**Introduction:** Transfixion wire tension appears to be an important factor in the overall stiffness of ring and hybrid external fixation. Wire tension is directly related to wire length, diameter, yield point, load, number per ring, and orientation, wire holders, ring diameter and pattern, and tensioning method. Wire tension from 30 to 130 kg has been reported to be used with the most popular range of wire tension from 90 to 130 kg. Numerous biomechanical studies of external fixation have been performed, but only a few studies have been reported on the effect of wire tension on the stiffness of external fixation. The tension achieved on a transfixion wire is based on the accuracy of the tensioner. The purpose of this study was to compare the accuracy of 5 commonly available fine wire tensioners and to evaluate the effect of changes in magnitude of transfixion wire tension on the stiffness of fine wire external fixation.

**Materials and Methods:** The tensioners testing was performed using a servo-hydraulic test frame (Figure 1). A 1.8 mm smooth transfixion wire was attached to a ring. A force transducer connected to the ring was used to measure wire tension. The force transducer was connected to the MTS (Materials Testing System Corp., Bionix 858, Minneapolis, MN, USA), which measured the applied tension. One end of the wire was connected to the Force Transducer, model 661.19 E-01, 5000 N capacity. The other end was tensioned using commercial tensioners: the Ilizarov, EBI, Synthes, Stryker, DePuyACE tensioners. Then the tensioners were subjectively assessed the overall ease of usage: physical effort, time, visibility of markings, tensioner size, and adjustability to ring. The real wire tension data of each tensioner were compared to nominal values. The percent error of each value for each tensioner was calculated.

The test model for testing the effect of changes in magnitude of wire tension was a fiberglass composite tibia (Pacific Research Laboratories, Vashon Island, WA, USA) fixed into an idealized fixator. This fixator was used as a test rig, which allowed testing the wires maximally avoiding ring deformation. The fiberglass tibia was fixed in the most proximal ring of the idealized fixator using two 1.8 mm smooth wires crossed at 60 degrees angle (most appropriate angle for percutaneous fixation), which were inserted 18 mm below the articular surface. The wires crossed in the center of the tibia, with the tibia centered in the ring. The distal end of the fiberglass tibia was not fixed. For more accuracy, a force transducer connected to the idealized frame was used to measure wire tension. One end of the wire was connected to the force transducer; using the Ilizarov tensioner, we tensioned the other end. In this way, the wire tension was set to the specific values of 50 kg, 60 kg, 70 kg, 80 kg, 90 kg, 100 kg, 110 kg, 120 kg, 130 kg, 140 kg. After the wire was tensioned, it was secured in the ring using two bolts on each end to prevent wire slippage. Markers on each wire were observed to detect any gross wire slippage. In cases when wire slippage was detected, the wires were retensioned and the tests were repeated. Loads were applied through a load plate using the MTS. Load deformation behavior was compared among different wire tensions (from 50 to 140 kg) under identical conditions of central axial compression, medial compression-bending, posterior compression-bending, posteromedial compression-bending and torsion. Five separate bones were tested and five repetitions were performed for each tension value in each loading pattern for each bone. The wires were loosened and retightened before each test. Stiffness values were calculated from the load-deformation and torque-angle curves. ANOVA followed by post-hoc t-tests with an alpha level of p<0.05 was applied to compare the stiffness corresponding to different tension values.

**Results:** The error of the Smith and Nephew tensioner ranged from -8.6% at 50 kg, to -13.9% at 130 kg. The EBI tensioner was the most accurate: 0.09% at 70 kg and -0.17% at 130 kg. Howmedica: -12.48% at 50 kg and -10.86% at 100 kg. Synthes: -0.2% at 50 kg, -8.81% at 100 kg and 24.28% at 130 kg. DePuyACE: -36.76% at 50 kg, -34.13% at 125 kg. Comparing the ease of usage, the EBI tensioner was the most difficult to use. The wire tension of 140 kg provided the greatest stiffness and there was a statistically significant difference (p < 0.05) compared to all other wire tension values in all load configurations.

**Discussion:** The study found that most commercially available fine wire tensioners (Smith and Nephew, Howmedica, DePuyACE, and Synthes), which were tested, undertensioned compared to their calibration markings. Although the EBI tensioner was an exception and was fairly accurate, it was rated the lowest for ease of usage. We recommend that when tensioning fine wires, surgeons use their discretion regarding the tension achieved, and consider tensioning beyond the marking of the tension desired in order to avoid undertensioning. The study also found that the increasing wire tension contributes to an overall increase in external fixation stiffness. The optimal wire tension is no greater than 50% of the yield strength of the wire, which equals to 210 kg for the 1.5 mm wires and 305 kg for the 1.8 mm wires. Maximum limits for tensioning the 1.8 mm wires is 130 kg, because of the yield strength of the stainless steel and slippage at the wire holders. Clamping a 1.8-mm tensioned wire cause a 22% reduction in wire tension, which correlates with the deformation caused by the bolts. The increase of wire tension from 50 to 110 kg accounted for a large increase of overall stiffness (60%), while the increase from 110 to 140 kg accounted for an increase of overall stiffness only by 17%. The 1.8-mm wires should be pretensioned to 140 kg for most cases of fine wire external fixation, which maintains a tension of 110 kg, avoids wire deformation and slippage, and takes into account a reduction in tension after clamping tensioned wire.

**Figure 1.**