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Measurement of strain and tensile force of the supraspinatus tendon under conditions that simulates low angle isometric elevation of the gleno-humeral joint: Influence of adduction torque and joint positioning☆

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ABSTRACT

Background: Recently, supraspinatus muscle exercise has been reported to treat rotator cuff disease and to recover shoulder function. However, there have been no report on the direct measurement of strain on the supraspinatus tendon during simulated isometric gleno-humeral joint elevation.

Methods: Ten fresh-frozen shoulder specimens with the rotator cuff complex left intact were used as experimental models. Isometric gleno-humeral joint elevation in a sitting position was reproduced with low angle of step-by-step elevation in the scapular plane and strain was measured on the surface layer of the supraspinatus tendon.

Findings: In isometric conditions, applied tensile force of the supraspinatus tendon increased significantly with increases in adduction torque on the gleno-humeral joint. Significant increases in the strain on the layer were observed by increase in adduction torque, which were recorded in isometric elevation at − 10° and 0°, but little increase in the strain was observed at 10° or greater gleno-humeral elevation.

Interpretation: Increased strain on the surface layer of the supraspinatus tendon was observed during isometric gleno-humeral elevation from − 10 to 0°. These findings demonstrate a potential risk of inducing overstretching of the supraspinatus tendon during supraspinatus muscle exercise.

1. Introduction

Recently, supraspinatus muscle exercise has been reported to treat cases with subacromial impingement or rotator cuff tear and to recover shoulder joint abduction strength (Bernhardsson et al., 2011; Klintberg et al., 2008; Kuhn, 2009). Therefore, when commencing exercise involving the shoulder joint, we should estimate the strain or tension of the supraspinatus tendon to set an appropriate exercise intensity.

Rotator cuff tendon strains have been measured in cadaver specimens with traditional optical strain measurement or DVRT strain gauge (Noyes and Grood, 1976; Woo et al., 1994). Based on recent development of knowledge about causative factors for cuff tendon delamination, strain of rotation cuff tendon was measured individually about the surface layer and deep layer, i.e., layer of the bursal side and articular side. Reports of cadaver experiments demonstrated strain of the surface layer by horizontal separation of the supraspinatus tendon (Huang et al., 2005; Nakajima et al., 1994; Reilly et al., 2003). Strain values of the surface tendon was 15% at yield point (Nakajima et al., 1994), 1.3% at 0–5% cyclic load (Huang et al., 2005), 1.4% at 100 N load to supraspinatus tendon (Reilly et al., 2003) by quasistatic tensile testing in which the supraspinatus tendon was totally isolated from infraspinatus or subscapularis tendon (Table 1).

Currently, novel measurement of imaging revealed possibility of non-invasive record of rotator cuff tendon strain in which rotator cuff tendon left intact. Bey et al. (2002) reported 2D finite strain tensor in MRI image using cadaver supraspinatus tendon, Andarawis-Puri et al.

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Table 1
Literature concerning surface tendon strain of the SSP during low gleno-humeral abduction.

Year of print				2011	2010	2002	2005	2003	1994
Author			Present study	Kim	Andarawis	Bey	Huang	Reilly	Nakajima
Material			Cadaver	Volunteer	Cadaver	Cadaver	Cadaver	Cadaver	Cadaver
Measurement			Strain gauge	2D STE	surface image FST	MRI 2D FST	Optic strain measure	Strain gauge	Optic strain measure
Age			81 yrs	27 yrs	48 yrs	46 yrs	55 yrs	69 yrs	58 yrs
Tensile force to SSP			80–110 N	Isometric contraction	90 N	31 N	Cyclic 0–5% strain	100 N	Yield point
Isolation of SSP			No	No	No	No	Yes	Yes	Yes
Surface strain of SSP	G-H abd	− 10 deg	13.0%						
		0 deg	10.0%	17.0%	7.0%			1.4%	15.0%
		10 deg	3.0%						
		15–30 deg	1–2%		5.0%	1.4%	1.3%		

SSP: supraspinatus tendon.
STE: speckle tracking echocardiogram.
FST: finite strain tensor.

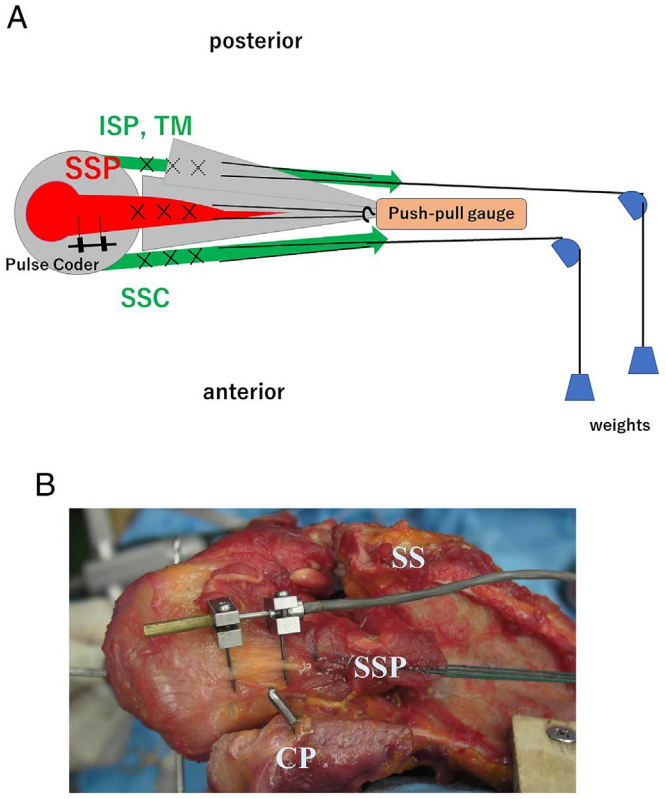

Fig. 1. a, b: Measurement of the strain of the surface layer of the supraspinatus tendon by Pulse Coder.
Fine needles of the Pulse coder were attached to the surface layer of the supraspinatus tendon measuring distance between pins. Intramuscular tendon of the supraspinatus was gloved by locking suture and was pulled by the Pulse Coder. Intramuscular tendon of the infraspinatus and subscapularis were gloved by locking suture and pulled by weights.
SSP: Supraspinatus, ISP: infraspinatus, SSC: subscapularis,
CP: coracoid process, SS: spine of the scapula

(2010) reported surface image finite strain tensor using cadaver supra- and infraspinatus tendons, and Kim et al. (2011) reported 2D speckle tracking echocardiogram using shoulders in healthy volunteers. Each of them applied some amount of tensile load to the supraspinatus tendons and measured strain of the surface layer of the supraspinatus. However, there have been no reports about the direct measurement of strain on the supraspinatus tendon during simulated gleno-humeral joint elevation in which rotator cuff left intact (Table 1).

In this research, isometric gleno-humeral joint elevation in a sitting position was reproduced using fresh-frozen cadaver specimens. When the supraspinatus muscle was in a contracted state by pulling with a digital push- pull gauge, strain on the surface layer of the supraspinatus tendon was measured directly. The hypothesis of this research is that during traction of the supraspinatus tendon in gleno-humeral elevation, strain on the surface layer of the supraspinatus tendon is the highest at 0- degree abduction or at adduction and decreases with increase in the angle of elevation.

2. Materials and methods

2.1. Preparation of specimens

Unilateral shoulder specimens from ten fresh-frozen cadavers (5 left, 5 right; 6 males, 4 females; average age 81.3 yrs) without evidence of tendon rupture, osteoarthritis, or fracture were used in this experiment. Rotator cuff tendons in the aged cadaver have microscopic degeneration, in this study macroscopic observation of the supraspinatus tendon at critical zone was performed and specimens with apparent tendon degeneration or tearing were excluded. All specimens had been transferred from the various institutions to the Department of Anatomy within 24 h after death.

Shoulder specimens were disarticulated from the thorax, clavicle and forearm, and kept in a freezer in a neutral shoulder position. Thawing of the shoulder specimens at room temperature (22 °C) was started 12 h before preparation. The serratus anterior muscle, latissimus dorsi muscle, rhomboid muscle, levator scapulae muscle, pectoralis major muscle, pectoralis minor muscle, coracobrachialis muscle, brachialis muscle, biceps brachii muscle, triceps brachii muscle, and deltoid muscle were removed. Muscle tissue of the supraspinatus, infraspinatus, teres minor, subscapularis was also removed while preserving the intramuscular tendons. Rotator cuff, joint capsule and coracohumeral ligament was preserved. Proximal part of the remaining intramuscular tendon of each cuff muscle was gripped by #2 Ethibond sutures with locking suture method. Then, traction force of 9.8 N was applied to subscapularis, 4.9 N was applied to infraspinatus, and 4.8 N was applied to teres minor by weights (Itoi et al., 1995; Muraki et al., 2007). An acrylic stick was then inserted perpendicular to the humeral shaft on the mid-point of the lateral and medial epicondyles which oriented in the anterior-posterior direction (Fig. 1a, b).

2.2. Testing apparatus

The scapula was fixed perpendicular to a jig so that the spine of the scapula was parallel to the floor (Muraki et al., 2006, 2007).

A digital push- pull type load measurement gauge RX-50 was connected to the intramuscular tendon of the supraspinatus using a suture and pulley. The angle of the gleno-humeral joint elevation was changed