch a single value representing the counts per minute was obtained by summing the vector magnitudes of the three orthogonal axes. A within-subject ensemble mean activity count was calculated for each segment for the three-day period of interest. A novel technique to evaluate activity over the course of the day included the use of activity bins.<sup>7</sup> The bins were created to calculate the amount of time patients were inactive, and the time spent performing activities categorized as low and high intensity. Inactive limb use time was calculated as a percentage of the total wear time: inactivity  $< 110 \text{ m/s}^2/\text{epoch}$ .<sup>6</sup> A within-subject normalization method was performed wherein the epoch data was divided into low and high activity bins based on the percentage of the maximum activity (MA) count determined from a control group<sup>7</sup>:

*Low activity:*  $110 \text{ m/s}^2/\text{minute epoch}$     Activity    33% of MA

*High activity:* Activity  $> 33\%$  of MA

where 33% of MA is greater than  $110 \text{ m/s}^2$  in a segment that experiences accelerations above  $0.01 \text{ m/s}^2$ . The epochs in each bin were summed to determine the percentage of each day spent at the different activity levels, and the total percent time spent in each bin was averaged across days for analysis.

## Functional Reach Area

Three-dimensional upper extremity functional reach area was recorded with a 10-camera Motion Analysis EVaRealTime system (Motion Analysis Corp., Santa Clara, CA, USA). Reach area was captured as subjects circumducted their limb, reaching as far as possible in a circular manner (right limb, clockwise; left limb, counterclockwise). During data collections subjects were standing and circumducted each limb three times in a clockwise direction. The average of the three trials was used for analysis.

Kinematic data were sampled at 500 Hz, and marker data were low-pass filtered at 6 Hz with a fourth-order zero lag Butterworth filter. Reflective markers were placed on the participant's trunk (spinous process of the seventh cervical vertebrae, sternal notch, and xiphoid process) and bilateral upper extremities (the lateral second metacarpal head, medial fifth metacarpal head, radial and ulnar styloid processes, medial and lateral epicondyles of the elbow, and acromion process) to identify anatomic landmarks, calculate joint centers and segment length, and track segment motion. A static reference position was captured with the upper extremities in an anatomic neutral position to define joint axes. Calculations were based on a three-dimensional kinematic model previously described.<sup>12</sup> A three-dimensional model of the upper extremity was developed using Visual3D (C-Motion, Inc, Germantown, MD, USA) and consisted of rigid body segments, including the trunk, upper arm, lower arm, and hand. A Matlab (MathWorks, Natick, MA, USA) routine was utilized to calculate the least-square fit of a circle to three-dimensional data to determine the circle's center and radius at the wrist.

## Statistical Methods

Functional limb activity variables of interest included mean activity, percentage of inactivity time, and percentage of low and high intensity activity time for the lower and upper arm. Circle radius was the variable of interest for functional limb reach area. Statistical testing was performed using paired t-tests to identify differences between limbs. Statistical significance was established at an alpha level = 0.05.

## RESULTS

For functional limb activity there was no difference between sides for the percentage of inactivity time for the lower ( $p=0.497$ ) or upper arm ( $p=0.918$ ) (Table 1). There was a significant difference between limbs for mean arm activity (lower arm,  $p=0.045$ ; upper arm,  $p=0.005$ ), with the uninvolved side exhibiting greater activity than the involved side (Table 1). The percentage of time spent performing low intensity activity was greater for the involved arm compared to the uninvolved arm (lower arm,  $p=0.007$ ; upper arm,  $p=0.015$ ) (Table 1). In contrast the percentage of time spent performing high intensity activity was greater for the uninvolved arm compared to the involved arm (lower arm,  $p=0.013$ ; upper arm,  $p=0.005$ ) (Table 1).

Functional reach area was significantly different between limbs, as the radius of the uninvolved limb (0.44 m; SD=0.07) was significantly greater than the involved limb (0.39 m; SD=0.10) ( $p=0.006$ ).

## DISCUSSION

Objective, functional measures were obtained from triaxial accelerometer activity monitors and a three-dimension motion analysis system to discern differences in side-to-side abilities among patients scheduled to undergo RSA. With the growing number of indications for RSA<sup>4</sup>, documenting functional outcomes will provide tremendous insight to the effectiveness of treatment based on the underlying pathology. The application of these novel approaches to capturing function may be used, however, among any population with shoulder injury. The imperativeness of objectively documenting patient function has been delineated. In this commentary Swiontkowski, Buckwalter et al<sup>14</sup> stated, “Valid, reliable information concerning the results or outcomes of treatment makes it possible to identify the most effective treatments and to make informed decisions concerning the allocation of health-care resources.” More than a decade later, little progress has been made in the field of objective testing techniques to document upper extremity function.

Functional limb use was objectively assessed in patients' natural living environment with triaxial accelerometers worn on both limbs. Not surprisingly the data revealed the uninvolved limb was significantly more active than the involved limb. What these data do demonstrate is the feasibility of utilizing these relatively low cost, easy to wear devices with a patient population for an extended time outside of the clinical setting. This approach to assessing function may be extremely useful for clinicians as they objectively document the impact of shoulder pathology to justify treatment, and aid in the assessment of recovery after intervention. In a healthcare era in which cost-efficiency is emphasized, this type of documentation is paramount to obtaining reimbursement for physician and rehabilitation services.

Novel data analysis techniques were implemented to gain insight into functional limb use. Inactivity time and mean activity are standard calculations implemented for interpretation of activity monitor data. Additionally, activity bins were created to determine what percentage of the day subjects performed low- and high-intensity activities. Patients spent significantly greater time performing low intensity activities with the involved arm, while time spent performing high intensity activities was greater for the uninvolved arm. In this sample the side-to-side difference in activity level was consistent with greater mean activity for the uninvolved arm. However, this analysis technique may be of greater use in elucidating functional abilities early in shoulder pathology presentation. A limb undergoing small magnitude accelerations for a greater percentage of the day compared to the contralateral limb, or when compared to a healthy individual, suggests a gradual diminution of function. Given the degenerative nature of rotator cuff and glenohumeral pathology, early recognition and intervention to address compromised function may abate disease progression.

There are few descriptions in the literature of upper extremity activity assessment in patient populations. The upper limb activity monitor, a variation of the triaxial accelerometer, is a piezoresistive acceleration based sensor that been utilized to quantify upper limb activity in individuals with chronic regional pain syndrome.<sup>13</sup> This system includes sensors worn at the shoulder, elbow, wrist, and sternum, which are connected to a waist-worn recorder. Because of the more obtrusive nature of the upper limb activity monitor and its sensitivity to

orientation, this device is less amenable to extended wear in a natural living environment. Uniaxial activity monitors have been utilized to assess upper extremity movements in hospitalized patients early after stroke. Lang et al<sup>10</sup> placed monitors bilaterally at the wrists to determine the number of hours per day subjects used their limbs. The investigators reported the hours of involved limb activity time were minimal. Lange et al<sup>10</sup> went on to propose that accelerometer measurements of the upper extremity may be useful in a variety of settings and the objective information would be of great value to clinicians as they select treatments and evaluate progress.

Functional reaching area of the upper extremity was calculated with a least-square fit of a circle calculated from three-dimensional data. We are unaware of previous studies that have utilized this technique for interpretation of upper extremity kinematics. Calculating reach area based on a circumduction task captures the inherent anatomy and function of the shoulder. The glenohumeral joint, the largest contributor to shoulder girdle motion, is modeled as a ball and socket. Although motion is traditionally described as occurring in cardinal planes the architecture of the joint produces functional mobility that rarely occurs this simplistically.<sup>3</sup> Performing a single circumduction task captures the functional ability of the upper extremity to position the hand in space to interact with the environment. A multitude of cardinal plane motions or specific tasks would alternatively need to be analyzed to garner similar information.

There are limitations associated with integration of these novel methodologies. Triaxial accelerometers are vulnerable to mechanical failure. Compliance may be an issue for extended wear time. Furthermore, data captured by the monitors are limited in nature and do not indicate the magnitude of motion through which the limb is moving. Data obtained from triaxial accelerometers are valuable, however, and these obstacles are relatively minor when considering the otherwise limited opportunities to capture objective function outside of the clinical setting. Limitations associated with functional reach area defined from a circumduction task include the lack of insight regarding which planes of motion may be restricted. Three-dimensional motion analysis systems are also expensive and may not be readily available to all clinicians. The functional reach area does answer a meaningful clinical question in an easy to interpret format. Rather than utilizing these methodologies in isolation, we advocate implementing these testing procedures in conjunction with clinical measures and patient-self reported function to obtain a comprehensive portrait of patient abilities.

## CONCLUSIONS

This study demonstrates the novel application of existing technologies were effective in objectively capturing upper extremity function in patients scheduled to undergo RSA.

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**Table 1**

Functional limb use. (Mean (SD))

	Mean	Inactive (%)	Low Activity (%)	High Activity (%)
<i>Involved</i>				
Lower Arm	930 (232)	11 (7)	58 (12)	29 (12)
Upper Arm	543 (124)	19 (11)	57 (11)	24 (8)
<i>Uninvolved</i>				
Lower Arm	1035 (292)	12 (7)	51 (13)	37 (16)
Upper Arm	609 (148)	18 (13)	51 (11)	30 (12)