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## Characteristics of dynamic magnetic resonance imaging of idiopathic severe frozen shoulder

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**Background:** The purpose of this study was to evaluate the effectiveness of current techniques for dynamic 3-dimensional magnetic resonance imaging (MRI) in the diagnosis of idiopathic severe frozen shoulder (FS).

**Materials and methods:** Subjects consisted of 5 healthy volunteers and 16 patients with idiopathic severe FS. We defined severe idiopathic FS as follows: range of motion  $\leq 100^\circ$  in forward flexion,  $\leq 10^\circ$  in external rotation, and  $\leq 5^\circ$  in internal rotation. All patients suffered from continued global range of motion loss for at least 6 months. We evaluated the diagnostic characteristics of 3-dimensional dynamic MRI in FS patients compared with those in healthy volunteers.

**Results:** MRI of all FS patients displayed an abnormal intake of blood flow from the acromial arterial network and the branches of circumflex humeral arteries into the axillary pouch and the rotator interval. We named this finding "burning sign." The burning sign was present at all phases of the condition. In the FS group, the patients with enhanced deposition of contrast medium in the axillary pouch in the delayed phase ( $n = 11$ ) had a statistically significant score for pain during exercise, higher than that of patients with reduced deposition of contrast medium at the same site ( $n = 5$ ;  $P = .027$ ).

**Conclusion:** Burning sign is an abnormal finding that appears in dynamic MRI of severe FS. Hence, the burning sign may be associated with pain and inflammation in idiopathic FS.

**Level of evidence:** Level IV; Case Control Design; Diagnostic Study

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**Keywords:** Frozen shoulder; dynamic MRI; healthy volunteer; pain; burning sign; abnormal vessel

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Frozen shoulder (FS) is a major orthopedic condition characterized by a limited range of motion (ROM) of the glenohumeral joint and shoulder pain. This condition was first described by Codman in 1934.<sup>4</sup> FS affects an estimated 2% to 5% of the total population.<sup>3,8</sup> Reeves studied the natural history of FS and described 3 phases of the condition: initial freezing, marked by an insidious onset of pain; frozen, involving pain and limited ROM of the shoulder; and thawing,

with gradual symptom resolution.<sup>17</sup> Although the pathologic process has been described as inflammatory thickening of the articular capsule<sup>6,18-20</sup> or the development of intra-articular or extra-articular synovial inflammation,<sup>14</sup> no causes have been identified.

Magnetic resonance imaging (MRI) has been used to identify changes in the appearance of the joint capsule and periarticular tissues (thickening, contrast enhancement, and obliteration of adjacent fat planes), at the rotator interval (RI), and at the joint capsule at the level of the axillary pouch (AP).<sup>2,5,7,10,13,15</sup> Nevertheless, diagnosis of FS based on imaging remains challenging. Alteration of the synovium can be demonstrated by dynamic MRI enhanced with intravenous administration of gadolinium. Using this technique, Tamai and Yamato reported a greater increase in signal intensity in the glenohumeral joint synovium in FS.<sup>22</sup> However, there have been no reports on dynamic MRI of FS using current techniques and devices. The purpose of this study was to evaluate the diagnostic potential of dynamic MRI in idiopathic severe FS.

## Materials and methods

Sixteen patients with severe idiopathic FS (16 shoulders) were referred to our hospital between January 2015 and September 2015, and all patients (FS group) underwent nonenhanced and dynamic enhanced MRI of the shoulder joint before treatment. The mean age of the patients was 54.4 (range, 39-79) years; 6 were men, 10 were women. Patients were diagnosed with severe idiopathic FS if they had limited ROM in all directions ( $\leq 100^\circ$  in forward flexion,  $\leq 0^\circ$  in external rotation at the side, at or below the fifth lumbar vertebral level in internal rotation) and did not respond to a combination of intra-articular steroid injections and physical therapy for at least 6 months. The mean time from shoulder pain onset to the procedure was 7.8 (range, 6-12) months. We recorded a mean ROM before dynamic MRI of  $83^\circ \pm 10^\circ$  in forward flexion,  $-1^\circ \pm 8^\circ$  in external rotation at the side, and L5 in internal rotation (median value). The mean Numeric Rating Scale (NRS) score at motion was  $6.4 \pm 2.1$  points, and the NRS score at rest was  $2.5 \pm 0.95$  points.

We defined exclusion criteria as follows: complete rotator cuff tear, shoulder osteoarthritis, calcified tendinitis, history of shoulder joint fracture, history of shoulder joint surgery, long head biceps tendon injury, diabetic stiff shoulder, possible diabetes indicated by a National Glycohemoglobin Standardization Program hemoglobin A1c (HbA1c) value of  $\leq 6.5\%$  or a Japan Diabetes Society HbA1c value of  $\leq 6.1\%$ , cervical radiculopathy, brachial plexus injury, dementia, schizophrenia, depression, panic disorder, and generalized anxiety disorder.

During the same period, 5 healthy volunteers were enrolled (as the HV group). All of the enrolled healthy volunteers had no history of shoulder pain or trauma of shoulder joints and presented without cervical spine, neuromuscular, or rheumatic disease. After approval by the Ethical Committee of our institution, MRI was performed in the subjects who provided consent. Their mean age was 47.6 years (range, 30-65 years), and all of the subjects were male. None of the subjects complained of shoulder pain at scanning, and the ROM was  $168^\circ \pm 13^\circ$  in forward flexion,  $55^\circ \pm 17^\circ$  in external rotation at the side, and T10 in belt-tying movement level (median value).

## MRI examination

MRI of the shoulder was performed in all patients and healthy volunteers using a 3T MRI system (Skyra; Siemens Medical Systems, Erlangen, Germany) and a wraparound multichannel coil. After a bolus intravenous injection of gadolinium-chelated contrast material, 3-dimensional (3D) fast low-angle shot images (repetition time, 3.1 ms; echo time, 1.26 ms) were obtained in the oblique coronal plane every 9 seconds for a total period of 3 minutes. At final phase, we obtained 4 T1-weighted images at each slice level (in-phase T1-weighted image, opposed phase image, water-only image [fat suppression image], and fat-only image). All the images were recovered from a digital database. The 3D dynamic magnetic resonance images were independently evaluated by 2 musculoskeletal radiologists (H.S. and A.F.) with  $>15$  years of clinical experience using a picture archiving and communication system station (Impax V5; Agfa HealthCare, Mortsel, Belgium). Then, capsular thickening of the AP ( $>3$  mm), thickening of the coracohumeral ligament ( $>4$  mm), and obliteration of the subcoracoid fat triangle, which have been reported as characteristics of routine enhanced MRI findings in FS, were evaluated by the same radiologists.<sup>11,12</sup> Images of the patients with FS and those of the HV group were mixed. The images were analyzed in 2 sessions, separated by a 3-week interval. The readers were blinded to clinical and demographic data, and the annotations on the screen were toggled off before the readouts. Interobserver and intraobserver agreement in the evaluation lists was also calculated. Discrepancies regarding MRI analysis between the 2 readers were rectified by mutual review and agreement in 5 cases.

## Statistical analysis

A Mann-Whitney *U* test was performed to compare mean age, mean duration of MRI from onset, NRS score at rest and motion, and shoulder ROM between the shoulders, between FS and HV patients, and to compare strongly enhanced signal in the AP at the delayed phase to shoulders with weak enhancement (SPSS version 20; IBM Corp, Armonk, NY, USA). The level of statistical significance was set at  $P < .05$ .

## Results

Dynamic MRI was capable of visualizing the axillary artery, circumflex humeral arteries, and acromial branch in the healthy subjects in the early phase. In the HV group, no evidence of abnormal blood flow or uptake of contrast medium around the glenohumeral joint was observed in any of the 5 shoulders from either the early or the delayed phase (Fig. 1).

Meanwhile, all the 16 shoulders in the FS group displayed an abnormal cluster of blood flow and dispersion of contrast medium around the RI (superior glenohumeral joint), AP (inferior glenohumeral joint), and groove in the early phase (Fig. 2). These abnormalities were found until the late phase. We named the phenomenon the "burning sign." The burning sign was observed in the RI of 15 shoulders, in the AP of all shoulders, and in the groove of 12 shoulders (Table I). AP thickening, coracohumeral ligament thickening, and obliteration of the subcoracoid fat triangle in routine enhanced MRI were identified in 15, 7, and 16 cases, respectively.

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