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Title

Kinematic analysis of reaching movements of the upper limb after total or reverse shoulder arthroplasty

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Abstract

Studies have analyzed three-dimensional complex motion of the shoulder in healthy subjects or patients undergoing total shoulder arthroplasty (TSA) or reverse shoulder arthroplasty (RSA). No study to date has assessed the reaching movements in patients with TSA or RSA. Twelve patients with TSA (Group A) and 12 with RSA (Group B) underwent kinematic analysis of reaching movements directed at four targets. The results were compared to those of 12 healthy subjects (Group C). The assessed parameters were hand-to-target distance, target-approaching velocity, humeral-elevation angular velocity, normalized jerk (indicating motion fluidity), elbow extension and humeral elevation angles. Mean Constant score increased by 38 points in Group A and 47 in Group B after surgery. In three of the tasks, there were no significant differences between healthy subjects and patients in the study groups. Mean target-approaching velocity and humeral-elevation angular velocity were significantly greater in the control group than in study groups and, overall, greater in Group A than Group B. Movement fluidity was significantly greater in the controls, with patients in Group B showing greater fluidity than those in Group A. Reaching movements in the study groups were comparable, in three of the tasks, to those in the control group. However, the latter performed significantly better with regard to target-approaching velocity, humeral-elevation angular velocity and movement fluidity, which are the most representative characteristics of reaching motion. These differences, that may be related to deterioration of shoulder proprioception after prosthetic implant, might possibly be decreased with appropriate rehabilitation.

1. Introduction

Many biomechanical investigations assessed the three-dimensional complex motions of the shoulder (Coley et al., 2007; Doorenbosch et al., 2003; Fayad et al., 2008; Jolles et al., 2011; Roren et al., 2012; Veeger et al., 2006). While most investigations analyzed one or more activities of daily living (ADLs), a few studies evaluated a part of the standardized activities described in the Simple Shoulder Test (Jolles et al., 2011) or specialized tasks such as sliding or lifting an object (de Toledo et al., 2012; Lin et al., 2006). In some studies, the assessments were made on healthy subjects. Other studies included both patients with shoulder conditions not operated on and patients who had undergone surgical procedures, including total shoulder arthroplasty (TSA) or reverse shoulder arthroplasty (RSA). In all these investigations the kinematic evaluation was performed using an electromagnetic motion tracking device, except for a few that used a videocamera motion analysis system (Doorenbosch et al., 2003) or accelerometers and gyroscopes (Coley et al., 2007; Lin et al., 2006). These studies provided important information on complex shoulder motion in patients undergoing shoulder arthroplasty. However, all investigations evaluated only patients with TSA (Coley et al., 2007; Lin et al., 2006; Veeger et al., 2006) or RSA (Alta et al., 2011; Bergmann et al., 2008; Kontaxis and Johnson, 2008; Kwon et al., 2012), except for one study that assessed 17 patients who had TSA and 8 with RSA (de Toledo et al., 2012). Furthermore, most studies were mainly aimed at analyzing the role of the scapulothoracic, or sternoclavicular joint during the glenohumeral movements.

Countless studies have investigated the reaching motion in healthy subjects or patients with various diseases: most of the research has been performed on individuals with neurological conditions. No study, however, has focused on the behavior of patients with shoulder arthroplasty during reaching tasks. These tasks, which involve the complex motion of multiple joints aimed at reaching definite points in space (Georgopoulos, 1986), are among the most important movements performed by the upper extremity (Wu et al., 2000). The analysis of the kinematic characteristics of these movements in specific pathological conditions is thus crucial in understanding the abilities or limitations of patients' interaction with the environment. At present, most patients undergoing shoulder arthroplasty obtain an almost complete active shoulder ROM and arm strength similar to the unaffected side. Patients thus expect to achieve the functional abilities of normal shoulder, including reaching movements that allow them to use the operated limb as normally as possible. It is therefore important to be aware of the limitations of reaching behavior after shoulder arthroplasty to better address with the appropriate rehabilitation programs.

Previous investigations on reaching movements used different methods to test the reaching ability of patients. The analyses were carried out under the patient's visual control or with patient's eyes closed, with arm movements only on the horizontal plane or also on other planes; furthermore stationary or moving targets and virtual or physical realities were used. In this study, the RM were assessed under visual control of virtual targets placed on the classical horizontal plane and on an upward plane, i.e. at shoulder height and at top of head, because these are the sites where the limb is most often directed to reach and grasp objects. The analysis of the reaching motion is aimed at specifically assessing the spatial-temporal features of motion, such as the velocity and smoothness, namely fluidity, of movements. We therefore used similar parameters that were used in previous studies on reaching behavior of patients with neurological diseases (Caimmi et al., 2008; Tavernese et al., 2013).

The prosthetic designs of TSA and RSA are considerably different. TSA is an anatomical prosthesis, emulating the ball-and-socket anatomy of the shoulder. In RSA, the prosthetic components are inverted, i.e. the ball is placed on the scapula and the socket on the proximal humerus. This inverted design considerably changes not only the anatomy, but also the biomechanics of the shoulder joint and the upper extremity motion patterns (de Toledo et al., 2012; Kwon et al., 2012). Nevertheless, the range of active shoulder movements, which is the main prerequisite for adequate reaching motion, is generally similar in patients with TSA or RSA, except for external rotation that is mostly better after TSA (Castricini et al., 2013; Kiet et al., 2015; Latif et al., 2012). Based on these findings, we hypothesized that the characteristics of reaching movements of the two groups of patients might be comparable. However, the empirical observation that most patients with unilateral arthroplasty exhibit slower active shoulder motion on the operated side, than the opposite non operated side, also led to hypothesize that the reaching ability of the limb with arthroplasty might be dissimilar to that of healthy subjects.

The lack of information on reaching behavior after total shoulder prosthesis prompted this study, which aimed at assessing the kinematics of reaching movements using a stereophotogrammetric system in patients with TSA or RSA in comparison with healthy individuals.

2.Methods

2.1 Participants

Participants were patients younger than 75 years of age who had undergone primary, single sided, TSA or RSA, performed for glenohumeral osteoarthritis, irreparable cuff tear or cuff tear arthropathy (CTA). To be included in the study, the patients had to exhibit a shoulder active forward flexion ≥120° after arthroplasty and they had to have no history of diseases or injuries causing dysfunction to the hand or wrist on the operated side. Exclusion criteria were: history of surgical procedures on the shoulder other than arthroplasty or active elbow ROM of less than 0°-130° of flexion-extension, 60° of pronation and 70° of supination on the operated side; neurological diseases affecting arm function; and inability to fully understand and accomplish the commands of the examiners. The limb dominance was not a criterion of inclusion or exclusion because it does not affect significantly the reaching motion performed under visual control (Tseng et al., 2002; Wang and Sainburg, 2007).

Patients were randomly selected from the databases of two hospitals from all patients who had undergone shoulder arthroplasty 1 to 3 years before the testing procedure. One surgeon in each hospital performed the arthroplasties. A total of 24 patients, 12 with TSA (Group A) and 12 with RSA (Group B) were included in the study. The control group (Group C) consisted of 12 subjects with no history of diseases in, or severe injuries to, the upper limbs and a normal healthy mental status. The controls were matched for age and sex with the patients in the study groups.

2.1.1 Preoperative evaluation, surgical treatment and assessment before kinematic testing

Before arthroplasty, patients had been evaluated using the Constant score (CS) method (Constant and Murley, 1987), consisting of two subjective sections, that are pain (0-15 points) and ADL (0-25 points) and two objective scales, represented by ROM (0-40 points) and strength (0-25 points). In both patients and controls, the ROM of the shoulder and elbow were measured with a manual goniometer.

All patients in Group A had undergone surgery for primary glenohumeral osteoarthritis. In all cases the rotator cuff was assessed intact preoperatively by ultrasonography and intraoperatively. In patients in Group B, the arthroplasty was performed for irreparable rotator cuff tear (5 cases) or severe CTA (7 cases). All operations were performed using a deltopectoral approach. In Group A, the subscapularis tendon was sectioned medially to the bicipital groove and repaired at the end of operation with the arm at 20° of external rotation. In Group B, the subscapularis tendon was severely torn and retracted in five cases, while the teres minor was present in 10 patients. In all cases, a thorough release of the glenohumeral ligaments was carried out. A Global prosthesis (DePuy) was implanted in Group A and a Global RSA prosthesis (DePuy) with a 36-mm glenosphere in Group B. Before kinematic testing, the patients were re-assessed using the CS method and both patients and controls had their height measured and weight recorded. An independent physician, blinded to the purposes of the assessments, carried out clinical evaluations. The experimental procedures were explained to all participants, who gave their consent prior to testing.

2.2 Instrumentation

An ELITE stereophotogrammetric system (BTS,Milano,Italy) with eight infrared cameras was used for acquisition of kinematic data, which were digitized with a sampling rate of 100 Hz. Seven spherical retro-reflective markers 15mm in diameter were placed at the following anatomical landmarks: (1) C7 spinous process, (2) acromion of operated side, (3) acromion of non-operated side, (4) sacrum, (5) lateral epicondyle of operated side, (6) ulnar styloid of operated side and (7) base of the third metacarpal bone of operated side (Tavernese et al., 2013). The eighth marker, namely the target marker (8), was placed in front of the subject in different positions depending on the kinematic task analyzed, at a distance corresponding to the length of the subject limb in any given position.

Cameras calibration procedure was performed before each trial to determine the precision and accuracy of markers detection by each of the eight cameras. Values of 1.5mm error ± 0.9mm of standard deviation were considered acceptable for the present experiment.

2.3 Experimental procedure

The kinematic tasks consisted of reaching movements towards four targets placed a) in front of the subject, at shoulder height (frontal target); b) in front of the subject, at the top of the head (frontal-top target); c) in front of the contralateral shoulder, at shoulder height (adduction target); d) in front of the contralateral shoulder, at the top of the head (adduction-top target) (Fig.1). The subject, sitting in a standardized position with the hands placed on the anterior aspect of the thighs, was asked to cyclically move his or her hand, always maintained in full pronation, toward the target marker as rapidly and precisely as possible without moving neither the back away from the backrest and his or her head.

Trials consisted of a series of 10 consecutive repetitions of each of the four reaching movements separately. The kinematic measures were taken from the six central repetitions and only in the forward phase of the movement, i.e. while reaching for the target, and the mean values were selected for data analysis. A trial was considered valid if the subject reached the target in every single movement, and the trunk or head did not appear to have moved, as detected by visual inspection. If any of the trials of a single reaching movement was not valid, the subject was asked to perform a new trial for that specific movement.

The following measures were calculated for all kinematic tasks: 1) mean target-approaching velocity (m/s), mean humeral elevation angular velocity (°/s) and NJ of the reaching movement; 2) hand-to-target distance (m), elbow flexion angle (°) and humeral elevation angle (°) at the end of movement.

Given the instantaneous distance between marker (7) and target marker (8) (hand-to-target distance: HTD), the 3-point differentiation method was used to calculate the target-approaching velocity and the jerk of the reaching movement, as well as the HTD parameters and subsequent derivatives, which were filtered using a low-pass, second-order Butterworth filter (cutoff frequency, 5 Hz).

The normalized jerk (NJ), a dimensionless number representing an index of the smoothness of the movement, was calculated with the following equation (Caimmi et al., 2008):

$$\sqrt{\left({}^{1}\!/_{2} * \int_{T_{start}}^{T_{end}} jerk^{2}(t)dt * duration^{5} / length^{2} \right)}$$

where T_{start} and T_{end} represent the start and end times of the movement, jerk is the third derivative of hand-to-target distance, duration is the movement execution time ($T_{start} - T_{end}$) and length is hand-to-target distance (T_{end}) minus hand-to-target distance (T_{start}). For the NJ, the lower the value the higher the fluidity of movement.

The elbow angle at the end of movement was the one between the vector formed by markers 2 and 5 and a vector defined by markers 5 and 6 at T_{end}. The humeral elevation angle at the end of movement was the angle between the vector joining markers 2 and 5 and the vector joining markers 1 and 4 at T_{end} (Wu et al., 2014). For elbow flexion a value of 0° was assigned to complete elbow extension. For humeral elevation, the value was 0° when the arm was at the body side, the positive values representing the flexion. The mean angular velocity during humeral elevation was calculated as the first derivative of the angle between the vector formed by markers 2 and 5 (humerus –

moving segment) rotating over the vector joining markers 1 and 4 (trunk – reference segment) in the sagittal plane during reaching movement.

2.4 Statistical analysis

The analysis was performed using the MedCalc® 12.2.1.0 (MedCalc Software). Normal distribution of all variables analyzed was verified by the D'Agostino-Pearson test, and parametric or non-parametric tests were used, as appropriate. The one-way ANOVA or Friedman's ANOVA were employed to determine baseline differences among groups for clinical, demographic and kinematic variables. The paired-sample t-test or Wilcoxon test were used to assess differences between preoperative and postoperative values of shoulder ROM and CS in patients in groups A and B. A two-way ANOVA with group (TSA vs RSA vs controls) as the between-subjects factor and target marker position (frontal, adduction, frontal-top, adduction-top) as within-subjects factor, was employed to assess differences in the kinematic variables among groups in the four tasks. A Tukey post-hoc comparison was used to analyze differences between the mean values when a significant main effect and interaction were found. The level of significance was set at $p<0.05$.

3. Results

Demographic data and sides that were tested are reported in Table 1 for both the patients and controls. No significant differences appeared among the groups. The mean time interval between surgery and kinematic testing in the entire patients' population was 22.3±8.1 months. The active ROM of the operated shoulders, the CSs assessed preoperatively and before testing, and the ROM in the controls, are reported in Table 2. There were no significant differences between the values of the mean ROM for both study groups and the control group. In patients with TSA the difference between the mean CSs evaluated preoperatively and before testing was 38 points ($t=7.743$; $p<0.0001$), while in those with RSA the increment reached 47 points ($t=7.686$; $p<0.0001$) (Table 2). No significant differences, however, were found between the mean scores of the two study groups.

No significant differences in the CSs were also found with respect to gender and age in each study group.

The HTD did not present significant differences when comparing controls and patients in the study groups; the same was true when comparing Group A and Group B (Table 3).

The mean target-approaching velocity significantly differed between groups (F=6.719; p=0.002), the controls approaching the targets faster than both patients of Group A (between group difference Δ=0.10±0.03 m/s; p=0.005) and Group B (Δ=0.11±0.03 m/s; p=0.004). The frontal-top and adduction-top trials were faster than the other trials in all groups (F=2.787; p=0.04). A difference, although not significant, was found between study groups, with the frontal movements being faster in TSA group and the adduction-top movement more rapid in RSA group (Fig.2).

The mean humeral elevation angular velocity presented significant differences when comparing groups (F=10.849; p<0.001), with the controls displaying a greater velocity compared to both the patients in Group A (Δ=11.0±2.9°/s; p=0.0007) and Group B (Δ=12.6±2.9°/s; p=0.0001). Again, the patients in Group A, compared with those in Group B, exhibited a greater, though not significant, humeral elevation angular velocity in all trials except for the adduction-top (Fig.3). The target position significantly influenced the mean humeral elevation angular velocity (F=11.739; p<0.001), the ‘top’ trials being faster in all three groups compared to frontal and adduction trials.

The NJ values showed significant differences between groups (F=10.832; p<0.001). The values were lower, that is the movement was smoother, in Group C than in Group A (Δ=46.5±10.0; p<0.0001) or Group B (Δ=29.1±10.0; p<0.01) (Fig.4). Although the difference between the study groups was not significant, the patients in Group B exhibited lower NJ values than those in Group A.

The elbow position at the end of movement differed among the groups (F=4.645; p=0.01) and different target positions (F=2.881; p=0.04). In Group A, the elbow was , on average, slightly more flexed at the end of movement than in Group B (Δ=6.6±2.6°; p=0.04) and in Group C (Δ=7.3±2.7°; p=0.02) (Table 3).

The humeral elevation angle at the end of movement showed no significant differences among groups, although it was obviously influenced by the target position (F=37.898; p<0.001). The relationship between groups and target position interaction was not significant (Table 3).

4. Discussion

In most studies assessing the clinical outcomes of TSA (De Wilde et al., 2013; Fucentese et al., 2010; Young et al., 2011) or RSA (De Biase et al., 2013; Ek et al., 2013; Ladermann et al., 2013) that used the CS method, the mean score after surgery was significantly higher than the preoperative score. However, the mean difference between the preoperative and postoperative CS was smaller than the one obtained by our patients. This is probably because we assessed patients with good or excellent results, namely those who had ≥120° of active forward flexion of the arm after arthroplasty.

The mean HTD was similar in the controls and the patients in both study groups, but those with TSA exhibited a slightly less completed extension of the elbow at the end of movement when compared to both those with RSA and controls. Since no patients in TSA group showed a decrease in active elbow motion, a possible explanation is that these patients may have, as found in a previous biomechanical study (de Toledo et al., 2012), a change of scapulothoracic kinematics, i.e. a scapular dyskinesis. On flexion of the arm, dyskinesis implies upward rotation, resulting in superior migration, of the scapula, external rotation of the medial scapular border and posterior tilt of the inferomedial border (Gumina et al., 2009). Such abnormal motion might lead the patient to flex the elbow to carry out the end of the reaching movement.

The mean target-approaching velocity and the mean humeral elevation angular velocity of the RM were greater in controls than in patients of both study groups, who generally performed the movements less rapidly. Differences, although not significant, were also found between the study groups, the frontal movements being faster in Group A and the adduction-top movements more rapid in Group B. A possible interpretation is that the difference was related, for the TSA group, to the presence of an intact rotator cuff, which is known to play a primary role in elevation of the arm.

As for the RSA group, the difference might depend on the increased force of the deltoid and petoralis major because of the lowering of the humerus. It is well known that such lowering lengthens the deltoid, which becomes the main forward flexor of the arm with its anterior and lateral parts (Boileau et al., 2006; Jobin et al., 2012). Furthermore, the shifting of the center of rotation medially to the glenoid fossa, typical of this prosthesis, may contribute to increase the moment arm of the deltoid by recruiting additional muscle fibers for forward elevation (Boileau et al., 2006). It is conceivable that the pectoralis major, which inserts on the anterior aspect of the humerus, is also lengthened after RSA. Since the anterior deltoid and the pectoralis major are adductors of the arm, a greater lever arm of these muscles may allow for a more efficient adduction with the flexed arm and more rapid adduction-top reaching movements compared to TSA.

The NJ values found in the study groups were higher than in the control subjects, which indicates that the reaching movements were performed with less fluidity by patients with arthroplasty than by healthy individuals. Although the difference between the study groups was not significant, the patients in Group B exhibited lower NJ values than those in Group A.

This investigation has shown that the patients with TSA or RSA were able to reach all the proposed targets with shoulder motion comparable to that of the controls. However, the patients performed the reaching tasks with lower target-approaching velocity, humeral elevation angular velocity and fluidity of movement. A possible hypothesis is that the differences might be related to a decrease in proprioception after surgery. This interpretation appears to be consistent with the results of a study (Maier et al., 2012) on the changes of shoulder proprioception following TSA implant. The authors found the proprioceptive inputs to be decreased at mid-term follow-up and attributed the decrease to damage to shoulder proprioceptive structures due to section (and subsequent repair) of the subscapularis tendon and release of the glenohumeral ligaments carried out during surgery. Proprioception, in fact, is a complex sensory modality, involved in the performance of several different tasks. Active and passive joint position sense, kinesthesia, movement replication, sensation of resistance, and appreciation of joint velocity, are all together specialized functions included in the general term of proprioception (Blasier et al., 1994). When carrying out a finalized movement, a centrally determined motor program defines and selects the appropriate way of performing the task. The increased jerk values in a given motor task suggest a decrease in proprioception, which probably implies a worse selection of motor strategy or an incorrect trajectory of the movement. Therefore, our results suggest that, to some extent, the presence of shoulder prosthesis negatively affects motor strategy in the execution of reaching movements.

This study first provided information on the prerogatives and limitations of the reaching ability of patients undergoing TSA or RSA. Although the reaching performance might appear to be of minor relevance when compared to other functional characteristics of shoulders with total prosthesis, it is worth noting that the reaching movements are those allowing patients to interact with their environments and accomplish many ADLs. This highlights the importance of thorough knowledge of the reaching behavior of patients with shoulder prostheses to determine appropriate rehabilitation methods to decrease or eliminate deficiencies in the reaching activities.

The aim of this kinematic analysis was to measure the HTD and its derivatives, including the fluidity of movement, which were interpreted as markers of the performances obtained by patients during reaching motion. The intention was to determine what were the joint angle coordinates and endpoint coordinate strategies that they adopted (Wu et al., 2014). To this purpose, we used a simplified biomechanical model that implies a limited number of markers and anatomical landmarks. This modeling does not allow the angular excursion waveforms in the three planes of motion to be determined for each joint involved in complex shoulder movements. However, it permits detection of the elbow and shoulder elevation angles at the end of movement.

A limitation of our study is the exclusion of patients with poor clinical outcomes. Such choice was made because in those patients the reaching performance may possibly be worse than in patients with satisfactory outcomes and this could generate unreliable results. Further studies are thus needed to assess the reaching motion in patients with unsatisfactory outcome after total arthroplasty. Another limitation might be that the participants performed the reaching movements under visual control, which precluded the evaluation of movements in abduction. However, the reaching movements in frontal and adduction directions are those more often performed in the ADL (Namdari et al., 2012) and the movements in adduction are more efficient, i.e. faster, than those in abduction (Keulen et al., 2007). Furthermore, the similarity of the ranges of flexion and adduction in both study groups suggests that the characteristics of reaching motion in abduction would be at least analogous to those found in flexion.

5. Conclusions

Patients undergoing TSA or RSA with satisfactory clinical results can have reaching movements comparable, to some extent, to those of healthy subjects. There was no significant difference between the controls and the study groups in three of the kinematic tasks. However, significant differences were found regarding the most representative characteristics of reaching motion, such as the target-approaching velocity, humeral elevation angular velocity and fluidity of movement. These differences are possibly related to deterioration of shoulder proprioception following shoulder arthroplasty. Patients with TSA or RSA exhibited different reaching performances in most kinematic tasks, but the differences were never significant, which suggests that the type of prosthesis does not considerably affect the reaching motion.

Conflict of interest

The authors state that there is no conflict of interest that could have influenced the content of the work presented.

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Captions

Figure 1 Position of the participant during the kinematic tasks. A: starting position; B: coronal view of the end position in frontal and frontal-top trials; C: coronal view of the end adduction and adduction-top trials; D: sagittal view of the final position in frontal and adduction trials; E: sagittal view of the final position in frontal-top and adduction-top trials.

Figure 2 Mean target-approaching velocity (m/s) in patients with TSA (Group A), RSA (Group B) and healthy controls (Group C) in the four different trials. Bars indicate 95% CI for mean.

Figure 3 Mean humeral elevation angular velocity (°/s) in patients with TSA (Group A), RSA (Group B) and healthy controls (Group C) in the four different trials. Bars indicate 95% CI for mean.

Figure 4 Mean values of normalized jerk in patients with TSA (Group A), RSA (Group B) and healthy controls (Group C) in the four different trials. Bars indicate 95% CI for mean.

Table 1. Demographic data and side examined in the study groups and controls. M: males; F: females; R: right; L: left; BMI: body mass index.

	Age at surgery (years) [Mean±SD (range)]	**Age at testing (years) [Mean±SD (range)]**	**Gender [n (%)]**	**Side [n (%)]**	**BMI [Mean±SD]**
Group A	70±4.4 (60-74)	72±4.8 (61-77)	M= 4 (33%) F= 8 (67%)	R= 7 (58%) L= 5 (42%)	23.4±1.6
Group B	73±1.9 (70-75)	74±1.9 (72-76)	M= 4 (33%) F= 8 (67%)	R= 8 (67%) L= 4 (33%)	24.3±1.5
Group C	-	72±2.7 (67-75)	M= 5 (42%) F= 7 (58%)	R= 8 (67%) L= 4 (33%)	24.4±1.1

Target Position	Group A	Group B	Group C

Table 2. Mean (±SD) and range of active preoperative and before testing ranges of motion (ROM) of the shoulder and Constant scores in the study groups, and of active ROM of the shoulder in controls. For internal rotation anatomical landmarks, rather than degrees, have been used to calculate ROM.

	Group A		**Group B**		**Controls**
	Preoperative	***Before testing***	***Preoperative***	***Before testing***	
Flexion (°)	95±20 (50-110)	165±16 (150-180)	80±40 (0-130)	170±13 (145-180)	170±10 (160-180)
Abduction (°)	85±18 (50-110)	155±13 (140-170)	70±25 (50-100)	165±7 (150-170)	165±12 (150-180)
External rotation (°)	8±20 (20-60)	35±13 (0-20)	5±4 (0-10)	30±10 (20-40)	45±17 (30-60)
Internal rotation	L3 (gluteus-L2)	D8 (L2-D6)	L5 (gluteus-L1)	D8 (L3-D6)	D8 (D6-D12)
Constant score	43±15 (21-60)	81±8 (65-85)	36±20 (10-48)	83±10 (64-85)	-

Hand-to-Target Distance (m)	Frontal	0.24±0.04 (0.21 to 0.26)	0.24±0.03 (0.22 to 0.26)	0.23±0.02 (0.20 to 0.25)
	Adduction	0.22±0.03 (0.20 to 0.24)	0.25±0.03 (0.22 to 0.27)	0.23±0.02 (0.21 to 0.25)
	Frontal top	0.26±0.05 (0.24 to 0.28)	0.27±0.04 (0.25 to 0.29)	0.26±0.05 (0.23 to 0.28)
	Adduction top	0.23±0.04 (0.21 to 0.25)	0.26±0.03 (0.23 to 0.28)	0.27±0.04 (0.24 to 0.29)
Elbow flexion angle at the end of reaching movement (°)	Frontal	25±11 (6 to 41)	37±14 (0 to 40)	38±13 (7 to 50)
	Adduction	28±11 (2 to 41)	17±13 (0 to 39)	18±13 (0 to 30)
	Frontal top	23±12 (3 to 50)	15±16 (0 to 36)	16±14 (0 to 40)
	Adduction top	30±9 (6 to 42)	24±15 (0 to 48)	24±9 (5 to 46)
Humeral elevation angle at the end of reaching movement (°)	Frontal	83±6 (78 to 88)	83±8 (78 to 88)	83±9 (78 to 89)
	Adduction	83±6 (70 to 88)	83±8 (79 to 88)	83±9 (78 to 89)
	Frontal top	99±6 (94 to 104)	99±10 (94 to 104)	99±10 (94 to 105)
	Adduction top	96±9 (91 to 101)	98±10 (93 to 103)	101±9 (96 to 106)

Table 3: Mean values ± SD (95% CI) of hand-to-target distance and of angular measurements in patients with total shoulder arthroplasty (Group A), reverse shoulder arthroplasty (Group B) and controls (Group C), for the four different target positions.