Introduction: The supraspinatus and deltoid muscles contract synergistically during glenohumeral abduction in the scapular plane. The delicate balance between individual muscles may be disrupted substantially by rotator cuff tear and other shoulder injuries. Cadaveric models and isolated suprascapular and axillary nerve blocks have been used to clarify the roles of the supraspinatus and deltoide [1-3]. However, there is still a lack of information on the abduction moment distribution among the individual muscles crossing the glenohumeral joint, especially under physiological and functional conditions. The purpose of this study was to determine in vivo the isometric moment distribution between the supraspinatus and deltoide during arm abduction in the scapular plane.

Methods: Three subjects with no prior history of upper limb musculoskeletal injury and neurological disorder participated in the study. Informed consent was obtained before the experiment. The subject sat upright and the upper arm was abducted at 45° in the scapular plane. With the elbow flexed at 90°, the forearm and upper arm were cast using fiberglass tape and fixed to an attachment that in turn was mounted onto a six-axis force sensor. The trunk and shoulder were strapped to the backrest. The experiment was conducted under an isometric condition.

The supraspinatus and the middle, anterior, and posterior heads of deltoid muscles were activated selectively using electrical stimulation. Intramuscular wire electrodes and surface electrodes were used to stimulate the supraspinatus and deltoide, respectively. Bipolar stimulation was used due to its more localized current flow. The amplitude of the constant current stimulation was varied systematically to activate the muscle over a range of contraction levels. Besides the pair of stimulation electrodes, a second pair of electrodes was used for each muscle to record the compound muscle action potential (M-wave). A train of stimulation pulses (0.3 ms pulse width, 25 Hz, and 500 ms train duration) was used to activate each individual muscle and the resulting M-waves and glenohumeral abduction torque were recorded.

After stimulating each individual muscle, a target abduction torque was displayed on a computer moni and the subject voluntarily abducted the arm under isometric condition to match and track the target torque in real-time. Different levels of glenohumeral abduction torque were specified for different trials, ranging from about 5 to 40% of the maximal abduction torque. The same pair of electrodes used to record the M-waves was used to record the voluntarily generated EMG signals. Six-axis moments and forces were also recorded together with the EMG signals.

The relationship between the glenohumeral abduction torque generated by an individual muscle and the amplitude of the corresponding M-wave was established over the different contraction levels for each muscle. The relationship was approximately linear under the moderate isometric contraction. Since exactly the same electrodes were used to record the M-wave and EMG signals for each muscle, the above abduction torque-M-wave relationship could be used to calibrate the corresponding EMG signal during voluntary contraction. Therefore, the electrode size, shape, material properties, location, inter-electrode distance, skin preparation, amplifier settings, and EMG signals etc. were matched closely between the M-wave and voluntary EMG signals for each muscle, and the uncertainties caused by these factors could be minimized.

Results: At the 45° arm abduction, electrical stimulation of the posterior deltoid produced glenohumeral abduction instead of abduction in the scapular plane, and extension moment was the major torque component generated by the posterior deltoid.

Glenohumeral abduction moment distribution among the supraspinatus, middle deltoid and anterior deltoid was determined in vivo using the above method and shown in Fig. 1(a). The anterior and middle deltoid produced the major portion of the abduction moment. The anterior deltoid was the most significant abductor at the lower torque levels, while the middle deltoid became more dominant as the abduction demand increased. On the other hand, the supraspinatus also generated significant abduction moment across the different levels of glenohumeral abduction moment. In addition to the target abduction torque, the subject also generated considerable flexion (and axial rotation) torques during the target matching/tracking process. This seems related to the strong contribution of the anterior deltoid.

If the glenohumeral adductor contribution was assumed insignificant, the absolute individual muscle moment generated by each individual muscle could be estimated and the results were given in Fig. 1(b). The absolute torque generated by each individual muscle increased gradually with the total demand.

Discussion: The above approach provides us an in vivo tool to determine load-sharing/moment-distribution among individual muscles crossing the glenohumeral joint. If there is no significant abductor-adductor co-contraction, the approach solves the abduction load sharing among the abductors. If the co-contraction is significant, the approach still provides information on the load sharing among the abductors. In general, the approach can be used to calibrate EMG signals and determine the relative torque generated by synergistic or antagonistic muscles. The experiment was conducted under the isometric condition and the results were valid under such a condition. Further study needs to be done to determine the dependence of load sharing on joint position and under non-isometric conditions.

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**Dept. of Orthopaedic Surgery, Northwestern University.