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Research Article

MRI evaluation of shoulder pathologies in wheelchair users with spinal cord injury and the relation to shoulder pain

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Objective: To describe the number, specifics and co-occurrence of shoulder pathologies detected by MRI in manual wheelchair users with spinal cord injury and to evaluate the association between shoulder pathologies and presence of shoulder pain.
Design: Cross-sectional observation study.
Setting: Community.
Participants: Fifty-one wheelchair-dependent persons with spinal cord injury (44 males, 7 females, median age 50 years (IQR 14), median time since injury 24 years (IQR 16)) were allocated to pain or no-pain group based on the Wheelchair User Shoulder Pain Index.
Interventions: Not applicable
Outcome measures: All persons underwent shoulder MRI. Pathologies were scored blinded by two experienced radiologists. Participant characteristics, number and severity of shoulder pathologies were analyzed descriptively. Logistic regression was performed to evaluate the association between MRI findings and shoulder pain.
Results: The median number of co-occurring MRI findings per person ranged from 0 to 19 (out of 31 possible findings). The cluster of MRI findings occurring most often together were tendon tears of supraspinatus (present in 84%), subscapularis (69%) and biceps (67%) and osteoarthritis of acromioclavicular joint (80%). When correcting for age and time since injury, the logistic regression showed no statistically significant correlation between the individual pathologies and shoulder pain.
Conclusion: MRI findings of shoulder pathology are very frequent in persons with and without shoulder pain. Therefore, when diagnosing the cause of shoulder pain and planning interventions, health care professionals should keep this finding in mind and MRI should not be interpreted without careful consideration of clinical history and functional testing.

Keywords: Shoulder pain, Shoulder pathology, Rotator cuff tear

Introduction

Shoulder pain is a common complaint of persons with spinal cord injury (SCI).[1,2] Especially in persons with SCI this is relevant since they rely on their upper extremities for mobility, such as wheelchair propulsions and transfers. Persons with SCI and shoulder pain also report higher incidence of work drop-out and a poorer quality of life.[3] In clinical practice, diagnosis of the cause of shoulder pain is not easy. Cornerstones of diagnosis are patient history and

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clinical exams. Clinical tests showed to have only moderate diagnostic value for identifying rotator cuff tears (RotCT) or other shoulder pathologies.[4,5] Often additional magnetic resonance imaging (MRI) of the shoulder is performed to confirm pathology and plan interventions, such as physiotherapy, exercise programs, oral anti-inflammatory drugs, infiltration of the joint (i.e. intra-articular corticosteroid injection), surgical therapy or a combination of those.[6–8] These interventions might be based on the findings of the MRI since it is generally assumed that shoulder pathology demonstrated by MRI findings is causing shoulder pain. Interventions, especially surgery, are not without risks and post-operative rehabilitation includes a period of 6–12 weeks of immobilization and inpatient rehabilitation. The outcome of shoulder surgery is diverging, some studies however reported a decrease of pain after surgical intervention.[7,9–11]

Results from previous studies on the association of shoulder pain and shoulder pathology in individuals with SCI are conflicting. Studies on shoulder pain and its relation to MRI findings in persons with SCI focused mostly on one or two pathologies, mainly on presence of RotCT,[12,13] biceps tendon tears[13] or acromioclavicular (AC) joint arthrosis.[14,15] It remains unclear if shoulder pathology demonstrated by MRI indeed is causing shoulder pain. A description of coexisting shoulder pathologies and existing clusters of pathologies and the association with shoulder pain in persons with SCI is currently missing. This information is important because it potentially affects therapeutic decision making to treat shoulder pain.[16]

The authors hypothesize that there are no differences in type of pathology in individuals with and without shoulder pain. In this study, we aim to evaluate whether shoulder pathology in manual wheelchair users with SCI with shoulder pain differs from those without shoulder pain by:

1. Describing number, specifics and co-occurrence of shoulder pathologies detected by MRI in this population
2. Evaluating the association between shoulder pathologies and the presence of shoulder pain.

Materials and methods

Study design

This study has a cross-sectional between-group design. Ethical approval was granted by the Ethikkommision Nordwest-und Zentralschweiz (EKNZ, Project-ID: 2015-192). The study follows the ICH Good Clinical Practice Guidelines and the Swiss regulation on research involving human beings. After having been informed about the burden and risks of the study, participants signed the informed consent.

Participants

A convenience sample of participants was recruited through the database of the Swiss Spinal Cord Injury (SwiSCI) cohort study. SwiSCI is a population-based cohort study that includes persons who are ≥16 years, diagnosed with traumatic or non-traumatic SCI and residing in Switzerland.[17] Eligible for study participation were individuals with a chronic paraplegia (T1-L3) or tetraplegia (C4–C8), aged between 18 and 65 years who are dependent on a manual wheelchair for activities of daily living, either with or without supportive propulsion (i.e. E-Motion, Swiss-Trac). Excluded were individuals with a major trauma of the upper extremity in the past three months, with a history of shoulder surgery or with contraindications to MRI.

The study information and a questionnaire were sent to individuals identified in the SwiSCI database who were fulfilling inclusion criteria (n = 311). The questionnaire included questions about the duration and intensity (numerical rating scale (NRS) 0–10) of shoulder pain in the past 3 months. Based on the intensity of shoulder pain, individuals who were willing to participate (n = 117) were allocated to having no/mild shoulder pain (NRS 0-3) or having shoulder pain (NRS 4-10). Out of this pool, individuals were selected and invited for participation based on lesion level (paraplegia, tetraplegia), sex and age. This was done in order to form matched pairs of persons with/without shoulder pain to prevent confounding from these variables (lesion level, sex, age). The selected participants (n = 52) were invited to the Swiss Paraplegic Center/Swiss Paraplegic Research to fill in a detailed questionnaire on presence and severity of shoulder pain (Wheelchair User Shoulder Pain Index (WUSPI)) and for an MRI evaluation of their selected shoulder. In participants with pain, MRI evaluation was performed on the most affected shoulder. For each participant without pain the same shoulder was evaluated as for their matched partner.

Outcome measures

Participant characteristics

Socio-demographic variables (age, sex) and characteristics of the injury (time since injury (TSI), lesion level) were self-reported, body weight was measured.

MRI protocol

MRI was conducted following standard clinical protocols of the Radiology Department of Swiss Paraplegic Center. All participants underwent multiplanar MRI imaging of the shoulder with a 3.0-T MRI system (Achieva dStream, Philips Medical Systems, Best, Netherlands) and a dedicated receive-only 8-element phased-array dStream shoulder coil. All participants were positioned consistently with the shoulder in the middle of the coil and the arm in neutral position beside the body. Fixation aircushions were used to provide the best image quality without moving artifacts. No intravenous or intraarticular contrast medium was administered.

The MRI protocol was identical for all examinations. For conventional 2D MRI, transversal PD-weighted HR turbo SE, oblique sagittal T1-weighted mDixon turbo SE, oblique coronal PD-weighted FS turbo SE und oblique coronal T1-weighted HR turbo SE images were obtained. For 3D MRI, transversal WATSc turbo SE sequence was used, particularly for cartilage visualization. Total acquisition time was 17 min.

MRI analysis

MRI images were assessed independently by two experienced consultant general radiologists with more than 10 years of experience in interpreting shoulder MRIs. Findings were described using a structured approach described below. The radiologists were blinded towards participants' group allocation and to each other's evaluation. Diverging ratings between the two radiologists were solved by agreement. Median percentage agreement was 82.4%, ranging from 49.0% (grading of supraspinatus tears) to 98.0% (supraspinatus calcifications). Interrater reliability for each pathology can be found in Appendix 1.

The following pathologies were evaluated:

Atrophy of rotator cuff muscles was graded as no pathology, $<30\%$ of atrophy (grade 1), 30-60% of atrophy (grade 2) or $\geq 60\%$ (grade 3).[18]

Rotator cuff tendons were graded as no pathology, tendinopathy, partial rupture, focal transmural rupture or complete transmural rupture. The tendon of the long biceps was graded as no pathology, tendinopathy, (sub)luxation or rupture. In addition, rotator cuff tendons were checked for the existence of calcification (present/not present).

Osteoarthritis of AC joint was graded based on Shubin Stein *et al.*[19] into no capsular distension, no joint space narrowing, and no evidence of osteophyte formation (grade 1), capsular distension, frequently an isolated finding but occasionally accompanied by mild joint space narrowing (grade 2), capsular distension with a combination of joint space narrowing, fat effacement and marginal osteophyte formation (grade 3) and all of in grade 1, 2 and 3 mentioned findings in addition to marked joint space irregularity and narrowing with large osteophytes (grade 4). The same grading was used for glenohumeral (GH) joint, omitting capsular distension and fat effacement.

Shoulder images were also checked for the presence of subchondral cysts in the humeral head and the glenoid and cysts on the humeral head at the insertion of the rotator cuff. The subacromial and subcoracoid bursa were checked for the presence of fluid or calcifications.

The labrum was divided into seven regions: superior, anterosuperior, anterior, anteroinferior, posteroinferior, posterior and posterosuperior.[20] Each region was checked for the presence of lesions.

To evaluate the number of existing pathologies and the co-occurrence of pathologies, each MRI finding was transformed into a dichotomous variable (no pathology vs. present pathology).

Shoulder pain

Shoulder pain at time of measurement was assessed with the WUSPI. This is a validated 15-item questionnaire assessing self-reported pain during transfers, wheelchair mobility, self-care and general activities during the past week.[21] A few participants with tetraplegia marked the option`not performed' for some activities assessed by WUSPI . To more accurately reflect the intensity of shoulder pain experienced during activities performed, we calculated a performance-corrected (PC-WUSPI) score, as described previously.[22] Based on the PC-WUSPI score, participants were allocated to the no pain group (nPG, PC-WUSPI score of 0–15 (out of 150)) or the pain group (PG, PC-WUSPI score 16–150).

Statistical analysis

Statistical analysis was performed with Stata version 14 (StataCrp LP, College Station, TX, SA, USA). Descriptive statistics comprise totals and percentages for categorical variables, and medians and interquartile ranges (IQR) for continuous variables. Multivariate logistic regression analysis was used to evaluate associations between the binary outcome "shoulder pain" and each of the MRI findings, corrected for age and TSI since these variables are likely to influence the occurrence of shoulder pathologies.[12,13,15] Significance level was adjusted for multiple testing using a Bonferroni correction and resulted in a significance level of $P < 0.0022$.

Clustering of MRI findings was analyzed using the Jaccard binary similarity coefficient as suggested by Cornell *et al.*[23] and was visualized with a dendrogram.

Results

Participant characteristics

Fifty-one wheelchair users with SCI (30 paraplegia, 21 tetraplegia) were included in the study (Table 1). One participant was excluded because he did not fulfill all inclusion criteria. The study population included 44 males and 7 females, with a median age of 50 years (IQR 14) and median TSI of 24 years (IQR 16).

On average, individuals in the PG were younger (median age 48 vs. 51 years in nPG), had a longer TSI (median TSI 28 vs. 18 years in nPG) and had the same weight as individuals in the nPG (median weight 72 kg).

MRI findings

The majority of the studied population had some grading of tears of the supraspinatus (PG 92%, nPG 78%), AC arthrosis (PG 87%, nPG 74%), and some grading of tears of the subscapularis (PG 88%, nPG 52%). The detailed MRI findings, stratified by shoulder pain and lesion severity (tetraplegia vs. paraplegia), are presented in Tables 2 and 3.

Rotator cuff tears occurred most often in the supraspinatus (see above), followed by subscapularis (PG 88%, nPG 52%) and infraspinatus (PG 42%, nPG 37%). The long biceps tendon was affected in 67% of the studied population (PG 79%, nPG 53%).

Atrophy of the rotator cuff muscle was less frequent and most present in subscapularis (paraplegia 20%, tetraplegia 57%), followed by atrophy of teres minor (paraplegia 7%, tetraplegia 43%). Tendon and bursa calcifications were rarely detected in the studied population (maximal value of 6% of calcification of subscapularis tendon). AC arthrosis was much more present (see above) than GH arthrosis (PG 38%, nPG 15%). Subacromial fluid was more present (PG 46%, nPG 26%) than subcoracoid fluid (PG 21%, nPG 30%). Labral tears were located most often anterosuperiorly (PG 13%, nPG 30%) and superiorly (PG 17%, nPG 22%).

Co-occurrence of MRI findings

Only two persons (allocated to the nPG) had no pathologies detected by MRI (Table 4). The number of co-occurring MRI findings in the participants' shoulders ranged from 0 to 19 (out of 31 possible findings), with a median of 7 co-occurring findings (IQR 3.5) in PG and a median of 5 co-occurring findings (IQR 7) in nPG.

In both groups the cluster of MRI findings that occurred most often together were tendon tears of the supraspinatus, biceps and subscapularis and AC arthrosis (Figure 1). This cluster of pathologies was present in 49% of the studied population (PG 63%, nPG 37%).

Regarding RotCT, if there was any grading of damage present in the infraspinatus, teres minor or subscapularis, it was always accompanied by a damage in supraspinatus. Teres minor tears were only found in co-occurrence with tears of all other rotator cuff muscles.

Relation to shoulder pain

The number of MRI findings and the occurring shoulder pain (WUSPI) is shown in Figure 2. The logistic regression showed no statistically significant correlation between the number of MRI findings and shoulder pain (PG vs. nPG) when correcting for age and TSI ($P = 0.192$).

The presence of pathologies and the severity is displayed in Figure 3. When correcting for age and TSI, the logistic regression showed no statistically significant correlation between the individual pathologies and shoulder pain (PG vs. nPG, Appendix2). Lowest P values were found for subscapularis tears ($P = 0.029$), where the odds for being in PG were 8.7 times higher if a tendinopathy was present or 7.4 times higher if a partial rupture was found. Regarding labral tears, the odds for being in PG were 5 times higher if no lesion in the anterosuperior part ($P = 0.031$) or in the posteroinferior part ($P = 0.065$) was present. Also, a trend was found for subchondral cysts on the glenoid, where the odds for being in PG was 15% higher if cysts were present ($P = 0.043$).

The odds for being in PG were 3.2 times higher if the prevalent cluster of MRI findings was present. However, the logistic regression showed no statistically significant correlation between the presence of the cluster and shoulder pain (PG vs. nPG) when correcting for age and TSI ($P = 0.075$).

Discussion

Participant characteristics

The studied population is a representative subsample of the Swiss community of wheelchair users with SCI, however selected based on self-reported shoulder pain and in order to form two similar groups of participants with and without shoulder pain. Compared to the Swiss community of wheelchair user with SCI, the studied population has a similar median age (50 vs 51

Table 1 Participant demographic information including performance-corrected Wheelchair User Shoulder Pain Index (PC-WUSPI) of the examined shoulder at day of measurement.

	Overall *N* = 51 (100%)	Pain group		No-pain group	
		Paraplegia *N* = 15 (29%)	Tetraplegia *N* = 9 (18%)	Paraplegia *N* = 15 (29%)	Tetraplegia *N* = 12 (24%)
Sex					
male	44 (86)	13 (87)	8 (89)	12 (80)	11 (92)
female	7 (14)	2 (13)	1 (11)	3 (20)	1 (8)
Age (years)					
Median (IQR)	50 (14)	49 (7)	46 (9)	48 (17)	56 (22)
16–30	3 (6)	0 (0)	0 (0)	2 (13)	1 (8)
31–45	16 (31)	5 (33)	4 (44)	4 (27)	3 (25)
46–60	25 (49)	8 (53)	5 (56)	8 (53)	4 (33)
61–75	7 (14)	2 (13)	0 (0)	1 (7)	4 (33)
Weight (kg)					
Median (IQR)	72 (18)	68 (16)	76 (16)	70 (23)	74 (24)
41–55	7 (14)	2 (13)	1 (11)	4 (27)	0 (0)
56–70	16 (31)	6 (40)	2 (22)	4 (27)	4 (33)
71–85	24 (47)	7 (47)	4 (44)	6 (40)	7 (58)
86–100	4 (8)	0 (0)	2 (22)	1 (7)	1 (8)
TSI (years)					
Median (IQR)	24 (16)	28 (8)	27 (14)	17 (25)	24 (17)
6–10	6 (12)	0 (0)	1 (11)	4 (27)	1 (8)
11–15	6 (12)	2 (13)	1 (11)	2 (13)	1 (8)
16–20	8 (16)	0 (0)	1 (11)	4 (27)	3 (25)
21–25	8 (16)	4 (27)	1 (11)	1 (7)	2 (17)
26–30	8 (16)	5 (33)	2 (22)	0 (0)	1 (8)
31–35	7 (14)	2 (13)	1 (11)	1 (7)	3 (25)
≥36	8 (16)	2 (13)	2 (22)	3 (20)	1 (8)
PC-WUSPI					
Median (IQR)	13 (39)	39 (27)	64 (35)	0 (5)	2 (6)

TSI = time since injury.

years[24]), a higher median TSI (24 vs. 19 years[24]), a lower percentage of women (14% vs 27%[24]) and has a lower percentage of persons with paraplegia (59% vs. 69%[24]).[25,26]

MRI findings

The results show that shoulder pathologies are very common in wheelchair users with SCI with and without shoulder pain. The three pathologies with the highest prevalence, as well as RotCT distribution are discussed in more detail.

The most common MRI finding was any grading of supraspinatus tear which has been previously reported in this population.[27] Our findings that supraspinatus tear is more common than tears of other rotator cuff tendon is similar to findings from the able-bodied population.[28] However, the number of partial thickness tear in our study is higher (41%) than reported in the able-bodied population (13% to 32%).[28] Similar differences between persons with SCI and controls have been reported previously.[29] Fatiguing wheelchair propulsion results in acute changes in the supraspinatus and biceps tendon, which may explain the high injuries presence of these tendons in our studied population.[30] Previous research has shown that persons with supraspinatus tear perform functional tasks such as forward reach, pulling or upward reaching with more internal rotation of the humerus than controls.[31] This altered motion could be the result of avoiding painful postures, which in turn may exposes the shoulder to impingement, particularly during higher elevation.[32] Alternatively, the increased internal rotation could be caused by muscle imbalance. Deltoid and pectoral muscle may compensate the absence of a fully functional rotator cuff, which may affect glenohumeral loading and could result in further joint damage,[33] such as arthrosis, which we found in 25% of the participants.

Frequencies of supraspinatus tears found in the present study are higher than in some previous studies using MRI. Boninger *et al.* only found RotCT in one out of 28 manual wheelchair users with and without shoulder pain.[26] In a similar population, Akbar *et al.* found RotCT (full or partial

Table 2 MRI findings of the rotator cuff muscles and biceps longus.

	Overall N = 51 (100%)	Pain group		No-pain group	
		Paraplegia N = 15 (29%)	Tetraplegia N = 9 (18%)	Paraplegia N = 15 (29%)	Tetraplegia N = 12 (24%)
Muscle atrophy					
Subscapularis					
no pathology	33 (65)	10 (67)	4 (44)	14 (93)	5 (42)
grade 1	14 (27)	4 (27)	3 (33)	1 (7)	6 (50)
grade 2	2 (4)	0 (0)	2 (22)	0 (0)	0 (0)
grade 3	2 (4)	1 (7)	0 (0)	0 (0)	1 (8)
Supraspinatus					
no pathology	42 (82)	14 (93)	5 (56)	13 (87)	10 (83)
grade 1	7 (14)	1 (7)	3 (33)	2 (13)	1 (8)
grade 2	2 (4)	0 (0)	1 (11)	0 (0)	1 (8)
grade 3	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Infraspinatus					
no pathology	41 (80)	14 (93)	6 (67)	15 (100)	6 (50)
grade 1	8 (16)	1 (7)	2 (22)	0 (0)	5 (42)
grade 2	2 (4)	0 (0)	1 (11)	0 (0)	1 (8)
grade 3	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Teres minor					
no pathology	40 (78)	13 (87)	5 (56)	15 (100)	7 (58)
grade 1	9 (18)	2 (13)	2 (22)	0 (0)	5 (42)
grade 2	2 (4)	0 (0)	2 (22)	0 (0)	0 (0)
grade 3	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Rotator cuff tears					
Subscapularis					
no pathology	16 (31)	3 (20)	0 (0)	10 (67)	3 (25)
tendinopathy	28 (55)	9 (60)	8 (78)	4 (27)	8 (67)
partial rupture	5 (10)	2 (13)	1 (11)	1 (7)	1 (8)
focal transmural rupture	1 (2)	0 (0)	1 (11)	0 (0)	0 (0)
complete transmural rup	1 (2)	1 (7)	0 (0)	0 (0)	0 (0)
Supraspinatus					
no pathology	8 (16)	0 (0)	2 (22)	4 (27)	2 (17)
tendinopathy	19 (37)	5 (33)	3 (33)	6 (40)	5 (42)
partial rupture	17 (33)	8 (53)	2 (22)	4 (27)	3 (25)
focal transmural rupture	4 (8)	1 (7)	1 (11)	1 (7)	1 (8)
complete transmural rup	3 (6)	1 (7)	1 (11)	0 (0)	1 (8)
Infraspinatus					
no pathology	31 (61)	9 (60)	5 (56)	10 (67)	7 (58)
tendinopathy	20 (39)	6 (40)	4 (44)	5 (33)	5 (42)
partial rupture	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
focal transmural rupture	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
complete transmural rup	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Teres minor					
no pathology	47 (92)	15 (100)	6 (67)	15 (100)	11 (92)
tendinopathy	4 (8)	0 (0)	3 (33)	0 (0)	1 (8)
partial rupture	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
focal transmural rupture	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
complete transmural rup	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Tendon long biceps					
No pathology	17 (33)	4 (27)	1 (6)	7 (47)	5 (42)
tendinopathy	24 (47)	7 (47)	5 (56)	7 (47)	5 (42)
(Sub)Luxation	7 (14)	2 (13)	2 (22)	1 (7)	2 (17)
Rupture	3 (6)	2 (13)	1 (11)	0 (0)	0 (0)
Present tendon calcifications					
Subscapularis	3 (6)	1 (7)	1 (11)	1 (7)	0 (0)
Supraspinatus	2 (4)	2 (13)	0 (0)	0 (0)	0 (0)
Infraspinatus	2 (4)	0 (0)	0 (0)	0 (0)	2 (17)
Teres minor	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Grading of muscle atrophy: grade 1: <30% atrophy, grade 2: 30-60% atrophy, grade 3: ≥ 60% atrophy

thickness tear) in 49% of the participants.[12] In contrast, Brose *et al.* found supraspinatus tendinopathy assessed by ultrasound in all 49 manual wheelchair users with SCI with and without shoulder pain.[25] Besides the difference in age and TSI of the studied populations, the difference in percentage findings

Table 3 MRI findings: joint arthrosis, bursitis, bursa calcification, subchondral cysts and labral tears.

	Overall $N = 51$ (100%)	Pain group		No-pain group	
		Paraplegia $N = 15$ (29%)	Tetraplegia $N = 9$ (18%)	Paraplegia $N = 15$ (29%)	Tetraplegia $N = 12$ (24%)
Joint arthrosis					
AC arthrosis					
grade 1	10 (20)	0 (0)	3 (33)	4 (27)	3 (25)
grade 2	13 (25)	6 (40)	3 (33)	2 (13)	2 (17)
grade 3	22 (43)	6 (40)	3 (33)	8 (53)	5 (42)
grade 4	6 (12)	3 (20)	0 (0)	1 (7)	2 (17)
GH arthrosis					
grade 1	38 (75)	9 (60)	6 (67)	12 (80)	11 (92)
grade 2	11 (22)	6 (40)	2 (22)	2 (13)	1 (8)
grade 3	2 (4)	0 (0)	1 (11)	1 (7)	0 (0)
grade 4	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Present fluid in bursa					
Subacromial	18 (35)	6 (40)	5 (56)	2 (13)	5 (42)
Subcoracoid	13 (25)	1 (7)	4 (44)	2 (13)	6 (50)
Present bursa calcification					
Subacromial	1 (2)	1 (7)	0 (0)	0 (0)	0 (0)
Subcoracoid	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Present subchondral cysts					
Glenoid	7 (14)	1 (7)	1 (11)	3 (20)	2 (17)
Humeral head	0 (0)	0 (0)	2 (22)	0 (0)	0 (0)
Present cysts on humeral head at insertion of					
Subscapularis	6 (12)	1 (7)	2 (22)	1 (7)	2 (17)
Supraspinatus	13 (25)	4 (27)	3 (33)	2 (15)	4 (33)
Infraspinatus	12 (24)	4 (27)	2 (22)	5 (33)	1 (8)
Present labral tears					
Superior	10 (20)	2 (13)	2 (22)	3 (20)	3 (25)
Anterosuperior,	11 (22)	2 (13)	1 (11)	3 (20)	5 (42)
Anterior	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Anteroinferior	3 (6)	0 (0)	0 (0)	0 (0)	3 (25)
Posteroinferior	4 (8)	0 (0)	1 (11)	1 (7)	2 (17)
Posterior	2 (4)	0 (0)	1 (11)	1 (7)	0 (0)
Posterosuperior	3 (6)	2 (13)	0 (0)	1 (7)	0 (0)

Grading of joint arthrosis:
grade 1: no capsular distension, no joint space narrowing, and no evidence of osteophyte formation,
grade 2: capsular distension, frequently an isolated finding but occasionally accompanied by mild joint space narrowing,
grade 3: capsular distension with a combination of joint space narrowing, fat effacement and marginal osteophyte formation,
grade 4: all findings of grade 1- 3 in addition to marked joint space irregularity and narrowing with large osteophytes

might also be related to the granularity of classification of RotCT and the sensitivity of the imaging technique used to detect RotCT.

Arthrosis of the AC joint showed a high prevalence of 80% in the studied population. Present AC arthrosis has an impact on RotCT. During a humeral elevation of 70° the humerus is directly under the AC joint[34] and present inferior projecting osteophytes will decrease the clearance of the greater tuberosity and will irritate the supraspinatus tendon.[35] Previous studies on AC arthrosis in persons with SCI reported divergent prevalences. This might be related to a difference in age and TSI of the studied populations, which has been shown to have an influence on presence of AC arthrosis.[15] Boninger at al. found AC arthrosis in 64% of a rather young group of manual wheelchair users with paraplegia.[26] Akbar *et al.* found a prevalence of AC arthrosis of 42% in persons with and without shoulder pain.[29] Eriks-Hoogland *et al.* reported a prevalence of 98% in persons with shoulder pain.[15] The two later studies examined a manual wheelchair user population with similar age and TSI as the present study.

MRI findings with the third-highest prevalence were any grading of subscapularis tear. Tendinopathy was the most prevalent finding among subscapularis pathologies, and more participants of the PG (44%) than of the nPG (67%) were affected. A high prevalence of 100% of subscapularis tendinopathy was reported previously in manual wheelchair users with SCI and shoulder pain, while 30% had a tear of subscapularis.[27] Lower prevalences of subscapularis tendinopathy of 1.9–25% are reported in the general population.[36]

Table 4 Number of MRI findings per participant: sum of all present MRI findings (dichotomous variables not present vs. any grading of pathology).

Numbers of MRI findings (total 31)	Overall *N* = 51, N (%)	Pain group		No-pain group	
		Paraplegia *N* = 15 (29%)	Tetraplegia *N* = 9 (18%)	Paraplegia *N* = 15 (29%)	Tetraplegia *N* = 12 (24%)
0	2 (4)	0 (0)	0 (0)	2 (13)	0 (0)
1	2 (4)	0 (0)	0 (0)	1 (7)	1 (8)
2	3 (6)	0 (0)	0 (0)	2 (13)	1 (8)
3	8 (17)	2 (13)	3 (33)	2 (13)	1 (8)
4	2 (4)	0 (0)	0 (0)	2 (13)	0 (0)
5	4 (8)	2 (13)	0 (0)	12 (7)	1 (8)
6	3 (6)	1 (7)	0 (0)	1 (7)	1 (8)
7	5 (10)	4 (27)	1 (11)	0 (0)	0 (0)
8	8 (16)	4 (27)	1 (11)	1 (7)	2 (17)
9	3 (6)	1 (7)	0 (0)	1 (7)	1 (8)
10	2 (4)	1 (7)	1 (11)	0 (0)	0 (0)
11	1 (2)	0 (0)	0 (0)	1 (7)	0 (0)
12	2 (4)	0 (0)	0 (0)	0 (0)	2 (17)
13	2 (4)	0 (0)	1 (11)	1 (7)	0 (0)
15	2 (4)	0 (0)	1 (11)	0 (0)	1 (8)
16	1 (2)	0 (0)	0 (0)	0 (0)	1 (8)
19	1 (2)	0 (0)	1 (11)	0 (0)	0 (0)

Co-occurrence of MRI findings

A distinct cluster of MRI findings (tears of the supraspinatus, biceps and subscapularis and AC arthrosis) was found in 49% of the participants. This cluster has not been described previously for the studied population. However, besides supraspinatus tears, also subscapularis tears with concomitant lesions of the long head of the biceps have previously been reported in the able bodied population.[37] The four pathologies of the cluster are related. Fatiguing wheelchair propulsion results in acute changes in the supraspinatus and biceps tendon, which might be related to tendinopathy.[30] In combination with an existing AC arthrosis and subacromial osteophytes that might impinge the tendons, irritation of the subacromial bursa and ultimately rotator cuff tears can follow.

Regarding co-occurrence of RotCT, similar results were found in previous studies.[13,29] Supraspinatus tears were often seen as isolated RotCT. If other rotator cuff muscles were affected, it was always in combination with a supraspinatus tear.[13]

Relation to shoulder pain

No correlation was found between shoulder pain and MRI findings in the study group. This finding is not necessarily unexpected since it has been reported that persons with full-thickness RotCT or affection of multiple rotator cuff tendons, may have only mild to no pain.[38]

However, our findings are in contradiction to some previous studies on MRI findings of RotCT in persons with SCI. In a group of 26 individuals with paraplegia, Escobedo *et al.* found a significantly higher prevalence of RotCT in persons reporting shoulder pain: 73% of persons with shoulder pain had a RotCT, while only 9% of the persons without shoulder pain had a RotCT.[13] A positive relationship between shoulder pain and pathology based on MRI findings in 299 persons with paraplegia was also found by Akbar *et al.* They showed that individuals with paraplegia and without RotCT reported significantly less shoulder pain than paraplegic persons with uni- or bilateral RotCT.[12] On the other hand, Brose *et al.* reported that shoulder pain in 49 persons with SCI was not correlated to shoulder pathology assessed by the ultrasound shoulder pathology rating scale.[25] Also Boninger *et al.* reported that manual wheelchair users with SCI who experienced pain were not significantly more likely to have abnormalities in MRI findings, as measured with a summated index score.[26]

Since MRI findings of shoulder pathology are also very frequent in persons without shoulder pain, and no correlation between pain and pathology was found, MRI should not be interpreted without careful consideration of clinical history and functional testing.

Limitations of the study include the lack of clinical tests for shoulder impairment. This could have given additional information on the severity of shoulder impairment and on the effect of shoulder pathology found by MRI on the shoulders' functionality. In addition, no information was obtained about medication taken by the participants. Intake of pain medication could have influenced pain severity and therefore group allocation of participants. In order to

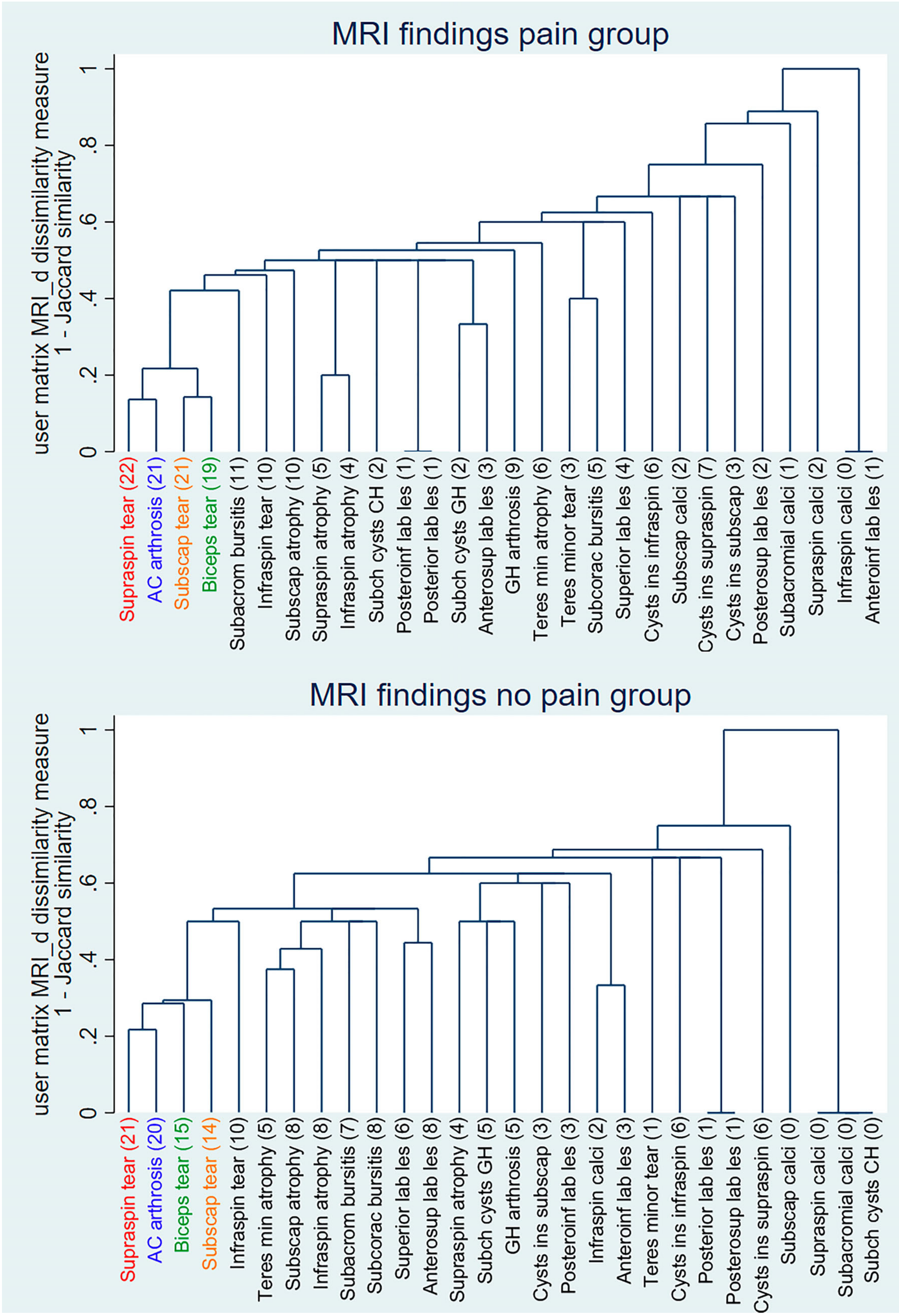

Figure 1 Clustering of MRI findings in the pain and the no pain group. The lower the dissimilarity measure the better the MRI findings are clustered. Numbers in brackets represent the number of MRI findings present in the according group.

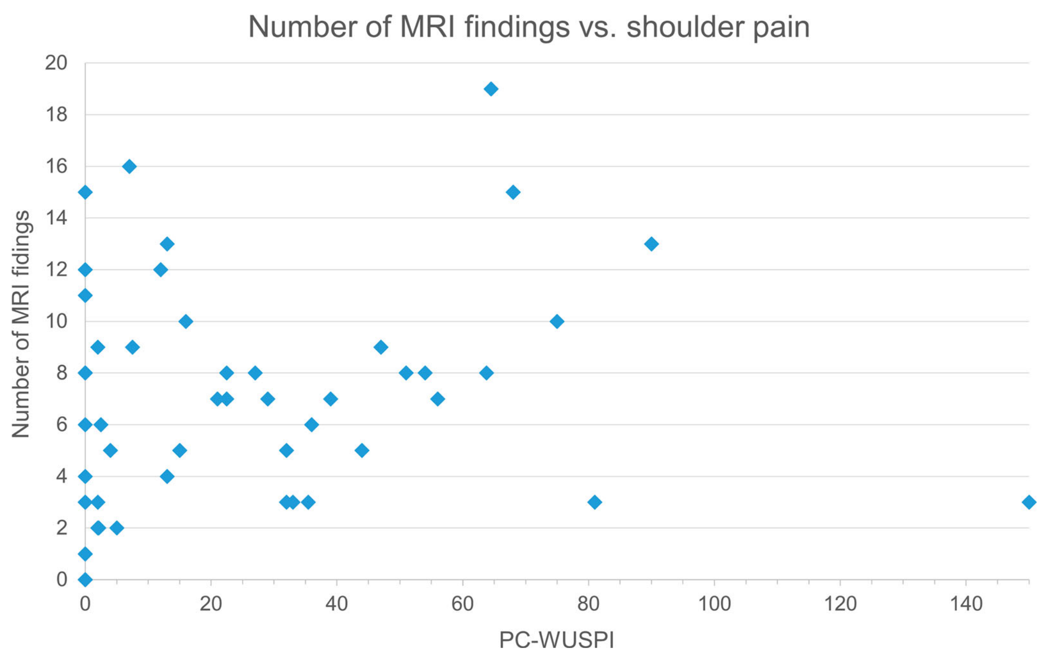

Figure 2 **Number of MRI findings and related shoulder pain assessed with the performance corrected wheelchair user shoulder pain index (PC-WUSPI, 0-150).**

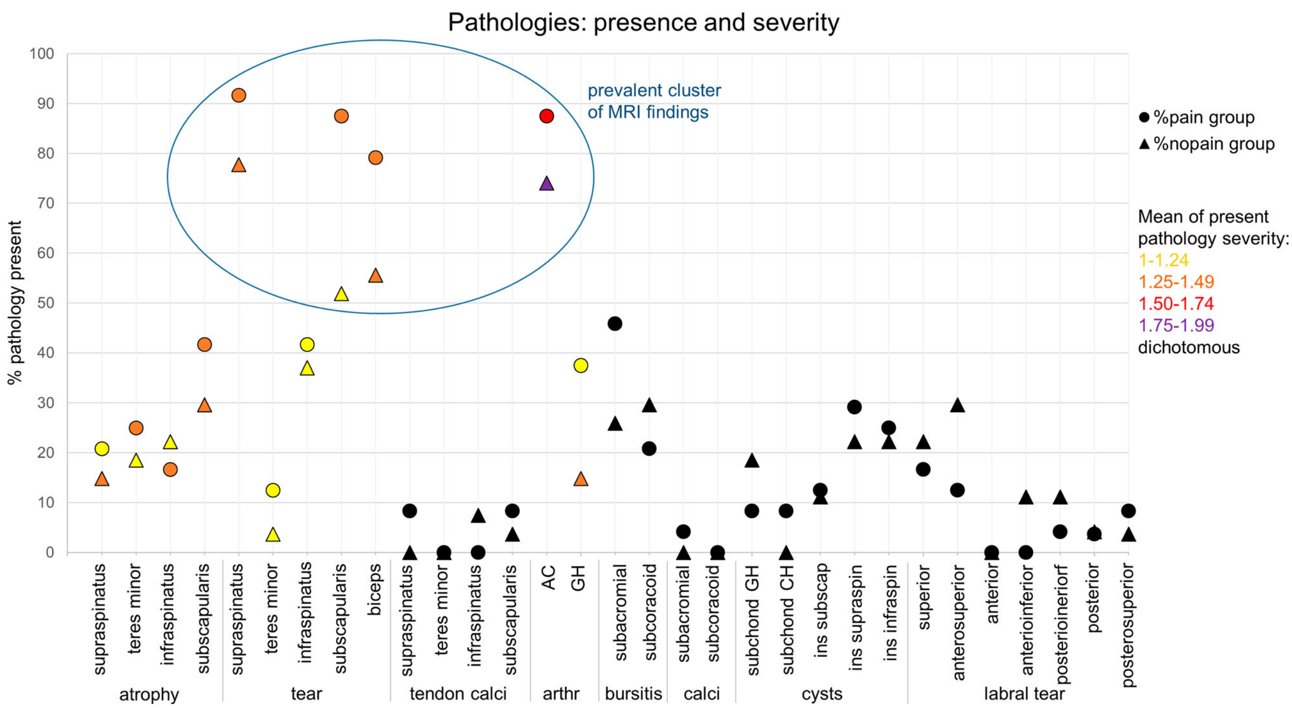

Figure 3 **Percentage of present shoulder pathologies in the pain and the no pain group and the corresponding severity. Tendon calci = tendon calcification, arthr = joint arthritis, calci = bursa calcification.**

analyze the influence of TSI and ageing on shoulder pain and shoulder pathology and to discriminate between these two variables, a longitudinal study is needed. Such a study could give further insight into the progression of shoulder pain and pathology and might elaborate risk factors based on MRI findings in order to predict which persons are becoming symptomatic.

Conclusion

Shoulder pathologies are common in persons with spinal cord injury, ranging from 0 to 19 co-occurring

MRI findings (out of 31 possible findings). The most common cluster of co-occurring MRI findings includes tear of the supraspinatus, biceps and subscapularis and AC arthrosis. MRI findings of shoulder pathology are very frequent also in persons without shoulder pain and no correlation was found between pain and pathology. Therefore, when diagnosing the cause of shoulder pain and planning interventions health care professionals should keep in mind that shoulder pathologies detected by MRI are equally present in persons with and without shoulder pain and MRI should only be used as an extended diagnostic measure in persons with shoulder pain and clinical symptoms.

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Disclaimer statements

Contributors: Study design: CW, DV, LvdW, MB, UA; data analysis: CW, MB, UA, WdV; data interpretation: all authors; manuscript drafting: UA; manuscript revision: all authors; approval of final version of submitted manuscript: all authors.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Statement of ethics

The study was approved by the ethics committee "Nordwest- und Zentralschweiz" (registration number EKNZ 2015-192). We certify that all applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during the course of this research.

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Appendix 1. Interrater reliability between the two examiners: percent agreement for each MRI finding.

	Percent agreement
Muscle atrophy	
Supraspinatus	78.4%
Teres minor	84.3%
Infraspinatus	62.8%
Subscapularis	82.4%
Rotator cuff tears	
Supraspinatus	49.0%
Teres minor	86.3%
Infraspinatus	74.5%
Subscapularis	56.9%
Tendon long biceps	56.0%
Tendon calcifications	
Supraspinatus	98.0%
Infraspinatus	96.1%
Subscapularis	96.1%
Joint arthrosis	
AC	60.8%
GH	68.6%
Bursitis	
Subacromial	72.6%
Subcoracoid	74.5%
Bursa calcification	
Subacromial	94.1%
Subcoracoid	96.1%
Subchondral cysts	
Glenoid	90.2%
Humeral head	90.2%
Labral tears	
Superior	72.6%
Anterosuperior,	66.7%
Anterior	82.4%
Anteroinferior	74.5%
Posteroinferior	88.2%
Posterior	94.1%
Posterosuperior	84.6%
Median	82.4%
Minimal value	49.0%
Maximal value	98.0%

Appendix 2. Logistic regression analyses for present MRI finding (binary outcome yes vs. no), corrected for age and time since injury.

		OR	(95% CI)	P
Muscle atrophy				
Supraspinatus	no pathology	1		0.348
	grade 1	0.88	(0.14–5.65)	
	grade 2	0.66	(0.03–14.03)	
Teres minor	no pathology	1		0.289
	grade 1	1.17	(0.23–6.06)	
Infraspinatus	no pathology	1		0.233
	grade 1	0.38	(0.06–2.34)	
	grade 2	0.48	(0.02–10.21)	
Subscapularis	no pathology	1		0.444
	grade 1	1.06	(0.21–5.24)	
	grade 3	0.91	(0.04–18.61)	
Rotator cuff tears				
Supraspinatus	no pathology	1		0.260
	tendinopathy	4.39	(0.46–42.11)	

Continued

Continued

		OR	(95% CI)	P
	partial rupture	9.17	(0.70–119.32)	
	focal transmural rupture	5.80	(0.20–167.20)	
	complete transmural rup	11.69	(0.30–460.15)	
Teres minor	no pathology	1		0.137
	tendinopathy	3.59	(0.30–42.84)	
Infraspinatus	no pathology	1		0.222
	tendinopathy	1.03	(0.28–3.76)	
Subscapularis	no pathology	1		0.029
	tendinopathy	8.69	(1.57–48.01)	
	partial rupture	7.41	(0.57–96.42)	
Tendon long biceps	No pathology	1		0.329
	tendinopathy	2.87	(0.64–12.81)	
	(Sub)Luxation	5.11	(0.51–50.92)	
Tendon calcification				
Subscapularis	no calcification	1		0.206
	present calcification	1.73	(0.14–21.49)	
Joint arthrosis				
AC arthrosis	grade 1	1		0.092
	grade 2	5.73	(0.08–41.00)	
	grade 3	1.28	(0.19–8.89)	
	grade 4	1.01	(0.09–11.86)	
GH arthrosis	grade 1	1		0.146
	grade 2	3.31	(0.68–16.15)	
	grade 3	0.96	(0.05–19.02)	
Bursitis				
Subacromial	no bursitis	1		0.151
	present bursitis	1.98	(0.49–7.98)	
Subcoracoid	no bursitis	1		0.125
	present bursitis	0.43	(0.10–1.84)	
Subchondral cysts				
Glenoid	no cyst	1		0.043
	present cyst	1.15	(0.02–1.14)	
Cysts on humeral head at insertion of				
Subscapularis	No cysts	1		0.208
	Present cyst	0.69	(0.11–4.20)	
Supraspinatus	No cysts	1		0.184
	Present cyst	1.58	(0.42–6.04)	
Infraspinatus	No cysts	1		0.223
	Present cyst	0.98	(0.26–3.78)	
Labral tears				
Superior	no lesion	1		0.148
	present lesion	0.93	(0.21–4.16)	
Anterosuperior	no lesion	1		0.031
	present lesion	0.21	(0.04–1.18)	
Posteroinferior	no lesion	1		0.065
	present lesion	0.20	(0.02–2.35)	
Posterior	no lesion	1		0.138
	present lesion	0.53	(0.03–10.12)	
Posterosuperior	no lesion	1		0.138
	present lesion	1.69	(0.14–20.71)	