INTRODUCTION: Loosening of glenoid components in total shoulder arthroplasty is a common clinical problem which can necessitate revision surgery. The mechanism of loosening is poorly understood and may be related to factors including implant design, component fixation techniques, and to tensile stresses at the interfaces. We are unaware of any studies that have examined the fundamental aspects of load transfer to bone for various joint loading configurations. The objective of this study was to investigate the effect of joint loading on bone strain adjacent to a polyethylene glenoid implant.

MATERIALS AND METHODS: Five specimens (4 males; average age: 59.5 yrs) implanted with a cemented, all polyethylene component (Anatomical Shoulder; Zimmer GmbH, Winterthur; Switzerland) were tested using an apparatus capable of producing loading vectors (via pneumatic actuators) with various angles, magnitudes and directions. Each specimen was tested using a ramp load of 0 to 150 N (at 10N/sec) in two directions (superior and inferior) and with six angles (θ in Figure 1) of load application. A uniaxial strain gauge (Micro-Measurement, Vishay, Malvern, Pa.) was placed in each of the four quadrants of the glenoid (superior, inferior, anterior and posterior), approximately 1 mm medial to the glenoid rim. The primary axis of each strain gauge was oriented medio-laterally to record bone strains. The humeral head was simulated by a custom steel ball with a radius of curvature with a nonconforming bone interprosthetic surface.

RESULTS: The relationship between strain and applied force was not linear (superior quadrant at 40°: linear fit R²=0.98; quadratic fit R²=0.99; p<0.0005), and was dependent on the loading angle (Figure 2). Figure 3 illustrates the average ipsilateral and contralateral tension for loading from 0 to 30 degrees between all tested specimens as well as the initiation of ipsilateral (superior quadrant) compression above 30 degrees. During pure compressive loading (θ=0 deg.), tension was observed in the superior and inferior quadrants of the glenoid. Strain measurements were less consistent in the anterior and posterior glenoid quadrants and varied between tension and compression. Superior and inferior loading each caused increasing same side (ipsilateral) tension, occurring from 0 to 30 degrees and 0 to 20 degrees, respectively.

DISCUSSION: The current study is thought to be the first to directly measure load transfer at the implant-bone interface. We demonstrated load transfer nonlinearities between a surgically implanted glenoid component and the underlying bone in all locations and for a wide range of loading conditions. This has important implications towards the modeling of these constructs using finite element analyses. The results also illustrated tensile loading during compressive and small eccentricity loading cases. These results suggest a polyethylene flexure phenomenon (termed the ‘umbrella’ effect), which causes the periphery of the glenoid implant to flex upwards thus placing the cement mantle and underlying bone in tension. Tensile loads that are linked to cement mantle fracture, which causes ipsilateral compression and contralateral tension, becomes more prominent as eccentricity increases. The interplay between these two mechanisms can be used to explain the results of Figures 2 and 3 as they are additive and increase tension contralaterally, while ipsilaterally the rocking horse counteracts the ‘umbrella’ effect at greater eccentricities by reducing the observed tension and finally by initiating compression.

Direct comparison of the above results to previous studies is difficult as other studies report load transfer in terms of glenoid implant micro-motion. Past studies have reported contralateral component distraction for superior loading at angles as small as 10°, which agree with the observed tensile strains but each of these studies found ipsilateral compression under all tested configurations. It is believed that the disagreement in ipsilateral results can be accounted for by the large initial testing angle (≥22.5°) used in some studies and in the case of Bicknell et al. (2007) due to the far stiffer all-metal implant utilized.

This study has provided insight into the mechanisms of load transfer between a cemented polyethylene glenoid implant and the underlying bone. Results show that loading consistent with daily activities produces tensile strains that may be linked to implant loosening. Marked tensile stresses around the glenoid periphery should be considered when developing novel methods for glenoid component fixation.

REFERENCES: