

Specimen Preparation and the Shoulder Simulator

The specimens were mounted to the simulator by cementing the inferior aspect of the scapula into a pot fixture with use of dental cement (Lang Dental Manufacturing, Wheeling, Illinois). The scapular pot has the ability to rotate from neutral to 30° of abduction to simulate composite shoulder girdle abduction. The testing system allows actuation of the individual rotator cuff muscles and the anterior, middle, and posterior heads of the deltoid. Muscle actuation was accomplished by placing sutures into the individual tendons at the musculotendinous junction and routing the sutures through alignment guides to replicate the physiologic direction of muscle action. The individual sutures were attached to computer-controlled pneumatic actuators that applied physiologic loads. A constant force of 5 N was applied to each of the three heads of the deltoid, 7.5 N to the supraspinatus, 7.5 N to the subscapularis, and 7.5 N combined to the infraspinatus and teres minor^{22-24,31}. In order to accurately assess continuous shoulder motion and instantaneous glenohumeral spatial relationships, optical markers (Optotrak Certus; Northern Digital, Waterloo, Ontario, Canada) were attached to the scapula and the humerus. The output data from the optical markers were captured in real time. The technique described by Woltring²⁵ was used to calculate the center of the glenohumeral joint by recording the kinematics of the intact shoulder with muscles loaded to simulate resting muscle tone during passive abduction, flexion, circumduction, and axial rotation.

After obtaining digitizations of the epicondyles, the humeral shaft was osteotomized at its midpoint. The loads and torques experienced by the proximal aspect of the humerus were measured with a six-degree-of-freedom load cell (Mini45; ATI, Apex, North Carolina) that was interposed between two custom-made steel rods. The proximal rod was cemented into the humeral shaft, using a custom-made computer-assisted image guidance system to align a small transverse bar on the instrumented humeral rod parallel to the previously digitized epicondylar axis. The distal rod was mounted to the testing apparatus.