Scapular Movement in Asymptomatic Shoulder - In Vivo Kinematic Analysis of the Shoulder using Model-based 3D-to-2D Registration -
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Introduction: Kibler reported that the scapula must be stabilized in a position of relative retraction during arm movement to maximize activation of all the muscles that originate on the scapula.[2] The goal of this study was to give a functional assessment of the shoulder from in-vivo kinematic alterations of the scapular movement with/without external loading during abduction. It is assumed that neuromuscular control mechanism of the scapular stabilization would be activated.

Materials and Methods: Ten healthy shoulders in ten subjects (8 men, 2 women, 27 to 38 years old, average 31.5 years) were studied. All shoulders were asymptomatic, had no history of injury, and lacked any clinical or radiographic sign of pathology. All subjects provided informed consent to participate in this study. The subject was positioned in front of a fluoroscope and motions were recorded during active abduction from arm at side to about 120° in the scapular plane. Before the fluoroscopic examinations were taken, each subject practiced several trials of abduction in the scapular plane so they were comfortable moving in the scapular plane at a constant speed. The subjects performed two trials: one trial holding a 3kg weight and one unloaded trial. We use the term "unloaded" to mean no additional external load was suspended by the arm – the subject still was required to lift the mass of their arm against gravity. All subjects provided CT scans, which were acquired at 0.5 mm intervals. 3D models of the scapula and proximal humerus were created from the CT images in two stages. Exterior cortical bone edges of CT images were segmented using commercial software, and the resulting point clouds were converted into polygonal surface models. Anatomic coordinate systems were embedded in each bone model using commercial software. The scapular origin was defined as the center of the line connecting the most superior and inferior bony edges of the glenoid surface. The humeral origin was placed at the center of the humeral head, with a long axis parallel to the humeral shaft. (Figure 1) In vivo 6 degrees-of-freedom shoulder kinematics determined using model-based 3D-to-2D registration with a custom program.[1] A human operator manually positioned the humerus and scapula models into rough registration in each image, and then an automatic non-linear least-squares optimization routine was used to refine the registration based on minimizing the distance between bone edges in the image and the projected bone model. (Figure 1) The scapular motion data were grouped into 10° intervals of the arm abduction angle. This data was analyzed with t-test and the significant level was set at p<0.05.

Results: From the starting position to 30° of abduction, the scapula was downward rotated. The scapular upward rotation was significantly diminished from 40° to 80° of abduction while loading. (Figure 2) The scapula moved toward the spinal process (scapular retraction) about 1-8mm from the starting position, but the magnitude of the retraction was not significantly different from each groups with/without external loading. (Figure 3)

Discussion: In the loading case, a neuromuscular coordination of scapular originated muscles was activated for the stabilization of the scapula. Consequently, the scapula upward rotation was reduced and the scapula was stabilized in a position of relative retraction. This kinematics demonstrated that the scapula may provide a stable fulcrum for the subsequent rotator cuff contribution during arm abduction.