INTRODUCTION
Arthritic conditions of the glenohumeral joint are increasingly treated by total shoulder arthroplasty (TSA), but the procedure is still relatively young compared to total hip and knee arthroplasties. Experience has shown that a more complete understanding of pre- and post-arthroplasty bone and joint loading is critical to designing newer implants with increased longevity, improved surgical techniques, and thus, better functional outcomes. Alterations in glenohumeral joint mechanics as a consequence of TSA have been explored in the past, but studies are limited and questions remain. In most previous studies of glenohumeral mechanics, in-vivo loading of the shoulder was simulated in cadaver models after removal of the capsule and rotator cuff. The humeral head was often simulated with a metallic ball. In contrast, the data reported here were gathered under more realistic conditions that better simulated physiologic loading of the shoulder as a result of deltoid and rotator cuff muscle activity. Peri-glenoid bone strains and glenohumeral translations were measured before and after TSA. Our null hypothesis was that TSA would have no significant effect on the pattern and magnitude of peri-glenoid strains and joint translations.

METHODS
Four cadaver shoulders, procured while preserving the intact capsule and rotator cuff, were dynamically loaded in a custom-built apparatus. Fluoroscopic guidance was used to precisely and rigidly fix the scapula to the apparatus, with the glenohumeral joint oriented in 25° inclination, 10° anterior tilt, and neutral version, i.e. the in vivo joint orientation. Reflective marker-clusters were fixed to the acromion and the humeral shaft. Tri-axial strain gauge rosettes (KYOWA, Japan) were glued onto the superior, anterior and posterior aspects of the glenoid beyond the boundaries of the joint capsule. Joint loading due to muscle activity was executed with the specimen in 90° of abduction (lateral position), and 90° of flexion (forward position) and extension (backward position) in planes 30° anterior and posterior to the mid-coronal respectively. Deltoid forces (from 0 to 200 N) were dynamically simulated by means of a linear actuator (IDC/Danaher Motion), connected to the distal end of the amputated humeral shaft in series with a load cell. Tensions in the rotator cuff muscles (30 to 50 N) were produced by applying static forces to the muscle bellies through cryogenic clamps. Peri-glenoid bone strains and 3D marker motion (Eagle, Motion Analysis Corp., CA) were captured at 100 Hz. Glenohumeral joint translation - the motion of center of the humeral head with respect to the center of the glenoid - was derived from the marker motion using global-to-anatomical coordinate system transformation. Principal compressive and tensile strains were derived from the recorded strains using the established formulas.

All operative procedures were performed by an experienced shoulder surgeon (AA). Repeated loading trials were conducted with the intact capsule, with the capsule released, after labrum removal, after superficial reaming, and following joint replacement. Standard Bigliani/Flattow® prosthesis (Zimmer Inc., IN) were implanted in all specimens in a consistent manner. Average principle strains and joint translations were compared across conditions using a general linear model repeated measures ANOVA, followed by Tukey paired comparisons where appropriate. Significance was set at a level of 0.05.

RESULTS
We observed that the compressive peri-glenoid principle strains were statistically similar following arthroplasty (p = 0.9917, 0.5197 and 0.2243 for the superior, anterior and posterior principle strains respectively; Figure 1a and 1b); likewise, the tensile principle strains were similar as well. Figure 1a shows the average compressive principle strains (n = 4) as the joints were dynamically loaded with increasing deltoid forces from 20 to 200 N, while Fig. 1b shows the strains at 200 N of loading. Likewise the average joint translations, i.e. the humeral head sliding about the center of the glenoid in the antero-posterior (AP) and supero-inferior (SI) directions, were also comparable before and after arthroplasty (p = 0.7721 and 0.9926 respectively). The AP translations when loaded in a functional forward position were considered to be most important. In general, the translations were directed more anteriorly following TSA.

DISCUSSION
Peri-glenoid strains are useful for assessing bone quality and strength, the uniformity of glenoid loading, and alterations in these parameters as a consequence of the implanted prosthesis. In a previous study, cyclic patterns of strains have been observed at the implant-keel during edge-loading in an attempt to simulate the rocking-horse phenomenon. Higher glenoid strains have been measured following prosthetic implantation in the past. In contrast, we observed lower strains around the glenoid following TSA. Though not statistically significant, lower strains following arthroplasty could provide some support for stress-shielding effect of the implant.

Joint translations under loading are a valuable indicator of joint stability, and have been measured in cadaver shoulder joints as well as in vivo. We observed joint translations, to be comparable before and after TSA. Specifically, the mean AP translation when loaded in 90° abduction and flexion was -1.2 ± 4.83 mm and 1.5 ± 4.28 mm before and after arthroplasty respectively. These findings are in concurrence with previous literature. Based on our earlier project, AP translations when loaded in the forward position - a functional position of 90° abduction and flexion along a plane 30° anterior to the mid-coronal - were considered to be most indicative of joint stability. Increased anterior sliding of the humeral head following TSA could be due to the fact that the anterior capsule was released, and the tendon of the long head of biceps was resected during the procedure.

In summary, alterations in the strain distribution around the glenoid and glenohumeral joint stability as a consequence of TSA, under dynamic joint loading in a cadaver model, are reported. We observed comparable peri-glenoid strains and glenohumeral joint translations before and after implantation of the prosthesis. Our model recreates physiological loading of the shoulder joint - intact with the capsule and rotator cuff - and therefore the results could be more realistic. Applications of the model could be further expanded for validation and comparison studies of different prostheses in the future.

REFERENCES
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ACKNOWLEDGEMENTS
Orthopaedic Research and Education Foundation for funding this project