Strength and motion after hemiarthroplasty in displaced four-fragment fracture of the proximal humerus

27 patients followed for 1–6 years

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ABSTRACT – We evaluated 27 patients with shoulder hemiarthroplasty after displaced four-fragment fracture of the proximal humerus after mean 4 (1–6) years. Isometric strength measurements (Kintrex) and three-dimensional motion analysis (Elite-System) were performed on the operated and unoperated shoulders. Clinical assessment was based on Constant's score and Neer's scoring system.

The isometric strength of the operated and unoperated sides were 22 (SD 8.6) Nm and 24 (SD 5.9) Nm in abduction and 48 (SD 14) Nm and 65 (SD 21) Nm, respectively in adduction (the latter was statistically significant). Motion analyses at follow-up showed a mean reduction in glenohumeral movement. Increases in acceleration and deceleration of the acromion at the operated side were noted, indicating a change in glenohumeral rhythm during maximal abduction. The Constant score was 45 (SD 15) points with a significant reduction in the range of motion. 15 patients had some degree of heterotopic ossification. On the basis of our findings, the impaired function seems to be caused by reduced glenohumeral mobility rather than muscle strength. We also found a better outcome after early than late hemiarthroplasty.

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Most four-fragment fractures of the proximal humerus are minimally displaced and suitable for closed management or percutaneous K-wire fixation (Young and Wallace1985, Gerber et al. 1998). Severely displaced four-fragment fractures are frequently treated with hemiarthroplasty (Neumann et al. 1992, Hawkins and Switlyk 1993, Kristiansen et al. 1994, Bosch et al. 1996, Dimakopoulos et al. 1997, Wretenberg and Ekelund 1997, Hartsock et al. 1998, Boss and Hintermann 1999). After hemiarthroplasty, the patients usually have pain-free shoulders, but reduced motion and strength (Hawkins and Switlyk 1993, Goldman et al. 1995, Zyto et al. 1998). Some surgeons prefer to perform primary osteosynthesis because they believe that this provides better function (Sturzenegger et al.1982, Munst and Kuner 1992, Darder et al. 1993, Resch et al. 1997, Movin et al. 1998).

Previous studies have evaluated the postoperative results after hemiarthroplasty by mainly using clinical scoring systems. This gives limited information about shoulder function. In addition to clinical findings, we did three-dimensional real-time motion analyses and measured isometric strength of shoulders, which had been treated with hemiarthroplasty after displaced proximal four-fragment fractures, to help analyze function.

Methods

Between 1993 and 1997, we treated 27 patients (16 women), who sustained a four-fragment fracture (Neer classification) of the proximal humerus with shoulder hemiarthroplasty (Global prosthesis, DePuy, Leeds, U.K.). Their mean age was 67 (36–82) years. In 18 patients, the fracture was due to a stumble followed by a fall on the shoulder and in 6 patients due to a fall from a bicycle. 3 patients were hit by a car. Shoulder hemiarthroplasty was performed primarily in 19 patients. The remaining

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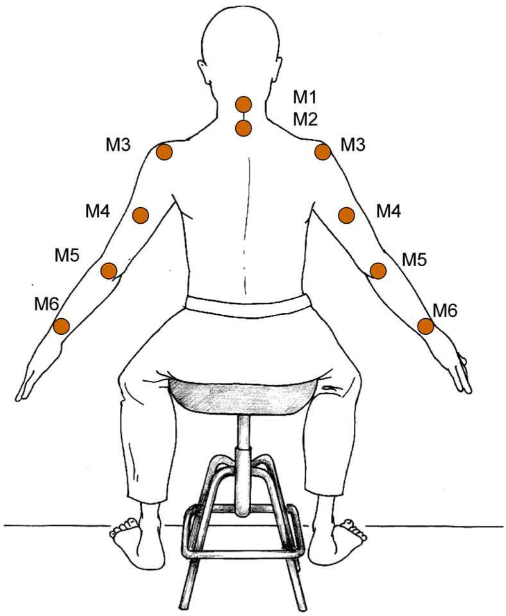

Figure 1. Infrared marker positions for bilateral shoulder motion analysis using the Elite-System.

8 patients received a prosthesis after failed closed reduction, or open reduction and internal fixation. The average time between trauma and operation was 10 (0–36) weeks. The average follow-up time was 45 (12–76) months.

Measurement of maximal abduction and adduction strength

The maximal isometric torque was tested in abduction and adduction in the scapular plane, using a dynamometer (Kin-Trex, Meditronic Instruments, Eucublens, Switzerland). The patient was placed in an upright position with the scapula parallel to the lever arm of the dynamometer to ensure isometric testing in the true AP plane of the shoulder. The fully extended arm was fixed to the lever arm of the dynamometer in 35° of shoulder abduction and the axis of rotation was aligned to the center of rotation of the shoulder joint. Maximal isometric abduction and adduction were measured on the operated and unoperated sides.

Three-dimensional motion analyses

Three-dimensional motion analysis was done using the Elite-System (BTS, Italy) equipped with two infrared cameras. 6 infrared markers were placed over the seventh cervical dorsal vertebra (M1), the fourth cervical dorsal vertebra (M2), the posterolateral corner of the acromion (M3), at the upper arm in the middle of a line drawn from the acromion to the olecranon (M4), over the olecranon (M5) and finally, over the styloid process of the ulna (M6) (Figure 1). The patient was placed in an upright position. Repeated bilateral motion ranging from 0° to maximal abduction was done at self-paced maximum speed for 15 sec. The three-dimensional motion of the marker was detected by two infrared cameras and recorded at a sampling rate of 50 Hz. The marker over the fourth and seventh cervical vertebrae, corresponding to the vertical axis of the body, served as the reference axis to evaluate the glenohumeral range of motion and the maximal isolated range of motion of the acromion. We calculated the maximal acceleration and deceleration of the acromion during each abduction-adduction cycle. Specially written software was used to calculate the summation vector for each parameter. The validity of these parameters had been confirmed in a previous study (Pap et al. 2000).

Clinical and radiographic assessment

The clinical evaluation was based on Constant's scoring system and Neer's score (Neer 1970, Constant and Murley 1987). At the time of follow-up, radiographs were taken in true AP and axial views of the shoulder. Heterotopic ossification was graded in the AP view using Kjaersgaard-Andersen et al.'s method (1989), which is based on the space filled by bone between the lateral border of the glenoid and the medial border of the humeral shaft: grade 0 indicates an absence of ossification, grade 1 less than 50% ossification of the space, grade 2 more than 50% ossification of the space, and grade 3 bridging in the space.

Statistics

The data are presented as means (SD). Wilcoxon's signed-ranks test was used to compare the operated and unoperated shoulders. Univariate analysis of variance (general linear model) was used to analyze the clinical outcome, muscle strength and motion parameters and were adjusted for differences in age, sex, delay in operation, and degree of heterotopic ossification. The level of statistical significance was set at an alpha level of $p < 0.05$. All

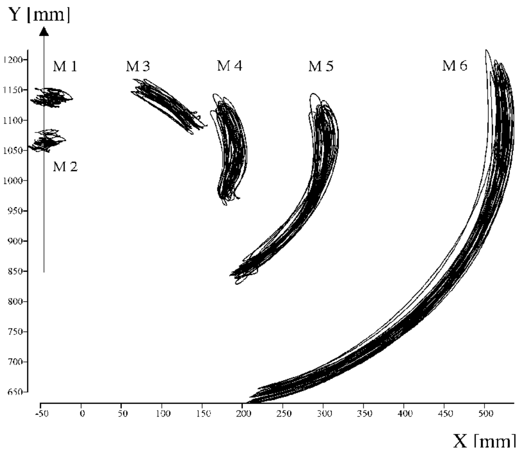

Figure 2. Motion of the infrared markers (M1-M6) during repeated abduction and adduction of the operated shoulder joint in the frontal plane. Markers M1-M2 indicate the vertical axis, marker M3 the acromion, markers M4-M5 the upper arm and markers M5-M6 the lower arm.

data were analyzed with the SPSS statistical package release 8.0 (SPSS Inc. Chicago, IL).

Results

Isometric strength of abduction and adduction

The maximal isometric adduction torque was 48 (SD 14) Nm on the operated side and 65 (SD 21) Nm ($p = 0.003$) on the contralateral side. The isometric abduction peak torque was 22 (SD 8.6) Nm on the operated side and 24 (SD 5.9) Nm on the contralateral side, which was not statistically significant. The ratio between the operated and unoperated sides in isometric strength was 0.7 for adduction and 0.9 for abduction. The age of the patient, delay in operation, and degree of heterotopic ossification did not affect the isometric strength.

Motion analyses

A typical course of motion of the sixth marker in the frontal plane on the operated side is shown in Figure 2. The movement of markers was consistent during repeated shoulder abduction. Figure 4 shows two cycles of shoulder abduction of the same marker, as seen in Figure 2, in the transverse, sagittal and horizontal planes.

The mean abduction of the shoulder joints was 153 (SD 10)° on the unoperated and 89 (SD 17)° on the operated sides ($p < 0.001$). The mean isolated glenohumeral abduction was 87 (SD 28)° on the unoperated and 57 (SD 21)° on the operated sides ($p < 0.001$). The ratio of glenohumeral to scapulothoracic motion at 80° of abduction was 1.4 on the operated and 1.9 on the unoperated sides.

Table 1. Acromion acceleration and deceleration (mm/sec^2) during abduction of the operated and unoperated sides

	Operated side	Unoperated side	Difference between sides
Acceleration	11 (3.8) [a]	6.9 (4.8)	4.1
Deceleration	–12 (5.6) [a]	–8.3 (4.1)	3.7

[a] Comparison of the operated and unoperated sides, $p = 0.01$

We found an increase in acromion acceleration of 4.1 mm/sec^2 and deceleration of 3.7 mm/sec^2 ($p = 0.01$) on the operated side, as compared to the unoperated side. The average durations of a single stroke was 1504 (SD 396) msec on the operated side and 1504 (SD 360) msec on the contralateral side (Table 1).

The maximal abduction of the operated side was better, when the operation was done within 14 days (117 (SD17)°) than when it was done later (59 (SD 20)°) ($p < 0.001$).

Clinical and radiographic assessment

The clinical result, based on Neer's scoring system, was 89 (SD 11) points at the time of follow-up. 12 patients had no pain, 8 slight pain with no loss of activity, 3 mild pain and 4 patients had moderate pain requiring occasional analgesia. The Constant score was 45 (SD 15) points. Excellent and good results were achieved in 17 patients and moderate results in 6. 4 patients were dissatisfied mainly because of intermittent pain and limited range of movement. The category entitled "pain" yielded a mean of 12.5 of the 15 points on the scoring system. The main reduction was obtained in the category "range of motion" (19 of 40 points). The clinical outcome was not affected by the patient's age.

Delay in the operation worsened the clinical outcome on the Neer score ($p < 0.001$) (Figure 3). When the operation was performed within a week,

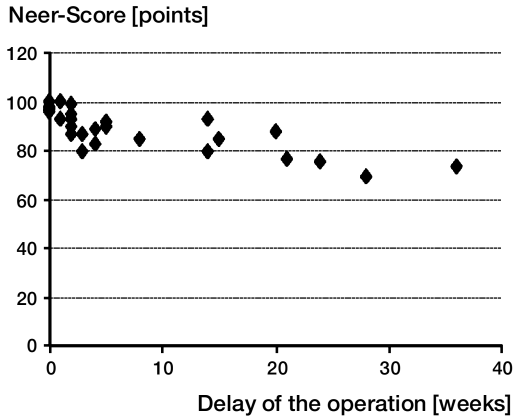

Figure 3. The interval between fracture and operation plotted versus the clinical results is based on Neer's scoring system by Neer.

the outcome was 97 (SD 2.6) points, after 2–4 weeks, it was 88 (SD 5.5) points, after 5–15 weeks, 87 (SD 4.6) points and after 20–36 weeks, 76 (SD 6) points. The range of motion is shown in Table 2. No signs of prosthetic loosening were detected on the radiographs. Heterotopic ossification in 2 patients was grade I, in 5 grade II, in 3 grade III and in 5 grade IV. The range of motion in abduction and anteelevation was reduced in patients with grade IV ossification ($p < 0.01$).

Discussion

We found less satisfactory function after hemiarthroplasty. The Constant score was a mean 45 points, which is comparable to other studies (Nayak et al. 1995, Zyto et al. 1998, Boss and Hintermann1999). The best clinical outcome was found when the operation was performed within the first 2 weeks, as reported from previous studies (Checchia et al. 1998, Gobel et al. 1999). Most patients became pain-free, and the main reductions in the Neer and Constant scores were due to limited range of motion and strength.

73% of the mean isometric adduction torque and 89% of the mean isometric abduction torque were achieved on the operated side as compared to the contralateral side; these results resemble those reported by Kuhlman et al. (1992). Strength was measured in the scapular plane in 30° of abduction, a position used to lift objects during daily activity. Measurement of strength during isometric or isokinetic condition showed similar results in 30° and 60° of abduction which is evidence for the validity of isometric testing (Kuhlman et al. 1992). Abduction of the humerus in the scapular plane is mainly carried out by the deltoideus and supraspinatus muscles (Kuhlman et al. 1992). A reduction in isometric abduction torque at 30° of abduction of about 50% was reported by Kuhlman et al. (1992) after anesthetizing the suprascapular nerve. This shows the importance of the supraspinatus muscle in contributing to shoulder abduction strength. Another important function is centralization of the head in the glenoid. The patient can still develop similar abduction strength in comparison with unoperated side regardless of the limited range of motion. Muscle weakness does not seem to affect postoperative motion. However, we compared the operated side with the unoperated side disregarding hand dominance. Other studies have shown that there are differences in strength when comparing the dominant with the non-dominant side (Cahalan et al. 1991). No definite conclusions can be drawn from the present study because of the limited number of patients.

The complexity of shoulder kinematics due to the contribution of the scapula and clavicle makes

Table 2. Range of active shoulder motion of the operated and unoperated sides showing the means (SD) in abduction-adduction, anteflexion-retroflexion and internal rotation-external rotation

	Operated side	Unoperated side
Abduction-adduction	68 (18)°–22 (11)° [a]	160 (26)°–65 (9)°
Anteflexion-retroflexion	52 (14)°–18 (8)° [a]	142 (18)°–33 (12)°
Internal rotation–external rotatation	65 (11)°–16 (9)° [b]	72 (8)°–48 (11)°

[a] $p < 0.001$, [b] $p < 0.5$, operated versus unoperated side.

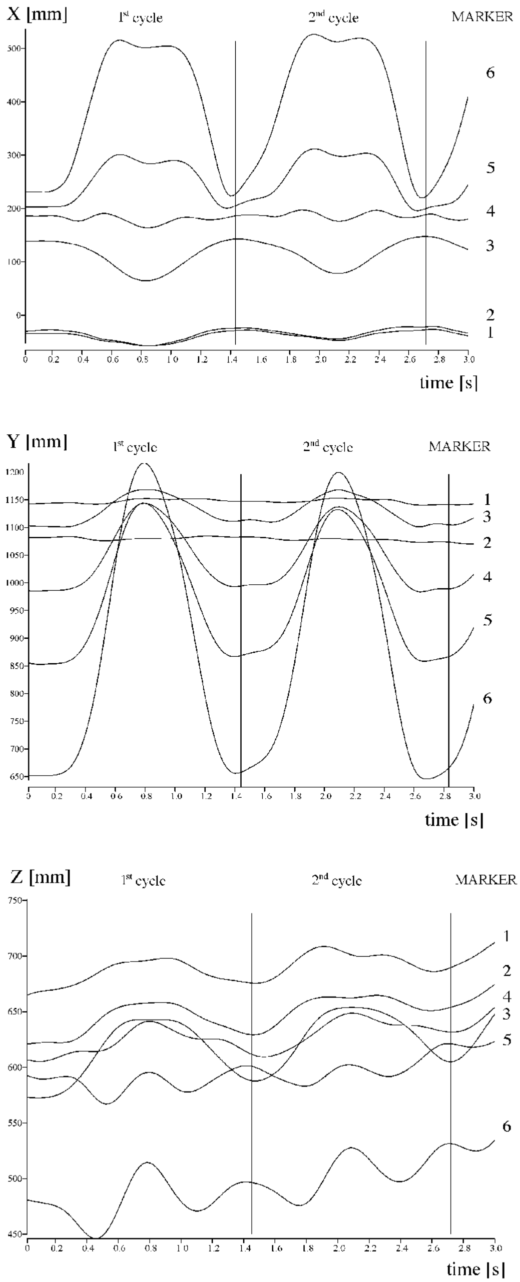

Figure 4. 3-dimensional motion of the 6 markers during 2 cycles of abduction and adduction of the shoulder (same patient as in Figure 2). Upper graph shows horizontal motion (x-axis), middle graph vertical motion (y-axis) of the marker in the frontal plane and lower graph motion perpendicular to them (z-axis) plotted against time.

it difficult to analyze shoulder motion. Although there is a risk of some displacement of the marker over the bony landmarks, which can limit the validity of the system (Van der Helm and Pronk 1995), we found the Elite-system suitable for assessing the total abduction and adduction of the shoulder joint and the isolated motion at the glenohumeral joint. A previous study (Pap et al. 2000) showed that acceleration and deceleration of the acromion constitute another reliable parameter. Moreover, this method also permits motion analysis in different planes of the shoulder. A glenohumeral angle of 57° on the operated side gave 65% of the total abduction and was significantly worse than the 89° on the non-operated side which gave 58% of the abduction. Graichen et al. (2000) reported a ratio of glenohumeral to scapulothoracic motion of 2.5 at 30° and 2.1 at 90° of abduction. The shoulder operated on in our patients showed a ratio of 1.4 at 80° of abduction, which indicates a reduced glenohumeral motion in relation to the scapulothoracic motion. The increased acceleration and deceleration of the acromion during abduction reflects significant change in scapula movement as well. Motion analysis of healthy subjects using the same method showed inferior acceleration (5.4 mm/s^2) and deceleration (–3.1 mm/sec^2) versus our findings (Pap et al. 2000). The reason for increased acceleration and deceleration of the acromion, which was significantly greater on the operated side, indicates a distortion of scapula movement during abduction. Reduced elasticity of periarticular tissue due to scarring or heterotopic calcifications may accentuate acceleration and deceleration, indicating a more sudden movement of the scapula, with an increase in abduction. Subacromial impingement of the prosthesis must be taken into account as well.

Heterotopic ossification occurred in 15 of our 27 patients. Other studies report heterotopic ossification in about 24% and 45% after open shoulder surgery (Kjaersgaard-Andersen et al. 1989, Sperling et al. 2000). Despite significant changes in strength and motion 23/27 of our patients were satisfied with the result. On the basis of our findings we consider hemiarthroplasty should be used for primary management of four-fragment fractures.

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