Biomechanical Effect of Transfixion Wire Tension on the Stiffness of Fine Wire External Fixation

Transfixion wire tension appears to be an important factor in the overall stiffness of ring and hybrid external fixation (1, 2, 3, 4, 5). 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 (1, 4, 5). 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 (1, 2, 3). 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 (1). The purpose of this study was to evaluate the effect of changes in magnitude of transfixion wire tension on the stiffness of fine wire external fixation.

Materials and Methods

The test model was a fiberglass composite tibia (Pacific Research Laboratories, Vashon Island, WA, USA) fixed into an idealized fixator, composed of four aluminum rings with an outer diameter of 20 cm, an inner diameter of 16 cm, and a thickness of 2 cm. Four 1.3 cm in diameter threaded rods connected the rings forming a 30 cm vertical frame. This fixator was used as a test rig, which allowed testing the wires maximally avoiding slippage. The fiberglass tibia was fixed in the most proximal ring of the idealized fixator using two 1.8 mm smooth wires (Smith and Nephew, Memphis, TN) crossed at 60° angle (most appropriate angle for periarticular 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 (load cell) device (Force Transducer, model 661.9 E-01, 5000 N capacity, MTS System Corp., Minneapolis, MN, USA) 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 (Smith and Nephew, Memphis, TN), we tensioned the other end. The load cell device was connected to the MTS (Materials Testing System Corp., Bionix 858, Minneapolis, MN, USA), which measured the applied tension. In this way, the wire tension was set to the specific values of 490.35 N, 588.42 N, 686.49 N, 784.56 N, 882.63 N, 980.7 N, 1078.77 N, 1176.84 N, 1276.91 N, 1372.98 N, which correspond to 50 kg, 60 kg, 70 kg, 80 kg, 90 kg, 100 kg, 100 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 kg to 140 kg) under identical conditions of central axial compression, medial compression-bending, posterior compression-bending, postero-medial 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 wire tension of 140 kg provided the greatest stiffness (Fig. 1) and there was a statistically significant difference (p < 0.05) compared to all other wire tension values in all load configurations. There was a trend toward increasing overall stiffness with the increase of wire tension. The wire tension of 130 kg provided significantly greater stiffness compared to all other wire tension values in all load configurations (p < 0.05). The wire tension of 120 kg provided significantly greater axial and medial bending stiffness compared to all other wire tension values (p < 0.05). The wire tension of 110 kg provided significantly greater stiffness compared to all other wire tension values in all load configurations (p < 0.05). The wire tension of 100 kg provided significantly greater stiffness compared to 50, 60, 70, and 80 kg of wire tension in all load configurations, and 90 kg in posterior bending (p < 0.05).

Discussion

The wire tension has been distinctly identified as a crucial factor in determining frame stiffness (2). This study 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 (3). The stiffness of the tensioned wire is limited by its yield point and the tension holding capacity of the wire connection bolts (1, 5). Aronson and Harp (1) indicated that the 1250 N (127 kg) wire tension and the 20 N-m bolt torque represent the safe and reliable upper limits for 1.8 mm wire. They found that wire tension above 1250 N (127 kg) cannot be maintained unless the nuts are tightened to a level that may result in bolt failures. Kummer reported maximum limits of 90 kg for the 1.5-mm wires and 130 kg for the 1.8-mm wires, because of the yield strength of the stainless steel and slippage at the wire holders (2). Watson et al. (4) demonstrated that clamping a 1.8-mm tensioned wire could cause a 22% reduction in wire tension, which was correlated with the deformation caused by the bolts. The increase of wire tension from 50 to 110 kg (present study) 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%. Considering the limits provided by Aronson and Harp (1) and Kummer (2), the conclusions of Watson et al. (4) and the results of present study, the 1.8-mm wires should be pretensioned to 140 kg for most cases of fine wire external fixation. This maintains a tension of 110 kg, avoids wire deformation and wire slippage, and takes into account a reduction in tension after clamping tensioned wire.

References