INTRODUCTION:
Rotator cuff tears are a common condition, affecting approximately 50% of the population over the age of 60 [1]. The etiology of rotator cuff tears is not well understood, but it is widely believed that abnormal glenohumeral joint (GHJ) motion leads to subacromial impingement and the development of rotator cuff tears [2]. The treatment of rotator cuff tears is based implicitly on the belief that restoring normal GHJ motion is necessary to obtain a satisfactory clinical outcome (i.e., strength, subjective assessment of function). However, the extent to which GHJ motion and clinical outcomes—specifically, shoulder strength and subjective assessments of pain/function—are related after rotator cuff repair is not well understood. The objective of this study was to assess the relationship between measures of shoulder strength, in-vivo GHJ motion, and subjective clinical outcome. We hypothesized that shoulder strength would be associated with GHJ motion and clinical outcome.

METHODS:
Testing Procedures: Following IRB approval and informed consent, 22 patients (age: 63.5±9.7) enrolled in this study. Each patient had arthroscopic surgical repair of an isolated supraspinatus tendon tear prior to testing. Each patient’s contralateral shoulder was asymptomatic. In addition, 36 subjects (age: 30.2±7.9) with no history of shoulder injury, surgery, or symptoms also enrolled in the study. Biplane x-ray images were acquired for each shoulder during coronal-plane abduction from full adduction to 120°. Isometric shoulder strength was measured during coronal-plane abduction (ABD), sagittal-plane elevation (ELEV), external rotation (ER), and internal rotation (IR). Conventional clinical outcomes were assessed using the Western Ontario Rotator Cuff (WORC) Index, where lower scores indicate a more satisfactory clinical outcome. Lastly, bilateral CT scans of the humerus and scapula were acquired for each subject. For the rotator cuff repair patients, all data were collected at 3, 12, and 24 months post-surgery. The control subject data were collected at only one time point.

Data Analysis: Three-dimensional (3D) models of the humerus and scapula were reconstructed from the CT images. Using these bone models, the 3D positions of the humerus and scapula were determined from the biplane x-ray images using an accurate (±0.4 mm, ±0.5°) model-based tracking technique [3]. To quantify joint motion, GHJ contact patterns were estimated by combining joint motion measured from the biplane x-ray images with the subject-specific bone models [4]. The GHJ contact center was estimated by calculating the centroid of the minimum distance between humerus and glenoid surfaces for each frame of data. This contact center was expressed in anterior/posterior (A/P) and superior/inferior (S/I) coordinates relative to a glenoid-based coordinate system. To account for differences in subject size, these data were normalized with respect to the subject’s glenoid height and width. Dynamic joint positioning was assessed by calculating the average contact center over the entire trial in both the A/P and S/I directions. In order to normalize strength across all subjects without relying on the contralateral shoulder, a shoulder strength ratio—defined as ER strength divided by ABD strength—was calculated for each shoulder.

Statistical Analysis: The relationship between the ER/ABD strength ratio, the WORC Index, and the average contact center was assessed with linear regression and correlation. Significance was set at p<0.05.

RESULTS:
Strength Ratio vs. GHJ Joint Motion: The ER/ABD ratio was significantly associated with the average S/I contact center in the control subjects (p=0.05, Fig. 1), while this relationship demonstrated a statistical trend in the rotator cuff repair patients (p=0.10, Fig. 1). Specifically, a higher ER/ABD strength ratio was associated with the humerus being positioned more inferiorly relative to the glenoid.

Strength Ratio vs. Clinical Outcome: The ER/ABD strength ratio was also associated with the WORC Index in the rotator cuff patients at 24 months post-surgery (p=0.04, Fig. 2). Specifically, a higher ER/ABD strength ratio was associated with a better clinical outcome.

DISCUSSION:
The finding demonstrating the relationship between the ER/ABD strength ratio and GHJ motion (Fig. 1) may suggest that a high strength ratio helps position the humerus centrally on the glenoid. This interpretation is consistent with the concept that the rotator cuff’s transverse force couple—i.e., the coupling of anterior (subscapularis) and posterior (infraspinatus) muscle forces—may be sufficient to stabilize the humerus against the glenoid even when the supraspinatus tendon is torn [5]. Thus, low ER strength relative to overall shoulder strength may lead to superior translation of the humerus relative to the glenoid. Alternatively, the relationship between the strength ratio and joint motion may indicate that a humerus that is positioned lower on the glenoid is capable of generating higher ER strength relative to overall shoulder strength. Regardless of the specific interpretation, the ER/ABD strength ratio is important because it allows us to relate not only shoulder strength and joint motion, but also shoulder strength and clinical outcome (Fig. 2). Furthermore, the strength ratio has clinical utility since ER strength and ABD strength can be easily measured (either qualitatively or quantitatively) in a clinical setting.

SIGNIFICANCE:
Our long-term goal is to improve the treatment of patients with rotator cuff tears. These findings improve our understanding of shoulder function by demonstrating important relationships between shoulder strength, in-vivo joint motion, and clinical outcome.

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REFERENCES: