Rotator cuff degeneration in the rheumatoid shoulder : 'the issue is soft tissue'

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Chapter 5

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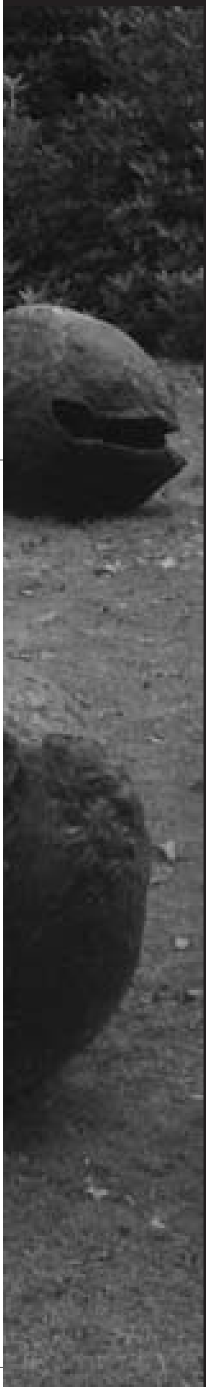

Fatty degeneration of the rotator cuff;

Clinical implications related to pain, function and force

Clinical Implications of Rotator Cuff Degeneration in the Rheumatoid Shoulder.

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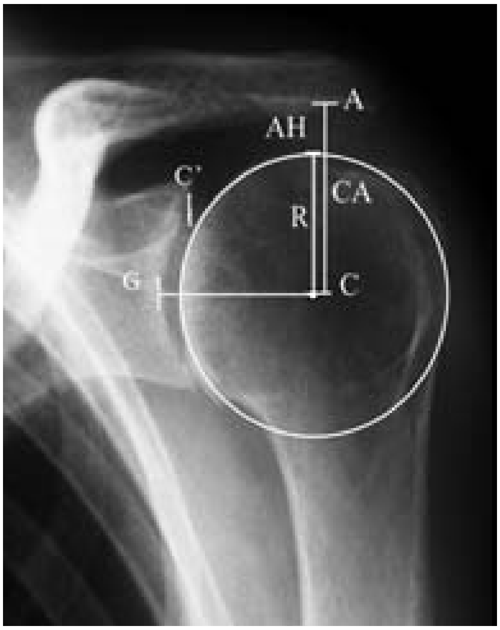
Summary

In Rheumatoid Arthritis (RA) disease of the shoulder, loss of cartilage and soft tissue degeneration co-exists with pain and reduced range of motion. In this study we evaluate the presence of bony and rotator cuff degeneration in RA of the shoulder joint and assess their relationship with pain and loss of function. We hypothesized that rotator cuff degeneration plays an important role in presence of pain and loss of function of the rheumatoid shoulder. To test this hypothesis a cross-sectional study was set-up to assess both bony and rotator cuff involvement using plain AP-radiographs, ultrasound and CT images. In addition we used an electromagnetic tracking device and a force transducer to evaluate the Range of Motion and the maximum force of the shoulder muscles. Between January 2003 and July 2004 we included 26 consecutive patients (51 shoulders) 21 showed no or slight joint destruction, 15 were intermediate and 15 severe. Only 19 shoulders showed an intact rotator cuff. Proximal migration of the humeral head and fatty degeneration of the Infraspinatus muscle especially showed a significantly strong correlation with increased pain and function loss.($R^2 = 0.36$ $p< 0,001$) In a multivariate regression analysis proximal migration and fatty degeneration of the Infraspinatus muscle, were related most significantly with the amount of pain and reduced function in the shoulder joint. Our results support the view that rotator cuff degeneration plays an important role in the daily function of the rheumatoid shoulder. Prevention of rotator cuff degeneration therefore may play an important part in the treatment of the rheumatoid shoulder.

Introduction

Rheumatoid Arthritis affects approximately 1% of the adult population and exhibits a chronic fluctuating course that often results in progressive joint destruction, deformity and disability.[166] In the etiology of glenohumeral arthritis, shoulder involvement generally occurs late in the disease process and usually after other joints have manifested arthritic change. Any of the four shoulder girdle articulations can be involved, but the glenohumeral joints are most frequently symptomatic.[3] Symptoms vary between patients, both in etiology and intensity. Swelling, stiffness, pain, decreased strength and loss of range of motion are cited as most important.[2] Rheumatoid arthritis destruction of the shoulder is characterized by proliferative synovitis (pannus), which is capable of degrading bone and cartilage matrix within and around the joint capsule. Thus, it not only results in cartilage thinning and bone loss but also in soft tissue detachment and destruction (e.g. muscle atrophy, fatty infiltration and tendonitis). Recent studies have reported that between 24-52% of all 50-year-old and older patients with rheumatoid arthritis of the shoulder joint have at least one large rotator cuff tear.[7; 167] This might explain poorer functional results and significantly more postoperative pain after shoulder arthroplasty in RA patients, compared to osteoarthritis.[22; 75] Further, fatty degeneration of the rotator cuff proved a significant predictor for inferior functional results after surgical rotator cuff tear repair.[15; 168; 169] In RA both bony and soft tissue involvement in the disease process have been related to increased pain and decreased range of motion and force in the shoulder joint.[2; 21; 22; 28] However, no report is available about the individual contribution of joint and soft tissue destruction on pain, motion and force. Further, physical function was scored mainly using the Health Assessment Questionnaire as a qualitative measure of pain, range of motion, shoulder function and force.[170; 171] No quantitative or individual measurements for pain, function and force of the shoulder were found in recent literature. Although complex, this study was set up to evaluate the incidence and severity of joint destruction and rotator cuff degeneration in the rheumatoid shoulder. In addition we set out to assess the relationship between shoulder joint degeneration and pain, range of motion and force. It was hypothesized that besides joint destruction, rotator cuff degeneration is also a relevant factor in the loss of function and force of the rheumatoid shoulder. Furthermore, as rotator cuff degeneration and proximal migration of the humeral head were strongly correlated[167], we hypothesized that proximal migration causing subacromial impingement significantly relates to the amount of pain experienced.

Figure 1. *Approximated true A-P radiograph used to calculate the Upward migration Index (UI=CA/R) and the medial displacement (CG/R and CC'/R) and rank the Larsen score (here 4). A = undersurface acromion; C = center of the humeral head; R = radius of the humeral head; AH = acromiohumeral interval; G = medial articular surface of Glenoid, C' most lateral border of the base of the coracoid process.*



Materials and Methods

To test our hypotheses, bony and soft tissue involvement were assessed using plain AP-radiographs, CT-images and ultrasound. Shoulder motion was recorded by means of six-degree-of-freedom electromagnetic tracking and a force transducer to accurately evaluate the range of motion (RoM) and the nett maximum force about the glenohumeral joint.

Between January 2003 and July 2004 26 consecutive patients with rheumatoid arthritis were included (51 shoulders). Patients were included initially after their treating physician had obtained bilateral AP-radiographs in the assessment their shoulder complaints. Final inclusion was based on the following criteria: (1) a clinical diagnosis of rheumatoid arthritis (RA) according to the "American Rheumatism Association criteria 1987" [172] (2) patients aged over 50 years of age. This age limit was chosen to impose the smallest risk from radiation exposure (effective dose 1.6 mSv, (EU guidelines)); (3) patient complaints of shoulder symptoms in at least one shoulder; (4) no prior trauma or surgery to the shoulder. The study had prior institutional review board approval. All patients were informed and provided signed informed consent. Six male and twenty female patients with an average age of 63 years (range: 50-81 yrs) participated in the study. The mean Constant score was 68 (95%-CI 35-88).[164] One shoulder was excluded due to insufficient clinical data, caused by a computer malfunction during RoM and force measurements. Forty-one shoulders were symptomatic (objective pain and loss of function) with a mean Constant score of 65.2. Ten shoulders were non-symptomatic (mean Constant score: 77.9). The mean interval between the diagnosis of RA and the CT scan was 13 years (range: 1-40 yrs).

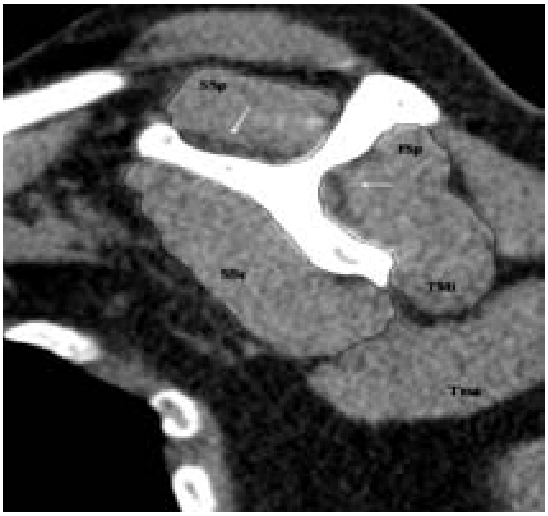
Image analysis

In order to assess the bony and cartilage involvement of RA a standardized protocol anterior-posterior radiograph was taken of each patient in the supine position, slightly turned to image side (20°), and the arm in external rotation, palm facing forward.[37] Focus-film distance was measured at 115 cm and a 15 degrees cranio-caudal tilt was used to project the undersurface of the acromion perpendicular. This created an optimal approximation of the true anterior-posterior projection perpendicular the glenohumeral joint (Figure 1). All radiographs were taken in a clinical setting in the presence of the principal investigator (MS) who controlled image quality and positioning.[167]

Proximal migration, an indicator for fatty degeneration of the rotator cuff muscles[5], was measured using the Upward migration Index (UI = CA / R)[13; 167] as the distance between the centre of the humeral head to the under surface of the acromion (CA) divided by the radius of the humeral head (R) (Figure 1). Subacromial space measurement using the UI was validated with CT-imaging.[148] The mean absolute difference between the upward migration index measured on AP radiographs and CT images was only 0.06 (SD 0.07), providing a difference smaller than 5% of the mean upward migration index measured on CT reconstructions. Medial displacement, an indicator for cartilage loss, was measured as the distance between the centre of the humeral head to the most medial articular surface of the glenoid (CG) divided by the radius of the humeral head (R).[13] We also calculated the medial displacement compared to the coracoid process as the distance between the centre of the humeral head to the most lateral surface of the base of the coracoid process (C’) divided by the radius of the humeral head (R) as a measure for bone loss (Figure 1).[105] All radiographs were scored for progression of rheumatoid disease using the Larsen score.[142; 173] (The Larsen score ranges from no to slight joint space narrowing: grade 0-1 to subchondral destruction; grade 3 to disappearance of original articular structure: [5])

Subsequently, all shoulders were scanned using a Toshiba Aquilion 16-slice CT-scanner using a constant protocol and calibration technique.[143] Fatty degeneration was measured using the Mean Muscle Density (MMD).[125] Individual rotator cuff muscles were outlined manually, carefully excluding pixels containing subcutaneous / inter-muscular fat (Figure 2).

Figure 2. *Regions of interest for the Supraspinatus, the combined Infraspinatus and Teres Minor and the Subscapularis muscles (SSp, ISp+TMI, SSc) on the parasaggital CT-images. In this example a mild fatty degeneration is present (white arrows). (TMa: Teres Major).*



A histogram was constructed from all voxels within the outlined region of interest in order to calculate the MMD of the rotator cuff muscles. The MMD is defined as the mean voxel intensity measured as the CT number within one outlined rotator cuff muscle in Hounsfield units. To correct for individual muscle-fat content, the MMD was divided by the body mass index (BMI) of the patient (normalised MMD = nMMD).[123] The MMD showed an interclass correlation coefficient for repeated measurements and interobserver measurements of 0.99. This indicates that 99% of variation was caused by the difference between the patients.[143] The Teres Minor and Infraspinatus muscles were analyzed together, as separation of these muscles has been proven very difficult and unreliable.[19]

All shoulders were examined for rotator cuff pathology by an experienced musculoskeletal radiologist using ultrasound. All rotator cuff muscles were screened for the presence of tendonitis, a small tear or a massive tear using standard ultrasonic methods.[162] Dinnes et al reported the pooled sensitivity of ultrasound in diagnosing full and partial-thickness tears was 0.87 and 0.67, respectively.[168]

Clinical analysis

The range of motion was measured using the six degree-of-freedom electromagnetic tracking device "Flock of Birds tm" (FoB) (Ascension Technology Inc., Burlington, VT, USA). This system consists of a transmitter, emitting an electromagnetic field in which position and orientation of several receivers can be tracked. Prior to the measurements a field calibration was performed.[159] Four receivers were applied around the patient's shoulder: one was taped to the sternum; one to the upper arm and another to the wrist. A fifth receiver was mounted on the flat upper surface of the acromion, in the most latero-caudal corner.[160; 174] The full active range of movement of the shoulder was measured. The skin-fixed method was found suitable for dynamic recordings of scapular rotations as its intra observer RMSE was only 5°.

***Table 1.** Average clinical results in relation to for rotator cuff pathology; mean (SD).*

					Severity of Fatty Infriltation of Supraspinatus muscle[167]			Severity of Fatty Infiltration of Infraspinatus muscle[167]		
	All (n=51)	No tear (n=39)	Supra-spinatus tear (n=12)	Infra-spinatus tear (n=3)	Absent (n=13)	Mild (n=20)	Severe (n=18)	Absent (n=12)	Mild (n=29)	Severe (n=10)
Pain in rest (0-100)	21 (2.3)	20 (2.4)	27 (1.9)	51 (1.2)	13 (2.1)	12 (1.7)	37 (2.3)	12 (1.4)	19 (2.2)	40 (2.4)
Pain during activities (0-100)	35 (2.8)	35 (2.8)	39 (2.9)	57 (3.1)	27 (2.7)	32 (2.9)	47 (2.7)	27 (2.6)	31 (2.6)	61 (2.6)
Abduction (Degrees)	109 (25.4)	114 (23.6)	107 (27.0)	75 (24.0)	124 (15.4)	114 (11.5)	91 (38.2)	121 (17.2)	112 (20.6)	81 (37.3)
External rotation (Degrees)	54 (25.1)	53 (23.8)	59 (23.2)	20 (21.6)	55 (23.6)	56 (16.5)	53 (13.2)	53 (19.0)	58 (16.6)	48 (11.8)
Forward flexion (Degrees)	105 (24.2)	111 (19.8)	88 (30.9)	74 (23.6)	114 (26.2)	109 (13.3)	94 (32.2)	116 (27.4)	107 (19.9)	86 (27.5)
Maximum force for abduction (N/kg)	0.52 (0.20)	0.51 (0.20)	0.54 (0.18)	0.35 (0.01)	0.58 (0.25)	0.55 (0.17)	0.47 (0.17)	0.64 (0.17)	0.52 (0.16)	0.43 (0.26)
Maximum force for forward flexion (N/kg)	0.52 (0.20)	0.53 (0.21)	0.47 (0.17)	0.40 (0.02)	0.43 (0.23)	0.60 (0.18)	0.43 (0.15)	0.54 (0.22)	0.56 (0.19)	0.38 (0.17)

Table 2. *Average clinical results subdivided for radiodiagnostic parameters, mean (SD.)*

	All (n=51)	No proximal migration (n=13)	Mild proximal migration (n=26)	Severe proximal migration (n=12)	No medial displace-ment (n=29)	Moderate severe medial displace-ment (n=22)	Larson 0-2 No-Mild destruction (n=29)	Larson 3-5 Moderate-Severe destruction (n=15)
Pain in rest (0-100)	21 (2.3)	15 (2.0)	16 (1.9)	39 (2.5)	20 (2.2)	26 (1.8)	18 (2.2)	29 (2.4)
Pain during activities (0-100)	35 (2.8)	25 (2.6)	33 (2.7)	52 (2.8)	21 (2.2)	50 (2.7)	30 (2.5)	48 (3.2)
Abduction (Degrees)	109 (25.4)	113 (16.9)	118 (18.0)	82 (36.4)	123 (14.8)	115 (22.6)	113 (25.0)	99 (30.7)
External rotation (Degrees)	54 (25.1)	55 (23.9)	56 (15.4)	49 (11.4)	39 (11.7)	55 (14.2)	58 (16.2)	47 (14.6)
Forward flexion (Degrees)	105 (24.2)	103 (24.6)	113 (16.8)	89 (33.8)	119 (15.9)	118 (29.8)	108 (24.7)	98 (25.4)
Maximum force for abduction (N/kg)	0.52 (0.20)	0.52 (0.10)	0.58 (0.20)	0.43 (0.22)	0.52 (0.19)	0.51 (0.20)	0.58 (0.20)	0.50 (0.19)
Maximum force for forward flexion (N/kg)	0.52 (0.20)	0.52 (0.19)	0.58 (0.21)	0.39 (0.13)	0.58 (0.20)	0.52 (0.21)	0.60 (0.21)	0.47 (0.18)

The maximum force of the shoulder muscles was assessed using a six-degrees-of-freedom force transducer (AMTI-300, Adv. Mech. Techn., Inc., Watertown, MA, USA). Subjects were seated with the right arm in a splint with the elbow in 90˚ of flexion. The humerus was elevated 60˚ in the scapular plane (30˚ angle to the frontal plane). The forearm was positioned in a splint. The splint was attached to a 3D force transducer measuring the task force in an x-y plane perpendicular to the longitudinal axis of the humerus. The arm was suspended in order to compensate for gravity. The force transducer was mounted on a sled so that it could move freely in the z-direction parallel to the humeral longitudinal axis. Axial rotation of the humerus was mechanically not restricted to prevent the subjects from generating supplementary moments. [112; 113] The force exerted on the force transducer was displayed to the subject by a cursor on a video screen. The subjects were asked to generate a maximum force in 12 equidistant directions, 30° apart, by moving the cursor along the displayed spokes of a wheel that denoted the force direction and where concentric circles denoted the force magnitude.

The maximum force that could be exerted in all 12 directions was measured (e.g. forward flexion 0°, abduction 120°). Force measurements were normalised for body weight.

Statistical analysis
A student t-test was used to evaluate the differences in shoulder joint abnormalities within subgroups for the parameters presented above. All parameters were checked for outliers and were verified to have a reasonably symmetric distribution. The modified t-test for unequal variances was used in case the Levene's test for equal variances was significant.

Multivariable linear regression analysis and Pearson and Spearman correlation were used to evaluate the relationship between bony and soft tissue involvement and the clinical parameters. Pearson's correlation coefficient was used on variables measured on a ratio scale using actual values; Spearman's Rank correlation was used only for ordinal or ranked data.

For each outcome (function, force, pain) a multivariable linear model was constructed starting from a full model incorporating radiodiagnostic parameters and using backward elimination of non-significant predictors. The resulting model is then the "smallest" model for prediction of the outcome in the sense that deletion of any of the remaining predictors would significantly reduce the predictive ability of the model.

By dividing each beta (slope of the regression line) by the standard deviation of the associated independent variable in the data set, the coefficient measures the effect on the outcome of one standard deviation (the unit of measurement becomes the standard deviation). Significances are of course not influenced by this linear transformation. This results in mutually comparable regression lines and emphasizes the individual reliability of the radiodiagnostic measures. Additional influences of age, sex, dominance, arm side and duration of rheumatoid disease were included in the analysis. All analyses were performed using SPSS for Windows version 14.0 (SPSS Inc. Chicago. Il. USA). Using a Bonferroni adjustment for our t-tests and correlation analysis, p-values smaller than 0,005 and 0,02 respectively were considered significant.

Results

Clinical results and incidence of bony and soft tissue degeneration in the rheumatoid patient: Results for pain, range of motion and force are subdivided for bony and rotator cuff degeneration and are presented in Tables 1 and 2.

Radiographic evaluation of bone destruction and cartilage los: Twenty-one shoulders showed no or slight joint destruction (Larsen 0-1), 15 were intermediate (Larsen 2-3) and 15 severe (Larsen 4-5). The average Medial migration Index, a relative measure for cartilage loss[13], was 1.08 (SD 0.17), median 1.05 (1st quartile to 3rd quartile Q_{1-3} = 0.95 – 1.18) relatively to the glenoid and 1.14 (SD 0.19), median 1.16 (Q_{1-3}: 1.06 – 1.28) relatively to the coracoid process.

The average Proximal Migration Index (UI), a relative indicator for rotator cuff pathology[167], was 1.31 (SD 0.07), median 1,32 (Q_{1-3}: 1.28 – 1.36). In 13 shoulders no proximal migration was observed (UI >1.35). In 26 shoulders moderate proximal migration (1.25 – 1.35) and in 12 shoulders severe proximal migration (UI ranging from 1 – 1.25)[170] was present.

Computed tomography analysis of rotator cuff quality:
The Mean Muscle Density divided by the BMI (normalised MMD = nMMD), a quantitative measure for fatty degeneration[167], for the Supraspinatus and Infraspinatus muscles were subsequently 1.30 (SD 0.9) and 1.60 (SD 0.47). There was no significant (cross) relationship between the BMI and the clinical parameters (pain, RoM and function of the shoulder). Fatty degeneration of the rotator cuff muscles is presented in three severity groups no (>1.74= Hounsfield units/BMI), mild (0.82-1.74) and severe fatty degeneration (<0.81).[167]

Ultrasound evaluation of the rotator cuff tendons:
The majority of shoulders showed rotator cuff pathology on ultrasound. Tendonitis was found in 20 Supraspinatus, 22 Infraspinatus and 13 Subscapularis tendons. Six small tears were found in the Supraspinatus tendon, 1 additional tear was found in the Infraspinatus and Subscapularis tendon. A massive tear was diagnosed in six Supraspinatus and in two Infraspinatus tendons.

The relation between radiographic parameters and functional results:
Coefficients of determination (R^2) between radiodiagnostic and clinical parameters are presented in Table 3. Proximal migration of the humeral head and especially fatty degeneration of the Infraspinatus muscle showed the strongest correlation with increased pain and a decreased Range of Motion (abduction/forward flexion). The maximum range of abduction (R^2=0.25) and forward flexion (R^2=0.16) also were related to the amount of pain experienced.

The partial correlation between range of motion and fatty degeneration of the Infraspinatus muscle, controlled for pain, remained relevant and significant (R^2=0.25 p<0.01). Bony deformation (Larsen score) correlated also with the perception of pain, but not as strongly.The presence of an Infraspinatus tear showed a stronger negative correlation with range of motion and pain, compared to an isolated Supraspinatus tear.

The combined correlation coefficients for all parameters presented in Tables 2 and 3 were: R^2=0.44 for pain, R^2=0.43 for abduction and R^2=0.66 for abduction force (p< 0.001).

Results for the univariable regression analysis of pain, function and force (dependants) with bony and soft tissue parameters (independents) are presented in Table 4. Using backward multivariable regression analysis for all parameters above, proximal migration and the mean muscle density of the Infraspinatus muscle, were calculated as the strongest and most significant predictors for the degree of pain and dysfunction in the shoulder joint. Proximal migration presented the most significant influence on the amount of pain experienced (Beta=-1; p=0.002). The mean muscle density of the Infraspinatus muscle was the most significant predictor for the amount of range of abduction (Beta=9.9; p=0.008) and forward flexion (Beta 12,5; p<0.0001). Further input of age, sex, side and duration of rheumatoid disease in this multivariable regression analysis revealed no confounders for the regression and correlation presented above. We found a significant relation between the Larsen score and fatty degeneration of the rotator cuff muscles. (R^2=0.15, Beta=0.37 (p<0.001)) and also a significant relation between the duration of the disease and pain in rest (Beta=1.2 (0.2/1.9). Yet, individually the Larsen score or the duration of rheumatoid disease were not relevant predictors for shoulder dysfunction in a linear regression analysis. We also found a significant difference for the mean amount of joint destruction, according to the Larsen score, between early (0-2 years) and progressed rheumatoid disease (>2 years). A significant difference for the mean amount of fatty degeneration of the rotator cuff muscles in early and progressed rheumatoid disease (mean difference 0.36 p =0.003) was found also.

Table 3. *Coefficients of determination (R^2) between clinical parameters and bony / soft tissue abnormalities (*p< 0,01, **p<0,001).*

	Larson score	Medial dis-place-ment	Proximal migra-tion	Supra-spinatus tear	Infra-spinatus tear	Fatty infiltra-tion of Supra-spinatus muscle	Fatty infiltra-tion of Infra-spinatus muscle
Pain in rest	0.08*	0.03	0.2**	0.1*	0.12*	0.13**	0.2**
Pain during activities	0.1	0.19	0.12*	0.13	0.1*	0.03	0.18**
Abduction	0.11*	0.001	0.24**	0.16*	0.26**	0.24**	0.38**
External rotation	0.07	0.21	0.01	0.15	0.06	0.007	0.007
Forward flexion	0.07	0.002	0.08	0.15**	0.25**	0.13*	0.30**
Maximum force in abduction	0.01	0.01	0.05	0.01	0.05	0.03	0.12*
Maximum force in forward flexion	0.02	0.07	0.05	0.05	0.03	0.02	0.11*

Discussion

Functional disability has been associated with pain, joint destruction and rheumatoid disease activity.[27; 28] In the early stage of the disease functional ability may be influenced more by disease activity than joint destruction.[32] Also reports show a significant relation between joint destruction and functional impairment later in the disease process.[27] However, in these studies pain and function loss were measured either subjectively or by use of a questionnaire.[28; 31] A quantitative comparison between pain, function (Range of Motion and force) and shoulder joint destruction has added value therefore. Primarily we set out to evaluate the incidence of bony and soft tissue abnormalities diagnosed using radiographs, computed tomography and ultrasound in the rheumatoid shoulder.

Additionally we sought to determine the relation between these radiodiagnostic changes and clinically relevant parameters such as pain, range of motion and force.

Our results indicate a diverse involvement of bony and the rotator cuff degeneration in the rheumatoid shoulder. Although shoulder dysfunction and pain were related to multiple factors, we observed that rotator cuff quality in the rheumatoid shoulder predicted a distinct increase in pain and a significant decrease of range of motion and force. Involvement especially of the Infraspinatus and Teres Minor muscles showed a relevant and significant relationship with these clinical parameters. Although abduction and forward flexion force are mainly the result of Deltoid muscle contraction, shoulder muscle imbalance caused by fatty degeneration of the Infraspinatus muscle causes the adductors to compensate for lost downward force resulting in a decreased total upward moment. We believe that pain and fatty degeneration of the Infraspinatus / Teres Minor muscles can therefore both induce proximal migration due to imbalance of shoulder muscle forces and cause 'secondary' pain due to impingement or shoulder instability.[42; 167] As fatty degeneration is thought irreversible early referral and treatment of shoulder involvement in rheumatoid disease may protect rheumatoid patients from this downward spiral.[12; 28; 42]

*Table 4. Univariable regression analysis between clinical and radiodiagnostic parameters. The Beta (slope) of the clinical parameter is provided per one standard deviation change of the radio-diagnostic parameter. (*significant relation).*

Standardized Beta (+/- 2 SD)	Larson score	Medial displace-ment (MMI)	Proximal migration (UI)	Fatty infitraltion- of Supra-spinatus Muscle (nMMD)	Fatty Infiltration of Infra-spinatus Muscle (nMMD)
Pain in rest (0-100)	6.6* (0.4/13)	-1.6 (-5/8)	-9.9* (-16/-4)	-8.2* (-14/-2)	-9.8* (-15/-4)
Pain during activities (0-100)	9.1* (0.4/13)	-1.1 (-5/8)	-9.9* (-16/-4)	-13 (-14/-2)	-12* (-15/-4)
Abduction (0-180°)	-8.8* (-16/1.2)	0.4 (-8/8.5)	12.8* (5.6/20)	13* (6/20)	16.6* (10/23)
External rotation (0-90°)	-4 (-9/1)	-7 (-20/5)	1.9 (-4.6/8.6)	2 (-6/10)	1.4 (-4/7)
Forward flexion (0-180°)	-6.5 (-13/0.5)	0.8 (-7/9)	-7.1 (-3/14.5)	9* (2.1-16)	13* (7-20)
Maximum force in abduction (0-50 N)	-0.1 (-0.8/0.4)	-0.03 (-0.8/0.7)	0.22 (-1.8/1.0)	0.16 (-0.03/0.1)	0.34* (0.01/0.13)
Maximum force in forward flexion (0-50 N)	-0.13 (-0.9/0.03)	-0.27 (-0.1/0.04)	0.22 (-0.2/1.1)	0.13 (0.4/0.1)	0.33* 0.01/0.1

Clinical implications

We hypothesized that pain caused by RA (e.g. synovitis, swelling or cartilage loss) leads to shoulder immobilization and disuse. This may initiate fatty degeneration of the rotator cuff muscles, causing shoulder muscle imbalance, dysfunction and 'secondary' subacromial shoulder pain.[42-44] Clinical reports on shoulder arthroplasty in rheumatoid patients have stated that they are referred too late for surgical treatment due to advanced shoulder joint destruction.[31; 75] Kelly hypothesized a relationship between this late referral and the clinical course of rheumatoid disease.[31; 75] Also, it has been stated that rheumatoid shoulders with a more rapid and progressive joint destruction showed significantly more rotator cuff abnormalities and that these were related to superior subluxation of the shoulder joint.[13; 31] In accordance with these findings we found a significant relation between the bony destruction and rotator cuff involvement, as well as a significant correlation between proximal migration of the humeral head and fatty degeneration of the rotator cuff. In particular, Infraspinatus and Teres Minor degeneration was related to proximal migration.[75] As we found no significant relation between the duration of rheumatoid disease and pain or function (RoM and force), it seems more likely that the severity of rheumatoid arthritis and not disease duration influences shoulder pain and function.

The presence of rotator cuff dysfunction, caused by fatty degeneration or tears, has been related to inferior functional results and increased pain after shoulder arthroplasty.[42; 82; 179] This may be explained by glenohumeral instability in rotator cuff deficient patients. In massive rotator cuff tear patients compensatory co-contraction of the adductor muscles (Teres Major, Latissimus Dorsi) was measured.[44] It was hypothesized that this co-contraction prevents superior subluxation due to Deltoid muscle forces in order to decrease subacromial pain.[43; 44]

Limitations of this study

We included both symptomatic and non-symptomatic shoulders as earlier reports suggested a significant relation between of rheumatoid disease activity and functional performance.[180] Although we did not analyze patients for disease activity using the DAS score, we could not reproduce the significance of disease duration or clinical activity of the disease on shoulder dysfunction. In addition, we did not find any correlation between duration of rheumatoid disease and pain, shoulder function, joint destruction or muscle involvement.

Only two dimensional AP-radiographs were used to assess bony and cartilage destruction. Soft tissue degeneration as well as function and force measurement were measured with very high accuracy and reliability. Thus, it could be argued that the presented relationship between bony destruction and clinical parameters is questionable. Further evaluation of cartilage and bone loss is needed to evaluate its relation with synovitis, function-loss and pain. A relationship between soft tissue degeneration and cartilage loss also can be hypothesised as the result of shoulder muscle imbalance and increased proximal joint loading. Although only assessed by qualitative measures we did find a significant relation between the Larsen score and fatty degeneration. More accurate measurement of cartilage and bone loss may provide better insight on its relationship with pain and loss of function.

Shoulder muscle force is thought to be related to pain.[44] Our results supported this relationship as pain was significantly correlated to abduction and anteflexion force (R^2 =0.3). Although pain in rest and during activities was evaluated before and after force and range of motion measurement, pain measurement remains subjective. This may explain the difference between pain in rest and pain during activities (Table 3).
Furthermore force measurement was only normalised for body weight, not for arm length (distance from GH joint to transducer on splint). Although we found decreased forces during abduction and forward flexion in patients with severe supra- and Infraspinatus degeneration, this relation was not found for mild degeneration. One could argue this difference originates from a less reliable measurement of force. However, we believe this difference supports our hypothesis that severe fatty degeneration of the rotator cuff muscles is related to subacromial impingement pain due to muscle imbalance and therefore relates to a decreased range of motion and loss of abduction force.

General conclusion:
Although no causal relationships were found, our results support the hypothesis that subacromial pain is induced by incapacity of the depressor muscles of the rotator cuff, as pain and range of motion are significantly related to proximal migration and fatty degeneration of the Infraspinatus en Teres Minor muscles. Prevention of rotator cuff involvement in rheumatoid disease of the shoulder may lead therefore to better functional results after shoulder arthroplasty. In already severely rotator cuff deficient shoulders a transfer of the Teres Major muscle combined with shoulder arthroplasty (in either one or two sessions) may be used as a salvage procedure in order to give rheumatoid patients sufficient pain relief and increased postoperative range of motion.[7;44]

We believe it is of great importance to screen rheumatoid arthritis patients for shoulder involvement at an early stage, even if other joints are the principle cause for medical concern. As proximal migration of the shoulder as measured with the Upward Migration index is strongly correlated (R^2 = 0.74) with rotator cuff disease an AP radiograph provides an easy to use and reliable screening of the rotator cuff.[167] This study again underlines the importance of this measurement, as it was also strongly correlated to shoulder pain and functional parameters. Measurement of proximal migration at an early stage can play an important role in timely initiation of functional and medicinal treatment of rheumatoid arthritis and may present patients with better possible outcome when shoulder arthroplasty is indicated.

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