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ORIGINAL ARTICLE

Comparing daily shoulder motion and frequency after anatomic and reverse shoulder arthroplasty

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Background: Both anatomic (TSA) and reverse total shoulder arthroplasty (RTSA) are common interventions for glenohumeral arthrosis, with the goal of relieving pain and restoring mobility. Understanding shoulder arthroplasty motion and frequency is of interest in evaluating effectiveness and in predicting bearing wear for implant development and optimization. The purpose of this study was to measure and compare the total daily shoulder motion of patients after TSA and RTSA.

Methods: Thirty-six human subjects who had undergone shoulder arthroplasty wore a custom instrumented garment that tracked upper extremity motion for the waking hours of 1 day. The 3-dimensional orientation of each humeral sensor was transformed with respect to the torso to calculate total joint motion and frequency, with comparison of TSA to RTSA. In addition, the yearly motion of the shoulder was extrapolated.

Results: The majority of shoulder motion occurred below 80° of elevation ($P < .001$), totaling on average 821 ± 45 and 783 ± 27 motions per hour for TSA and RTSA, respectively. Conversely, elevations >80° were significantly less frequent, totaling only 52 ± 44 ($P < .001$) and 38 ± 27 ($P < .001$) motions per hour for TSA and RTSA, respectively. No significant differences were detected between TSA and RTSA shoulders ($P = .22$) or their respective contralateral asymptomatic sides ($P = .64$, $P = .62$). When extrapolated, it was estimated that each TSA and RTSA shoulder elevated above 60° approximately 1 million and 0.75 million cycles per year, respectively.

Discussion: Mean shoulder motions after TSA or RTSA were not significantly different from the contralateral asymptomatic side. In addition, no significant differences were detected in shoulder motion or frequency between TSA and RTSA.

Level of evidence: Basic Science Study; Kinesiology

Keywords: Shoulder arthroplasty motion; total shoulder arthroplasty; reverse total shoulder arthroplasty; upper extremity motion; wearable motion tracking; daily shoulder posture

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Total shoulder arthroplasty, both anatomic (TSA) and reverse (RTSA), is a common intervention for shoulder joint arthritis associated with pain and poor function.[2,8] The primary goal of both shoulder arthroplasty techniques is to relieve pain and to restore mobility, thus allowing patients to function and to conduct their activities of daily living.[7,8]

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Optical tracking with skin-based tracker placement has been used in a laboratory setting to assess upper extremity range of motion (ROM) during activities of daily living before and after hemiarthroplasty[5] and RTSA.[4] Post-hemiarthroplasty adduction, abduction, internal and external rotation, and flexion ROM increased compared with the preoperative state. Maier et al[4] reported in a study cohort of 9 patients that RTSA increased flexion, adduction, and abduction ROM at 1 year follow-up after surgery compared with preoperative values, with no significant changes detected in internal and external rotation.

The development of an upper limb motion-tracking device using inertial measurements was described by Zhou et al,[9-11] using a wearable mini-computer and sensors attached to the elbow and wrist. Hurd et al applied wearable triaxial accelerometer sensors to assess shoulder motion.[3] The authors assessed the daily shoulder motion of patients scheduled to undergo surgery. Motion was defined as inactive, low activity, or high activity, and the percentage of time each limb spent in each category was calculated. They found that the mean activity of the uninvolved limb was greater than that of the involved limb, and the involved limb was more commonly in the low-activity state compared with the uninvolved limb. Unfortunately, the authors did not assess motion postoperatively.

Investigation into the postoperative motion of patients who undergo shoulder arthroplasty may yield insight into the effectiveness of the procedures in restoring normal healthy shoulder motion. Furthermore, the postoperative motion that these implants observe in vivo is of particular interest in the development and biomechanical testing of implants. The purpose of this study was to ascertain the total daily shoulder motion of patients after TSA and RTSA, to compare the motion of the arthroplasty shoulder with that of the contralateral asymptomatic natural joint, and to compare the daily motion of TSA and RTSA shoulders.

Methods

Research apparatus

A custom, instrumented, motion-tracking long-sleeved garment was developed to permit the measurement and tracking of upper extremity motion. The garment consisted of a stretchable compression shirt (Nike Inc., Beaverton, OR, USA) that incorporated 5 inertial measurement units (IMUs; YEI Technology, Portsmouth, OH, USA); onboard triaxial accelerometers, gyroscopes, and compasses tracked their 3-dimensional orientation in space to an accuracy of ±1° in all orientations. The dimensions of each IMU were approximately 60 × 35 × 15 mm. One IMU was inserted into a pocket sewn onto the anterior surface of the shirt directly adjacent to the sternum, which yielded the orientation of the torso. Another 2 IMUs were then affixed to both arms into pockets sewn onto the lateral aspect of the midhumerus, which allowed the measurement of the orientations of both humeri. An additional 2 IMUs were affixed into pockets sewn onto the dorsal aspect of the wrist, which allowed the measurement of both forearms.

All IMUs were capable of recording their historical orientation data to an on-board micro-Secure digital (SD) card, which facilitated the post hoc collection and analysis of their motion. All sensors were time synchronized immediately before donning of the motion-tracking garment, and on retrieval of the data the sensors were consistently observed to still be in synchronicity. To further extend the battery life of the IMUs to permit deployment of the system for durations exceeding 12 hours, an external battery pack was placed in a storage pack affixed to a belt, which was wired to each IMU using low-voltage low-gauge wiring such that the resulting power distribution system did not alter the subject's upper extremity motion through discomfort and constrict IMU motion via wire tension. The resulting motion-tracking system was low profile enough to be worn beneath normal clothing and still permitted the subject to perform most daily activities, barring those that included submersion of the torso in water (such as bathing or swimming).

Each testing day, the subjects performed their normal daily morning bathing and grooming activities and were then dressed in the motion-tracking garment by a research associate in a clinical setting as early as feasible for their daily schedule. The subject's ROM was then assessed manually using a long-arm goniometer to determine the natural range of flexion-extension, adduction-abduction, and internal-external rotation. The subject was then asked to assume a "tin soldier" position, which was defined as 0° of abduction (or as close to 0° as possible) and 0° of internal-external rotation. The sensors were then activated and the patient was asked to perform a series of motions throughout maximum ROM; this was performed to allow IMU measurement of the subject's full ROM as well as to visually confirm that there were no physical impingements of the sensors or their power distribution system, which would have a negative impact on the study results.

Each subject was then sent away to continue on with his or her normal daily routine and was asked to briefly log activities for the rest of the day on a log sheet provided to allow the investigation of any potential motion anomalies. At the end of the test day, just before the subjects retired to bed, they were asked to remove the shirt and to cease the recording of motion. The motion-tracking garment was then returned to the clinic, and the data were downloaded and analyzed.

Research subjects

Thirty-six human subjects (73 ± 10 years) who had undergone shoulder arthroplasty (21 TSAs [9 left, 12 right; 8 dominant, 12 nondominant], 5 bilateral; 20 RTSAs [6 left, 14 right; 5 dominant, 6 nondominant], all unilateral) wore the custom instrumented garment for the remaining waking hours of 1 day (11 ± 3 hours). All patients were >1 year postoperative status at the time of inclusion in the study, had undergone primary arthroplasties, lived independently, and were fully ambulatory without aids. Exclusion criteria included revision cases, institutionalization, and contralateral shoulder disease.

Data and statistical analysis

The 3-dimensional orientation of each humeral sensor was first transformed with respect to the torso sensor to yield the orientation of the humerus with respect to the torso to allow the calculation of humeral elevation and the plane of elevation angles. Humeral elevation is the angle created between the torso and the humeral shaft (Fig. 1). The plane of elevation is defined as the direction in which the humeral elevation occurred, with forward flexion (arm elevated to the front) defined as 0° (Fig. 2). For example, a plane of elevation