INTRODUCTION:
Some of the leading causes for revision of total elbow replacement (TER) implants are related to loosening, implant failure (bearing wear or prosthetic fracture), and instability [1]. Implant designs must satisfy constraint requirements to allow natural elbow function and prevent loosening, and material requirements in order to prevent premature failure. Some of the most widely used designs fail to meet these requirements when used in younger higher-demand patients where durability remains problematic. The underlying mechanisms behind the failure of these joints are poorly understood.

We employed finite element analysis (FEA) to investigate the relationship between the intrinsic constraint (stability), stress, loading and design of three different linked TER design concepts.

It was hypothesized that designs will respond differently to applied loads, and the constraint forces and stresses developed by implants will also vary.

METHODS:
Three different concepts in linked TER design were considered (Figure 1). The concepts are denoted the “sloppy hinge” (SH), “hourglass” (HG), and “concave cylinder” (CC) designs. All designs feature cobalt chrome (CoCr) axles which articulate against ultra high molecular weight polyethylene (UHMWPE) bearings. Three-dimensional parametric FE models of each design were generated within ANSYS (Canonsburg, PA). The stiffness of the UHMWPE was described using nonlinear elastic material properties. CoCr components were modeled as rigid bodies. The coefficient of friction for CoCr-on-UHMWPE was $\mu = 0.04$. Typical element sizes or each design (SH = 1 mm, HG/CC = 2.5 mm) were determined by a mesh convergence study. SH:Varus-valgus (VV) laxity testing at 90° of elbow flexion was simulated numerically by applying a ±1000 Nmm VV moment to determine the intrinsic constraint and stresses of each design. Axial loads (50 N, 100 N, or 200 N) or internal torques (100 Nmm, 200 Nmm, or 400 Nmm) were applied to the ulnar component to investigate the effect of load. Implant shape parameters were modified in order to yield low conformity (LC), medium conformity (MC), and high conformity (HC) shapes which were designed to provide 10°, 7°, and 4° (respectively) of VV laxity under 100 N of axial load.

<table>
<thead>
<tr>
<th>Design</th>
<th>Ulnar</th>
<th>Humeral</th>
<th>Assembly</th>
<th>Cross-section</th>
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<tbody>
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<td>SH</td>
<td></td>
<td>UHMWPE</td>
<td>CoCr axle</td>
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<td>HG</td>
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<td>CC</td>
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<td>UHMWPE</td>
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Figure 1: Three different linked TER design concepts that were considered during this study. For each design, low, medium, or high conformity (LC, MC, HC) versions were considered.

RESULTS:
The maximum Von Mises stresses in the UHMWPE components of each design during simulated laxity testing are depicted in Figure 2. The SH design consistently had the highest stresses under VV loading. This was caused by edge loading that is inherent to that design and not observed with the HG and CC designs. Regardless of loading, the maximum stress increased with decreased conformity. The VV laxity of the medium conformity (MC) version of each design for all loading scenarios is shown in Figure 3. The VV laxity of the HG design was much more sensitive to axial load than the others. Increased load caused a substantial decrease of the laxity envelope. The CC design had consistent constraint characteristics regardless of axial load (like the SH design), without any edge loading.

Figure 2: Maximum UHMWPE Von Mises stresses predicted during simulated laxity testing under (a) axial load and (b) internal torque loading conditions. Results are shown for each conformity level (LC, MC, HC) of each design concept. Shaded area depicts the range of maximum stresses which varied with the magnitude of the applied load.

Figure 3: Varus-valgus (VV) laxity envelopes predicted during simulated laxity testing under (a) axial load and (b) internal torque loading conditions. Results are shown for the medium conformity level (MC) of each design. Results are shown for each loading condition, with a dashed line indicating the target 7° VV laxity envelope.

DISCUSSION:
Each design responded differently to the applied loads in terms of the constraint forces generated and the stresses developed within the UHMWPE. Some clinical implications are suggested based on these findings. First, the stability of the HG design is particularly sensitive to loads applied to the joint. This design cannot provide a known and reproducible laxity envelope, and could result in excessive load transfer through the bone-implant interface. This behavior may increase the risk of premature implant loosening for this design. Second, the SH design may not be optimal due to edge loading and increased stresses. These stresses will often exceed 21 MPa, the approximate compressive yield strength of UHMWPE [2] which may result in premature bearing failure. The CC design provides a predictable laxity envelope regardless of the applied load. Also, the bearing surface of the CC design prevents edge loading from occurring, which keeps maximum stresses well below the compressive yield strength.

SIGNIFICANCE:
The general concern that elbow implant durability is insufficient for younger patients may stem from poor results with implants like the SH, the most widely used design. With further clinical evidence, improved implant shapes (such as the CC design), might make TER a more attractive option, even for younger patients.

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REFERENCES: