Shoulder Kinematics and Impingement

Dynamic Radiostereometric analysis of the shoulder

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E Hallström and J Kärrholm. *Clinical Orthopedics and Related Research, 448: 22-27, 2006.*

II Kinematic evaluation of the Hawkins and Neer sign,
E Hallström and J Kärrholm. *J Shoulder Elbow Surgery, 17 (15): 40-47, 2008.*

III Shoulder Rhythm in Patients and Controls, Dynamic RSA during active and passive abduction.
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Dynamic Radiostereometric analysis of the shoulder

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Abstract: This study aimed to evaluate the three-dimensional kinematics of the shoulder joint in patients with shoulder impingement and normal volunteers with focus on three well-known diagnostic tests: painful arc test (active abduction), Neer sign (passive elevation) and Hawkins sign. The shoulder rhythm, the speed of motion and whether successful treatment of impingement could be associated with changes of the shoulder kinematics were studied.

Dynamic radiostereometry (RSA) is a feasible method for studying rotations and translations of the glenohumeral joint because of its high precision. In all studies the relative motions of the glenohumeral joint was analyzed. In one of them the contribution of the motions in this joint to the absolute or global motions of the shoulder (the shoulder rhythm) was delineated. The median age of the patients and volunteers varied between 49-51 and 30-36 years in the different studies.

25 patients and 12 subjects without shoulder symptoms were studied during active abduction (painful arc test). The humeral centre displaced medially, proximally, and anteriorly. In the patient group, slightly more (1–1.5 mm) proximal translation was observed in the early phase of the arc of motion.

18 patients and 11 volunteers were tested in the Neer and Hawkins position. In the Hawkins position the centre of the humeral head was positioned more laterally and superiorly in the patients than in the volunteers.

In order to analyze the shoulder rhythm and the speed of motion at active abduction, 30 patients and 11 volunteers were studied during active abduction, as well as 21 patients and 9 volunteers during passive abduction, to evaluate the relative and absolute motion. The patient group showed more scapular and trunk motions ($p=0.04$) and especially up to 40°. The distribution of motion between the glenohumeral joint and the trunk in both patients with impingement and volunteers was less than or equal to 1:1.

19 patients were randomized to three treatment options: physiotherapy (n=7), open surgery (n=7) or arthroscopic surgery (n=5). RSA studies and clinical evaluation were done before and median 29 and 24 months later.

According to Constant-75, patients treated with surgery improved significantly more than those treated with physiotherapy ($p<0.05$). In the total material there was a tendency to increasing Constant score with increasing medial and posterior position of the humeral head center in a test for Hawkins sign.

In conclusion, the patients showed an increased proximal translation in the painful arc test and when placed in the Hawkins position a more lateral and posterior position of the humeral head center. The glenohumeral-thoracoscapular ratio was less than or equal to 1:1 in patients and volunteers, where the patients had reduced glenohumeral motions in the early phase of active abduction. Correlation between changed humeral head translation after treatment during the test for the Hawkins sign and improvement of the Constant-75 score in the total patient material might represent a causal relationship, but these findings need to be further studied in larger patient groups.

Keywords: *Shoulder kinematics, radiostereometry, impingement, open surgery, arthroscopic surgery, physiotherapy, clinical outcome*

Definitions and abbreviations

AP	anterior-posterior
Abd	abduction
Add	adduction
IR	internal Rotation
ER	external Rotation
RSA	RadioStereometric Analysis
SEM	Standard Error of Mean
UmRSA	RSA software provided by RSA Biomedical, Umeå, Sweden
OpenMRI	open Magnetic Resonance Imaging

Introduction and background

The term “impingement syndrome” was coined by Neer in 1972[1]. He came to the conclusion after studies in the anatomy laboratory and at surgery that impingement occurs against the anterior edge and undersurface of the anterior third of the acromion, the coracoacromial ligament, and on occasion, to the acromio-clavicular joint. Physical signs and symptoms include the impingement sign, arc of pain, crepitus and varying weakness.

Neer[2] proposed three stages in the progress of impingement syndrome: stage I, a reversible stage in which edema and hemorrhage dominate; stage II, an irreversible stage in which tendinitis and fibrosis have occurred; stage III characterized by tendon degeneration and tearing. In all three stages of impingement the symptoms are almost identical but in stage III with advanced cuff rupture the weakness of the shoulder is more pronounced.

Impingement syndrome of the shoulder is by many believed to be the most common cause of shoulder pain[3] and accounting for half of the patients consulting physician because of shoulder pain[4-6].

Impingement syndrome is thought to be caused by inadequate space for clearance of the rotator cuff tendon as the arm is elevated[7-9]. Kinematic changes are believed to occur primarily in symptomatic patients and to result in additional decrease of the subacromial space, which could aggravate the symptoms[7, 10, 11]. Motions that bring the greater tuberosity closer to the coracoacromial arch may be particularly problematic. These motions include excessive superior or anterior translation of the humeral head on the glenoid fossa, inadequate lateral (external) rotation of the humerus, and decreased normal scapular upward rotation[12-16].

These theories were questioned by Budoff et al[17] who thought that 90%-95% of all rotator cuff abnormalities could be attributed to intrinsic breakdown of the rotator cuff tendon because of tension overload, overuse, and traumatic injury rather than mechanical compression. Other factors such as ischemia and degeneration related to age and overload of the short rotator muscles may contribute to the complaint[18]. Although controversial, most authors acknowledge that compression is one of the factors, which can lead to rotator cuff pathology[19, 20].

Physiotherapy with a physical training program is suggested as an initial treatment option for patients with impingement syndrome[8, 21-23]. Böhmer[24] described a new physiotherapy method in 1984[24] which has gained interest and been recently described in a study by Virta et al[25].

One of the tools used by Böhmer[24] was a Sling. Järvholm[26] demonstrated that the load on the supraspinatus muscle was reduced by approximately 30% by the use of a sling. Correct instruction and feedback given by the physiotherapist in order to correct dysfunction in the shoulder rhythm and motivate for regular exercise may be crucial in the method described by Böhmer[24].

Experimental and observational studies have described that the subacromial space is influenced by muscle activity. A study[14] examined the subacromial space by MRI of four normal volunteers and found that it was narrowed by protraction and widened by retraction of the scapula. In a cadaver study Wuelker et al[27] observed that lack of force in the infraspinatus, teres minor and subscapularis increased the subacromial pressure by 61%, whereas lack of force in the supraspinatus muscle did not significantly alter the subacromial pressure. It is commonly described that the purpose of the surgical treatment is to enlarge the subacromial space and thus decompress the subacromial structures[28].

This study aimed to evaluate the three-dimensional kinematics of the shoulder joint in patients with shoulder impingement as compared to volunteers with a focus on three well-known diagnostic tests: painful arc test (active abduction), Neer sign (passive elevation) and Hawkins sign (passive abduction, flexion and internal rotation). The shoulder rhythm, the speed of motion and whether successful treatment of impingement could be associated with changes of the shoulder kinematics were studied.

Anatomy

The shoulder joint has greater range of motion than any other joint in the body[29]. For normal function a complex interaction between the muscles and four articulations, the stenoclavicular, acromioclavicular, glenohumeral and scapulothoracic joint is required (Figure 1).

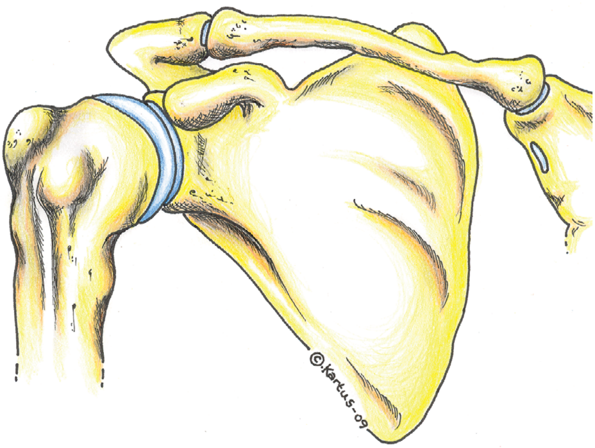


Figure 1. The four articulations of the shoulder, the sternoclavicular, acromioclavicular, glenohumeral and scapulothoracic joint.

The articular bony surface of the glenoid measures only 33% of the humerus[30]. It is less curved than the surface of the humerus[29, 31, 32]. Consequently, the glenohumeral joint can function not only as a ball-in-socket joint, but in a more compound mode. The humeral head cannot only rotate but also translate[33-35].

The articular surface of the glenoid and the labrum constitute an opening that is about 9 mm deep in the proximal/distal direction and 5 mm deep in the anterior-posterior direction. According to Saha[36] the labrum widens the glenoid surface to embrace 75% of the humeral head vertically and 57% horizontally. Because of the small bony surface of the glenoid the stability of the shoulder is to a substantial extent dependent on the ligaments and surrounding muscles.

At zero degrees of abduction of the humerus, the main stabilizer of the glenohumeral joint to counteract inferior humeral subluxation and anterior/posterior tension is the *superior glenohumeral ligament* (SGHL[37], Figure 2). When the arm is in less than 90° of abduction, *the middle glenohumeral ligaments* (MGHL) reduces the external rotation, but otherwise it does not have an effect on the movement of the arm.

The inferior glenohumeral ligament (IGHL) is, according to O´Brien et al[37], arranged in three segments: an anterior thick part, a posterior somewhat thinner but well defined part, and a still thinner overriding axillary purse creating a "hammock-type" model. With external rotation, "the hammock" glides anteriorly and superiorly. The anterior part is stretched and the posterior part relaxes. The reverse occurs at internal rotation.

When the shoulder is abducted to 45° *the anterior* (IGHLa*) and inferior* (IGHLb*) glenohumeral ligament* is the main stabilizer to anterior and posterior tension (Figure 2).

From the coracoids process *the coracohumeral ligament* (LCH) expands nearby the plane of the capsule to the tuberosity between the supraspinatus and subscapularis tendons and continues to the tendinous insertion of the cuff.

The coracoacromial ligament (CAL) extends from coracoids to the anterior acromion. Together with coracoids, the anterior acromion and the distal part of the clavicle it creates the coracoacromial arc under which the supraspinatus extends to reach its insertion at the greater tuberosity[1, 2]. The supraspinatus (SSP) tendon and the tendons of the subscapularis (SCL), infraspinatus (ISP), and teres minor (TM, Figure 3) insert into the underlying glenohumeral capsule near the greater tuberosity[1, 2]. The space between the humeral head and the anterior-inferior edge of the coracoacromial arch has been named the supraspinatus outlet by Neer and Poppen[38].

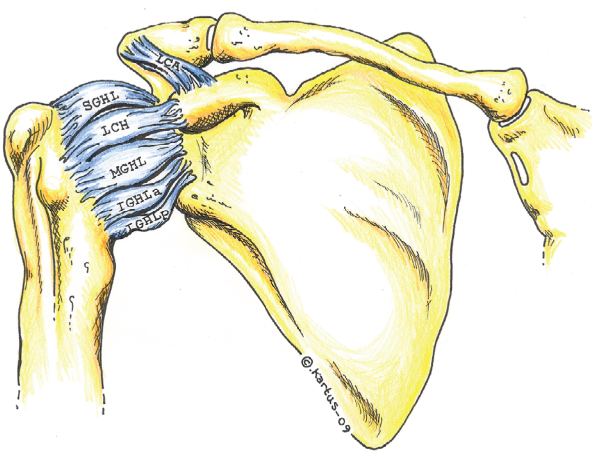


Figure 2. The ligaments of the glenohumeral joint.

The muscles of the shoulder work as a dynamic stabilizer where the rhomboids (RH), levator scapulae (LSC), trapezius (TR) and serratus anterior (SERA), which also control movements of the scapula, interact with the muscles of the rotator cuff (subscapularis, supraspinatus, infraspinatus and teres minor). The deltoid (DLT), pectoralis major (PMA), latissimus dorsi (LAT), and the biceps brachi control (BB) *the glenohumeral joint* in a synergistic way to achieve joint compression (Figure 3)[33, 34, 39-44].

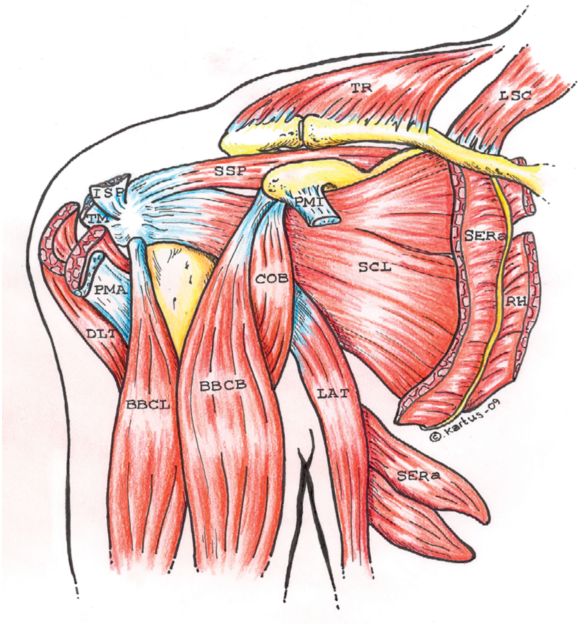


Figure 3. The muscles of the glenohumeral joint.

The Kinematics of the shoulders

In vitro studies

Harryman et al[33] studied 8 shoulders with disarticulation of the scapulothoracic and sternoclavicular joints, using of a load-cell and a spatial sensor with six degrees of freedom. The receiving coil of this sensor was rigidly attached to the humeral shaft as close to the humeral head as possible without interfering with a full range of motion. With flexion of the glenohumeral joint they recorded anterior translation - and with extension posterior translation - of the humeral head. Posterior translation was also observed during external rotation. During adduction (cross-body movement) the sensor at the humerus shifted anteriorly.

Despite application of a posteriorly directed force of 30 to 40 Newton the anterior translations occurred with flexion and consequently could not be avoided. In one experiment the posterior portion of the capsule was tightened by suturing. After this procedure anterior translation was increased during flexion as well as during adduction (cross-body movement). The translations also started earlier in the arc of motion. At the same time a more proximal translation during flexion of the glenohumeral joint was registered.

Thompson et al[45] used 8 fresh-frozen full upper extremities acquired from human cadavers to evaluate the effects of rotator cuff deficiency on shoulder biomechanics and humeral translations in a cadaveric model. The dynamic shoulder testing device consisted of 6 servo-actuated hydraulic cylinders to apply forces to each of the rotator cuffs and the middle deltoid tendons through a tendon clamp-cable-pulley system. To accurately represent the extremity mass distribution an intact human upper extremity was used. Glenohumeral joint motion was measured using a six degree-of-freedom magnetic tracking device with an accuracy of 0.8 mm and 0.8° [46].

No statistically significant difference existed between muscle force for the 1, 3 or 5 cm full thickness rotator cuff tears, provided that the subscapularis, infraspinatus and teres minor tendon remained intact with full glenohumeral abduction. The translation of the humerus with respect to the glenoid was found to be less than 2.0 mm in all three planes (anterior-posterior, medial-lateral, proximal-distal).

Also Wuelker et al[47] used 8 cadaveric samples to study the translation of the centre of the humeral head with simulated active elevation. The deltoid muscle and the rotator cuff were connected to a controlled hydrodynamic actuator through wire cables. The glenohumeral joint was elevated 90° using a constant force. An ultrasonic device was used to determine the position of the arm in all spatial directions. The author found mean translations of the centre of the humeral head to be 9.0 mm ± 5.2 superiorly and 4.4 mm ±1.3 anteriorly between 20 and 90° at active elevation of the joint.

Later the Wuelker et al[27] used an electronic device (capacitive sensor) to evaluate the subacromial pressure with use of the same set-up. The peak pressure (mean 57 N/cm^3) was in the majority of the samples recorded at the anterior border of the acromion. Relaxation of the supraspinatus muscle showed an 8% decrease of the mean coracoacromial pressure, whereas relaxation of the subscapularis and infraspinatus/teres minor and the rotator cuff resulted in a corresponding increase of 61% and 35%, respectively. After anterior acromioplasty the mean coracoacromial pressures decreased by only 5%.

Zuckerman et al[9] measured a subacromial width of 6-7 mm, but under the coracoacromial ligament it was only 1.5 mm. 10 years later Maeskers et al[48] described three-dimensional geometry of the supraspinatus outlet in 32 cadaver samples. They measured the maximum mean width to be about 6.0 mm and found a range between about 1.4 to 6.9 mm. They also observed how the size of this outlet changed with changes to the relative orientation of the humerus with respect to the scapula during motion of the arm in the frontal and sagittal plane in 10 normal volunteers[49]. The geometrical and kinematic data were combined to study the supraspinatus outlet during elevation of the humerus in the frontal and sagittal plane. Throughout arm elevation, the greater tuberosity was shifted away from the coracoacromial arch resulting in narrowing of the outlet during elevation in the frontal plane but only from 60° to 120°. The variations between sequential trials and individuals were large, caused by differences in anatomy and pattern of motion. Both Zuckerman et al [9] and Maeskers et al [48] noted that the critical zone of the supraspinatus outlet is located under the coracoacromial ligament and not under the acromion.

Billuart et al[50] studied the kinematics of the glenohumeral joint in 6 cadavers using an optoelectronic system. The humerus was moved by pull of the deltoid without constraining the humerus. By pulling horizontally in the anterior and medium fibers of the deltoid the glenohumeral joint was abducted 24° to 30.5°, minimally flexed (1.5°) or extended (31°), externally (12°) or slightly internally rotated (5°). The humeral head translation along the three coordinate axes was less than 5 mm. They concluded that these results propose that the deltoid alone can abduct in the glenohumeral joint with maintained stability of the joint.

In vivo studies

The complex interplay between the scapula and the glenohumeral joint during elevation of the arm was probably first described in 1884 by Cathcart (quoted from Crosbie et al[51]), but the term "scapulohumeral rhythm" which describes this phenomenon appeared later[52]. Inman, Saunders and Abbot 1944[41] studied living subjects both with radiography and after insertion of pins into the bone during active abduction. They concluded that this motion involved four joints: the sternoclavicular, the acromioclavicular, the scapulothoracic and the glenohumeral joints, that in a synchronous way acted together.

They found that in between 30° to 60° of elevation the scapula and humerus try to find a position of stability which they may obtain in one of numerous ways. Motion may take place in the glenohumeral joint while the scapula stays fixed until stability is reached. Alternatively, the scapula may translate laterally or medially on the chest wall, or it may move back and forth to find a stable position. This early phase of motion was labeled the "setting action" or "setting phase". Once 30° of abduction or 60° of flexion had been accomplished, the relation between scapular and humeral motion remained constant. Thus, with further motion, they found the ratio of one to two corresponding to 10° of glenohumeral motion for every 15° of motion of the arm. Overall the entire contribution of scapular motion to the total amount of elevation never surpassed 60°.

Doody et al[53] evaluated the contribution of scapular motion to shoulder abduction a 30° intervals in 25 women with goniometric technique. Abduction in the scapular plane with and without resistance was studied. With no added stress the mean scapular and glenohumeral contributions were 59° and 113°.

Freedman et al[54] evaluated the scapular and glenohumeral movements in the scapular plane during abduction of the arm. Fifty-two male medical students were studied with their arms in five positions (0°, 45°, 90°, 135° and at maximum elevation) in the scapular plane corresponding to an angle of 30° in relation to the coronal plane. The ratios of glenohumeral to total arm movement (GH/A) and glenohumeral to scapular movement (GH/S) for the four intervals between the five positions were calculated (Table 1). The ratios were rather similar up to 135° of arm abduction. Past 135° the ratios increased indicating increasing motion in the glenohumeral joint

Interval	GH/A	GH/S
0-45°	*0.589*	*1.431*
45-90°	*0.58*	*1.379*
90-135°	*0.556*	*1.253*
135-max	*0.738*	*2.729*

Table A. *Ratio of glenohumeral/arm (GH/A) and glenohumeral/scapula (GH/S) motion during abduction according to Freedman et al[54].*

Poppen at al[12] used radiography to evaluate the movement of the arm and the relationship between the scapula and the glenohumeral joint motion during abduction in the plane of scapula (elevation). The centre of rotation of the glenohumeral joint was also studied. 12 volunteers without shoulder symptoms and 15 patients took part in the study. Between 0°- 30° most of the motion was in the glenohumeral joint. After about 30° of abduction they recorded a ratio of glenohumeral to scapulothoracic movement corresponding to 5:4. The centre of rotation of the glenohumeral joint during elevation was located within a 6-mm distance from the geometric centre of the humeral head. For every 30° of elevation the average proximal/distal translation of the humeral head was less than 1.5 mm in the volunteers.

Prior injury to the rotator cuff resulting in impaired function of the shoulder joint was associated with abnormal translation of the instant centre of rotation. The instant centre of the humeral head showed from 0 to 30°, and often from 30° to 60° this centre displaced about 3 mm proximally in the patients. Thereafter it shifted 1-2 mm proximally or distally between the sequential positions studied. In the volunteers the average movement from position to position was only about 1 mm.

Howell et al[34] studied the relationship of the humeral head to the scapula in the horizontal plane of motion on axillary roentgenograms in volunteers and patients with anterior instability were evaluated. In the control group the humeral head was center in the glenoid throughout the horizontal plane of motion except when the arm was in maximum extension and external rotation then the center of the humeral head was rested approximately 4 mm posterior to the centre of the glenoid cavity. When the arm was flexed or rotated from this the humeral head displaced anteriorly.

Paletta et al[55] evaluated glenohumeral kinematics and glenohumeral-scapulothoracic motion with two-plane radiography in patients with anterior instability or rotator cuff tear before and after surgical treatment and rehabilitation. 6 normal adults constituted a control group. 18 patients with anterior shoulder instability (group A) and 15 patients with rotator cuff tears (group B) were studied before surgery. In 7 of 18 patients with anterior instability and in all with rotator cuff tears there was demonstrated a superior translation during scapular plane abduction. Anterior translation of the humeral head was only found in cases with instability (14 of 18). Both groups of patients demonstrated an altered relationship between glenohumeral and scapulothoracic motion compared with the control group. In group A all patients studied (n=12) and 12 of 14 in group B demonstrated normal glenohumeral kinematics in both planes after open anterior stabilization or rotator cuff repair. In group A the changed relationship in the glenohumeral-scapulothoracic motion persisted, whereas in group B this relation became normal.

Grachien et al[56] studied humeral head translation during passive and active elevation using an open MR technique and 3D digital post processing methods. 15 normal volunteers were examined with an open MR system at different abduction positions under muscular relaxation (30°-150° of abduction) and during loading of the shoulder muscle (1kg, 60° - 120°). Their relative positions were calculated after segmentation and 3D reconstruction and the centre of the glenoid and the midpoint of the humeral head were analyzed.

During passive elevation, the humeral head translated about 1 mm inferiorly and 1.5 mm posteriorly from 30° to 150°. During loading of the shoulder muscle the humeral head obtained a more inferior position and was more centered, particularly at 90° and 120° of abduction. Along the AP axis the humeral head was more centered at 60 and 90° of abduction during loading of the shoulder. The authors concluded that neuromuscular control was of important to achieve stability of the joint.

Later these authors[57] studied glenohumeral-scapulothoracic motion and the supraspinatus muscle with the same technique. 14 volunteers were examined in 5 positions of abduction (30°-150°) The axis of the supraspinatus, humerus, clavicle, and the plane of the glenoid were determined, and the relative movements were calculated. The ratio for glenohumeral to scapulothoracic motion was 1.5:1 at 60° and 2.4:1 at 120° of abduction. At 30° the axis of the supraspinatus was nearly horizontal but tilted with further abduction to reach slightly more than 120° at 150° of abduction. In the transverse plane, the angle between the supraspinatus and the clavicle axis became larger during abduction because of an increasing retroversion of the clavicle.

In further studies Grachien et al[58] evaluated 20 patients with unilateral impingement and 14 volunteers without shoulder symptoms at 30°, 60° and 120° of abduction with and without abducting muscle activity. There were no major differences in glenoid rotation between the patients and the healthy subjects. Comparison between muscle activity and muscular relaxation showed no major difference between the groups.

The ratio of glenohumeral to scapulothoracic motion (relative to the spinal axis) showed no large differences between the control group and the affected shoulders of the patients. The authors concluded that patients with various stages of impingement syndrome did not display altered motions on the affected side under the given conditions of these examinations. These findings applied both to elevation with and without muscle activity. They also reported a scapulothoracic-glenohumeral motion ratio between 1:1.8 and 1:2.4, which corresponded to previous studies[12, 54, 55].

Finally this group[59] analyzed the effect of abducting and adducting muscle activity on glenohumeral translation, scapular kinematics and subacromial space in healthy volunteers at 30°, 60°, 90°, 120° and 150° of arm elevation. A force of 15 N was applied to the distal humerus, to obtain isometric contraction of the abductor and adductor muscles. Adducting muscle activity resulted in an increase of the subacromial space in all arm positions, whereas the scapular-humeral rhythm (2.2-2.5) and scapular tilting (2-4°) remained relatively constant during elevation without any large variation between abducting and adducting muscle activity. Comparison between adduction and abduction in midrange elevation (60-120°) revealed that the position of the humerus in the former position was more inferior and anterior. Thus, the subacromial space could be widened by adducting muscle activity.

Mesckers et al[48] also observed how the size of this outlet changed in 10 normal volunteers with changes in the relative orientation of the humerus with respect to the scapula during motion of the arm in the frontal and sagittal plane.

Throughout arm elevation, the greater tuberosity was shifted away from the coracoacromial arch resulting in a narrowing of the outlet during elevation in the frontal plane but only from 60° to 120°. The variations between sequential trials and individuals were largely caused by differences in anatomy and pattern of motion

Ebaugh et al[60] evaluated the effects of active and passive arm elevation on the scapulothoracic motion in 20 subjects without any history of shoulder problems. The motion was calculated from electromagnetic sensors adapted to the scapula, thorax and humerus in three dimensions. Muscle activity from the upper and lower trapezius, serratus anterior and posterior deltoid and infraspinatus was recorded with surface electrodes. They found a more upward and external rotation of the scapula, clavicular retraction and elevation, especially during active compared to passive elevation between 90° and 120°. They concluded that especially throughout the mid-range of arm elevation, the upper and lower trapezius and serratus anterior muscles seemed to have an important role for scapular rotation.

Recording methods of shoulder kinematics

Since 1899, physical models of the shoulder have been used in attempts to replicate glenohumeral joint motion and to study the function of tendons and muscles[62-64]. These early models replaced muscles with cords whose change in length during motion of the bones at the shoulder were quantified.

Later work examined the contribution of the static restraints (osteoarticular surface, capsulo-ligamentous structures, and weight of bone and soft tissue) to achieve glenohumeral joint stability[33, 65, 66]. Commonly used methods to measure joint motion such as film and video recordings of markers glued to the skin are less accurate, because most of the scapula is surrounded by a comparatively thick soft tissue envelope. Nonetheless, such methods have also been used also rather recently.

The methods used in recording the shoulder kinematics can be divided into the following subgroups, based on the different procedures and tools used when carrying out the investigation. The subgroups are skin-based methods, methods evaluating the shadows, pins in the skeletal area, use of external devices measuring the kinematics (goniometry), conventional radiography, magnetic resonance imaging (MRI) and radiostereometric analysis (RSA).

Markers/transmitters fixed to the skin

The Electromagnetic sensor device has been used to measure the three-dimensional shoulder movement and has been described by Johnson et al[67]. This is a method based on spherical polar coordinates previously described by Kapandji[68].

The 3-space Isotrack (Polhemus navigation Systems, U.S.A.) is an electromagnetic sensing device for the measurement of the location and orientation of a sensor in space, each connected to an electronic unit including the hardware and primary software for data collecting control. The source (transmitter) generates an electromagnetic field (detected by the sensor) and the electronics package computes the relative location and direction from the detected magnetic field with the full 6 degrees of freedom. The system is associated to a PC which calculates the results obtained by specifically designed software. The sensors are attached to the skin and can be mounted at the sternum, scapula and humerus using adhesive tape. Subjects are standing anterior to the transmitter.

With a high speed reflex camera (Bolex model H16 high speed 16-mm reflex camera) Bagg et al[69] was evaluated the scapular rotation during arm abduction in the scapular plane. Both arms were moved in the plane of the scapula by placing the subject`s forearms and palms against two vertical guiders that were aligned 30° anterior to the coronal plane.
Specific landmarks were (1) the root of the scapular spine, (2) the acromial angle and (3) the inferior angle of the scapula. Two markers were also placed along the long axis of the humerus. In addition, reference markers were positioned over the spinous process of several vertebrae. During film analysis, the three markers of the scapula, the two on the humerus and two of the lower vertebral reference markers were digitized on a Vanguard model M-16C motion analyzer. Programs were then developed to measure the scapular humeral angles and to estimate the location of the scapular ICR for each 15° increment of arm abduction.

Shadow-based methods

Moiré topography (Figure 4) is a form of biostereometry, and has been very useful in describing the three-dimensional character of the human body[70]. The subject is positioned behind a grid of horizontal lines which is illuminated by a light source.

An optical effect is seen when the line shadow through the grind conforms to the surface topography of the subject. Edging models are formed that appear as contour lines on the subject. The contour lines of the surface will accurately reflect the asymmetry of the scapulothoracic area as long as the subject`s back is kept parallel to the apparatus[70].

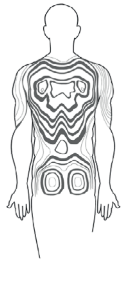


Figure 4. Moiré topography.

During testing the subjects are positioned with their backs approximately 1 cm from the apparatus. Then static and dynamic testing of the shoulder is possible to achieve in a proper way. For minimizing technique variation, one tester supervised all Moiré evaluations and photographs were taken by one photographer. All Moiré photographs were evaluated according to a uniform measurement technique[70].

Radiography

Radiographic studies in which the positions of the scapula and clavicle have been projected on roentgen films at various angles of humeral abduction or anteflexion[12, 54, 180]

Magnetic resonance imaging

Recently several studies have been done with an open MRI [58, 59, 71-74]. The subject is placed in a supine position where the investigator is able to study the shoulder girdle in various positions but dynamic procedure is not possible to obtain. Images are acquired by use of a 3D gradient recalled echo (GRE) pulse sequence with 20 milliseconds of echo time, 37 milliseconds of repetition time, a 20 x 20 cm field of view, and a 256 x 160 – pixel matrix.
Each 3D GRE scan yielded 42 consecutive 2 dimensional images with a segment deepness of 2 mm and needed a total scan time of 4 minutes 34 seconds[74].

Radiostereometric analysis

Radiostereometric analysis (RSA) is an alternative approach in studying kinematics[61, 163-4].This method is based on fixed skeletal landmarks and has a documented high resolution. It has been frequently used in evaluating the migration and wear of prosthetic implants[165, 166]. Dynamic radiostereometry[75, 76] also enables recordings during active joint motion. This application has gained interest in the last decades[167, 168, 170-1]. The technique has also been used in evaluating knee motions in different aspects after total arthroplasty[169].

Under local anesthesia 4-6 spherical tantalum markers (Ø = 0.8 or 1.0 mm) were inserted into the scapula (acromion) and the humeral head. A set up including two film-exchangers, placed side by side designed for simultaneous exposures (Figure 5). The exposure rate was set at 2 per second during 5 seconds during the abduction/elevation of the arm.

The radiographic examination was initiated with a starting or reference position corresponding to a well defined anatomic position. All subsequent recordings were related to this position of the arm.

A fictive point corresponding to the humeral head centre was constructed by circular templates to enable measurements of humeral head translations in a reproducible way. The X-ray films were scanned at 300 dpi using a flat-bed scanner (Sharp JX610, Osaka, Japan) and measured using dedicated software[75]. The data were then analyzed by specifically designed software (UmRsa).

Other methods

Goniometers and pins inserted into clavicle and scapula and other bones have been used to measure externally the motion of the bones used[53, 193-4].

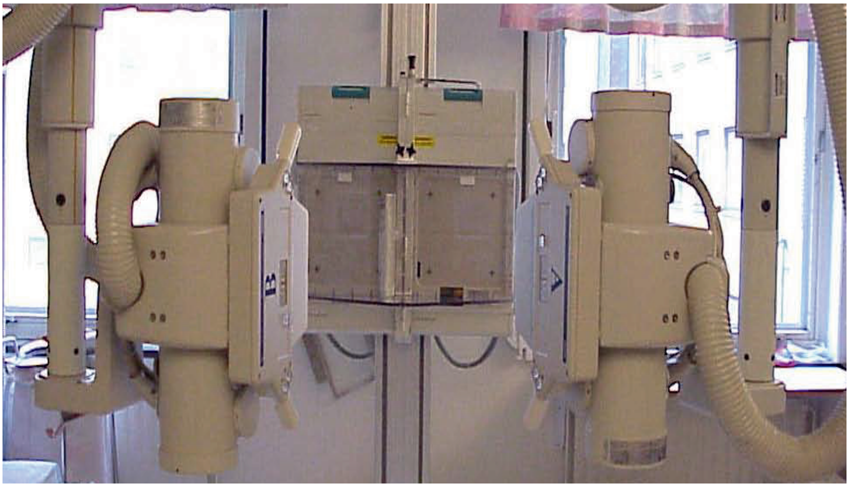


Figure 5. A set up of X-ray tubes and two film-exchangers, placed side by side designed for simultaneous exposures.

Impingement syndrome

Epidemiology

Shoulder pain is a common disorder. In the general population the prevalence of shoulder pain may be as high as 6 - 11% under the age of 50 years, increasing to 16 - 25% in the elderly[77-79]. Estimates of the annual incidence of shoulder disorder incurred in general practice varies from 7 - 25 per 1000 registered patients per year[5]. Inability to work and to carry out household activities in addition to loss of productivity can become a considerable burden to the patient as well as to society[80].

Shoulder impingement syndrome

In the past, many authors described abnormal conditions in the subacromial space[1, 2, 52, 85, 86], but the true reason why impingement syndrome develops remains unclear. In 1931 Meyer[87] proposed that because of the friction between the rotator cuff and the undersurface of the acromion, tears of the rotator cuff could develop secondary to attrition. He also described tears close to the greater tuberosity, but did not explain their etiology. In 1934 Codman[52] focused on a specific and vulnerable location on the rotator cuff, situated one centimeter medial to the insertion of the supraspinatus on the greater tuberosity where most of the degenerative changes were found.

Neer[1] described shoulder impingement as a mechanical phenomenon corresponding to impingement of the rotator cuff tendon beneath the anterior-inferior acromion. This condition occurs when the shoulder is placed in forward flexion and internal rotation. He hypothesized that the rotator cuff is impinged by the anterior one-third of the acromion, the coracoacromial ligament, and the acromioclavicular joint. Neer also proposed that the insertion of the supraspinatus tendon on the greater tuberosity is involved in the impingement conditions. In addition he suggested that these tears also could be caused by bony spurs in the coracoacromial ligament.

In 1983 Neer[2] characterized 3 stages of impingement. Stage I is described as edema and hemorrhage of the bursa and the rotator cuff, a common disorder among patients who are less than 25 years old. Stage II represents permanent changes such as fibrosis and tendinitis of the rotator cuff, and is normally found in patients who are 25–40 years old. Stage III corresponds to more chronic changes, such as partial or complete tears of the rotator cuff. It is usually seen in patients who are more than 40 years old.

Although the more advanced stages of this process, including rotator cuff tears are more common in older individuals, impingement and rotator cuff pathology are also frequently seen in younger, athletic individuals, who are engaged in repetitive overhead activities or in young workers, who expose their rotator cuff to similar conditions.

Etiology and pathogenesis

Shoulder impingement can be divided into external and internal categories. External impingement is caused by structural changes outside the joint and includes primary, secondary and subcoracoid types. Internal impingement is secondary to rotator cuff and capsular dysfunction. It may be divided into 4 types: posterior-superior (classic internal impingement), anterior-superior, anterior and entrapment of the long head of the biceps tendon.

Extra articular impingement (External impingement)

It is important to be familiar with the anatomical features of the subacromial space to understand the pathogenesis of subacromial impingement. The superior limit consists of the coracoacromial arch: the acromion, the coracoacromial ligament and the coracoids process. The acromioclavicular joint is directly superior and posterior to the coracoacromial ligament.
The inferior limit consists of the greater tuberosity of the humerus and the superior part of the humeral head. According to radiographic measurements, the height of the space between the acromion and the humeral head varies between 1.0 – 1.5 cm[81]. The rotator cuff tendons, the long head of the biceps tendon and the bursa are localized in the subacromial space. This reduces the subacromial space considerably more than seen on radiographs. Impingement may develop due to any deviation that changes the relationship of these subacromial structures.

Primary impingement is considered to be caused by degenerative changes of the acromioclavicular joint or due to certain variations of the acromial morphology. Secondary impingement may develop due to elevation of the humeral head and/or joint laxity and instability.

Impingement occurs when the supraspinatus tendon is squeezed in the supraspinatus outlet space. It starts as an inflammatory process involving the subacromial bursa and the tendon itself. Bursitis, inflammation, edema and hemorrhage may develop. If the process continues, fibrosis of the subacromial bursa and tendinitis may develop. Further progression of this condition may evolve to partial or full thickness tears of the supraspinatus tendon[1].

Acromial morphology in shoulder impingement syndrome

Differences in the shape and slope of the acromion were described as early as 1909[88]. In the past the treatment of the shoulder pain caused by subacromial impingement was mainly focused on removing different fractions of the acromion. Armstrong[85] suggested that total acromionectomy would relieve these symptoms as did Diamond[81]. McLaughlin and Asherman[89] proposed that lateral acromionectomy would be sufficient. These treatment options were not the solution and numerous complications ensued, especially detachment of the deltoid muscle.

In 1972[1] Neer proposed that differences in the shape and the slope of the anterior portion of the acromion could explain subacromial impingement and associated tears of the rotator cuff. These conclusions were based on his own clinical remarks as well as dissection of more than 100 cadaveric scapulae. In addition, a spur on the coracoacromial ligament was often found distally directed into the subacromial area.

Bigliani et al[90] described three frequently observed variations of the morphology of the acromion based on cadaveric dissections and radiographs. In 139 shoulders from 71 cadavers they identified 3 types of morphology. Twenty-four (17%) were rather flat, 60 (43%) were described as curved, and 55 (40%) as hooked.

A higher prevalence of full thickness tears of the rotator cuff was noted in association with the hooked or type III acromion. This observation was confirmed by Morrison et al 1987[91], who studied 200 consecutive patients with supra outlet radiographs. Sixty-six (80%) of the 82 patients who had rotator cuff tear according to arthrography had a hooked acromion. Morrison et al[92] confirmed these observations and preferred supraspinatus outlet radiographs to MRI to arrive at correct diagnosis.

In 1986 Aoki[93] et al described that presence of spurs was common with the flat type of acromion and these cases had increased pitting on the surface of the greater tuberosity. In the 130 specimens studied they found that the prevalence of spurs in the subacromial space increased with age. Nicholsson et al[94] studied 420 specimens and noted that the prevalence of spur formation at the anterior part of the acromion increased after 50 years of age, whereas the morphology of the acromion did not seem to change with age.

The hypothesis that the anterior part of the acromion is associated with the pathogenesis of tears in the rotator cuff was supported by Zuckerman et al[9]. They studied 140 cadaveric shoulders and found that the supraspinatus outlet was 22.5% smaller and the anterior projection of the acromion was larger in the specimens with rotator cuff tear.

Rockwood and Lyons[95] emphasized the importance of the anterior prominence of the acromion in impingement syndrome. They suggested a two step acromionectomy, resection of the anterior part of the acromion at the level of the clavicle and removal of bone from the inferior aspect of the acromion.

Despite these studies the association between the morphology of the acromion and supraspinatus pathology has been questioned, mainly as it is related to the reliability of those classifications presented. Poor levels of interobserver reliability[96] or a more complex and subtle variation of the acromial shape in association with difficulties to obtain a representative image of its true shape on MRI or radiographs has been debated. More recently, a study by Chang et al[97] used complex 3D computer modeling of the acromial undersurface. He concluded that the shoulder impingement or rotator cuff tears are not primarily caused by osseous impingement by the acromion.

Impingement by the Coracoacromial ligament

The “snapping shoulder,” a condition starting with shoulder pain is believed to be caused by inflammation and swelling of the subacromial bursa, which becomes squeezed under the edge of the coracoacromial ligament, was described by McLaughlin and Asherman[89]. Later, Neer [1, 2] incorporated resection of the coracoacromial ligament as an essential part of the anterior acromioplasty procedure. This procedure has also been recommended by others and especially in athletes engaged in overhead activities[98-101].

In a cadaveric study, Burns and Whipple[102] noted that the supraspinatus and biceps tendons were stabbed against the lateral edge of the coracoacromial ligament as the arm was flexed forward to 90° and then forcibly internally rotated. Soslowsky[103] proposed that enlargement of the coracoacromial ligament could result in subacromial impingement. However, this hypothesis is questioned by Sarkar[104] and Uthoff[105], who in histological studies only found degenerative changes without any swelling of this ligament.

Degeneration of the Acromioclavicular (A-C) joint

Degenerative changes of the A-C joint are a widely accepted reason for subacromial impingement[1, 2, 106-108]. When the cuff passes underneath the joint, osteophytes from the lateral end of the clavicle or from the medial part of the acromion in the A-C joint extend beyond the A-C joint and interfere with the rotator cuff.

Kessel and Watson[106] found that the pain disappeared in about 2/3 of 97 patients with "painful arch" syndrome after local injection of anesthetics and a steroid or after division of the coracoacromial ligament. These patients had lacerations of either the anterior or posterior part of the rotator cuff. In the remaining patients with degenerative changes in the A-C joint, excision of the distal part (1 cm) of the clavicle resulted in pain relief for patients.

Osteoarthritis of the A-C joint may be one reason for unsuccessful operative treatment of subacromial impingement. However, resection of the lateral clavicle should only be done if the patient has symptoms localized to the AC-joint in combination with radiographic changes in this region[20].

Subcoracoid impingement

In subcoracoid impingement the subscapularis tendon, the subcoracoid bursa, and the anterior joint capsule is squeezed between the coracoids and the lesser tuberosity. In this condition the distance between the coracoid and the lesser tuberosity (the coraco-humeral interval) is considered to be narrowed due to lengthened coracoids. This can be a hereditary condition or post-traumatic with deformity of the coracoid or the humeral head or iatrogenic as a consequence of glenoid osteotomy or coracoplasty[109]. The normal coraco-humeral interval has been shown to vary between 8 and 11 mm[84, 110, 111]. It is smaller in females than in males[84, 112]. Subcoracoid stenosis has been defined as a coraco-humeral interval less than 6 mm. As measured on CT scans the coraco-humeral interval decreased from about 9 to 7 mm when the arm was placed in flexion and internal rotation, a position recognized to induce subcoracoid impingement[84]. When the coraco-humeral interval was evaluated by MRI (axial view) the mean distance amounted to about 10 mm. In a group of patients with torn subscapularis tendons this distance decreased to about 5 mm[194].

A "roller-wringer effect" has been thought to cause tears in the subscapularis tendon in patients with subcoracoid impingement[110]. The coracoid displaces the surface of the tendon during rotation of the shoulder and performs a roller-like action, which induces progressive damage, eventually leading to macroscopically visible tears.

Giaroli et al[112] tried to evaluate if the distance of the coraco-humeral interval as measured on routine shoulder MRI could be used as a diagnostic tool for this condition, but came to the conclusion that subcoracoid impingement was primarily a clinical diagnosis, which can only may be confirmed by MRI.

Os Acromiale

In 1863 Gruber described os acromiale, a bony formation corresponding to a remaining separated distal acromial epiphysis (Quoted from Bigliani 1997)[20]. The prevalence of this condition has been estimated within a range of 1 - 15%[113, 114]. Axillary radiographs may be necessary to observe this bone. An os acromiale might be movable. This bone may also slope anteriorly and cause impingement[115, 116].

Intra-articular shoulder impingement (Internal impingement)

Internal impingement syndrome involves the intra-articular surface fibers rather than the bursal surface fibers of the rotator cuff. Posterior-superior internal impingement was originally described by Walch, who observed undersurface tears of the supraspinatus and infraspinatus tendons between the posterior-superior glenoid rim and the humeral head[117]. Internal impingement also includes anterior-superior impingement, anterior impingement, and entrapment of the long head of the biceps tendon.

Posterior-superior impingement syndrome

The posterior-superior impingement syndrome is defined as a condition where the intraarticular side of the supraspinatus and infraspinatus tendons is impinged on the posterior edge of the glenoid when the arm is in abduction and external rotation[117]. It causes rotator cuff undersurface tears in athletes during the late elevating-early speeding up phase of overhead movement[117, 118]. It may occur in baseball and tennis players, javelin throwers and swimmers. These subjects have posterior shoulder pain that starts during the late elevating phase of overhead movement and becomes worse during the early speeding up phase[119].

MRI might be helpful and may reveal tears and degeneration of the posterior undersurface of the rotator cuff (supra- and infraspinatus), defects in posterior-superior labrum (SLAP IIB lesion), subcortical cysts at the humeral head, anterior capsule laxity, instability and posterior capsule enlargement[119-121].

It has been proposed that presence of anterior laxity of the capsule in these patients has been proposed that this is the primary problem especially in athletes who engage in overhead activities[117].

Anterior-superior Impingement

Anterior-superior impingement is induced when the deep surface of subscapularis tendon and the common humeral insertion of the superior glenohumeral and coracohumeral ligaments (the reflective pulley) are impinged between the humeral head and the anterior-superior edge of the glenoid.

Habermeyer et al[122] evaluated patients with this condition during arthroscopy. They found tears at the subscapularis undersurface and "reflective pulley" lesions, defects of the long head of biceps tendon, and partial tears of the supraspinatus tendon. This condition may develop when the arm is horizontally adducted, maximally internally rotated and to a varying extent elevated anteriorly[123].

Anterior impingement

Anterior impingement occurs in younger patients with typical subacromial impingement symptoms. Arthroscopic evaluation reveals ragged tendon fibers of the rotator cuff between the superior humeral head and the anterior superior labrum[124].

Entrapment of the long head of biceps tendon

Patients suffering from entrapment of the long head of biceps tendon have persistent anterior shoulder pain which increases during active elevation of the arm above the head. In this condition the intraarticular portion of the long head of the biceps tendon becomes enlarged and adopts the shape of an hour glass[125]. When the shoulder is elevated it does not succeed to enter the biceps groove and the tendon becomes squeezed resulting in pain and limitations of motion.

The place for the biceps groove is tender and at passive elevation there is a reduction of 10-20° compared to the opposite side. Arthroscopic evaluation gives the final diagnosis. The "hourglass test" is performed where the incarceration and bulging of the tendon is seen when passive elevation of the arm with the elbow extended is performed. MR and CT scans are of minor diagnostic value[125].

Impingement not primarily related to shoulder joint anatomy

Muscle weakness

Because of weakness of the rotator cuff muscles tension overload may occur resulting in pathological changes in the supraspinatus tendon[126]. This happens when the arm is in the overhead position. These conditions are commonly seen in athletics that swim or participate in racquet or throwing sports. Manual labor that requires overhead motions such as those performed by carpenters mechanics, plumbers, and other works might also affected. Muscle fatigue, injury and degenerative changes in tendons[127, 128] have been associated with proximal migration of the humeral head. Jerosch et al[128] studied 8 cadavers and concluded that impingement could be caused by muscle imbalance. Consequently, these authors proposed that impingement should be treated with muscle-strengthening exercises rather than acromioplasty.

Overuse of the Shoulder

The overuse syndrome, which is based on repetitive overhead motions, is another reason for tendinitis, bursitis, and impingement[129, 130]. The overuse syndrome commonly occurs in young competitive athletes who perform forceful repetitive tasks that involve overhead motion. The most common of these activities include throwing, racquet sports, and swimming. The balance of the forces of the shoulder can be disturbed by negligible changes in the technique that an athlete uses to perform a motion, exceeding tolerance level of the soft tissue with an injury as a consequence.

Inflammation and thickening of the rotator cuff tendons or the subacromial bursa may develop into subacromial impingement. The primary cause is an overuse of the shoulder and as a consequence soft-tissue inflammation. This increases the volume of the cuff tendon and bursa in the subacromial space and impingement against the coracoacromial arc[129, 131, 105]. A variety of diseases e.g. rheumatoid arthritis can induce inflammation with increasing volume of the rotator cuff and the bursa.

Degenerative tendinopathy

In a radiographic and histological study of 76 cadaveric shoulders, Ogata and Uhthoff[132] showed that degenerative tendinopathy may play an important role in impingement syndrome. Those authors evaluated the degenerative changes that they came across on the undersurface of the acromion. They proposed that tendon degeneration is the primary reason for partial tears of the rotator cuff. They suggested that proximal migration of the humeral head occurs when there is a partial tear, resulting in impingement and over the time develops to a complete tear.

Glenohumeral Instability

It is important to exclude glenohumeral instability especially in young competitive athletes with symptoms of impingement[133]. This condition might be one reason why these patients do not recover after an anterior acromioplasty[7, 133, 134]. Glenohumeral instability might also be difficult to differentiate from other intra-articular reasons for impingement such as the anterior, anterior-superior or posterior-superior types.

Rotator cuff tears

The normal rotator cuff is 10-12 mm wide. Partial tears have been classified[82] depending on their depth into 3 grades (less than 3 mm, 3-6 mm, more than 6 mm). Neer classified the involvement of the rotator cuff into three stages: Type I - inflammation without any tear, Type II - partial tear and Type - III full thickness tear. Full thickness tear has been further divided into three degrees depending on size (less than 1 cm, 1 up to less than 3 cm, more than 3 cm).

An avulsion type of partial tear of the articular surface of supraspinatus at its insertion on the greater tuberosity should be considered when young athletic patients are complaining of shoulder pain[83].

The supraspinatus tendon is mostly involved in developing rotator cuff tears probably because of impingement by the subacromial spurs and degenerative changes of the AC-joint. A posterior-superior internal impingement has also been described in which the posterior humeral head contacts the posterior glenoid during abduction with external rotation.

The tears of the supraspinatus tendon are in the majority of cases located anteriorly and may develop further anteriorly or/and posteriorly. The rotator interval, the capsule and the coracohumeral ligament are involved and the cranial portion of subscapularis tendon may also be engaged. If the tears expand further the infraspinatus tendon may also be involved.

In patients with symptoms of shoulder impingement signs of biceps tendon injury should also be looked for. There might be tears of the superior fibers of the subscapularis tendon and the anterior fibers of the supraspinatus tendon resulting in a subluxation of the biceps tendon out of the intertubercular groove.

As mentioned previously, the subscapularis may also be injured when tears of the supraspinatus extend anteriorly. The subscapularis tendon may also be damaged after traumatic glenohumeral dislocation or as a consequence of subcoracoid impingement. When the coracohumeral interval is narrowed impingement of the subscapularis tendon may occur[84]. An avulsion of the portion of the lesser tuberosity is commonly seen because tears of the subscapularis tendon usually take places near or at its insertion.

Diagnosis

Symptoms

Pain is the most frequent symptoms in subacromial impingement. As a consequence of pain stiffness and weakness may develop. When the pain subsides, the stiffness and weakness should to a great extent disappear. If the weakness persists other diagnoses such as cervical radiculitis or entrapment of the suprascapular nerve should be considered. If the stiffness persists, frozen shoulder, inflammatory arthritis and calcific tendinitis might be present.

Pain should be analyzed with respect to localization, quality, persistence, appearance and association to activity. The subacromial impingement is characterized by increasing pain, especially when working with the arm elevated corresponding to the range of motion described in the painful arc test[106]. Quite often, acute traumatic disorders such as bursitis may not completely resolve and may develop into impingement lesion with a persistent procedure. Therefore, the patients quite often bring to mind a specific occasion as a cause of the symptoms.

Specific shoulder test

The impingement sign

The impingement sign (Figure 6), as described by Neer[1], is performed by standing behind the patient and passively elevating the arm in the scapular plane with one hand, while the other is stabilizing the scapula.

The impingement test

The impingement test as described by Neer[1] can be a useful instrument in the diagnosis of impingement (Neer sign, Figure 6). After sterile injection of local anesthetics into the subacromial space, the test is repeated. The injection should relive the pain in case of impingement.

Painful arc test
Kessel and Watson introduced the “painful arc syndrome” (Figure 7) in 1977[106]. This is a painful position of the shoulder joint between 60 and 120° during active abduction of the arm, which indicates a disorder of the subacromial region. It should be distinguished from increasing pain up to full abduction, which is regarded as a sign of a disorder in the acromial-clavicular joint.

Hawkins sign
Hawkins and Kennedy[100] proposed that pain during internal rotation of the arm after passive elevation of the arm to 90° as a diagnostic test of impingement (Figure 8).

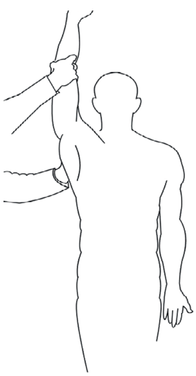


Figure 6. Neer sign

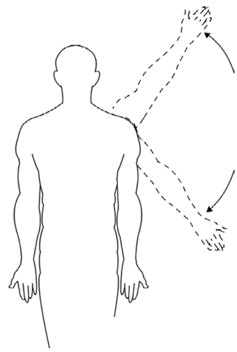


Figure 7. Painful arc test

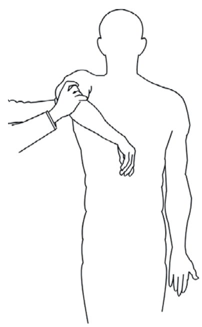


Figure 8. Hawkins sign

The apprehension test and relocation test
Young patients could have impingement caused by slight glenohumeral instability. Consequently, the apprehension test and the relocation test described by Jobe[135] also should also be performed and especially when younger patients seek medical attention because of shoulder pain.
The apprehension test is performed in the supine position with the involved shoulder in 90° of abduction. The arm is externally rotated beyond 90°. The test is positive when the patient is apprehensive, because the humeral head begins to dislocate anteriorly[95, 135]. The relocation test is then performed by directing a posterior force on the proximal aspect of the humerus, thereby relieving the sensation of apprehension[95, 135].

The lift-off-test
Disorders of the subscapularis tendon is evaluated by the lift off test where the elbow is in 90° of flexion and the arm in maximum internal rotation behind the back. The patient is then asked to lift the arm from the back. The test is considered positive if it is not possible to lift the arm from the back[136].

The body cross test
Disorders of the acromion-clavicular joints are associated with pain by direct palpation of the joint. Internal rotation of the extended arm and adduction of the arm across the chest may also elicit pain (body cross test). However, these maneuvers may also cause impingement in the subacromial space and therefore may not be specific for the identification of disorders of the A-C joint. To more specifically identify the cause of symptoms, selective injections into the both the AC-joint and the subacromial bursa are helpful[137].

Posterior-superior impingement test
With the patient supine, posterior pain should occur when the arm is abducted 90 -110° and then externally rotated maximally.

Anterior-superior impingement test
Anterior pain occurs when the arm is horizontally adducted, maximally internally rotated, and anteriorly elevated to varying extents[123].

Radiographic Evaluation

Ordinary AP radiographs could demonstrate areas of sclerosis or spur formation on the anterior edge of the acromion with corresponding areas of subcondral cysts or sclerosis of the greater tuberosity[138, 139]. Other differential diagnoses such as osteoarthritis of the AC or glenohumeral joints, tendinitis calcarea and indirect signs of GH instability (Bankart lesion or Hill-Sachs lesion) can be identified. An anterior-inferior projection of the acromion tilted caudally 30° may be helpful to reveal spurs of the anterior edge of acromion[140]. Correspondingly an AP radiograph tilted 10° in the cephalic direction may facilitate visualization of inferiorly protruding osteophytes. An axillary radiographs may be needed to diagnose an unfused acromial epiphysis[114]. The AC-joint is also well visualized.

Neer and Poppen[38] introduced the supraspinatus outlet view. This is a lateral radiograph in the scapular plane with the X-ray beam directed 10° caudally. The slope of acromion and spurs adjacent to the AC-joint are visualized[90]. However, superimposition of osseous structures such as the thoracic spine, the ribs, the clavicle or the scapular body may jeopardize the interpretation of this view.

Ultrasonography
Ultrasonography may be useful to identify moderate or large full thickness tears[141, 142]. Presence of subacromial impingement during abduction or elevation of the arm can be diagnosed. One major advantage with ultrasonography is that dynamic studies are possible.

Magnetic Resonance imaging (MRI)
The ability to diagnose partial tears and small full thickness tears has increased the last decade with the use of MRI, although it remains difficult to differentiate these lesions from rotator cuff tendinitis[143].

Treatment of subacromial shoulder pain

Non-Operative Treatment
The majority of patients with impingement improve without any surgical treatment (success rate between 50-80%)[1, 10, 21, 137]. Treatment usually amounts to a restriction of certain activities, both at work and during leisure time, when necessary. Non-steroidal anti-

inflammatory medications, subacromial injections of steroids, and physical therapy programs are frequently used.

Böhmer[24] introduced a new type of physiotherapy with the purpose of enabling activity without causing pain and with the intention of finding the normal “shoulder rhythm” for the individual patient. The gravitational forces on the arm were removed by a sling fixed to the ceiling (Figure 9).

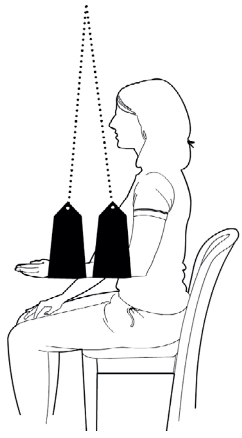


Figure 9. Training with a sling according to Böhmer.

The training program started with rotational motions and when the patient was pain-free the program continued with flexion-extension and lastly abduction-adduction exercises. Repetitive motions in the sling with minimum experience of pain were done for about 1 hour/day. Patients trained with the physiotherapist twice a week. Gradually load was added to strengthen the rotator cuff and the muscles that stabilize the scapula. Training continued for 3 – 6 months, gradually reducing supervision. Patients were encouraged to gradually engage in leisure-time activities, which could replace the training. Three lessons were given on the anatomy and function of the shoulder, pain management and ergonomics. According to Böhmer[24, 144], this treatment should be successful. In their study only 8 of 150 cases with rotator cuff disease needed surgery.

Morrison et al[22] evaluated 616 patients who had isolated subacromial impingement syndrome. The patients received specific physical therapy that included isometric and isotonic muscle-strengthening exercise and non-steroidal anti-inflammatory drugs. After slightly more than 2 years 413 patients (67%) had a satisfactory result and 172 (28%) an unsatisfactory result. Patients who had a type I acromion were more likely to have satisfactory results than those who had a type II or III acromion.

The duration of non-operative treatment is a clinical decision that should be based on the specific set of circumstances associated with the individual patient. However, on the basis of the findings of the majority of the authors, a minimum six months trial of nonoperative treatment seems to be reasonable[145-147].

Operative Treatment

Anterior acromioplasty with resection of the coracoacromial ligament is an established method in treating subacromial pain operatively. Removal of the lateral portion of the acromion has, however been associated with complications and unacceptable results[1, 81, 85, 89]. Resection of the lateral clavicle is not regularly done as part of a subacromial decompression.

It is indicated only when this joint is tender or when there is osteoarthritis and osteophytes causing impingement. Anterior acromioplasty can be performed with use of either the open technique described by Neer[1] and modified by Rockwood[95] or the arthroscopic technique[148].

Open acromioplasty

Open anterior acromioplasty was first described by Neer in 1972[1]. Anterior acromiopalsty involves debridement of inflamed subacromial bursa, resection of the coracoacromial ligament and any spurs, resection of the anterior-inferior aspect of the acromion and resection of distal osteophytes or if indicated of the entire acromion-clavicular joint (Figure 10). This procedure was modified by Rockwood who introduced two-step acromioplasty. In this procedure the anterior edge of the acromion is cut and then the acromioplasty according to Neer is accomplished. It is necessary to suture the anterior part of the deltoid to the acromion to preserve deltoid function.

Neer[1] reported that out of 16 patients all but one with AC-joint osteoarthritis had a successful outcome after acromioplasty. Post and Cohen[149] studied 72 patients with subacromial impingement treated with acromioplasty. After a mean of 23 months (range 5 – 48) 64 (89%) had postoperative relief of pain. Strength and range of motion were modestly improved. Hawkins at al[150] evaluated 108 decompressions in patients with chronic impingement (none with rotator cuff tear) after a longer period of time (mean 5 years). 94 patients (87%) had satisfactory results. Unsatisfactory results were more common in patients with workers´ compensation. Later studies including 50-60 cases with about 1- 4 years follow-up have revealed about 75% excellent or satisfactory results[151-153].

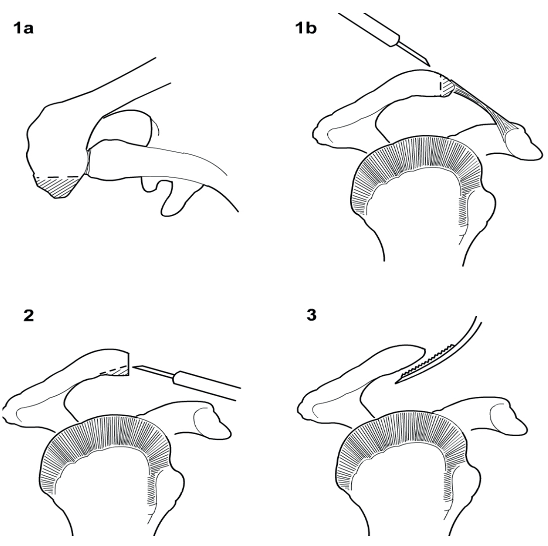


Figure 10. Acromioplasty according to Neer with modification described by Rockwood.

Arthroscopic Subacromial Decompression
In 1987 Ellman[148] introduced arthroscopic subacromial decompression as an alternative to open acromioplasty (Figure 11). The following year, Gartsman et al[154] evaluated open acromioplasty versus arthroscopic decompression in 7 cadavers each. They found no difference concerning the location and amount of bone resected and proposed that the two methods could be equally effective.

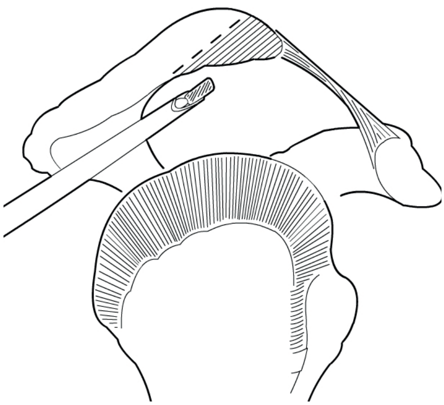


Figure 11. Arthroscopic Acromioplasty according to Ellman.

Esch et al[155] studied 71 patients with subacromial impingement treated with arthroscopic subacromial decompression. After mean of 19 months follow-up of 19 months 60 (85%) patients were satisfied and 56 patients (77%) had an excellent or good result. 28 of the 71 patients were less than forty years old with a potential for non-diagnosed subtle instability. Paulos and Franklin[156] reported on 66 patients with impingement syndrome who after six months of unsuccessful non-operative treatment had arthroscopic acromioplasty. After 32 months 57 patients (86%) were satisfied with the outcome of the procedure although 14 continued to have pain at night.

Adolfsson and Lysholm[157] evaluated 79 patients who were operated on using arthroscopic acromioplasty for the treatment of subacromial impingement syndrome. All of the patients had instability testing and diagnostic arthroscopy. The mean follow-up was 17 months (range 9-24 months). 53 patients (67%) had an excellent or good result. Roye et al[158] reported the result of arthroscopic acromioplasty in 88 patients (90 shoulders) with stage II impingement syndrome. After a mean of 41 months (24-82) 46 patients (47 shoulders) had no tear of the rotator cuff (stage-IIa impingement according to Gartsman[159]), and 42 patients (43 shoulders) had a partial-thickness tear (stage-IIb impingement according to Gartsman[159]). The result was rated as satisfactory for 72 shoulders (80%) without any difference between stages IIa and b.

Open versus Arthroscopic Acromioplasty
Norlin et al[160] compared arthroscopic with open decompression in 20 patients with 4-5 years duration of symptoms before the operation. The preoperative symptom was 5 years for the group that had operative arthroscopy and nearly 4 years for the group that had an open procedure. After 2 years the clinical results were comparable[192].
Van Holsbeeck[161] compared 53 patients treated with open decompression and 53 with arthroscopic decompression according to their surgeon's preference. The preoperative

duration of symptoms was a mean 26 months in both groups but with a very wide range (2 months -14 years). After 2 years both groups had a high percentage of satisfactory results. Associated abnormalities, such as AC-joint osteoarthritis, adhesive capsulitis, calcific tendinitis and small tears of the rotator cuff did not influence the result.
Lazarus et al[162] retrospectively evaluated the result of acromioplasty in 68 patients (70) shoulders. Twenty-four shoulders were treated with open acromioplasty and 46 with arthroscopic acromioplasty. The treatment option was based on the preference of the surgeon. The mean time of non-operative treatment was 14 months for the patients who had an open procedure and 9 months for the patients who had an arthroscopic procedure. The follow-up was 12 months in both groups. The mean scores for the two groups were comparable, but there was a higher percentage of excellent results in the group of patients who had been operated on using an open procedure (54% compared with 42%) and a higher percentage of worse results in the group of patients who had been managed arthroscopically (28% compared with 17 %). Patients with Workers`Compensation tended to have inferior results.

Physiotherapy versus Arthroscopic Acromioplasty

In the purpose of evaluating the efficiency of arthroscopic surgery, a supervised exercise regime[24], and placebo soft laser treatment in patients with rotator cuff disease (stage II) Brox[144] performed a randomized clinical trial in 125 patients with at least 3 month of clinical symptoms. The follow-up took place after 6 month and no difference was found between the surgery and physiotherapy groups when evaluating them according to Neer score.

Aims of the Study

The overall aim of the study was to evaluate the kinematics of glenohumeral joints in healthy individuals in relation to patients suffering from subacromial impingement and also determine the effect of three different treatment options (physiotherapy, open surgery and arthroscopic surgery).

The specific aims were:

Study I: Shoulder Kinematics in 25 Patients with Impingement and 12 Controls

▪ to study three-dimensional motion of the shoulder joint at *active* abduction (painful arc test) in patients with impingement syndrome stage II and controls.

▪ to evaluate the relative contribution of the glenohumeral joint in relation to the scapular rotation, the glenohumeral joint motion and spine at maximum *active* abduction of the arm.

▪ to determine the repeatability of *active* abduction of the shoulder joint.

Study II: Kinematic evaluation of Neer sign and Hawkins sign

▪ to evaluate the three-dimensional motion of the shoulder joint in patients with impingement syndrome as compare to controls when placed in the Neer and Hawkins position (*passive* elevation and internal rotation and *passive* forward flexion to 90 ° in combination with internal rotation of the arm).

▪ to evaluate the relative contribution of the glenohumeral joint in relation to the scapular rotation, the glenohumeral joint motion and the spine at maximum *passive* abduction of the arm.

▪ to determine the repeatability of Neer sign (*passive* elevation with the arm internally rotated).

Study III: Shoulder rhythm in patients with impingement and controls

▪ to study the relative contribution of glenohumeral motion to the total or absolute (the scapular rotation, the glenohumeral joint motion and the spine) *active* and *passive* abduction of the humerus throughout the motion and to find out if there is any difference between patients with impingement syndromes and the control group.

▪ to study whether the speed of motion (angular velocity, velocity of proximal translation of the humeral head centre) differs between those groups.

Study IV: Shoulder Kinematics evaluated before and after treatment of impingement syndrome. 19 patients randomized to open surgery, arthroscopic surgery or physiotherapy

▪ to study the three-dimensional motions of the shoulder joint in patients with impingement syndrome stage II who were treated with physiotherapy, arthroscopy and open surgery.

▪ to evaluate the clinical outcome on the basis of Constant-75 score.

▪ to determine if there is correlation between changes in Constant-75 score before and after treatment and any corresponding changes of the shoulder kinematics.

Patients, methods and study design

Patients and controls

Study I: Shoulder Kinematics in 25 Patients with Impingement and 12 Controls
The kinematics of the glenohumeral joint at *active* abduction was studied. 25 patients, 16 men and 9 women mean aged 51 years, median aged 50, *range 29–63* years with shoulder symptoms (Neer Stage 2) for more than 18 months and without rotator cuff tears or osteoarthritis were included. All patients were examined using radiography and ultrasonography Twelve healthy volunteers (controls), 8 men and 4 women (mean and median age 32, *22–59* years) without shoulder symptoms constituted the control group (Table B, appendix)

Study II: Kinematic evaluation of Neer sign and Hawkins sign
The kinematics in Neer sign and Hawkins sign were evaluated in 18 patients, 11 men and 7 women (median age 49, *29-65* years) with shoulder symptoms (Neer stage 2) for more than 18 months and without rotator cuff tear or osteoarthritis were included. They were recruited from a clinical study aimed to evaluate different treatments of shoulder impingement syndrome. All patients were examined with radiography and ultrasonography. Eleven volunteers without shoulder symptoms constituted a control group, 4 men and 7 women (median age 32, *22-58* years). Only one of each patient/volunteers' shoulders was used in the study. The gender distribution between controls and patients did not statistically differ (p=0.26, *Fisher's Exact Test*), but the controls was significantly younger (p=0.02, *Mann-Whitney Test*, Table B, appendix).

Study III: Shoulder rhythm in patients with impingement and controls
In the evaluation of the shoulder rhythm, relative contribution of glenohumeral motion to the total or absolute *active* and *passive* abduction (the scapular rotation, the glenohumeral joint motion and the spine) of the humerus throughout the motion were studied. Thirty patients (median age 49, *29-63* years, 20 men) respectively 21 patients (median age 50, *29-63* years, 13 men) were included.

Four men and 7 women (mean age 38, median 36, *22-58* years) without shoulder symptoms constituted a control group in the *active* abduction group and 4 men and 5 women (mean age 35, median 30, *22-58* years) without shoulder symptoms constituted a control group in the group performing *passive* abduction. The gender distribution between the control group and patients in the studies of *active* and *passive* abduction did not statistically differ (p=0.09, and 0.28, *Fisher's Exact Test*), but the individuals in the control group were younger (p= 0.008, 0.004, *Mann-Whitney Test,* Table B, appendix).

Study IV: Shoulder Kinematics evaluated before and after treatment of impingement syndrome. 19 patients randomized to open surgery, arthroscopic surgery or physiotherapy
52 patients primarily recruited to the subgroup evaluated with RSA, 19 (13 male, 6 female, median age 51, *37 - 63* years) participated throughout the study period. All of the patients had had symptoms for at least 18 months and were examined using radiography and ultrasonography for exclusion of rotator cuff tear, osteoarthritis of generalized joint disease such as rheumatoid arthritis.

In *the physiotherapy group* 17 patients were originally recruited. Six did not reach the relative abduction 30°-50° at one or both of the occasions. Three patients had no follow-up, 1 had a stroke and 2 did not want to participate). One patient was excluded because of poor scatter of visualized tantalum markers (high conditions number) leaving 7 patients, 6 male and 1 female (54, *39-63* years), to be studied.

In *the open surgery group* 19 patients were at first randomized to this treatment option. Two refrained from surgery due to spontaneous improvement and one after having changed his occupation. Three patients lacked complete observations between relative abduction 30°-50° at the follow-up evaluation, in 2 patients too few markers had been visualized, 2 turned out to have rupture of the rotator cuff, one was suffering from severe heart disease and one emigrated leaving 7 patients, 5 male, 2 female (52, *39-61* years) with complete data.

In *the arthroscopic surgery group* only 5 patients, 2 male and 3 female (54, *49-58* years) could be included. Reasons for drop out were spontaneous recovery (4), unwillingness to participate (2), and lack of complete observations 30°-50° (1), poor marker scatter of visualized tantalum spheres (1), additional surgery because of shoulder instability (1) and detection of rotator cuff injury (1). Eleven patients participated in studies with their left shoulder and 10 patients with the right shoulder (Table B, appendix).

Methods

Patient history and Clinical examination (Study I-IV)

Patient history

All of the patients were recruited from a larger study where the aim was to evaluate the result of treating patients with impingement, stage II with 3 different treatment options: physiotherapy, open surgery and arthroscopic surgery.

In this evaluation the patients had a formula including questions regarding SF 36, Simple shoulder test, UCLA score and Constant score and Constant-75 score (only outcome parameter accounted for in this Thesis). The surgeon (EH) did an initial examination first and the follow-up (after 3, 6, 12, and 24 months) was done by an independent physiotherapist. These form posed questions about possible neurologic disorders, spine disorder, chronic disorders of the joints (OsteoArthritis, Rheumatoid Arthritis), beginning of symptoms, period of symptoms, nature of pain; whether it occurs during activity, at rest, at night. In addition they were asked about pain localization, strength physical condition, instability of shoulder, side of dominant arm, occupation, psychosocial situation, frequency of sick leave and instability.

Clinical examination

The clinical examination took place at the first consultation done by the surgeon (EH) but the follow-up (3, 6, 12 and 24 months later) was carried out by an independent physiotherapist.

The examination was focused on patients with suspected subacromial impingement and shoulder disorders that might resemble this diagnosis. The examination followed the above described formula for the 4 different score system. The investigation included the cervical spine to exclude any nerve disorders or muscle disorders, possible shoulder instability by testing apprehension, and relocation test, possible chronic joint disorders by testing adjacent joints as far as range of motion goes and also other joints of the body if there was any sign of disorders. The body cross test was used for testing the AC-joint.

Inspection of the shoulder then followed with the aim of finding muscle atrophy. Palpation of the glenohumeral joint, AC-joint, and sternoclavicular joint was done and any tenderness of the joints was registered. The active and passive range of motion was documented with goniometric measurements. A specific test for diagnosing subacromial impingement was used, such as Neer sign and Hawkins sign. Also the painful arc test was performed. For testing the rotator cuff, Jobe`s sign (supraspinatus muscle) and lift of sign was used. The diagnosis was confirmed with the Neer test where 10 ml Xylocain 1% or similar anaesthetic was injected in the subacromial space resulting in substantial pain relief.

Radiographic examination (Study I-IV)

Because of this study, one the authors of this study and one of the radiologists of the Radiographic Department of Uddevalla Hospital decided to list a series of important radiographic examinations and views for the diagnosis of impingement of the shoulder and also to find any other disorders.

The painful shoulders of all of the patients were examined with anterior-posterior radiographs with the shoulder in internal and external rotation. Through this examination any disorders of the glenohumeral joint including the AC-joint could be detected. Also if there were any signs of total rotator cuff tear with a minimum distance of 6 mm between the acromion and the humeral head, this could be detected. The patients were also examined by a "supraoutlet view" for the purpose of evaluating the morphology of acromion and also to determine whether there were any spurs interfering with the supra outlet area (Neer).

An axillary view was also taken for the purpose of further evaluating the AC-joint.

Ultrasonographic examination (Study I-IV)

Every patient who took part in the study was examined by an experienced radiologist who knows ultrasonography. 2 radiologists performed the study.

The opposite shoulder was also examined to determine whether there was any pathology. The radiologists were looking for partial and total tears of the rotator cuff and also observing the way the rotator cuff reacted while the patient was moving, his or her arm.

Radiostereometry (Study I-IV)

In our study the kinematics of the shoulder was evaluated by use of both static technique (Hawkins sign) and by dynamic technique (Painful arc test and Neer sign). Four to 6 spherical tantalum markers (Ø = 0.8 or 1.0 mm) were inserted into the scapula (acromion) and the humeral head under local anaesthesia. Two to six weeks later the patients were coming to the laboratory for performing the RSA evaluation. A set up was used in which two radiographic-tubes were attached to the ceiling in front of the two film exchangers (Figure 12). These were placed side by side and designed for simultaneous exposure.

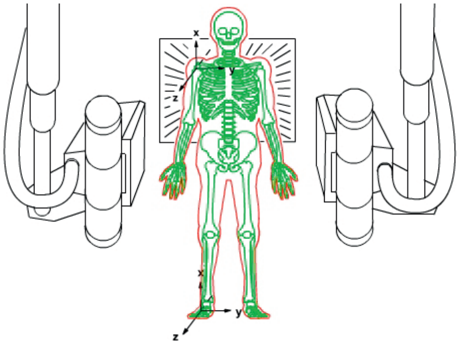


Figure 12. A set up of 2 radiographic-tubes and 2 film-exchangers, side by side designed for simultaneous exposures.

The height of the tubes and the film exchangers could be adjusted according to the height of the shoulder. Each film exchanger had a reference plate facing the screen adapted with tantalum markers in a regular manner[167, 169, 172]. A calibration exposure was done to determine the positions of the 2 roentgen foci and the coordinates. This exposure was used as a reference examination and the information from this exposure (the coordinates of the tantalum markers) was later transferred by a computer program (UmRsa) to the subsequent exposure of the patient and the calculation of the subsequent motion of the arm was referred to the reference examination[61].

Hawkins sign (Figure 13) was studied statically, i.e. the shoulder joint was exposed with only one double exposure when the examiner (E.H) placed the arm and shoulder in elevation and internal rotation.

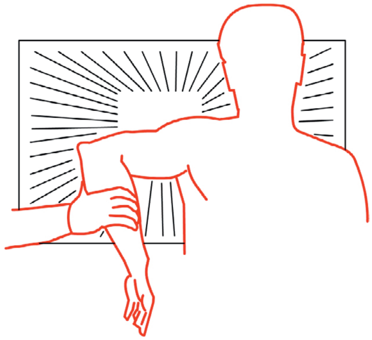


Figure 13. Hawkins sign. Patient placed in front of the film-exchangers.

Each subject (patients and controls) performed together with one of the authors (E.H.) several trials of *passive* (Neer sign, Figure 14) and *active (*Painful arc test, Figure 15) abduction to feel as comfortable as possible before the radiographic examination were initiated and to obtain a constant speed as possible.

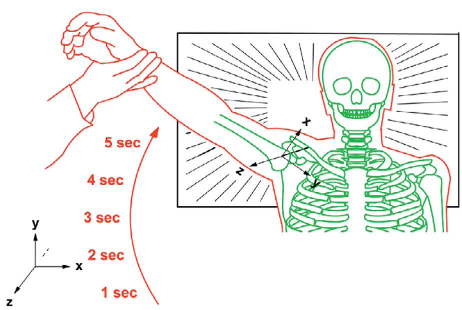


Figure 14. Neer sign. Patient placed in front of the film-exchangers.

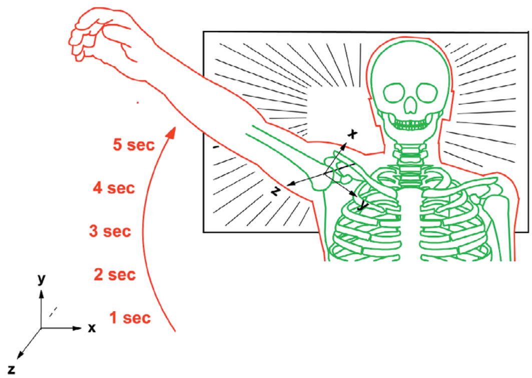


Figure 15. Painful arc test. Patient placed in front of the film-exchangers

In these trials in passive elevation (Neer sign) the examiner initially stabilized the scapula with his hand until the patients themselves could maintain the scapula at as fixed a position as possible without this intervention so that the hand of the examiner would not be included in the radiographic field of view. The patients were trained to maintain the glenohumeral joint within the limits of the aperture (film size 35 x 35 cm). A starting or reference position initiated the radiographic examination. A pair of stereoradiographs was exposed with the arm aligned to the longitudinal axis of the body and the forearm in external rotation with the palm facing forward corresponding to a well-defined anatomic position. All subsequent recordings were related to this position of the arm (Figure 12).

The dynamic recordings were started using a speed of two simultaneous stereo-radiographic exposures per second during five to six seconds. Due to failure to obtain exact synchronization between the speed of the film-exchanger and the motion of the arm there was always a reduction but at least 6 or more (of 10 available) representative pairs of stereographs (films) could be included in the final analysis in each study for patients. There were at least 7 corresponding representative pairs of stereographs (films) for the controls.

The radiographs were scanned at 300 dpi using a flat-bed scanner (Sharp JX 610, Osaka, Japan) and measured using dedicated software[173]. A fictive point corresponding to the humeral head centre was constructed to enable measurements of humeral head translations in a reproducible way. Circular templates were used to find the head centre, but only on the two images of the reference position. By using the RSA digital software the position of these centres was measured on the two images and its three dimensional coordinates were computed in the same way as for a tantalum marker, see above Thus, this plotting was done once in each shoulder. Thereafter, the position of this point was transferred to all other subsequent examinations of the same shoulder using its computed position relative to the humeral head markers. Presence of documented stable and sufficiently well-scattered tantalum marker in the humeral head is a prerequisite for these computations[172].

We measured rotations and translations of the humeral head using the scapula as a fixed reference segment. This was managed mathematically by using reversed rotation matrix calculations (Figure 16)[163].

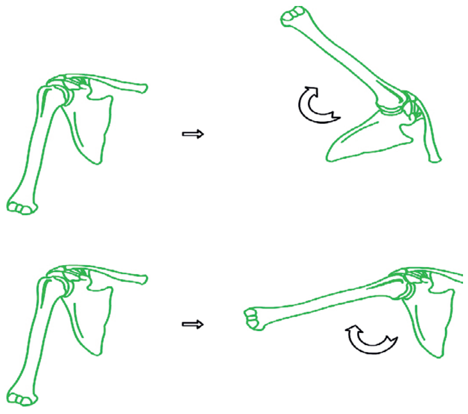


Figure 16. Schematic illustration of absolute (top) and relative glenohumeral motions.

In RSA rotations are calculated in a specific order: first around the transverse, thereafter around the longitudinal and finally around the anterior-posterior axis. Since the examiner elevated the patients arm corresponding to rotations around the anterior-posterior (AP) axis, we decided to adjust the position of the cage coordinate system 90° by rotation around the longitudinal axis. This means that in this study rotations were calculated in the order abduction/adduction (AP axis), internal/external rotation (longitudinal axis) and flexion/extension (transverse axis, Figure 17).

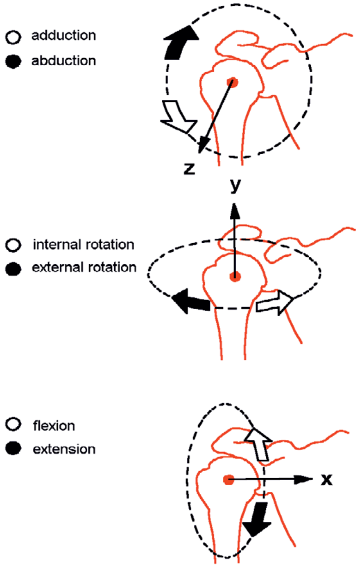


Figure 17. Order of calculation of the glenohumeral rotation used in this Thesis.

To estimate the contribution of scapular abduction at maximum relative abduction in the glenohumeral joint, we also recorded the absolute abduction of the humerus at maximum abduction recorded as humeral rotation around the AP axis. These data were extracted from the same recording used to obtain information about the relative motions. The absolute abduction is the rotation of the humerus around the anterior-posterior axis in relation to the cage coordinate system. It is the sum of the relative abduction in the glenohumeral joint, the scapula and the trunk.

The mean values for the error of rigid body fitting (mean value for each patient segment - an indicator of marker stability) were calculated in the reference segment (scapulae) and the moving segment (humerus) in each study. The mean of values indicating marker scatter (condition numbers) were also calculated in the reference segment (scapulae) and in the moving segment (humerus) in each study.

The reproducibility was tested in both *active* abduction (Painful arc test, 6 patients) in study I and *passive* abduction (Neer sign, 3 patients) study II, who repeated the *active* respectively *passive* abduction after a time interval of 15 minutes.

Randomization (Study IV)

The patients were allocated into three treatment options: physiotherapy, open surgery and arthroscopic surgery using closed envelopes. The randomization was based on age (<55, >55) years and gender.

Treatment options (Study IV)

Non-Operative Treatment

The patients in study IV who were randomized to physiotherapy were following the method described by Böhmer[24]. The purpose of the treatment was to let the patients find their normal kinematics of the shoulder, "the shoulder rhythm" without experiencing pain.

The gravitational forces on the arm were removed by suspending the arm in a sling fixed to the ceiling (Figure 9). The training program started with rotational motions of the arm. As soon as the patient could perform this movement without pain the therapy went on to include flexion/extension and lastly abduction-adduction. Repetitive motions in the sling with minimum experience of pain were done for about 60 minutes every day. Patients were trained together with the physiotherapist twice a week and performed the training program by themselves, the rest of the week. Gradually load was added to strengthen the rotator cuff and the scapular stabilizing muscles. The training continued for three to six months, with the supervision gradually being reduced. Patients were encouraged to gradually engage in leisure activities that could replace the training session depending upon what kind of physical activities they were used to. At the same time as the patients got instructions for training the physiotherapist also explained the pathogenesis for the patient. The aim being that they understand why they were undergoing a specific training program. It was our intension to make the patients more motivated to do the exercises.

Open acromioplasty

Before surgery the patient had had his symptoms for at least 18 months and had had conventional physiotherapy and other treatments such as anti-inflammatory drugs and steroid injections in the subacromial space.

Open anterior acromioplasty was first described by Neer in 1972[1]. Anterior acromioplasty involves debridement of inflamed subacromial bursa, resection of the coracoacromial ligament and any spurs that are present, resection of the anterior-inferior aspect of the acromion, and resection of distal osteophytes from the acromioclavicular joint or of the entire joint if there is preoperative tenderness. The procedure was modified by Rockwood and Lyons[95] who introduced two-step acromioplasty. In this procedure the anterior edge of the acromion cuts and then the acromioplasty according to Neer is accomplished. In this procedure it is necessary to suture the anterior part of the deltoid to the acromion to preserve the deltoid function. This was not always necessary and depended on the amount of bone that was removed at the anterior edge of the acromion (Figure 10).

This procedure was done on an out-patient basis. Before leaving the hospital subjects were Informed about postoperative treatment of the wound and given a training program as well as a postoperative appointment with the surgeon (one of the authors) 3 to 6 weeks later. At the same time there was a message sent by the patient to the physiotherapist with instructions on physiotherapy according to Böhmer. The patient was given an ice-pack in a sling for reducing the pain postoperatively and this function as well as a sling the first day after the operation. The patient was ordered as soon as possible to start with physical activity as soon as possible, but within the limit of pain.

Arthroscopic Subacromial Decompression

Prior to the surgery the patient had has his symptoms for at least 18 months and had had conventional physiotherapy as well as other treatments such as anti-inflammatory drugs and steroid injections in the subacromial space.

In 1987 Ellman described arthroscopic subacromial decompression as an alternative to open acromioplasty[148]. In our study the arthroscopic procedure was done with the patient in a lateral decubital position. A traction device was applied to the arm and a tension to the arm corresponding 40 Newton was applied. The shoulder was in 10° of flexion and 40° of abduction. The procedure started with marketing the bony landmarks of the shoulder, acromion, the clavicle, the AC-joint and the coracoid and the coracoacromial ligament. A portal for the arthroscopy was created at the dorsal site of the shoulder one cm medial of the most lateral point of the acromion of the shoulder and two cm distal of the lateral part of acromion ("soft spot"). The glenohumeral joint is first evaluated by the arthroscopy where one is looking for cartilage changes and rotator cuff disorder. The biceps tendon and the labrum are also investigated. The subacromial space is then visualized from the same portal and a bursectomy is performed by a shaver introduced to the subacromial space by a lateral portal. A resection of the anterior edge of the acromion of about 5-8 mm is done depending on the amount of spurs according to the preoperative radiographs and what is detected by the arthroscopic procedure. Finally a resection of about 5-8 mm of the anterior third of the under space of acromion is done (Figure 11).

The same procedure postoperatively was done as described after surgery with open arthroplasty

Clinical evaluation (Study IV)

The clinical outcome has also been evaluated by Constant-75 Score (Constant score excluding strength test[174, 175]) and its sub score for pain.The Constant score was preoperatively recorded by one of the authors (EH) and then after 3, 6, 12 and 24 months by an independent physiotherapist.

Statistics

Study I. Data for each type of motion analyzed were interpolated linearly at 5° intervals of abduction. Statistical analyses (SPSS 13.0 for Windows, Chicago, Il, USA) were based on recordings between 25° and 55° of abduction in the glenohumeral joint using scapulae as a fixed reference segment. The selection of the 25° to 55° interval was done to maximize the number of observations and meant that 25 patients and 12 controls could be included in the statistical analysis. Repeated measure ANOVA was used. The significance level was set at $p < 0.05$.

In the test of repeatability pooled (= a way to average) standard deviations are presented as a simplification to account for changes of variations during the arc of motion in each individual.

Study II. Statistical analyses (SPSS 13.0 for Windows, Chicago, Il, USA) were based on recordings between 20° and 55° of passive elevation in the glenohumeral joint using scapulae as a fixed reference segment. This interval was chosen to maximize the number of available observations from each group (18 patients, 11 controls).

Repeated measure ANOVA (MANOVA) was used to evaluate shoulder motions during the Neer manoeuvre. Any differences of humeral head position between patients and controls in the Hawkins position were evaluated using Mann-Whitney u-test. The significance level was set at $p<0.05$.

In the test of repeatability pooled (= a way to average) standard deviations are presented as a simplification to account for changes of variations during the arc of motion in each individual.

Study III. Statistical analyses (SPSS 13.0 for Windows, Chicago, Il, USA) were based on recordings between 20° and 55° of relative active and passive abduction in the glenohumeral joint using scapulae as a fixed reference segment. This interval was chosen to maximize the number of available observations from each group, *active* abduction (painful arc test, 30 patients, 11 controls) and *passive* abduction (Neer sign, 21 patients, 9 controls)

Non-parametric tests were used in evaluation where each patient contributed with one observation. Repeated measure ANOVA (MANOVA) was used when each subject contributed with a series of dependent observations. Non-parametric correlation was used. The significance level was set at $p<0.05$.

In the test of repeatability pooled (= a way to average) standard deviations are presented as a simplification to account for changes of variations during the arc of motion in each individual.

Study IV. All statistical evaluations were based on non-parametric tests because of the limited number of observations. Changes between the preoperative and follow up examinations were evaluated using the Wilcoxon signed rank test. Comparison of radiostereometric data at *active* abduction was done based on data recorded at 50 degrees of active abduction using Kruskal-Wallis test. The same test was used to evaluate radiostereometric data recorded for the Hawkins test and Constant75 score and its subscore for pain.

All statistical evaluations were done on the observed differences. Radiostereometric data were based on differences between the studies done before and those recorded after the treatment (physiotherapy: median 38 months 14-68, arthroscopic surgery: median 27 months 26-35, open surgery median 29 months (13–34) after the treatment.

The clinical data were based on differences between the first evaluation before the initiation of the treatment and the one performed 2 years later after the treatment. Stepwise linear regression analysis was used to study whether a change of Constant-75 score was associated with changes of the humeral head position at 50° of active abduction or the test for Hawkins sign.

Ethics

The local ethics committee at the Medical Faculty at the University of Göteborg approved both the study of patients and controls based on two separate applications (registration numbers 475-95, 520-97).

Results

Study I: Shoulder Kinematics in 25 Patients with Impingement and 12 Controls

Painful arc test (active abduction)

The rotation and translation around the 3 cardinal axes in *active* abduction (painful arc test) in patients with impingement stage II and controls were as follows:
During the initial phase of *active* abduction, the humerus was slightly extended compared to its reference (starting position) of the hanging arm and the palm facing forwards. With proceeding abduction, there was an associated flexion in both groups, which reached a mean of 10° at 60º abduction, irrespective of the presence of impingement or not (Figure 18). In both groups there was also similar external rotation of the humerus of about 20º and 35º in the patients and controls, respectively (Figure 19).

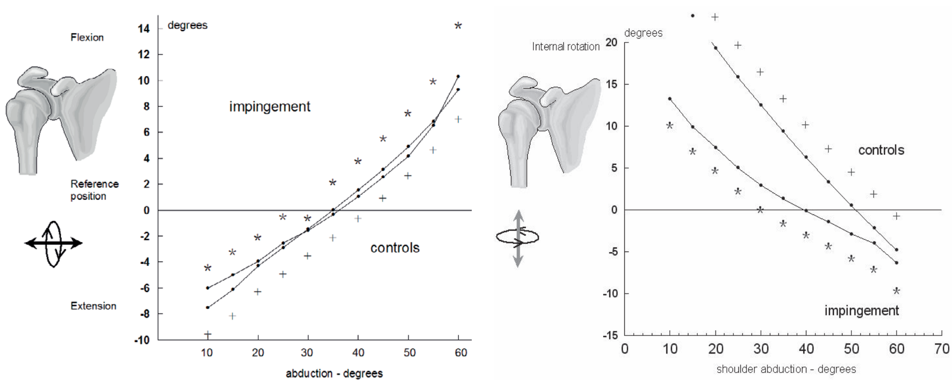
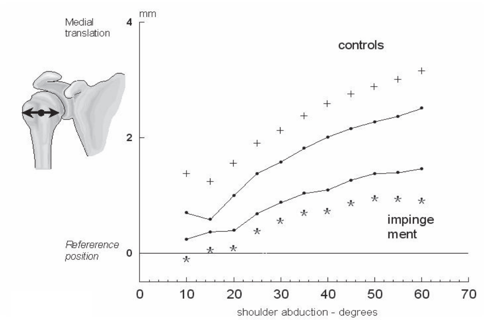


Figure 18-19. Flexion/Extension of humerus during active abduction, Mean, SE. The “distortion” of the mean at 0-10° and 60 - 70° of abduction is partly due to missing observations (left). Internal/External rotation during abduction. Mean, SE (right).

In patients and controls, the humeral head center shifted at a mean of 1 and 2 mm medially with abduction of the shoulder joint (p=0.2**,** Figure 20). Small proximal displacements were observed in both groups. Patients with impingement did, however, maintain a position, which was 1 to 1.5 mm more proximal (p=0.04) during the motion (Figure 21). Patients with impingement showed almost no mean AP shift of the head centre. In controls there was a minor mean anterior displacement but without any difference compared to the patient group. (p=0.3, Figure 22).



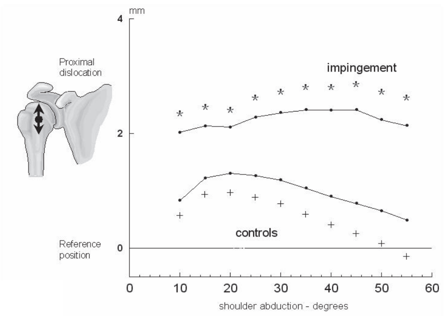


Figure 20-21. Medial/Lateral translation of humeral head centre during active abduction (left). Proximal/Distal translation of humeral head centre during active abduction (right). See also legend to Figure 18-19.

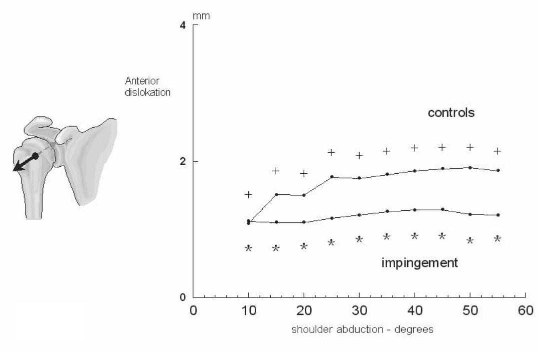


Figure 22. Anterior-posterior translation of humeral head centre during active abduction, Mean, SE See also legend to Figure 18-19.

The glenohumeral ratio at maximum absolute and total active abduction (Painful arc test)

The relative contribution of the glenohumeral joint and the scapula/trunk to the abduction of the arm was about the same in patients and controls. The abduction of the arm related to the fixed coordinate system of the cage and amounted to 139°, *101°–168°* and 137°, *126°–155°* in patients and controls, respectively. The corresponding mean relative maximum abduction of the humerus with the scapula fixed (in the glenohumeral joint) was also similar in the 2 groups (patients: 70°, *57°–93°*, controls: 72°, *42°–83°*). Thus, only about 50% of the total motion occurred in the glenohumeral joint, irrespective of the presence of impingement or not.

Reproducibility
Repeated examinations of active abduction flexion/extension varied by 3.0° and internal/external rotation by 4.2º (2 pooled standard deviations). The corresponding values for medial/lateral, proximal/distal, and anterior/posterior translations of the humeral head centre were 0.6, 0.2 and 0.2 mm, respectively.

Study II: Kinematic evaluation of Neer sign and Hawkins sign
The three-dimensional motions of the shoulder joint in patients with impingement syndrome and controls were studied in tests of Neer sign (*passive* elevation and internal rotation) and Hawkins sign (*passive* forward flexion to 90° in combination with internal rotation of the arm).

Neer sign

Rotation and translation
All the patients and the controls managed to reach at least 55° relative abduction of the glenohumeral joint (mathematically fixed scapula). Initially the humerus also moved into slight flexion. With proceeding abduction up to 55°, the flexion turned to extension in both groups and reached a mean of 28°, *-36°–63°* in patients and a mean of 22°, *-48°–42°* in controls.

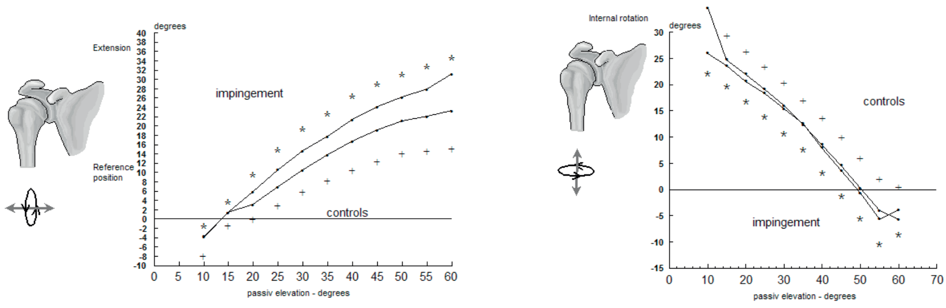


Figure 23-24. Flexion/extension of humerus during passive elevation, Mean, SE (left). Because of partly missing observations there is a "distortion" of the mean at 0-10 and 60-70 degrees of passive elevation. Internal/external rotation during passive elevation, Mean, SE (right).

(p=0.55, Figure 23, Table C, appendix). In the early phase of the motion the humerus rotated slightly internally followed by an external rotation to about a mean of 6°*,-55°–35°* in patients and 4°, *-30°–33°* in controls at 55° of relative humeral abduction (p=0.9, Figure 24, Table C, appendix).

The mean *proximal translation* of the humeral head centre was 1.1 mm *, -7–8* at 55° in patients and -0.1 mm, *-4–5* in controls (p=0.4, Figure 25 , Table C, appendix).

A minimum *anterior translation* (about 1 mm) was observed in the two groups. At 55 ° of abduction the mean anterior translation in the patient and control groups was 0.7 mm *,-7–3* and 0.9 mm, *-0,4–2* respectively (p=0.9, Figure 26 , Table C, appendix).

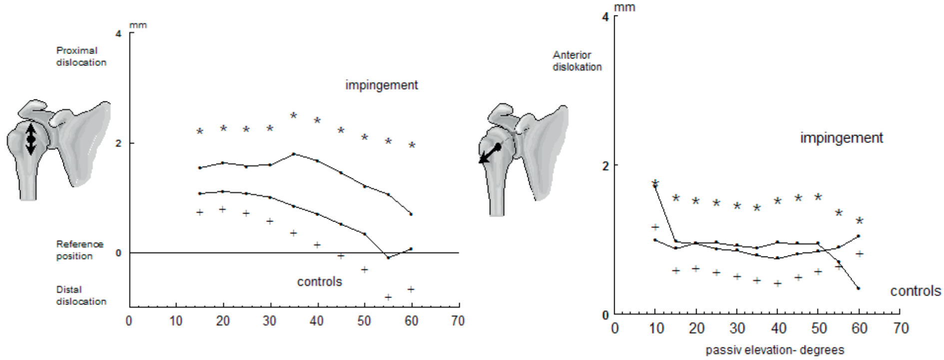


Figure 25 -26. (left) Proximal/distal translation of humeral the humeral headcentre during passive elevation (left). Anterior/posterior translation of the humeral headcentre during passive elevation (right). Mean, SE.

The humeral head centre *translated medially* both in patients (mean 1.1 mm, *-6 mm – 7 mm*) and controls (2.7 mm, *0 – 5 mm*); p=0.12, Figure 27, Table C, appendix).

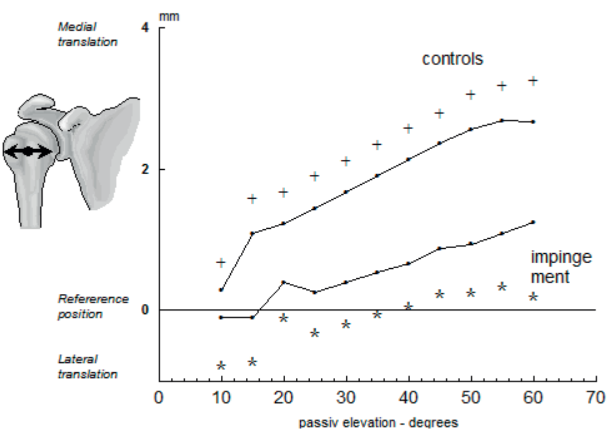


Figure 27. Medial/Lateral translation of humeral headcentre during passive translation.

Hawkins sign

Rotation and translation

In the Hawkins position the humerus showed no mean *rotation* into flexion or extension in the patients (mean -1°, *-71° – 46°*) and a tendency to flexion in the controls (mean 14°, *-71°-74°*

,p=0.16, Table D, appendix). Internal rotation of the humerus was observed in the two groups (patients: mean 65°, *22°-106°*; controls: 57°, *-40° - 107°*, p=0.7, Table D, appendix).

The corresponding mean abduction reached 50°*, -88°–16°* and 71°*, -128°–2°*, respectively, (P=0.07, Table D, appendix). In the patient group the humeral head centre had a more lateral position than in the control group (mean -0.1 mm, *-7– 7* versus 2.1 mm, *-4– 4* ; p=0.02, Table D, appendix). The humeral head centre of the patients was also positioned more superiorly than in the control group (mean 3.2 mm, *-1–12 vs*. -1.0 mm , *-21– 6*; p=0.04, Table D, appendix). The anterior/posterior translations during the test did not differ (patients: mean 2.5 mm, -*2–11* versus controls: mean –1.3 mm, *-35 –6*; p=0.07, Table D, appendix)

The glenohumeral ratio to maximum absolute or total passive abduction (Neer sign)

The absolute *passive* abduction of the humerus at maximum movement of the arm was about the same in patients and controls (patients: 151° *120–182°*, controls: 158° *146–172°*). The corresponding mean relative maximum abduction of the humerus with fixed scapula and trunk was also about the same (patients:67° *55–83°*, controls: 66° *34–80°*). Thus, only about 40% of the total motion occurred in the glenohumeral joint, irrespectively of the presence of impingement symptoms or not.

Reproducibility. Repeated elevation of the arm by the same examiner was associated with a variability corresponding to 6.4° (2 pooled standard deviations) for relative flexion/extension and 9.9° for relative internal/external rotation. The corresponding values for relative medial/lateral, superior /distal, and anterior/posterior translations of the humeral head centre were 0.4, 0.5 and 0.4 mm, respectively.

Study III: Shoulder rhythm in patients with impingement and controls

Rotations

During *active* abduction the patients had a reduced mobility in the glenohumeral joint up to 40˚ of relative abduction in the shoulder joint (Table E, appendix), Figure 28. Thereafter, the relative contribution of the glenohumeral joint was about the same as in controls (all observation from 20 to 55˚ of relative glenohumeral abduction: p=0.04)

The pattern of mobility at absolute *passive* abduction was rather similar in patients and controls (Table F, Figure 29, p=0.8).

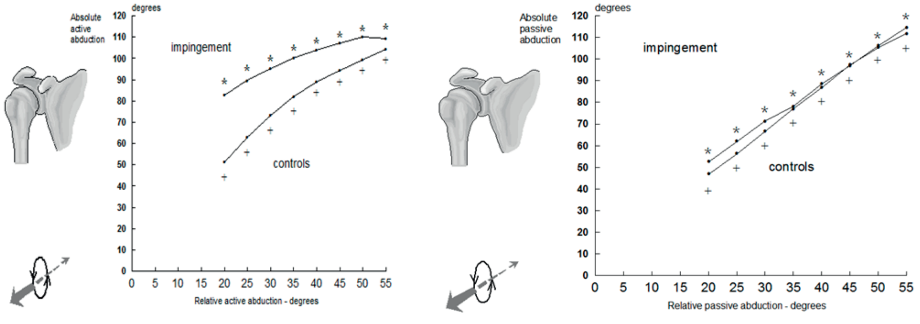


Figure 28-29. Absolute and relative active abduction of the humerus in the patients and the controls (left). Mean, SE. Absolute and relative passive abduction of the humerus in patients and the controls (right, p=0.8).

Translations

Both groups showed an increasing *proximal displacement* of the humeral head centre with increasing active and passive abduction of the glenohumeral joint and humerus (Tables G and H (Figures 30 and 31) without any statistically significant differences between the groups (absolute active abduction: p=0.2; absolute passive abduction: p=0.1). In the control group the mean maximum absolute proximal displacement amounted to about 20 mm and in the patient group about 30 mm. The corresponding relative displacement (with fixed scapula) constituted only 0.5 and 2 mm, respectively.

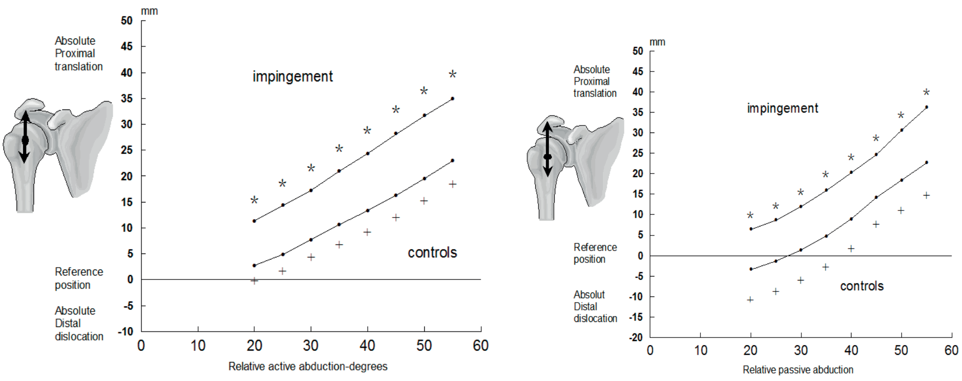


Figure 30-31. Absolute and relative active proximal translation of the centre of the humerus head and relative active abduction of the GH-joint in patients and the control group (left). Mean, SE. (p=0.2). Absolute and relative passive proximal translation of the centre of the humerus (right), Mean, SE. (p=0.1)

Influence of age

When analyzing the influence of age, in the whole material (patients and controls, 20-55º of relative abduction) there was no correlation between any of the variables recorded to describe shoulder motion and age (r = -0.1 to 0.2, p>0.4). A separate analysis only including the control group only showed that the amount of active absolute shoulder rotation increased with decreasing age (relative abduction 40 to 55º: r=0.64–0.66, p=0.04). The other parameters studied did not show any correlation to age (r = -0.3–0.6, p>0.05).

Motion velocity

Active abduction was initiated with angular velocity of almost 80 degrees/s in controls and 50 degrees/s in patients. It decreased with increasing abduction in both groups down to about 20 degrees/s (controls) after 3 seconds without any difference (p=0.4, Figure 32).

The examiner accelerated the *passive* abduction of the arm for 2 seconds up to about 40-50 degrees/second followed by a decelerating motion. As expected the speed of motion between the groups was rather similar (p=0.7, Figure 33).

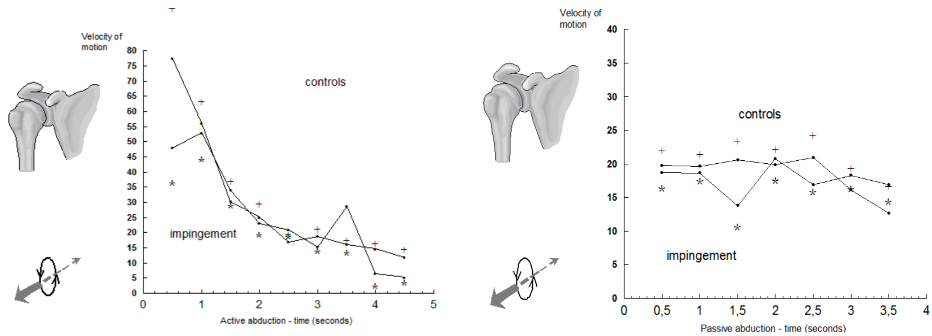


Figure 32-33. Angular velocity during active abduction. Patients with impingement versus the control group. Mean, SE. (left, P =0.4). (Right) Angular velocity during passive abduction. Patient with impingement versus control group. Mean, SE. (right, p=0.7)

The speed of proximal translation during active abduction peaked 0.5–1 s earlier than the speed of proximal translation during passive abduction and maintained a more even speed of motion for about 1s, followed by a deceleration.

Patients with impingement did not deviate from the control group (p=0.4, Figure 34). The speed and pattern of translation during passive abduction was rather equal to the pattern observed during active abduction and without any difference between the control and patient groups (p=0.5, Figure 35).

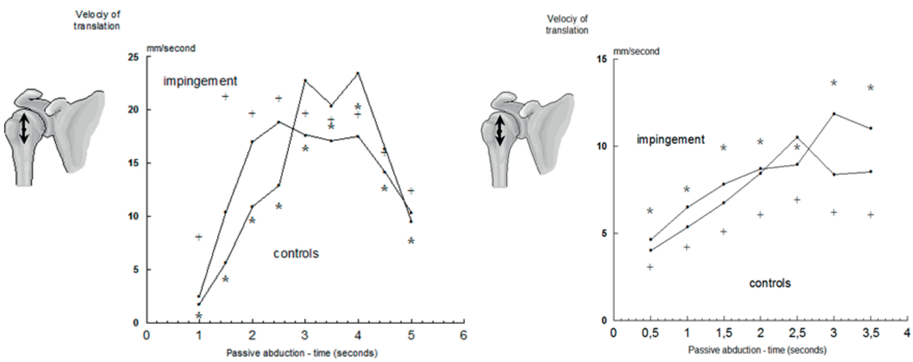


Figure 34-35. The translation velocity during active abduction. Patients with impingement versus controls. Mean, SE. (left, p=0.4). The translation velocity during passive abduction. Patients with impingement versus controls. Mean, SE. (right, p=0.5).

Reproducibility. Repeated active abduction of the arm was associated with a variability corresponding to 4° (2 pooled SD) for absolute abduction. The corresponding value for absolute active proximal translation was 3.5 mm. The equivalent values for repeated passive abduction of the arm by the same examiner were 9° and 7 mm (2 pooled SD).

Study IV: Shoulder Kinematics evaluated before and after treatment of impingement syndrome. 19 patients randomized to open surgery, arthroscopic surgery or physiotherapy

Painful arc test (active abduction)

Comparison within the group

Two years after initiation of the treatment the humeral head had not changed its position at 50° of *active* abduction (flexion/extension, internal/external rotation; medial/lateral, proximal/distal, anterior/posterior translation: p>0.06) in two of the groups (physiotherapy, arthroscopic surgery). In the group treated with open surgery the humerus displayed about 13° increased internal rotation (p=0.03) and the humeral head centre was displaced 2 mm more laterally at 50 °of *active* abduction (p=0.04).

Comparison between the three groups

Rotation

During *active* abduction of the shoulder joint between 30° and 50° there mean flexion up to 15° (physiotherapy group at follow up) to a mean maximum of 7-8° of extension (open surgery group – before treatment). There was also internal or external humeral rotation with mean values ranging from about 13° of internal to about 10° external rotation. The most pronounced changes and absolute maximum values were observed in the group of patients treated with open surgery. Evaluation of the changes caused by the 3 treatments revealed no differences between the treatment groups for neither flexion/extension nor internal/external rotation (p=0.29 and 0.25, Table J, appendix)

Translation

Between 30°and 50° of abduction the humeral head center displaced mean 0 to 2 mm medially at both the initial and the follow up examinations. Simultaneously it displaced at a mean of 1 to 3 mm proximally and the mean displacement in the anterior/posterior direction varied between +/- 2 mm. The change of the recordings at 50° of abduction performed before and after treatment did not differ between the 3 groups (medial/lateral p=0.61, proximal/distal p=0.77, anterior/posterior p=0.57, Table K, appendix).

Hawkins test

Comparison within groups

In neither of the groups were the humeral rotations or the translations of the humeral head centre found to be influenced by the treatment (comparison of data recorded before treatment and at the follow up occasion (p≥0.07, Table L, appendix).

Comparison between groups

The shoulder joint rotated both into mean flexion and extension in the Hawkins position. The mean internal rotation varied between 48°and 64° before and 46° to 56° after treatment. In most patients abduction was observed with mean values between 16° and 54° before and 35 to 70° after treatment in the three groups, respectively. The before/after treatment change of the rotational position of the joint during this test did not differ between the three groups (flexion/extension: p=0.71, internal/external rotation: p=0.19, abduction/adduction: p=0.23, Table L, appendix).

At 30° and 50° of abduction the humeral head center displaced by a mean of 0 to 2 mm medially at both the initial and the follow up examinations. Simultaneously it displaced by a mean of 1 to 3 mm proximally and the mean displacement in the anterior/posterior direction varied between +/- 2 mm. The change of the recordings at 50° of abduction performed before and after treatment did not differ between the 3 groups (medial/lateral: p=0.28, proximal/distal: p=0.75, anterior/posterior: p=0.76, Table M, appendix).

Clinical results

Comparison within groups

Two years after inclusion the Constant-75 score had improved from 38 to 75 (median) in the group treated with arthroscopy (p=0.04). In the other 2 groups there was no certain change (physiotherapy group: p=0.14, open surgery group: p=0.18).

At evaluation of the sub score for pain no improvement was observed in the physiotherapy (p=0.23) or in the open surgery group (p=0.06), whereas the patients in the arthroscopic surgery group improved from 2 to 15 (median) points (p=0.04, Table N, appendix).

Comparison between groups

Patients treated with surgery improved more than those treated with physiotherapy (p=0.025, Table 13). The group treated with arthroscopy had improved with 37 points in Constant-75 score, whereas the physiotherapy group only improved with 7 points (arthroscopy vs. physiotherapy groups=0.008, Table 13. The group treated with open surgery had improved with 22 points (open surgery vs. physiotherapy: p=0.048, arthroscopic vs. open surgery: p=0.6, Table N, appendix).

Evaluation of the sub score for pain revealed that the improvement (median 5, 13 and 11 for the physiotherapy, arthroscopic surgery and open surgery groups) did not differ (p=0.43, Table N, appendix).

Change of motion data and change of score

Regression analysis of all cases showed a tendency to more pronounced improvement of Constant-75 score with increasing shift of the humeral head centre in the medial (p=0.009, adjusted r^2=0.29, p=0.02) and posterior direction at test of Hawkins sign (p=0.02, improvement of r^2 to 0.52). Motion data at active abduction (50°) had no influence.

Discussion

Repeatability

Both the Neer and Hawkins signs are considered highly sensitive but have poor specificity and poor predictive value[176-178]. The reproducibility of shoulder motions in the test of Neer sign was fairly high in our study. In accordance with Harryman et al[33], we also found a large scatter of data among patients and controls, but in the individual patient the shoulder motion could be repeated with a reasonable reproducibility.

According to our observations the associated flexion/extension and internal/external rotation could in the majority of cases be reproduced with a precision of less than 10° and concerning femoral head translations an upper limit of 0.5 mm was recorded. It should, however, be noted that the deviation tended to increase with increasing abduction. It is also important to emphasize that we only studied the intra-observer error. If more examiners had been involved the scatter would probably have increased. In comparison with our studies of active abduction the repeatability (precision) of rotations was poorer. Repeated active abduction could be performed with a corresponding maximum error of about 4 degrees, whereas the maximum translation error in any of the three directions was 0.6 mm. Thus it seems that the patient more accurately can repeat a defined shoulder motion than can be done by an examiner who subjects the shoulder joint to passive motions during an impingement test.

Measurement error – RSA

In this study we did not evaluate the error of the RSA method itself, because an absolutely fixed position of the shoulder joint could not be obtained, which is necessary to study the actual marker configurations. Based on the documented marker stability (mean error of rigid body fitting) and marker scatter (condition number) 2 standard deviations of error (95% confidence limit) for the motion parameters studied (proximal-distal translations and ab-adduction) would most probably constitute 0.25 mm and 1 degree or less respectively.

This would mean that most of the variability observed could be attributed to difficulties for the patient to consistently repeat the same shoulder motion twice despite a preceding period of training. They could, however, do so with a higher reproducibility than could the examiner, when performing the passive elevation. Thus, the variability presented is partly caused by technical and partly by biological factors.

Shoulder joint anatomy and kinematics

Computation and presentation of three-dimensional motions may be done in different ways. The mathematical method mainly used in RSA (Euler angles) mimics the way chosen by most orthopedic examiners to describe motions. We therefore think that this method is clinically relevant even if there are alternatives. Another limitation is that data only were collected from a single and standardized series of RSA examinations only. Dynamic recordings during performance of different activities, including tasks requiring shoulder abduction above the horizontal plane would have been more relevant, but can at present not be done using RSA, for ethical and methodological reasons. Our studies may, however, provide new and basic information about shoulder joint kinematics during a standardized motion.

Generally, the rotational center of the humeral head cannot be reliably determined with active or passive motion of the intact glenohumeral joint because the motion will not necessarily be purely rotational, particularly if one assumes mismatch in curvature between the glenoid and the humeral head[29, 32, 179, 180]. We simplified the humeral joint area configuration to a circle. This means that the point of measurement might not always have been located at the center of rotation. The measuring point was, however, equal in patients and controls to minimize the risk of any systematic differences. Such differences are more likely to occur if any of the randomly located bone markers or the center of these markers have been used.

Meskers et al[181] found that the average radius of the humeral head is slightly larger than that of the glenoid. He assumed that the cartilage was relatively deformable, which means that in vivo the contact between the two articular areas would become closer. He, like Soslowsky et al[30] declared that at least in normal shoulders the glenohumeral joint behaves like a perfect ball and socket joint, which from a methodological point of view supports our use of the head centre to represent humeral translations. Computation of the shortest distance between the humeral head and the acromion would add still more information. Such studies may become possible provided that in addition to the RSA examinations the shoulder joint is examined with computed tomography to map out the skeletal surface and at the same time is used to determine the position of the tantalum markers.

Kinematics- methodology

Recordings of the absolute motions are as accurate as recordings of relative motions, but they are more difficult to interpret, because they refer to a fixed coordinate system. Another and more universal problem with kinematic recording is alignment of the coordinate system to the axis of the body or a specific joint. In our study the coordinate system was aligned to the body. The transverse axis should then ideally travel through the centers of e.g. humeral heads, the longitudinal axis is vertically aligned along the humerus when placed in an anatomic position with the arm hanging along the trunk and the sagittal axis is angulated 90° in relation to these axes. To standardize our reference position we aligned the patient as well as possible to the coordinate system and all patients positioned their palms facing forwards which means that the arm and the shoulder joint was in neutral extension/flexion and abduction/adduction whereas the rotational alignment was close to maximum external rotation. During active and passive abduction most individuals initiated their motion with internal rotation probably partly because this measure implies that the activity can be performed in a more comfortable way.

Kinematic evaluation of shoulder motions could be based on measurements of movements related to an external and fixed global coordinate system or "internal" coordinate systems fixed to each bone of interest. In radiostereometry tantalum markers are used to define each bone and the alignment of one of the bones to the coordinate system is defined at an arbitrarily used reference examination. During motion all bone will move in relation to the global coordinate system. These motions are labeled "absolute." By use of inverse matrix rotations the coordinate system of one of the bones e.g. scapula might be reoriented at each position examined to its original location. By subjecting the second bone segment (e.g. the humerus) to the same inverse rotation matrix, the true relative motion of a specific joint is computed. Detailed information on the absolute motions of the humerus might, however, be of interest because they are easier to estimate through visual inspection of the patient.

One problem is their interpretation, because they are the sum not only of the humeral and scapular motions, but also include any motions of the trunk. Even if the examiner tried to train the patients and the controls to avoid any such motions, this measurement cannot be expected to have been completely successful. Thus, more or less pronounced motions between the thorax and the scapula and bending of the spine are in addition to scapular and relative humero-scapular rotations included in the parameter "absolute rotation." We focused our analysis on the glenohumeral joint rotations and translations, because symptoms are regarded to be due to shoulder joint pathology and these motions could be exactly described.

Shoulder motion and age

Degenerative changes of the rotator cuff are supposed to increase with age[182]. In our study we found no such correlation in the total material. In the control group the subjects were, however, more mobile when performing an active abduction regarding rotations around the anterior-posterior axes. This finding is difficult to interpret not least because comparison of this parameter between patients and controls revealed no difference. Concerning proximal translation during active abduction, the only parameter that differed between the groups, we found no age related influence.

In this study we isolated the *relative abduction* in the glenohumeral joint and related this mobility to the *global motion* of the arm, which is closer to what the examiner actually observes. This implies a simplification because out-of-plane motions are not accounted for and the contribution of different parts of the body to the absolute motions could not be mapped out in detail. For the purpose of our study we do, however, think that analysis of shoulder abduction and proximal humeral translation is of particular interest. In study I we found that the patients with impingement have significantly increased proximal translation of the humeral head at active relative abduction of the glenohumeral joint compared to a control group[75]. We also observed the same phenomenon when evaluating the Hawkins sign in patients with impingement [76]. Abnormal shoulder motions in these patients suggest that they also have reduced, delayed, or otherwise changed synchronization of motions in the glenohumeral joint. This hypothesis could partly be confirmed in Study IV.

Patient selection

Some patients randomly allocated to the three treatments in study IV were excluded because of an inability to reach 50° of relative abduction corresponding to an estimated absolute motion of 105° of abduction. This could have introduced some bias in the interpretation of data. To be more inclusive we did, however, want to ascertain that active motion within the range of abduction, which causes pain, actually had occurred and therefore required observations between 30° - 50° for the each subject to be included. Another problem was that as many as 8 patients in the surgery groups spontaneously recovered partly due to the long waiting list. Even if this could be regarded as advantageous from the patient's point of view, it also implies a selection bias, probably by an overrepresentation of patients with a more severe disease.

Shoulder kinematics and impingement

According to our findings, external humeral rotation is coupled to active abduction of the arm. This rotation could facilitate motion of the tuberosity under the acromion, and thereby avoid impingement of soft tissues. Our observations are not quite on line with those of MacGregor[183] concerning internal humeral rotation at the end of the movement. This discrepancy could partly be because many of our patients did not reach 180° of absolute motions. Another important difference is that MacGregor studied passive motions in fresh cadavers, which may not correspond to the situation in vivo.

We found no significant kinematic differences between the patients and controls during the test of Neer sign. In our study the humerus was slightly flexed and internally rotated at the beginning of the motion. Extension increased with continuing abduction, whereas the early internal rotation changed to external rotation at the later part of the motion. This external rotation might explain why Flatow et al[184] did not observe any subacromial rotator contact at the end of the elevation in their study. The external rotation at the end of motion may place the greater tubercle away from the undersurface of acromion and thereby facilitate the motion.

Harryman et al[33] used cadaver shoulders and found translational motions of the humeral head. These researchers applied pressure on the humerus and the effect of any muscle activation was not studied. Chen et al[185] studied 12 male volunteers (mean age, 27 years) without any shoulder symptoms using conventional radiography. They found essentially no change in the position of the humeral head as the arm was abducted from 0° to 130° (mean change = 0.3 mm). After fatigue, the motion did, however, increase to an average of 2.5 mm, perhaps because of a more distal position before the motion was initiated.

We found a slight proximal displacement of about 1 mm during the early phase of abduction probably because of effect of muscular activation. With proceeding abduction there was a slight distal displacement past 20°, resulting in a position close to the one reported by Chen et al[185] at maximum abduction. In accord with Deutsch et al[186] and Paletta et al[55] we found that presence of cuff dysfunction implied a subtle but measurable increase of the proximal shift of the humeral head. This motion had occurred before 10° of abduction. Thereafter, the head center seemed to maintain a relatively fixed position when studied in the horizontal plane.

The pathophysiologic background to the observed pattern of translation in patients with impingement is unclear. It could be caused by an unknown anatomical defect or variation or changed innervations of the muscles. Another and perhaps more probable explanation could be that these patients try to stabilize their shoulders during active abduction to reduce pain.

Itoi et al[187] used nine fresh frozen cadaver shoulders to simulate standard clinical tests of instability, including anterior and posterior translation and sulcus tests. In all tests the anterior and inferior humeral displacements were significantly restricted if they were done with the humerus in internal but not in neutral and external rotation. Harryman et al[33] postulated that humeral rotation caused asymmetric tightening of the capsule, which can result in translation of the humeral head. If the arm is internally rotated, the posterior capsule becomes tightened and pushes the head anteriorly. They called this the capsular constraint mechanism. We observed external rotation and would, according to this theory, have recorded posterior translation of the humeral head with increasing abduction. Instead, we found a minimum anterior shift, which places this theory into question.

Neer sign and Hawkins sign

The humeral head centre showed a consistent pattern of translation for both patients and controls in our study. It displaced superiorly, anteriorly and medially in the glenohumeral joint. Wuelker et al[47] described the translations of the glenohumeral joint in eight cadaver specimens using a dynamic shoulder model during elevation. Controlled hydrodynamic actuator forces were applied to the deltoid muscle and the rotator cuff through wire cables. Using a constant force ratio, the glenohumeral joint was elevated to 90°. Translation during elevation of the glenohumeral joint between 20 ° and 90° averaged 9.0 mm superiorly and 4.4 mm anteriorly. In our study the corresponding values were smaller in patients (1.1 mm), whereas the mean value in controls was almost zero (-0.1 mm). This discrepancy may be caused by post-mortem changes in cadavers, different techniques of recording and above all presence of muscular tension in the living subjects.

We found that the patients with symptoms had a significantly more lateral position of the humeral head centre when tested with Hawkins sign. The centre was also positioned more proximally than in the subjects without symptoms. The relationship between humerus and acromion during abduction and rotation of the shoulders has recently been evaluated by open MRI[56, 71]. In these studies the minimum acromio-humeral distance decreased significantly from 30° of abduction to 120° of abduction. The supraspinatus tendon was affected at its most sensitive part at 90° of abduction and 45° of internal rotation, but the minimum acromio-humeral distance was larger than in neutral or external rotation.

In our study, the head centre in the control group did not migrate superiorly, which could be interpreted as inconsistent with the above mentioned study. It should, however be noted that we did not measure the same parameter, which could explain these seemingly divergent findings.

The shoulder rhythm

There has been a considerable divergence in the past concerning the relative influence of scapular rotation and glenohumeral movement during abduction of the arm[188, 189,41,189] stated that during coronal abduction, scapular rotation and increasing abduction of the glenohumeral joint occur simultaneously throughout most of the movement. Between 30° and 170º, the ratio of humeral to scapular rotation was claimed to be about 2 to 1. During the first 30° of abduction, they found a great variability of the scapular motions and reported translations in both the medial and lateral direction. Freedman and Munro[54] reported that for every 3° of glenohumeral movement there were 2° of scapular rotation. This ratio was constant up to the final phase of abduction, when an increase corresponding to relatively more motion in the glenohumeral joint was found.

Freedman and Munro[54] reported mean total scapular rotation of 65° and mean total glenohumeral movement of 103°. According to our data, the relative contribution of the glenohumeral joint to the global abduction of the humerus was smaller, even though we included any rotations of the trunk. Contrary to Freedman and Munro[54], we found that the latter part of arm abduction did not occur in the glenohumeral joint but rather as isolated rotation of the scapula and/or the trunk. Further only about 40-50% of the total motion occurred in the glenohumeral joint, irrespective of the presence of impingement symptoms. The reasons for these discrepancies are unclear. Different patient selection and examination techniques could 2 reasons, but it seems probable that the methods used to measure rotation and the resolution of these methods is the most important factors.

We found that patients with impingement had a different distribution between absolute active abduction of the humerus and relative abduction in the glenohumeral joint. Even if the total amount of relative abduction was similar, patients tended to reduce glenohumeral abduction in the early phase of the motion. No such difference was observed during passive abduction. The reason for this difference is unknown, but could be an effect of pain. Instead of using the glenohumeral joint, which during the early phase of motion probably is more painful, patients activate their spinal and thoracoscapular muscles to benefit from bending of the spine and thereby reach the arc of motion, which is less painful. Another and perhaps less probable reason for early reduction of active glenohumeral abduction could be early degenerative changes in the acromioclavicular joint resulting in pain and secondary changes of the pattern of scapular and glenohumeral motions.

Freedman and Munroe[54] and Doody et al[53] analyzed abduction in the scapular plane on conventional radiographs. They computed a ratio of distribution between the glenohumeral joint and thoracoscapular joint to 3:2, whereas Poppen and Walker[12] measured a ratio of 5:4 after 30 degrees of abduction. In our study the relative contribution of the glenohumeral joint to the absolute active or passive abduction was smaller. In both patients and controls it constituted only about 40% during the early phase and then gradually increased to around 50% during both passive and active motion. Thus, the glenohumeral to scapula/trunk ratio was less then 1:1 during the majority of the observations.

Most of the early studies monitored scapulohumeral rhythm over 45˚ intervals. Greater variability was observed when measurements were taken at 30˚ increments. Inman et al[41] and

Saha[180] studied abduction in the coronal plane, whereas others[12, 53, 54] studied the arm elevation in the scapular plane.

In a more recent analysis of arm elevation past 30° using an electro-mechanical device with a reported accuracy of about 1-2 mm and 1° GH to ST ratios lower than 2:1 was found beyond 30°, which is more consistent with our findings[190]. Based on our results it does, however, seem that the scapular contribution to arm elevation is greater than previously reported.

Our analysis during passive abduction showed a similar pattern of the distribution of glenohumeral and scapulo-thoracic motions in patients and controls. Grachien et al[58] could not demonstrate any difference in glenoid (scapula) rotation on sequential MRI images between patients with impingement and 14 controls. They studied the shoulder at 30˚, 90° and 120˚ of abduction, with and without muscle activity. These results are consistent with our concerning the passive motion, but differ concerning active abduction. This difference may be because the MRI studies were done statically, whereas we exposed the shoulder joint during motion.

Grachien at al[191] studied the relative glenohumeral translation during active and passive abduction with three-dimensional open MRI. Fifteen healthy subjects were studied at 5 different positions of passive abduction (30°- 150°) and at 3 different positions during active abduction of the shoulder, with and without an adducting load to the arm at 60, 90 and 120˚ of adduction. The center of the glenoid and the midpoint of the humeral head were determined by 3D reconstruction and their relative position calculated.

They found that the humeral head translated inferiorly 1-2 mm at both passive and active abduction, with slightly reduced motions during muscular activity. We found that in a control group the humeral head center displaced about 1 mm proximally during early passive and active abduction and tended to be displaced slightly distally with proceeding abduction[75, 76]. Even if Grachien´s observations differed from ours performed during continuous shoulder motions, the magnitude of the observed displacement were within the range of 1-2 mm in both studies

We found that impingement syndrome is associated with minor changes of the shoulder kinematics. These changes include an increased proximal displacement of the humeral head centre during active abduction and the test of Hawkins sign. During the test of Hawkins sign the humeral head centre also had a more lateral position in patients with impingement compared to controls. If these changes are associated with the pathogenesis of impingement syndrome clinical improvement could be expected to be associated with their disappearance, perhaps in a more or less gradual way. Findings of an association of improved Constant-75 score and a more medial shift of the humeral head centre in the Hawkins position supports this hypothesis.

Effects of treatment

At two years follow-up we did not find any effect of treatment on the pattern of shoulder in 2 of the groups. In patients treated with *open surgery* there was a significant increase of internal humeral rotation and the centre of humeral head was displaced more laterally at 50° of relative active abduction ("painful arc test"). None of these changes were consistent with normalization, which would be implying a more distal position of the humeral head centre.

The etiology of the actually observed kinematic change is somewhat unclear. They might be a consequence of open treatment and surgical exposure of the subacromial space. The significance of this finding and its possible clinical implications might be weak, not at least because the comparison of the changes caused by treatment revealed no difference between the three treatment groups.

The interpretation of the kinematic changes occurring in patients with impingement syndrome and after treatment is difficult. It could be that shifts of the humeral head centre in the proximal/distal direction not are firmly associated to the impingement syndrome. It could also be that due to the laxity of the shoulder joint patients might to some extent adapt to such changes. More or less visible degenerative changes inside and around the shoulder joint may also result in at least some of the changes in the pattern of motion. If so, such changes can be expected to remain and especially after conservative or less invasive surgical treatment using arthroscopy.

Another problem is the comparably small sample sizes resulting in low statistical significance. We also found a comparatively high intra-individual variability and especially when recording rotations in testing of the Neer sign. This variability is probably an effect of the high degree of multiplanar mobility of the shoulder joint. During a test of passive mobility it seems to be more difficult to move the arm and simultaneously avoid changes between repeated examinations of concomitant rotations around the longitudinal and transverse axis of the arm compared to the situation at active abduction. This means that it becomes difficult to statistically verify small changes of rotations. To what extent such small changes are of clinical importance is uncertain. According to our findings of association between improvements in Constant-75 score and shift of the humeral head in the Hawkins position, it seems that this could be the case at least concerning humeral head translations.

The patients in this study were recruited from a prospective randomized clinical study to evaluate any clinical differences between three treatment options. When evaluated with Constant-75, the patients treated with surgery improved significantly more than those treated with physiotherapy. This result differs from a study by Brox[144] who compared arthroscopic surgery and physiotherapy. The follow-up time was shorter (6 months) and more patients were included, which might explain the different outcomes.

The future

The motions of the shoulder joint complex has a high degree of complexity because motions originate from four joints, the sterno-clavicular joint, the acromio-clavicular joint, the glenohumeral joint and the thoracoscapular joint. In this thesis dynamic radiostereometry was used for the first time to study glenohumeral motion. This method is well suited for this purpose because motions of individual joints can be studied separately. One important limitation with our set-up is, however, is that it only allows studies of certain specific activities limited to the flexibility of the radiographic set-up and the speed of exposure. In the future, use of fast digital detectors with exposure rates of 20-40/s and use of more flexible equipment may overcome some of these problems.

One limitation with study IV was the limited sample size. This means that further studies are needed to draw relevant conclusions regarding the effects of different treatments on the kinematics of the shoulder joint. Further studies are also needed to more firmly confirm any association between the glenohumeral kinematics, symptoms of impingement and any effect on these symptoms by normalization of the pattern of motion caused by this disease.

Other fields of interest for dynamic studies of shoulder joint kinematics are shoulder joint instability, degenerative rupture of the supraspinatus tendon, osteoarthritis and joint replacement. Such studies have the potential to facilitate the evaluation of the pathogenesis of some of these conditions, to delineate their influence on glenohumeral motion and also be of value to assess the effect of treatment.

Conclusions

Study I: Painful arc test (active abduction) Shoulder Kinematics in 25 Patients with Impingement and 12 Controls

- Patients with impingement syndrome showed only minor deviations of the glenohumeral kinematics compared to controls. There was an increased proximal shift of the humeral head centre, which occurred in the very early phase of activity.
- About 50% of the total motion of the arm occurred in the glenohumeral joint, irrespective of the presence of impingement.
- The repeatability of rotations and translations during the test varied between 3.0-4.2° and 0.2-0.6 mm (2 pooled SD).

Study II: Kinematic evaluation of Neer sign and Hawkins sign

- Shoulder kinematics did not differ between patients with impingement and controls during the Neer manoeuvre.
- In the Hawkins position the humeral head centre had a more lateral and superior position in the patient group, but the relative humeral head rotations did not differ.
- About 40% of the total motion occurred in the glenohumeral joint, irrespective of the presence of impingement symptoms.
- The repeatability of rotations and translations during the test varied between 6.0-9.9° and 0.4-0.5 mm (2 pooled SD).

Our findings do not support the theory that abnormal passive shoulder motions precede development of impingement syndrome. The reasons for abnormal humeral head translations during active abduction (Study I) and at Hawkins sign (Study II) are not known. It could be an effect of degenerative changes or a way for the patient to avoid or reduce pain.

Study III: Shoulder rhythm patients with impingement and controls at painful arc syndrome and Neer`s sign (active respectively passive abduction)

- The distribution of movement between the glenohumeral joint and the upper body, during both passive and active abduction of the scapula was less or equal to 1:1 in both patients and controls.
- During *active* abduction the patients had a reduced mobility in the glenohumeral joint up to 40˚ of relative abduction in the shoulder joint. The pattern of mobility at *passive* abduction of the arm was rather similar in patients and controls.
- In the control group, but not in the patient group, the amount of active absolute shoulder rotation increased with decreasing age. The other parameters studied did not show any correlation to age.
- The angular velocity and the speed of proximal translation during active and passive abduction of the arm did not differ between patients and controls.

Study IV: Kinematics evaluated before and after treatment of impingement syndrome. 19 patients randomized to open surgery, arthroscopic surgery or physiotherapy

- Two years after initiation of the treatment the humeral head had not changed its position at 50° of *active* abduction in two of the treatment groups (physiotherapy, arthroscopic surgery). In the group treated with open surgery the humerus displayed increased internal rotation and the humeral head centre was displaced more laterally.

- Comparison of the changes in shoulder joint kinematics (rotations and translations) caused by the 3 treatments revealed no differences during active or passive abduction or in the position used to test Hawkins sign.
- Open or arthroscopic surgery resulted in a better outcome measured as Constant-75 score.
- Regression analysis of all cases showed a tendency to more pronounced improvement of Constant-75 score with increasing shift of the humeral head centre in the medial and posterior direction in the test of Hawkins sign. Motion data at active abduction (50°) had no influence.

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Appendix

Table B Randomization to A=Arthroscopic Subacromial Decompression, O=Open Acromioplastic, P=Physiotherapy

(I) Shoulder Kinematics in 25 Patients with Impingement and 12 Controls,

(II) Kinematic evaluation of the Hawkins and Neer sign,

(III) Shoulder Rhythm in Patients and Controls, Dynamic RSA during active(III(a)) and passive(III(p)) abduction.

(IV) Shoulder Kinematics in 19 patients with impingement after arthroscopic surgery(as), open surgery(os) and physiotherapy(pt).

Gender	age	sida	rand	I	II	III(a)	III(p)	age	IV(pt)	IV(os)	IV(as)
female	58	left	A	X	X	X	X				
female	56	left	O	X	X	X	X				
male	40	right	P	X	X	X	X				
male	49	right	A	X		X					
female	63	right	P								
male	37	left	P	X		X					
male	57	left	P					60	X		
male	50	left	A	X	X	X	X	52			X
male	49	right	O	X		X	X	52		X	
male	34	right	O	X		X					
male	68	right	O								
female	62	left	P								
male	76	left	O								
male	49	left	A			X		79			X
female	32	left	P								
female	48	right	A					52			X
female		right	S								
female	53	left	O	X		X					
female	54	right	A	X		X					
female	57	right	O					60			X
male	53	left	O								
female	28	left	A	X	X	X	X				
female	54	left	P		X	X	X				
female	55	right	A	X			X	58			X
female	58	right	O								
male	37	left	P	X	X	X	X	41	X		
female	45	right	P	X	X	X	X				
male	54	left	O	X		X		56		X	
female	50	left	A								
male	40	left	A	X	X	X					
female	31	left	P								
male	63	left	P	X	X	X	X	66	X		
female	39	right	Ö	X		X				X	
male	56										
male	69	right	A								
male	60	right	P	X	X	X	X	62	X		
female	39	left	P	X	X	X	X	42	X		
female	45	left	O		X	X	X	48		X	
male	51	left	O								
female	53	right	O								
male	56	left	P	X	X	X	X				
male	62	right	P	X	X		X	66	X		
female	45	right	A		X	X	X				
male	60	right	A								
male	49	left	P	X	X	X	X	52	X		
female	45	left	O								
male	49	right	A								
male	51	left	O	X		X		54		X	
female	58	left	O								
male	52	right	O			X	X	55		X	
female	42	right	A								
male	48	left	P			X	X				
male	61	right	O	X	X	X	X	64		X	
subjects											
female	29	left		X	X	X	X				
female	52	left		X	X	X					
male	40	left		X	X	X	X				
male	22	left		X	X	X	X				
male	32	left		X	X	X	X				
female	25	left		X	X	X	X				
female	51	right		X	X	X	X				
female	58	left		X	X	X	X				
male	30	left		X	X	X	X				
female	27	left		X	X	X	X				
female	49	right		X	X	X					
375		left									

Table C. Kinetics of Neer sign at 55 degrees of relative abduction

Type of motion	Patients				Controls				
	Mean	SEM	CI-95%	Median	Mean	SEM	CI-95%	Median	*p-value*
Rotations *degrees*									
Extension/flexion(-)	28	5	18 - 38	26	22	7.5	7 - 37	30	0.55
Internal/external(-)	-6	5	4 - 16	-5	-4	6	-16 - 8	-4	0.9
Translations *mm*									
Anterior/posterior(-)	0.7	0.7	-0.7 - 2.1	1.3	0.9	0.25	0.4 - 1.4	0.9	0.9
Proximal/distal(-)	1.1	1.0	-0.9 - 3	0.9	-0.1	0.7	-1.5 - 1.3	-0.7	0.4
Medial/lateral(-)	1.1	0.8	-0.5 - 2.7	1.0	2.7	0.5	1.7 – 3.7	2.5	0.12

Table D. Kinetics of Hawkins sign

Type of motion	Patients				Controls				
	Mean	SEM	CI-95%	Median	Mean	SEM	CI-95%	Median	*p-value*
Rotations *degrees*									
Extension/flexion(-)	-1	7	-15 - 13	3.5	14	12	-9.5-37.5	23	0.16
Internal/external(-)	65	5	55 - 75	66	57	11	35 - 79	65	0.7
Adduction/abduction(-)	-50	7	-36 - 64	-51	-71	10	-91-(-51)	-71	0.07
Translations *mm*									
Anterior/posterior(-)	2.5	0.65	1.2 - 3.8	2.3	-1.3	3.4	-8 - 5	1,0	0.07
Proximal/distal(-)	3.2	0.7	1.8 - 4.6	2.6	-1.0	2.2	-5.3 - 3.3	0.8	0.04
Medial/lateral(-)	-0.1	0.9	-1.9 - 1.7	0.04	2.1	0.4	1.3 - 2.9	2.5	0.02

Table E. Combined spine, trunk, scapular and humeral motions (absolute motions) at increasing degrees of motions inside the glenohumeral joint (relative motion). Recorded values and distribution between the absolute and relative glenohumeral motions in percent are presented at active abduction.

Patients						Controls					
Active abduction						Active abduction					
Gleno-humeral	Spine, trunk, scapula and glenohumeral		Gleno-humeral	Spine, trunk, scapula and glenohumeral		Gleno-humeral	Spine, trunk, scapula and glenohumeral		Gleno-humeral	Spine, trunk, scapula and glenohumeral	
mean	*mean*	*CI-95%*	*mean*	*mean*	*CI-95%*	*mean*	*mean*	*CI-95%*	*mean*	*mean*	*CI-95%*
	degrees			*percent*			*degrees*			*percent*	
20	82	70 - 94	28	72	68 - 76	20	51	36 - 66	47	53	40 - 66
25	89	78 - 100	31	69	66 - 72	25	63	48 - 77	46	54	43 - 65
30	94	85 - 103	34	66	63 - 69	30	73	58 - 88	45	55	45 - 65
35	100	91 - 109	38	62	49 - 66	35	82	67 - 97	46	54	45 -63
40	103	95 - 111	38	62	59 - 66	40	90	77 - 103	48	52	44 - 60
45	107	100 - 114	44	56	53 - 58	45	94	82 - 106	50	50	43 - 57
50	110	103 - 117	48	52	49 - 55	50	99	88 - 110	52	48	42 - 54
55	114	107 - 121	50	50	47 - 53	55	104	94 - 114	54	46	40 - 52
65	125	120 - 131	53	47	43 - 51	*73*	*125*	118 - 132	*58*	*42*	37 - 47
70	144	138 -150	51	49	48 - 54	77	*146*	139 - 153	53	47	43 - 51

Table F. Combined spine, trunk, scapular and humeral motions (absolute motions) at increasing degrees of motions inside the glenohumeral joint (relative motions) Recorded values and distribution between the absolute and relative glenohumeral motions in percent are presented at passive abduction.

Patients						Controls					
Passive abduction						Passive abduction					
Gleno-humeral	Spine, trunk, scapula and glenohumeral		Gleno-humeral	Spine, trunk, scapula and glenohumeral		Gleno-humeral	Spine, trunk, scapula and glenohumeral		Gleno-humeral	Spine, trunk, scapula and glenohumeral	
mean	mean	CI-95%	mean	mean	CI-95%	mean	mean	CI-95%	mean	mean	CI-95%
degrees			percent			degrees			percent		
20	53	43 - 63	43	57	51 - 63	20	47	32 - 62	52	48	32 - 63
25	62	51 - 73	45	55	49 - 61	25	57	43 - 71	50	50	38 - 62
30	71	62 - 81	46	54	48 - 60	30	67	54 - 80	49	51	41 - 62
35	78	67 - 89	49	51	44 - 58	35	77	64 - 90	48	52	44 - 60
40	88	78 - 98	49	51	46 - 50	40	87	75 - 101	49	51	43 - 59
45	97	87 - 107	50	50	45 - 55	45	97	83 - 111	48	52	45 - 59
50	106	88 - 106	49	51	47 - 55	50	105	93 - 117	49	51	45 - 57
55	115	105 - 125	50	50	45 - 55	55	112	101 - 129	51	49	41 - 57
62	129	122 - 136	48	52	48 - 56	63	129	115 - 143	49	51	46 - 56
67	153	150 - 159	44	56	53 - 59	69	159	154 - 164	44	56	52 - 62

Table G . Proximal translation of the humeral head in combination with active spine, trunk, scapular and humeral motions (absolute motion) at increasing degrees of motion insida the glenohumeral joint (relative motion). Recorded values in mm proximal translations of the humeral head are presented.

Patients						Controls					
Active abduction						Active abduction					
Relativ GH motion	Absolute motion	Relative prox transl		Absolute prox transl		Relative GH motion	Absolut motion	Relative Prox Transl		Absolut prox transl	
mean	mean	mean	CI-95%	mean	CI-95%	mean	mean	mean	CI-95%	mean	CI-95%
degrees		mm		mm		degrees		mm		mm	
20	82	2.1	(1.0 - 3.2)	11.1	(3,4 - 18.7)	20	51	1.3	(0.6 - 2.0)	2,7	(-3,2 - 8,6)
25	89	2.3	(1.0 - 3.6)	14.0	(6.1 - 22.0)	25	63	1.3	(0.2 - 1.7)	4,8	(-1,5 - 11,1)
30	94	2.4	(1.7 - 3.0)	17.0	(8.7 - 25.6)	30	73	1.2	(0.4 - 1.5)	7,7	(-0,9 - 14,5)
35	100	2.4	(1.6- 3.2)	20.6	(12.3 - 28.8)	35	82	1.0	(0.2 - 1.9)	10,6	(2,4 - 17,6)
40	103	2.4	(1.6- 3.2)	24.0	(15.7 - 32.1)	40	90	1.0	(-0.07 - 1.9)	13,3	(5,2 - 21,4)
45	107	2.4	(1.5 - 3.3)	27.7	(18.8 - 36.5)	45	94	0.8	(-0.3 - 1.8)	16,3	(7,6 - 24,4)
50	110	2.2	(1.3 - 3.3)	31.2	(22.1 - 40.2)	50	99	0.6	(-0.5- 1.8)	19,5	(10,9 - 28,1)
55	109	2.1	(1.2- 3.1)	34.5	(25.8 - 43.3)	55	104	0.5	(-0.8 - 1.7)	23	(14,1 - 31,9)

Table H. *Proximal translation of the humeral head in combination with passive spine, trunk, scapular and humeral motions (absolute motion) at increasing* degrees of motion insida the glenohumeral joint (relative motion). Recorded values in mm proximal translations of the humeral head are presented. At 55 degrees of relative motion there are missing observation at absolut proximal translations in patients and the control group.

Patients						Controls					
Passive abduction						Passive abduction					
Relativ GH rotation	Absolute rotation	Relativ prox transl		Absolut prox translation		Relative GH rotation	Absolute rotation	Relativ Prox transl		Absolut prox transl	
mean	mean	mean		mean		mean	mean	mean		mean	
degrees		mm	CI-95%	mm	CI-95%	degrees		mm	CI-95%	mm	CI-95%
20	53	1.5	(0.9 - 2.1)	6.4	(-0.3 - 13.0)	20	47	1.1	(0.7 - 1.9)	1.3	(-18.1- 11.4)
25	62	1.7	(1.1 - 2.3)	8.7	(2.0 - 15.4)	25	57	1.0	(0.3- 1.6)	0	(-13,4 - 16.1)
30	71	1.8	(0.6 - 3.1)	12	(5.0 - 18.9)	30	67	1.0	(0.1 - 1.8)	1.3	(13.3 - 15.9)
35	78	1.6	(0.3 - 3.0)	15.9	(8.1 - 23.6)	35	77	0.9	(-0.1 - 1.9)	4.7	(10.0 - 19.4)
40	88	1.7	(0.4 - 3.1)	20.2	(12.8 - 27.6)	40	87	0.7	(-0.5 - 1.8)	8.9	(-5.2 - 23.1)
45	100	1.4	(-0.1 - 2.8)	24.7	(16.9 - 32.4)	45	97	0.6	(-0.6 - 1.7)	14.2	(1.1 - 27.3)
50	106	1.3	(-0.3 - 3.0)	30.6	(23.4- 37.9)	50	105	0.2	(-1.3 - 1.4)	18.4	(3.8 - 32.9)
55	115	1.0	(-1 - 3.1)	36.1	(28.7-43.5)	55	111	0.0	(-1.3 - 1.4)	22.6	(7.1 - 38.2)

Table J. *Flexion/extension, internal/external rotation (fixed scapulae) of patients with impingement syndrom randomised to arthroscopic surgery,* opens surgery and physiotherapy after inclusion(preoperatively) and 38 months(follow up) after inclusion. Recorded values (mean and 95% CI) in degrees. P-value of the difference at 50° within and between the groups

	Flexion (-)		***Extension (+)***				***Internal rotation (-)***		***External rotation (+)***			
relative	*physeotherapi*		*artro - surgery*		*open - surgery*		*physeotherapi*		*artro - surgery*		*open - surgery*	
active			***preoperatively***						***Preoperatively***			
abduction	*mean*	*CI-95%*	*mean*	*CI-95%*	*mean*	*CI-95%*	*mean*	*CI-95%*	*mean*	*CI-95%*	*mean*	*CI-95%*
30	*-5*	(-)11 - 1	*0*	(-)8 - 8	*0*	(-)7 - 7	*12*	8 - 17,0	5	(-)12 - 21	1	(-)12 - 13
35	-4	(-)10 - 2	2	(-)6- 10	1	(-)6 - 8	11	7 -16,0	3	(-)13- 20	-2	(-)15 - 11
40	-3	(-)9 - 4	4	(-)4- 12	3	(-)5- 11	10	5 - 15,0	2	(-)15 - 18	-4	(-)17 - 9
45	-1	(-)7 -5	7	(-)5 - 19	5	(-)3 - 13	9	4 - 14,0	0	(-)16 - 17	-6	(-)19 - 7
50	***1***	***(-)8 -6***	***9***	***(-)4 - 21***	***8***	***(-)1 - 16***	***8***	***2 - 13,0***	***4***	***(-)13 - 21***	***-9***	***(-)22 - 5***
			Follow up 38 months						***Follow up 38 months***			
30	-17	(-)31 - (-)2	2,9	(-)25 - 31	-4	(-)6- 2	3	(-)7- 14	5	(-)12 - 22	11	3-19,0
35	-17	(-)32 - (-)3	2,6	(-)26- 31	-2	(-)8 - 3	3	(-)8 - 14	5	(-)12 - 22	10	1-18,0
40	-17	(-)32- (-)3	2,4	(-)27- 32	-1	(-)6 - 5	4	(-)8 - 15	*5*	(-)13 - 23	8	(-)1 - 17
45	-17	(-)32 - (-)3	2,4	(-)28 - 33	2	(-)4 - 7	4	(-)9- 16	5	(-)14 - 24	6	(-)0 - 10
50	***-17***	***(-)31 - (-)3***	***2,4***	***(-)30 - 34***	***4***	***(-)2 - 9,0***	***3***	***(-)9 - 16***	***4***	***(-)16 - 24***	***4***	***(-)5 - 13***
p value (within the group)	0,139		*0,893*		*0,31*		*0,595*		*0,5*		*0,028*	
p value (between the groups)			0,29						0,25			

Table K. Proximal/distal, medial/lateral, anterior/posterior translation (fixed scapulae) of the centre of the humeral head in patients with impingement syndrom randomised to arthroscopic surgery, opens surgery and physiotherapy after inclusion(preoperatively) and 38 months(follow up) after inclusion. Recorded values (mean and 95% CI) in mm. P-values at 50° abduction within and between the groups.

	Proximal(+)		**Distal (+)**				**Medial(+)**		**Lateral (-)**				**Anterior(+)**		**Posterior (-)**			
relative	*physiotherapy*		*artro - surgery*		*open- surgery*		*physiotherapy*		*arto- surgery*		*open - surgery*		*physiotherapy*		*artro - surgery*		*open - surgery*	
active			***Preoperatively***						***Preoperatively***						***Preoperatively***			
abduct.	*mean*	*CI-95%*	*mean*	*CI-95%*	*mean*	*CI-95%*	*mean*	*CI-95%*	*mean*	*CI-95%*	*mean*	*CI-95%*	*mean*	*CI-95%*	*mean*	*CI-95%*	*mean*	*CI-95%*
30	2,2	0,8-3,6	*1,6*	0,3-3,1	*2,4*	0,8-4	*1,6*	0,6-2,6	1,5	(-)0,9-3,9	1,3	(-)0,1-2,7	1,7	0,7-2,7	1,1	(-)0,3-2,5	0,8	(-)0,8-2,4
35	2,1	0,7-3,5	1,6	0,3-3,2	2,4	0,8-4	1,9	0,9-2,9	1,6	(-)0,8-4	1,5	0,1-2,9	1,6	0,6-2,6	1,2	(-)0,2-2,6	0,8	(-)0,8-2,4
40	1,9	0,5-3,3	1,7	(-)0,1-3,5	2,4	0,6-4,2	1,8	0,6-3	1,6	(-)0,9-4,1	1,6	0-3,2	1,5	0,5-2,5	1,3	(-)0,3-2,9	0,8	(-)0,8-2,4
45	1,9	0,3-3,5	1,8	(-)0,2-3,8	2,4	0,4-4,4	2,1	0,7-3,5	1,8	(-)0,7-4,3	1,8	(-)0,7-4,3	1,4	0,4-2,4	1,7	(-)0,5-3,9	0,8	(-)0,6-2,2
50	***1,8***	***0,2-3,4***	***1,9***	***(-)0,3-4,1***	***2,3***	***0,3-4,3***	***2,2***	***0,8-3,6***	***2***	***(-)0,5-4,5***	***2,1***	***0,3-3,9***	***1,2***	***0-2,4***	***1,8***	***(-)0,6-4,2***	***0,7***	***(-)0,5-1,9***
			follow up						***follow up***						***follow up***			
30	1,7	0,5-2,9	2,1	0,7-3,5	2,5	0,5-4,5	0,7	(-)0,5-1,9	1,3	(-)1,1-3,7	(-)0,1	(-)1,1-0,9	0,2	(-)0,8-1,2	2,1	0,5-3,7	0,7	(-)0,3-1,7
35	1,5	0,3-2,7	1,9	0,3-3,5	2,5	0,5-4,5	0,8	(-)0,6-2,2	1,3	(-)1,1-3,7	(-)0,1	(-)1,3-1,1	0,2	(-)0,8-1,2	2	0,2-3,8	0,8	(-)0,4-2
40	1,3	0,1-2,5	1,7	(-)0,1-3,5	2,4	0,2-4,6	0,9	(-)0,7-2,5	1,2	(-)1,1-4,3	(-)0,1	(-)1,5-1,3	0,2	(-)0,8-1,2	1,9	0,1-3,7	0,9	(-)0,3-2,1
45	0,9	(-)0,3-2,1	1,5	(-)0,7-3,7	2,3	0,1-4,5	0,9	(-)0,9-2,7	1,1	(-)1,8-4	(-)0,1	(-)1,7-1,5	0,2	(-)0,8-1,2	1,8	(-)0,2-3,8	1	(-)0,2-2,2
50	***1,2***	***(-)0,4-2,8***	***1,3***	***(-)1,2-3,8***	***2,2***	***0-4,4***	***1,3***	***(-)0,7-3,3***	***1,1***	***(-)2-4,2***	***0***	***(-)1,6-1,6***	***0,2***	***(-)0,8-1,2***	***1,6***	***(-)0,4-3,6***	***1***	***(-)0,2-2,2***
p value *within* the group	*0,678*		*0,893*		*0,31*		*0,26*		*0,89*		*0,043*		*0,314*		*0,893*		*0,31*	
p value *within* the group			0,77						0,61						0,57			

Table L. Rotation of the humeral head centre in the glenohumeral joint (relative motion) at **Hawkins sign** in patients at inclusion and after mean 38 months follow up after physiotherapy, open surgery or artroscopic surgery. Recorded values in degrees of rotation P-valeus within and between the diffrent treatmengroups.

treatment options	**open surgery**		**arthroscopic surgery**		**physeotheraphy**		**P-values**
rotation	mean (°)	*CI-95%*	mean (°)	*CI-95%*	mean (°)	*CI-95%*	Between the groups
after inclusion							
flexion(-), extension(+)	13	(2 - 23)	-32	(-86 - 22)	-7	(0- 3)	
follow up							0,71
flexion(-), extension(+)	14	(1 - 27)	7	(-31 - 46)	-13	*(-2- 3)*	
p-value	*0,735*		*0,345*		*0,953*		
after inclusion							
utåtrot.(-), inåtrotation(+)	48	(35 - 62)	64	(43- 86)	63	(53 - 74)	
follow up							0,19
utåtrot.(-), inåtrotation(+)	56	(42 - 71)	55	(37 - 72)	46	(34 - 58)	
p-value	0,237		*0,893*		*0,86*		
after inclusion							
abd(-), adduktion(+)	-54	(-62 - -45)	-16	(-65 - 34)	-46	(-70 - -22)	
follow up							0,23
abd(-), adduktion(+)	-70	(-88 - -51)	-58	(-68 - -48)	-35	(-61 - -9)	
p-value	*0,063*		*0,225*		*0,515*		

Table M. Proximal translation of the humeral head inside the glenohumeral joint (relative motion) at **Hawkins sign** in patients after inclusion and at mean follow up 30 months including physeotherapi, open surgery and artroscopic surgery. Values in mm. P-valus within and between groups

treatment options	**Open surgery**		**artroscopic surgery**		**physeotherapi**		**P-values**
translation	mean (mm)	*CI-95%*	mean (mm)	*CI-95%*	mean (mm)	*CI-95%*	Between the groups
after inclusion							
lateralt(-), medialt(+)	1.6	(-0.9 - 4.1)	1.2	(-0.8 - 3.3)	1.4	(-0.4 - 3.1)	
follow up							0.28
lateralt(-), medialt(+)	0.2	(-2.6 - 3.0)	3.3	(-2.3 - 9.0)	0.3	*(-2.2- 2.7)*	
p value	*0.31*		*0.465*		0.038		
after inclusion							
distalt(-), proximalt(+)	2.3	(0.8-3.8)	1.5	(-0.3 - 3.3)	2.8	(0.3 - 5.3)	
follow up							0.75
distalt(-), proximalt(+)	3.6	(1.5 - 5.1)	2.5	(0.7- 4.2	3.1	(0.8 - 5.4)	
p-value	*0.128*		*0.465*		*0.594*		
after inclusion							
posteriort(-), anteriort(+)	1,5	(-0.6 - 3.5)	2.2	(-0.2 - 4.6)	2.4	(0.1 - 4.8)	
follow up							0.76
posteriort(-), anteriort(+)	1.8	(0.3 - 3.3)	1.9	(-2.7 - 6.6)	1.7	(-0.3- 3.8)	
p-value	*0.612*		*0.715*		0.857		

Table N. The clinical outcome evaluated by Constant score 75 (Constant score without strength test) and its subscore for pain(points) 3,6 12, and 24 months after 3 diffrent treatement options (physiotherapy, open surgery or artroscopic surgery). P-valus within and between the treatment groups at 24 months follow-up

treatment options	**Open surgery**			**artro- surgery**			**physiotherapy**			**Open surgery**			**artro- surgery**			**physiotherapy**		
score	*con stant 75*			*con stant 75*			*con stant 75*			*pain*			*pain*			*pain*		
after treatment (month)	*median*	*range*	*valid*	*median*	*range*	*valid*	*median*	*range*	*valid*	*median*	*range*	*valid*	*median*	*range*	*valid*	*median*	*range*	*valid*
0	*43*	(12-54)	7	38	(18-48)	5	47	(39-68)	7	*1*	(1-9)	7	2	(0-3)	5	3	(0-15)	7
3	*55*	(33-67)	3	60	(24-68)	5	49	(60-74)	3	*6*	(3-10)	7	10	(4-10)	5	6	(3-8)	3
6	*56*	(51-70)	5	66	(42-75)	5	43	(60-78)	5	*7*	(3-13)	6	10	(0-15)	5	6	(0-10)	5
12	*65*	(23-73)	5	75	(52-75)	4	41	(37-80)	5	*11*	(4-15)	7	15	(3-15)	4	8	(1-9)	5
24	*65*	(20-66)	5	75	(49-75)	5	54	(45-80)	5	*12*	(2-15)	7	15	(4-15)	5	8	(3-9)	5
P-values within the group		0,18			0,04			0,14			0,06			0,04			0,23	
arhtroscopy versus physiotherpy (p-value)					0,008													
open surgery versus physiotherpy (p-value)					0,048									0,43				
arhtroscopy versus open surgery (p-value)					0,6													
arhtro. and op surg ver physiotherpy (p-value)					0,025													