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On the impact of calcified deposits within the rotator cuff tendons in shoulders of patients with shoulder pain and dysfunction

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Abstract We wanted to prove the hypothesis that calcified deposits within the rotator cuff tendons are merely an epiphenomenon of complex morphological alterations in the shoulders of patients with shoulder pain and dysfunction. The shoulders of 92 patients with calcified deposits within the rotator cuff tendons as noted on plain radiographs were investigated by means of magnetic resonance imaging (MRI; mean age of patient 51.1 years), as well as the shoulders of 28 age- and sex-matched patients with similar clinical symptoms but without any signs of such calcified deposits on plain radiographs. The MRI protocol comprised a coronal, oblique, T1-weighted, spin-echo sequence, a T2-weighted, turbo spin-echo sequence, a sagittal, oblique, T2-weighted, turbo spin-echo sequence, and an axial, T1-weighted, spin-echo sequence. Furthermore, a coronal, oblique, short tau-inversion recovery sequence and a gradient echo sequence were used. The results were compared with data from healthy, asymptomatic volunteers as reported in the literature. The MRI investigations showed no substantial differences between patients with or without calcified deposits within the rotator cuff tendons, but distinct differences between such patients and healthy, asymptomatic volunteers. For patients with shoulder pain, shoulder dysfunction, and calcified deposits within the rotator cuff tendons, these calcified deposits are most probably not the main cause of the clinical symptoms. Rather, it seems to be useful to consider the results of MRI investigations whenever planning therapeutic procedures for patients with shoulder pain and dysfunction, irrespective of whether or not there are signs of calcified deposits within the rotator cuff tendons on plain radiographs.

Keywords Shoulder · Shoulder pain and dysfunction · Calcifying tendinitis · Magnetic resonance imaging

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Introduction

Shoulder pain and dysfunction are clinical findings which are related to various pathologic conditions of the shoulder [18]. For many of such patients, imaging diagnostic evaluation of the affected shoulder joint demonstrates the presence of calcified deposits within the rotator cuff tendons [9]. In common clinical use, the coincidence of such calcified deposits and chronic or acute shoulder pain and dysfunction are designated as calcifying tendinitis [31]. However, the relevance of these calcified deposits to shoulder pain and dysfunction is still under discussion. For example, calcified deposits within the rotator cuff tendons have been regarded as one possible trigger of shoulder pain and dysfunction [31]. In contrast, such calcified deposits may also be incidental radiographic findings in healthy, asymptomatic volunteers [3]. As a consequence, various therapeutic approaches have been described in the literature for obtaining pain relief and functional improvement in patients with calcified deposits within the rotator cuff tendons, ranging from recommendations to remove the calcified deposits completely by surgical intervention to leaving the calcified deposits untouched [14, 30]. However, approximately 30% of patients continue to have pain and shoulder dysfunction after curettage of the calcified material [20]. At least in these patients, the calcified deposits cannot be the only explanation for shoulder pain and dysfunction.

It is therefore our hypothesis that calcified deposits within the rotator cuff tendons are merely an epiphenomenon of complex morphological alterations within the shoulders of patients with shoulder pain and dysfunction. Obviously, this would have a considerable impact on therapeutic approaches to such patients. To prove this hypothesis, we investigated patients with a similar extent of shoulder pain and dysfunction either with or without calcified deposits within the rotator cuff tendons – as noted on plain radiographs – by means of magnetic resonance imaging (MRI), recording 12 variables describing shoulder morphology. The results were compared with MRI findings of shoulders of healthy, asymptomatic volunteers as reported in the literature [8, 22, 27].

Patients and methods

Three groups of patients were investigated, who were matched for age, sex, and clinical appearance (details are given below). Patients differed concerning the type of calcified deposits within the rotator cuff tendons, as noted on plain radiographs. Inclusion criteria for patients were shoulder pain and dysfunction. Exclusion criteria were metal implants (e.g., prosthesis), pacemakers, shoulder instability, and previous trauma or surgery on the investigated shoulder. According to these criteria, 132 patients were investigated over a 3-year period (1995–1998). The affected shoulder of each patient was examined by MRI. During this investigation, 8 patients had to be excluded from the study due to either movement artifacts or claustrophobia. From the remaining 124 patients, 6 were examined in both shoulders due to bilateral shoulder pain and dysfunction. Therefore, a total number of 130 MRI investigations was analyzed here. Since for patients examined by MRI on both shoulders the clinical appearance was recorded separately for each shoulder, in the following text the 130 MRI investigations will be presented and discussed as 'investigation of 130 patients'.

Table 1 summarizes the data of the patients with respect to age, sex, and type of calcified deposits within the rotator cuff tendons as noted on plain radiographs. Patients in the first group (n = 28; henceforth referred to as ∅) showed no any signs of calcified deposits within the rotator cuff tendons. Patients in the second group (n = 48; henceforth referred to as I_{DP}) showed calcified deposits within the rotator cuff tendons which were classified as type I according to the established morphological classification of DePalma and Kruper [6], i.e., deposits amorphous in character with a fluffy, fleecy appearance. Patients in the third group (n = 54; henceforth referred to as II_{DP}) showed calcified deposits within the rotator cuff tendons which were classified as type II according to DePalma and Kruper [6], i.e., more or less discrete and homogeneous deposits with uniform density. Concerning the patients' age, the Kruskall-Wallis test showed no statistically significant difference between the three groups (p = 0.2256). Concerning the distribution of patients's sex, the chi-square test showed no statistically significant difference between the three groups (p = 0.7848, chi-square = 0.4847; df = 2).

Clinical assessment of the patients was evaluated according to the established score of Constant and Murley [5]. Using this score, pain, activities of daily living, range of motion, and power are considered, with a maximum of 100 points if the shoulder is painfree with full function (pain, maximum of 15 points; activities of daily living, maximum of 20 points; range of motion, maximum of 40 points; power, maximum of 25 points). The results of the clinical assessment are shown in Fig. 1. For the three groups of patients, similar mean scores were found for the mentioned variables (pain, ∅: 1.250, I_{DP}: 1.042, II_{DP}: 1.204; activities of daily living, ∅: 6.536, I_{DP}: 6.979, II_{DP}: 7.056; range of motion, ∅: 23.93, I_{DP}: 23.75, II_{DP}: 23.37; power, ∅: 10.79, I_{DP}: 12.00, II_{DP}: 11.82; total, ∅: 42.50, I_{DP}: 43.77, II_{DP}: 43.45). By applying the Kruskal-Wallis test, the three groups of patients showed no statistically significant difference for the variables pain (p = 0.8945), activities of daily living (p = 0.7661), range of motion (p = 0.8501), and total score (p = 0.5194). For the variable power, the Kruskal-Wallis test showed a statistically significant difference between the three groups of patients (p = 0.0462), but post-hoc Dunn's multiple comparison test showed no statistically significance between the groups (∅ vs I_{DP}: $p > 0.05$; ∅ vs II_{DP}: $p > 0.05$; I_{DP} vs II_{DP}: $p > 0.05$).

MRI investigations

For MRI investigations, patients were randomly assigned to either a low-field system (n = 76; 0.2 T Magnetom Open, Siemens, Germany) or a high-field system (n = 54; 1.0 T Magnetom Impact, Siemens, Germany). Standard technique for all patients comprised a coronal, oblique, T1-weighted, spin-echo (SE) sequence, a T2-weighted, turbo, spin-echo (TSE) sequence, a sagittal, oblique, T2-weighted TSE sequence, and an axial, T1-weighted, SE sequence. Furthermore, a coronal, oblique, short-tau inversion recover (STIR) sequence and a gradient-echo (GRE) sequence were used. Technical details are given in Tables 2 and 3. Slice thickness differed between the Magnetom Open (4 mm) and Magnetom Impact (3 mm) investigations. All patients were examined in a supine position using either a sp-shoulder coil or a multipurpose surface coil. MRI investigations were evaluated as follows:

- If observable, the exact location of calcified deposits was determined (classification: not observable, deposits within the supraspinatus tendon, deposits within the supraspinatus and the infraspinatus tendon).
- Morphology of the supraspinatus tendon was classified using the established MRI categories of Carrino et al. [4] in a slightly modified manner (classification: normal, tendinitis, degeneration, partial tear, complete tear; for details see Table 4).
- Quality of the supraspinatus muscle was evaluated with respect to the presence and quantity of bands of bright signal in its course [classification: grade I (no signs of bands of bright signal), grade II (discrete signs of bands of bright signal), grade III (distinct signs of bands of bright signal); for details of this classification see Nakagaki et al. [21]].
- The acromion was classified according to its shape (classification: flat, curved, hooked [1]).
- Signs of presence or absence of acromial spurs (AS) were recorded (classification: no AS, AS in connection with flat acromion, curved acromion, or hooked acromion, respectively; see Fig. 2 a).

Table 1 Data of the patients investigated here with respect to age, sex, and type of calcified deposits within the rotator cuff tendons as noted on plain radiographs: ∅, no calcified deposits within the rotator cuff tendons; I_{DP}, type I calcified deposits within the rotator cuff tendons; II_{DP}, type II calcified deposits within the rotator cuff tendons (according to DePalma and Kruper [6])

Sex:		Female			Male		
Groups:		∅	I_{DP}	II_{DP}	∅	I_{DP}	II_{DP}
Number	n_{left}	9	9	16	8	12	11
	n_{right}	8	18	18	3	9	9
	n_{total}	17	27	34	11	21	20
Age (years)	Mean	51.6	50.3	50.4	55.8	52.5	54.1
	SD	5.10	8.14	7.80	5.47	6.66	9.43
	Minimum	43	33	33	46	37	35
	Maximum	59	63	60	67	65	75

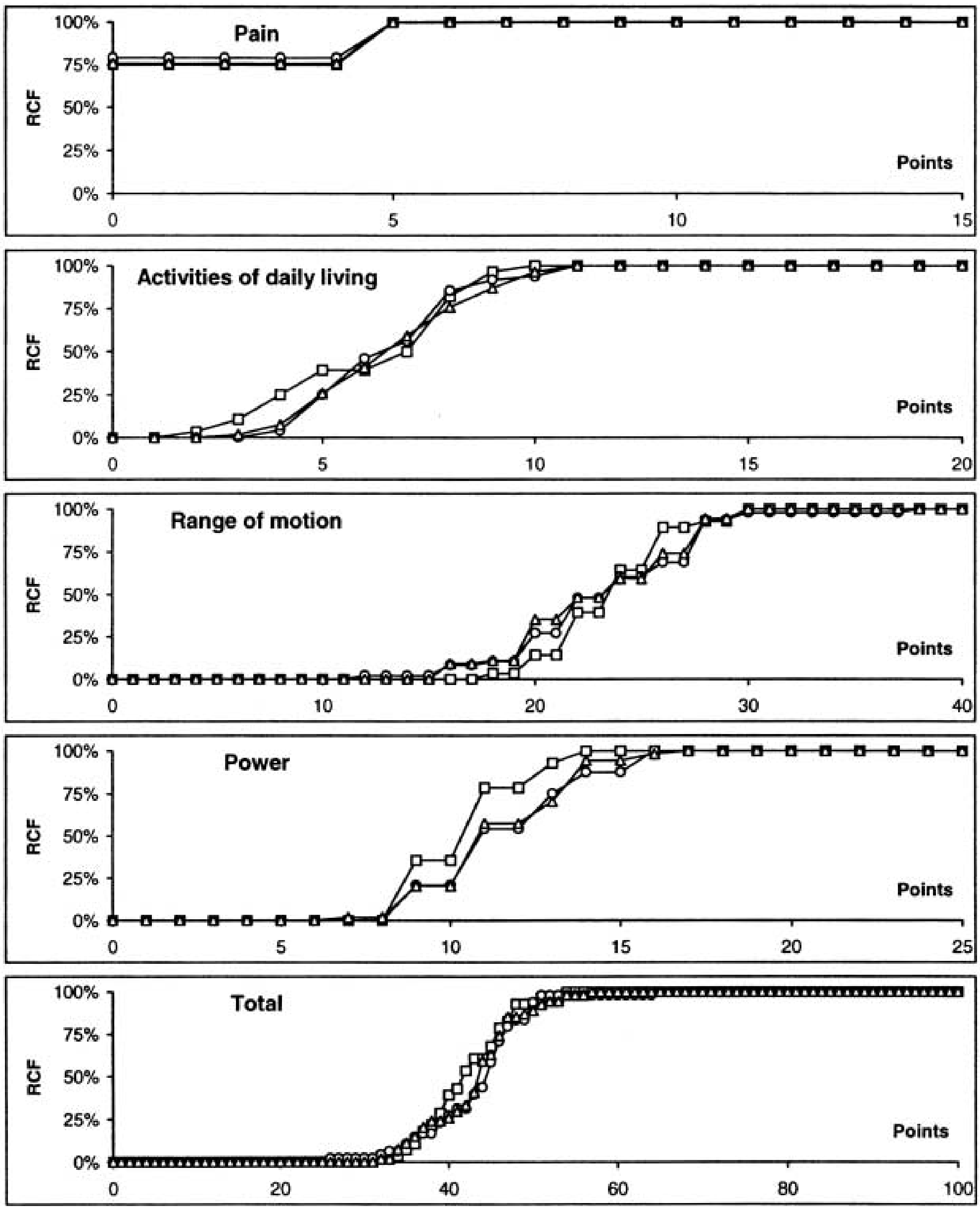

Fig. 1 Results of clinical assessment of the patients investigated here, shown as relative cumulative frequency distributions (RCF) as a function of the number of points allocated according to the criteria of Constant and Murley [5]: *squares* patients showing no signs of calcified deposits within the rotator cuff tendons on plain radiographs (i.e., group ø); *circles* patients showing calcified deposits within the rotator cuff tendons which were classified as type I (i.e., group I_{DP}); *triangles* patients showing calcified deposits within the rotator cuff tendons which were classified as type II according to DePalma and Kruper [6] (i.e., group II_{DP}). For interpretation, see Patients and methods section

Table 2 Technical details of the magnetic resonance imaging (MRI) investigations. *CO* coronal oblique parallel to supraspinatus muscle, *SO* sagittal oblique perpendicular to coronal acquisition, *OCSA* off-center standard axial, *SE* spin-echo, *TSE* turbo spin-echo, *STIR* short tau-inversion recover sequence, *GRE* gradient-echo sequence, *A* time of repetition, *B* time of relaxation, *C* time of inversion, *D* flip angle

Plane of MRI	Type of sequence	High-field system				Low-field system			
		A (ms)	B (ms)	C (ms)	D	A (ms)	B (ms)	C (ms)	D
CO	T1-weighted SE	15	655			26	576		
CO	T2-weighted TSE	85	2421			102	3204		
SO	T2-weighted TSE	96	3694			102	3204		
OCSA	T1-weighted SE	15	450			26	528		
CO	STIR	30	4522	99		48	3444	150	
CO	GRE	18	623		90°	17	444		70°

Table 3 Investigated structures and type of MRI investigations as explained in detail in Table 2: *1* T1-weighted spin-echo sequence in CO, *2* T2-weighted turbo spin-echo sequence in CO plane of MRI, *3* T2-weighted turbo spin-echo sequence SO, *4* T1-weighted spin-echo sequence in off-center standard axial plane of imaging, *5* STIR in CO plane of MR imaging, *6* GRE in CO plane of MRI

Investigated structure	Type of MRI investigation					
	1	2	3	4	5	6
Calcified deposits	X					X
Supraspinatus tendon	X	X	X		X	
Supraspinatus muscle	X	X	X		X	
Acromion			X			
Acromial spurs			X			
Acromioclavicular joint	X				X	
Acromio-humeral distance	X					
Subdeltoid and subacromial bursae					X	
Coraco-acromial ligament	X					
Greater tubercle	X		X		X	
Humeral head					X	
Subacromial-subdeltoidal fat plane	X					

Table 4 Criteria of MRI evaluation with respect to morphological classification of the supraspinatus tendon using the MRI categories of Carrino et al. [4] in a slightly modified fashion. Note that a partial thickness tear of the rotator cuff was assigned to its site towards the bursa or the joint cavum

Classification	Criteria of MRI evaluation
Normal	No or uniform low signal intensity on T1- and no signal on T2-weighted images and normal morphology of the supraspinatus tendon
Tendinitis	Increased signal intensity less than that of fluid in the supraspinatus tendon on T1- and T2-weighted images, including a morphologic abnormality with thickening or other irregularities
Degeneration	T1-weighted signal increased and T2-weighted signal decreased in the supraspinatus tendon, including a morphologic abnormality with thinning of the tendon
Partial tear	Focal discontinuity along the supraspinatus tendon surface with a defined focus of increased signal on T2-weighted images that did not extend through the full thickness of the tendon
Complete tear	A well-defined area of increased signal intensity on T2-weighted sequences extended through the entire thickness of the supraspinatus tendon

– The morphology of the acromioclavicular joint was evaluated (classification: normal, diminution of joint space and/or joint osteophytes, bone marrow edema within the acromion and/or the lateral part of the clavicle as well as intra-articular hydrops).
– The acromio-humeral distance was measured (classification: < 7 mm, 7–8 mm, > 8 mm).
– Subdeltoid and subacromial bursae were evaluated on the basis of their signal intensity (classification: normal, increased).
– Signs of the presence or absence of the following morphological features were recorded: (i) coraco-acromial ligament, (ii) bony cysts within the greater tubercle (see Fig. 2 b), (iii) bone marrow edema within the humeral head [19], (iv) subacromial-subdeltoidal fat plane (classification: not observable, observable).

All MRI evaluations were carried out by two experienced radiologists in consensus who had neither knowledge of the patients' clinical assessment nor of the corresponding radiographs.

Statistical analysis

Differences between the three groups were evaluated using the chi-square test or Fisher's exact test. Statistical significance was established at $p < 0.05$.

Results

In Part I of Table 5, the results of the MRI evaluation are summarized, given as frequency distributions of absolute and relative values of the investigated variables as a function of the type of calcified deposits within the rotator cuff tendons as examined on plain radiographs. With the exception of the location of calcified deposits, no statistically significant differences were found for the investigated variables between the three groups of patients with the chi-square test (location of calcified deposits, $p < 0.001$, $\chi^2 = 90.83$, df = 4; morphology of the supraspinatus tendon, $p = 0.2779$, $\chi^2 = 9.819$, df = 8; quality of the supraspinatus muscle, $p = 0.1586$, $\chi^2 = 6.600$, df = 4; acromial shape, $p = 0.8443$, $\chi^2 = 1.399$, df = 4; acromial spurs, $p = 0.2902$, $\chi^2 = 7.344$, df = 6; morphology of the acromioclavicular joint, $p = 0.1310$, $\chi^2 = 7.095$, df = 4; acromio-humeral distance, $p = 0.5490$, $\chi^2 = 3.053$, df = 4; signal intensity of subdeltoid and subacromial bursae, $p = 0.5021$, $\chi^2 = 1.378$, df = 2; coraco-acromial ligament, $p = 0.5681$, $\chi^2 = 1.131$, df = 2; bony cysts within the greater tubercle, $p = 0.7280$, $\chi^2 = 0.6349$, df = 2; bone marrow edema within the humeral head, $p = 0.5311$, $\chi^2 = 1.266$, df = 2; subacromial-subdeltoidal fat plane, $p = 0.4065$, $\chi^2 = 1.801$, df = 2).

Part II of Table 5 shows the results of the MRI evaluation of the patients with calcified deposits within the rotator cuff tendons as ecamined on plain radiographs, given as frequency distributions of absolute and relative values of the investigated variables as a function of the MRI device used. By applying either the hhi-square test (CT) or Fisher's exact test (FT), no statistically significant differences were found for the investigated variables between the MRI devices used (location of calcified deposits, CT, $p = 0.1537$, $\chi^2 = 3.745$, df = 2; morphology of the supraspinatus tendon, CT, $p = 0.3483$, $\chi^2 = 4.452$, df = 4; quality of the supraspinatus muscle, CT, $p = 0.1849$, $\chi^2 = 3.376$, df = 2; acromial shape, CT, $p = 0.7264$, $\chi^2 = 0.6392$, df = 2; acromial spurs, CT, $p = 0.2154$, $\chi^2 = 4.465$, df = 3; morphology of the acromioclavicular joint, CT, $p = 0.0589$, $\chi^2 = 5.665$, df = 2; acromio-humeral distance, CT, $p = 0.6059$, $\chi^2 = 1.002$, df = 2; signal intensity of subdeltoid and subacromial bursae, FT, $p = 0.8235$; coraco-acromial ligament, FT, $p = 0.4791$; bony cysts within the greater tubercle, FT, $p = 0.6803$; bone marrow edema within the humeral head, FT, $p = 0.5202$; subacromial-subdeltoidal fat plane, FT, $p = 0.3198$).

Part III of Table 5 shows the results of the MRI evaluation of the patients with no signs of calcified deposits within the rotator cuff tendons as examined on plain radiographs, given as frequency distributions of absolute and relative values of the investigated variables as a function of the MRI device used. By applying either CT or FT, no

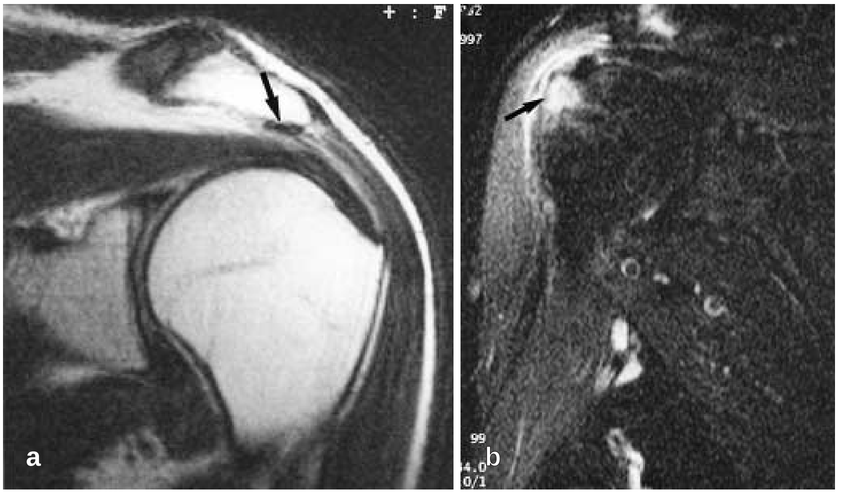

Fig. 2 a, b Characteristic MRI findings of a patient showing no signs of calcified deposits within the rotator cuff tendons on plain radiographs (male, 58 years old). **a** Subacromial spur (*black arrow* coronal, oblique, T1-weighted SE). **b** Cyst of the humeral head near the insertion of the supraspinatus tendon (*black arrow* CO STIR)

statistically significant differences were found between the MRI devices used for the following variables: acromial shape, CT, $p = 0.9882$, $\chi^2 = 0.6101$, df = 2; morphology of the acromioclavicular joint, CT, $p = 0.3177$, $\chi^2 = 2.293$, df = 2; acromio-humeral distance, CT, $p = 0.1292$, $\chi^2 = 4.093$, df = 2; signal intensity of subdeltoid and subacromial bursae, FT, $p = 0.0549$; coraco-acromial ligament, FT, $p = 1.000$; bony cysts within the greater tubercle, FT, $p = 1.000$; bone marrow edema within the humeral head, FT, $p = 0.3531$; subacromial-subdeltoidal fat plane, FT, $p = 0.4601$). For the variables calcified deposits, morphology of the supraspinatus tendon, quality of the supraspinatus muscle, and acromial spurs, no statistical analysis was possible. This was due to the number of patients investigated with no signs of calcified deposits within the rotator cuff tendons as examined on plain radiographs, which resulted in frequencies of 0%.

Discussion

One central finding of this study is that there were no statistically significant differences in MRI morphologic aspects of the affected shoulders between patients with shoulder pain, shoulder dysfunction, and calcified deposits within the rotator cuff tendons and patients with similar shoulder pain and dysfunction but without any signs of such calcified deposits on plain radiographs. Furthermore, there was no statistically significant difference of the evaluated MRI morphologic aspects of the affected shoulders between type I and type II calcified deposits within the rotator cuff tendons according to DePalma and Kruper [6]. With the exception of the frequency of detection of the calcified deposits, there were no statistically significant differences in the results of the MRI morphologic examination with regard to the MRI device used. The impact of these findings is based on the high number of patients, their comparability in clinical symptoms, age, and sex, and the use of standardized MRI sequences and examination planes. Furthermore, the present study comprises the greatest number of patients with calcified deposits within the rotator cuff tendons published thus far. To the best of our knowledge, there is only one study in the literature presenting MRI findings of a comparable number of patients with calcified deposits within the rotator cuff tendons (i.e., $n = 75$) [16]. However, the results of this study are not comparable with the findings presented here as in this study [16], the evaluation was based only on a limited number of MRI sequences and examination planes for investigating the location and morphology of the calcified deposits as well as the condition of the rotator cuff. Furthermore, the authors did not distinguish between type I and type 2 calcified deposits according to DePalma and Kruper [6], nor did they investigate patients with similar clinical symptoms but without calcified deposits within the rotator cuff tendons.

The other central finding of this study is that our results are remarkably different to data of MRI investigations of shoulders of healthy, asymptomatic volunteers reported in the literature [8, 22, 27], although in these investigations MRI devices similar to ours were used and the age of the investigated persons was comparable (e.g., in the study of Needell [22] the age range was between 40 and 60 years, in the study of Sher [27] it was from 40 to 60 years, and Farley [8] investigated persons with a mean age of 30 years). This is demonstrated in Table 6. Needell [22] reported a higher rate of rotator cuff tendons classified as normal than found here, but also a higher rate of partial and complete rotator cuff tears. The high rate of partial and full-thickness tears in age-related healthy, asymptomatic volunteers was confirmed by Sher [27]. We observed a higher rate of supraspinatus tendons classified as tendinitis than described by Needell et al. [22]. Furthermore, acromial types classified according to Bigliani et al. [1] differed between our patients and the data reported by Needell et al. [22], with distinctly less flat and distinctly more curved and hooked types in our findings. In addition, higher rates of acromial spurs, cysts within the greater tubercle, and increased signal intensity of the subdeltoid and subacromial bursae were found here than in asymptomatic volounteers [22]. Zlatkin et al. [32] recorded even no fluid in subacromial-subdeltoid bursae in healthy, asymptomatic volunteers.

Table 5 Results of MRI evaluation of shoulders of patients with shoulder pain and dysfunction with a mean score of approximately 43 points as assessed according to Constant and Murley [5]. Results are given as frequency distributions of absolute and relative values of the investigated variables as a function of the type of calcified deposits within the rotator cuff tendons as examined on plain radiographs (part I) or as frequency distributions of absolute and relative values of the investigated variables as a function of the type of MRI device used (parts II and III): *low* low-field system (0.2-T Magnetom Open, Siemens, Germany), *high* high-field system (1.0-T Magnetom Impact, Siemens, Germany), *A* location of calcified deposits, *B* morphology of the supraspinatus tendon, *C* quality of the supraspinatus muscle, *D* acromial shape, *E* acromial spurs (AS), *F* morphology of the acromioclavicular joint, *G* acromio-humeral distance, *H* signal intensity of subdeltoid and subacromial bursae, *I* coraco-acromial ligament, *K* bony cysts within the greater tubercle, *L* bone marrow edema within the humeral head, *M* subacromial-subdeltoidal fat plane, *sst* calcified deposits within the supraspinatus tendon, *sst/ist* calcified deposits within the supraspinatus and the infraspinatus tendon, *AS-flat* (or *AS-curved* or *AS-hooked*, respectively) acromial spurs in connection with flat acromion (or with curved or hooked acromion, respectively), *dim./osteoph.* diminishment of joint space and/or joint osteophytes, *bme/hydrops* bone marrow edema within the acromion and/or the lateral part of the clavicle as well as intra-articular hydrops. Data are given as explained in the following by means of an example (part I, variable A). Investigating the location of calcified deposits, calcified deposits were not observed during the MRI investigations for 28 of the 28 patients in group ∅ (100%). For 2 of the 48 patients in group I_{DP} (4%), calcified deposits were not observed during the MRI investigations, but for 45 (94%) patients, they were, and for 1 (2%) of these patients, calcified deposits were observed within both the supraspinatus and the infraspinatus tendon. Similarly, for 6 of the 54 patients in group II_{DP} (11%), calcified deposits were not observed during the MRI investigations, but for 46 (85%) of these patients, they were observed within the supraspinatus tendon, and for 2 (4%) of these patients, they were observed within both the supraspinatus and the infraspinatus tendon. For interpretation, see Results section

Type of calcified deposits		Part I						Part II				Part III			
Type of MRI device		∅	I_{DP}	II_{DP}	∅	I_{DP}	II_{DP}	I_{DP} and II_{DP}				∅			
Kind of data		Low and high						Low	High	Low	High	Low	High	Low	High
Variable	Classification	Absolute values			Relative values [%]			Absolute values		Relative values [%]		Absolute values		Relative values [%]	
A	Not observed	28	2	6	100	4	11	7	1	12	2	17	11	100	100
	sst	0	45	46	0	94	85	51	40	86	93	0	0	0	0
	sst + ist	0	1	2	0	2	4	1	2	2	5	0	0	0	0
B	Normal	2	1	3	7	2	6	4	0	7	0	2	0	12	0
	Tendinitis	18	39	38	64	81	70	43	34	73	79	11	7	64	64
	Degeneration	3	5	10	11	11	18	9	6	15	14	3	0	18	0
	Partial tear	5	3	2	18	6	4	2	3	3	7	1	4	6	36
	Complete tear	0	0	1	0	0	2	1	0	2	0	0	0	0	0
C	Grade I	20	30	32	71	63	59	40	22	68	51	14	6	82	55
	Grade II	8	15	22	29	31	41	17	20	29	47	3	5	18	45
	Grade III	0	3	0	0	6	0	2	1	3	2	0	0	0	0
D	Flat	2	4	7	7	8	13	7	4	12	9	1	1	6	9
	Curved	21	34	39	75	71	72	43	30	73	70	12	9	71	82
	Hooked	5	10	8	18	21	15	9	9	15	21	4	1	23	9
E	No AS	11	7	17	39	15	31	18	6	31	14	7	4	41	36
	AS-flat	0	2	2	0	4	4	2	2	3	5	0	0	0	0
	AS-curved	13	29	27	47	60	50	31	25	52	58	7	6	41	55
	AS-hooked	4	10	8	14	21	15	8	10	14	23	3	1	18	9
F	Normal	3	9	13	11	19	24	16	6	27	14	1	2	6	18
	dim./osteoph.	6	16	21	21	33	39	16	21	27	49	5	1	29	9
	bme/hydrops	19	23	20	68	48	37	27	16	46	37	11	8	65	73
G	< 7 mm	3	13	11	11	27	20	15	9	25	21	1	2	6	18
	7–8 mm	21	28	35	75	58	65	37	26	63	60	15	6	88	55
	> 8 mm	4	7	8	14	15	15	7	8	12	19	1	3	6	27
H	Normal	6	11	17	21	23	31	17	11	29	26	6	0	35	0
	Increased	22	37	37	79	77	69	42	32	71	74	11	11	65	100
I	Not observed	4	11	13	14	23	24	12	12	20	28	2	2	12	18
	Observed	24	37	41	86	77	76	47	31	80	72	15	9	88	82
K	Not observed	15	30	33	54	63	61	35	28	59	65	9	6	53	55
	Observed	13	18	21	46	37	39	24	15	41	35	8	5	47	45
L	Not observed	23	42	49	82	87	91	54	37	92	86	15	8	88	73
	Observed	5	6	5	18	13	9	5	6	8	14	2	3	12	27
M	Not observed	15	23	21	54	48	39	28	16	47	37	8	7	47	64
	Observed	13	25	33	46	52	61	31	27	53	63	9	4	53	36

Table 6 Comparison of results of MRI investigations of shoulders of different types of persons, given as relative frequencies in percent: L_1 to L_3 healthy, asymptomatic volunteers. Data of patients in the groups ∅, I_{DP}, and II_{DP} are presented here, whereas data of healthy, asymptomatic volunteers were originally reported in the literature (L1, Needell [22]; L2, Sher [27], L3, Farley [8]). For interpretation, see Discussion section

Variable	Classification	∅	I_{DP}	II_{DP}	L_1	L_2	L_3
Rotator cuff tendon	Normal	7.0	2.0	6.0	42.0		
	Tendinitis	64.0	81.0	70.0	27.0		
	Degeneration	11.0	11.0	18.0			
	Partial tear	18.0	6.0	4.0	27.0	24.0	
	Complete tear	0.0	0.0	2.0	4.0	4.0	
Acromion	Flat	7.0	8.0	13.0			44.0
	Curved	75.0	71.0	72.0			35.0
	Hooked	18.0	21.0	15.0			12.0
Acromial spurs	Observable	61.0	85.0	69.0	35.0		
Signs of acromioclavicular joint osteoarthritis	Observable	89.0	81.0	76.0	89.0		
Cysts within the greater tubercle	Observable	46.0	37.0	39.0	12.0		
Increased signal intensity of subdeltoid and subacromial bursae	Observable	79.0	77.0	69.0	19.0		

As explained in the following, it is not possible at present to match all the described results obtained using MRI exactly to certain histopathologic findings.

– MRI-morphologic evaluation of the supraspinatus tendon according to Carrino et al. [4] is exclusively based on the interpretation of imaging findings but not on histomorphologic observations. To prevent the so-called magic-angle effect caused by the orientation of the tendon's collagen fibers, evaluation of the supraspinatus tendon was based on two different sequences here (see above). Only for a small number of patients were normal-graded supraspinatus tendons found. Most patients demonstrated an increased signal intensity of the supraspinatus tendon, which had to be classified as tendinitis according to Carrino et al. [4]. Interestingly, Iannotti et al. [13] found no histopathologic alterations of supraspinatus tendons which were classified as tendinitis using MRI. By contrast, Kieft et al. [15] described an increased signal intensity of the rotator cuff tendons as corresponding to inflammation of the rotator cuff.
– Quality of the supraspinatus muscle was evaluated as an indirect sign of rotator cuff pathology [29]. According to the literature, the MRI finding of bands of bright signal within the muscle belly might be indicative of muscular fiber fatty degeneration [2, 21].
– In most shoulders curved acromions were recorded. Furthermore, there was a high co-incidence of acromial spurs with this type of acromion. This is in line with observations by Panni et al. [23]. The high co-incidence of hooked acromions with rotator cuff tears reported by Epstein et al. [7] could not be confirmed here.
– Degenerative signs of the acromioclavicular joint, which were observed in over 75% of the investigated shoulders, are often seen in patients with shoulder pain and dysfunction [26]. However, the frequency distributions of acromiohumeral distance, which may also be used as an indirect sign of rotator cuff tendon desintegration, did not differ from observations in healthy, asymptomatic volunteers obtained using MRI [11].
– According to Schraner and Major [25], the increased signal intensity of the subdeltoid and subacromial bursae points to local bursal inflammation.
– The role of the coracoacromial ligament in shoulder impairment was described by Gallino et al. [10]. According to the thickness of the coracoacromial ligament, the subacromial space decreases and may therefore play a role in subacromial impingement.
– More than 50% of the patients showed bony cysts of the greater tubercle. In contrast to Sano et al. [24], the cystic changes at the attachment near the supraspinatus tendon were not specific to rotator cuff tears.
– In the literature, bone marrow edema is regarded as an MRI indication of bony disorder such as trabecular bone impairment [12], and STIR sequences are most sensitive for the detection of this phenomenon [28].
– Signs of obliteration of the peribursal (i.e., subacromial-subdeltoidal) fat plane are frequently observed as a side-effect of inflammatory processes in adjacent tissues [32].

Finally, it should be mentioned that calcified deposits within the rotator cuff tendons were best detected in the GRE sequence, which is known to be sensitive to susceptibility effects induced by such calcified deposits (i.e., field inhomogenities) [17]. Deposits not detected on MRI images were mainly classified as type II according to DePalma and Kruper [6]. Using the low-field MRI device, significantly fewer calcified deposits were detected than with the high-field MRI device.

Summarizing, it is reasonable to draw the following conclusions from the results presented here:

– For patients with shoulder pain, shoulder dysfunction, and calcified deposits within the rotator cuff tendons, these calcified deposits are most probably not the main reason for the clinical symptoms. Rather, MRI investigations reveal distinct morphological alterations in the affected shoulders, which may also be found in the shoulders of patients with similar shoulder pain and dysfunction but no signs of calcified deposits within the rotator cuff tendons. However, these morphological alterations are not found when investigating the shoulders of healthy, asymptomatic volunteers by means of MRI.

- At present, it is not possible to match all the described results obtained using MRI exactly to certain histopathologic findings. However, it seems to be useful to consider the results of MRI investigations when planning therapeutic procedures for patients with shoulder pain and dysfunction, irrespective of whether or not there are signs of calcified deposits within the rotator cuff tendons on plain radiographs.
- To confirm the presence of these calcified deposits by MRI, the corresponding investigations should be carried out using a high-field MRI and GRE as described here.

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