INTRODUCTION:
The shoulder is the most commonly dislocated joint of the human body. Glenohumeral ligaments play an important role in stabilizing the shoulder as the static factor. The main contributions of them were to maintain anterior stability and to restrict superior-inferior translation, whereas a lesion of them may be result in disability, instability, and dislocation of the shoulder. Different function was performed by various ligaments that depended on both arm position and the direction of load. Therefore, numerous studies have attempted to determine the relative contributions to glenohumeral stability of the superior, middle, and inferior glenohumeral and the coracohumeral ligament. However, previous in vitro studies based on cadaveric shoulder do not reflect the actual events in the living body because of muscle removal. The purpose of this study was to investigate in vivo and three-dimensional (3D) length changes of the glenohumeral ligaments during shoulder abduction using 3D-MRI and image matching technique.

MATERIALS and METHODS:
The method comprised 2 steps. In the first step, we obtained 3D attachment points of the ligaments using formalin-embalmed shoulders. We inserted marker pins into the centroid of each ligament and scanned the ligaments by 3D computed tomography (CT). Using a graphics workstation, a software program generated 3D bone models showing the marker pins. And we made accurate 3D measurements to specify the attachment of each ligament.

In the second step, 14 shoulder joints of 7 healthy volunteers were studied in vivo during arm abduction using a noninvasive 3D motion-analysis system. Based on anatomical study data and motion analysis, the software calculated the change in length of each ligament in vivo during arm abduction. The 3D ligament lengths were based on the shortest calculated paths between each origin and insertion in 3D space along the 3D bone surface with each abduction position.

1) Anatomical study: Obtaining the attachment point of the ligaments
Ten formalin-embalmed shoulders of 5 cadavers amputated scapulothoracic joint were investigated (2 men and 3 women, age range from 60 to 96 years, average 83.4 years). All skin, subcutaneous tissues, and the musculature were removed except for the glenohumeral joint capsule. With a posterior approach, the capsule was opened. The structures of the CHL, SGHL, MGHL, and AIGHL were characterized (Fig. 1). Respectively, we inserted a metal pin (ø0.3mm) into the centroid of the attachment of each ligament as a marker (Fig. 2). Then, all specimens were scanned using a computer tomography (SOMATOM Spirit; SIEMENS, Munich, Germany: scan time 60 s; scan pitch 2mm ;80 mAs; 120 kV; slice thickness 0.5mm).

Creating a 3-D bone surface model
Scan data were uploaded into a graphics workstation, and regions of individual bones were semi-automatically segmented from 3D-CT images with use of a software program (Virtual Place-M; AZE, Tokyo, Japan). The software generated three-dimensional surface bone models with use of the marching cubes algorithm. Visualization of the geometrical models of each shoulder was obtained with a software program that was developed in our laboratory (Orthopedics Viewer; Osaka University, Osaka, Japan). There was variation in individuals. We equalized all subjects using the function of adjustment of this software. By this method, all positions of the centroid were plotted on one model. And the mean 3D-position data of the centroids of the ligamentous attachments could be determined (Fig. 3).

2) Kinematics and ligament paths
We examined 14 shoulders of seven healthy male volunteers (age range, 19–30 years; mean age, 23.6 years). We obtained 3D-MR images of their shoulder in seven abducted positions of the arm, using a vertically open MRI. The voxel-based registration technique is used to identify the transformation from the coordinate system of one image to another. This method is based on matching of bony contour and content data in all images by the similarity of the image intensity. We evaluated the 3D movements of humeral bone relative to the scapula. Then, the ligament lengths between the insertion and the origin were calculated as the shortest paths in three-dimensional space along the 3D surface of the bone models. In this program, the information of the attachments of the ligaments was obtained from anatomical study.

RESULTS:
Patterns of the length changes of the ligaments during shoulder abduction were shown in the figure 5 and 6.

DISCUSSION:
Glenohumeral ligaments are the most important stabilizing mechanism of a shoulder joint under the dynamic condition. Each ligament may have a different function according to the change of the arm positions or motions. Using our method, we could evaluate the change of each ligament in vivo 3D analysis.

REFERENCES: