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The three-dimensional motions of glenohumeral joint under semi-loaded condition during arm abduction using vertically open MRI

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Abstract

Background. Magnetic resonance imaging is an accurate non-invasive tool for visualizing muscles, tendons, and bones. It also provides 3D coordinate values. The purpose of the present study was to visualize and quantify the 3D positions of the glenohumeral joint during isometric abduction of the arm using vertically open magnetic resonance imaging.

Methods. We examined 14 shoulders of seven healthy volunteers. Magnetic resonance images were obtained in a seated position and in seven static positions of the arm from 0° to maximum abduction using vertically open magnetic resonance imaging. 3D surface models were created and 3D movements of each bone in the glenohumeral joint were calculated using a computer algorithm. We analyzed the translation and contact pattern of the glenohumeral joint.

Findings. In supero-inferior direction, the humeral head translated slight inferiorly from +1.9 (SD 1.0) mm at 0° to +0.8 (SD 1.8) mm at the maximum abduction. In antero-posterior direction, the humeral head translated anteriorly from 0° to 90° (mean +2.4, SD 2.6 mm) and posteriorly from 90° to 150° of abduction (mean −1.4, SD 2.7 mm). Furthermore, the humeral head had a unique contact patterns with the glenoid; the contact part of the humeral head with the glenoid changed from the central part to the posterior in the midrange of abduction.

Interpretation. The humeral head showed a small translation in the antero-posterior direction between 90° and 150° of abduction. In addition, the posterior part of the humeral head contacted the glenoid in this range of abduction. These findings of motion patterns in asymptomatic subjects will be necessary when comparing the kinematics with pathologic condition such as the glenohumeral instability and rotator cuff tear.
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Keywords: Translation; Humeral head; 3D glenoid motion; Glenohumeral joint; Vertically open MRI

1. Introduction

The glenohumeral joint has the largest range of motion of any major diarthrodial joints in the human body. The motion of the shoulder complex has been conducted using cadaveric models, radiography, magnetic resonance imaging (MRI) and three-dimensional (3D) electromagnetic tracking systems, but it has been the topic of concern and controversy for a long time (Beaulieu et al., 1999; de Groot et al., 1999; Debski et al., 1995; Graichen et al., 2000; Inman et al., 1944; Meskers et al., 1998; Poppen and Walker, 1976). The reasons for this debate are numerous and include the imperfect devices or means of measurement

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as follows (Morrey et al., 1998). Cadaver studies are impractical due to the lack of physiologic tonus of musculature and fixation of the scapula (Kelkar et al., 2001; Wuelker et al., 1994). Radiographs are two-dimensional (2D) representations of the 3D body, and are subject to magnification and true distortion (Howell et al., 1988; Paletta et al., 1997). Also, slight postural variations such as rotation away from or towards the film would affect results (Lewis et al., 2002). A horizontally open MRI was often used for the shoulder motion by evaluating in the supine position. However, the problems of this position involved some restriction of the scapular motion and an impractical force direction of the gravity and weight, which turned backward (Beaulieu et al., 1999; Graichen et al., 2000; von Eisenhart-Rothe et al., 2002). Recently, 3D electromagnetic tracking systems enabled the measurement of motion in a seated position and overcame the above-described problems. They have become the most popular method for analysis of kinematics of the shoulder (de Groot et al., 1999; Meskers et al., 1998; Stokdijk et al., 2003). But their methods cannot precisely obtain the morphological information of bones such as the center of the humeral head and glenoid, since their methods obtains only 3D position of bony landmark, not the bony shape.

We have developed a kinematic analysis system to analyze and visualize 3D movement of any joint using 3D MR images, and reported the kinematics of the cervical spine and wrist joint using this system (Goto et al., 2004; Ishii et al., 2004; Moritomo et al., 2003). In addition, acquisition of MR images in a seated position using vertically open MRI allows analysis of the kinematics of the shoulder under conditions of gravity. The purpose of the present study was to investigate in vivo 3D movement patterns and relative positions of the glenohumeral joint during isometric abduction of the arm.

2. Methods

We examined 14 shoulders of seven healthy male volunteers (age range, 19–30 years; mean age, 23.6 years). None of the subjects had shoulder pain or a medical history of shoulder joint disorders. All participants gave informed consent to participate in this study. The analysis consisted of the following steps: acquisition of 3D MR images; creation of 3D surface model by segmentation; calculation of the movement by voxel-based registration and the motion analysis of the glenohumeral joint.

2.1. Image acquisition

3D MR images were obtained using a MR scanner with a vertically open configuration (Signa SP/i 2, 0.5T, GE Medical Systems, Milwaukee, WI, USA). We used the 3D Fast Gradientecho imaging sequence (TR, 15.6 ms; TE, 7.2 ms; flip angle, 30°) with a reconstructed section thickness of 1 mm. All images were obtained with a $240 \times 240\ mm^2$ field of view and a 512×512 matrix. The time required for scanning was 2 min and 35 s per image.

The subject was placed in a seated position between two gantries of a vertically open MRI system, and wore a flexible RF coil (GE Medical Systems, Milwaukee, WI, USA) around its shoulder. It was necessary to fix the arm and body to minimize the motion artifact while isometrically elevating the arm, since the time for scanning was too long to maintain the arm position without any support. For fixation of the body, it was inclined anteriorly about 20°; the sternum was fixed using an original stand which was attached on an anterior gantry of MR scanner; and the sacral region was fixed by a posterior gantry (Fig. 1). The body was then fixed without restriction of the scapular motion. For maintaining the abducted position of the arm, the subject isometrically held a removal knob attached on a vertical wall standing beside the subject (Fig. 1).

The subject isometrically elevated the arm at the hanging arm position (0°), 30°, 60°, 90°, 120°, 150° and the maximum abduction (seven isometric positions) in the frontal plane. At 0° of abduction, the arm was positioned at the side of its body with the neutral rotation of the humerus and the elbow flexed to 90°. From 30° to 150° of abduction,

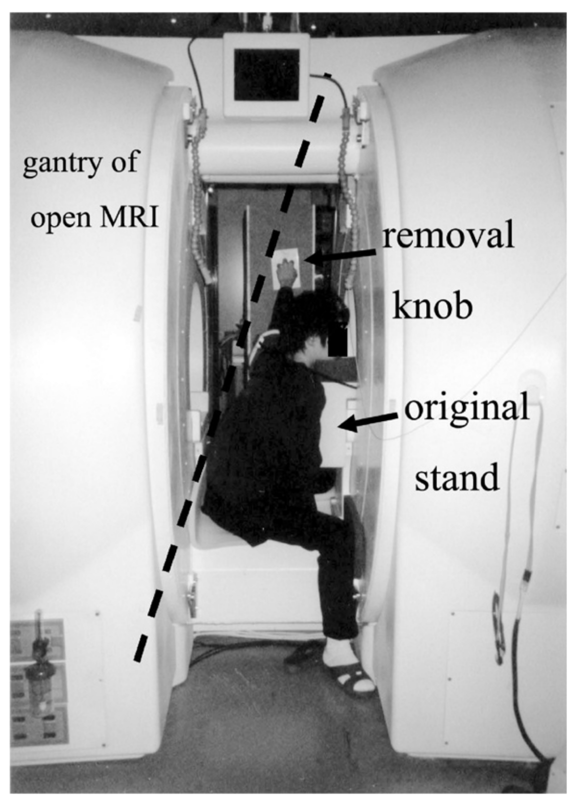

Fig. 1. The photograph of scanning images. The body of subject was inclined anteriorly about 20° to minimize the motion artifact in scanning images. The sternum was contacted to the original stand and the sacral region was contacted to a posterior gantry. A dotted line indicates the abducted plane of the arm. The right arm of subject was located at the side in this figure, but in fact both arms were abducted at scanning images.

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