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Joint slippage in the Hoffmann external fixator

No effect of loading rate in bench experiments

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For tibial fractures, half-frames, such as the Hoffmann fixation device, sometimes fail when subjected to weight-bearing loads. Because the joints of the Hoffmann system are known to slip, which could lead to frame failure, three interfaces of the standard Hoffmann joint were tested at different clamp torques and different rates of load application. No difference in mean slippage values was noted for any interface at similar clamp torques. Joint slippage and any subsequent frame failure are thus not related to rate of load application, but to the magnitude of the load alone.

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Finlay et al. (1987) showed that the universal joints of the Hoffmann single half-frame would slip at vertical loads of only 10 kg. Such joint slippage could lead to frame failure. Behrens and Searls (1986) stated that fractures treated with half-frames would be more prone to malunion. Benum and Svenningsen (1982) did a comparative study of quadrilateral and half-frame Hoffmann devices and found the malunion rate to be almost double in fractures treated with half-frames. Thus, joint slippage can be seen as a detrimental side effect of the use of half-frames.

To counteract this weakness, some authors have advocated encouraging patients to bear weight "quietly" on the fractured limb (Jorgensen 1972a, b, Terjesen and Benum 1983).

We have sought to evaluate whether or not the rate of load application has any effect on the resistance to slippage of Hoffmann universal joints.

Materials and methods

Five Hoffmann universal joints were used in this experiment. A number of universal joints were disassembled, washed, and autoclaved according to standard surgical procedure, and then reassembled in a random manner from the available parts. After assembly, each joint was tested for binding in all ranges of motion and those binding were rejected. A group of five joints were then chosen from those not rejected.

The joints were tested in an MTS Bionix testing machine. Special fixtures were developed to allow testing of the individual interfaces as shown in Figure 1 for one test configuration. All the testing was done in displacement control. This form of testing was chosen because it offered several advantages. First, there would be no preload on the joint. Secondly, the MTS would deliver whatever force was necessary to cause the preset displacement, and so there would be no possibility of the slippage resistance being out of range for the force-servo control. Thirdly, and lastly, slippage would be virtually guaranteed in every test provided that the prescribed displacement was large enough.

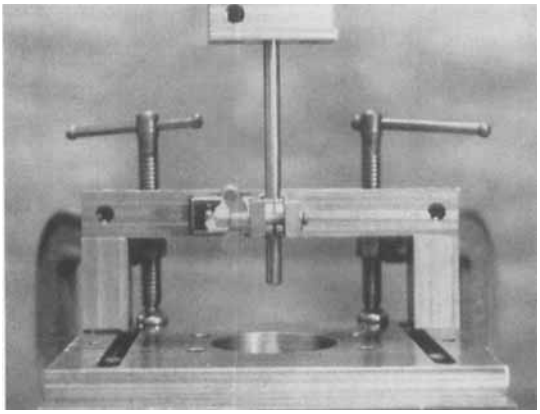

Figure 1. Jig used for testing of the rod/clip torsional interface.

The joints were tested with tightening torques of 6, 8, 10, and 12 Nm on the clamp. These values were chosen because they represented the range found clinically (Shiba et al. 1984, Vossoughi et al. 1989). These torques were applied in ascending increments of 2 Nm to avoid any bias resulting from damage as the torque increased (Chao and Hein 1988). A calibrated torque wrench was used to ensure accuracy and consistency in tightening.

The tests were done at 1°/sec, 10°/sec, and 100°/sec. The rates chosen were based on the study of Harper et al. (1961), who found that the most rapidly applied rotational loads to be no greater than 40°/sec and the average to be about 10°/sec. It was felt that varying the application rate by a factor of 10 on either side of the median value should account for both extremes of load application, that is, the "heaviest" and "quietest" walkers. The data were recorded through a Hewlett Packard 100 MHz digitizing oscilloscope (Model #54501A) with a second-order, low-pass filter with break frequencies of 48 and 72 Hz. The oscilloscope output was recorded as a voltage-versus-time graph on a printer with the voltage representing the torque applied by the MTS and time representing displacement. Slippage was defined as the point of deviation from original linearity. In the cases where stick-slip was observed and the determination of the exact point of deviation was difficult to ascertain, slippage was defined at the midpoint of the curve's plateau (Figure 2). The slippage voltages obtained were converted into equivalent torques.

Each joint was tested once at each level of clamp torque and at each test rate for each interface. Between each test, that is, each test of rate at each clamp torque, the clamp was loosened and the joint tested in all ranges of motion to ensure no binding was occurring. If binding occurred the joint would not be tested further and the tests were repeated on a new joint.

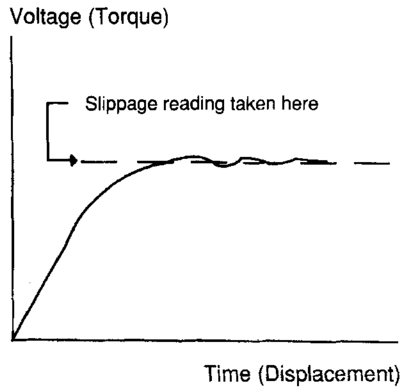

Figure 2. Interpretation of slippage value for those interfaces exhibiting stick-slip.

The data acquired from this analysis were evaluated at each wing-nut torque for each interface at all the rates employed using an ANOVA table and the Tukey *t*-test for multiple range post-hoc comparisons.

Results

None of the original five universal joints had to be rejected because of binding during testing. There were no differences ($P < 0.05$) as regards the slippage values at any level of clamp-tightening torque for any interface at any of the different test rates (Figure 3). These results indicate that resistance to slippage is not rate dependent for these interfaces of the Hoffmann universal joint.

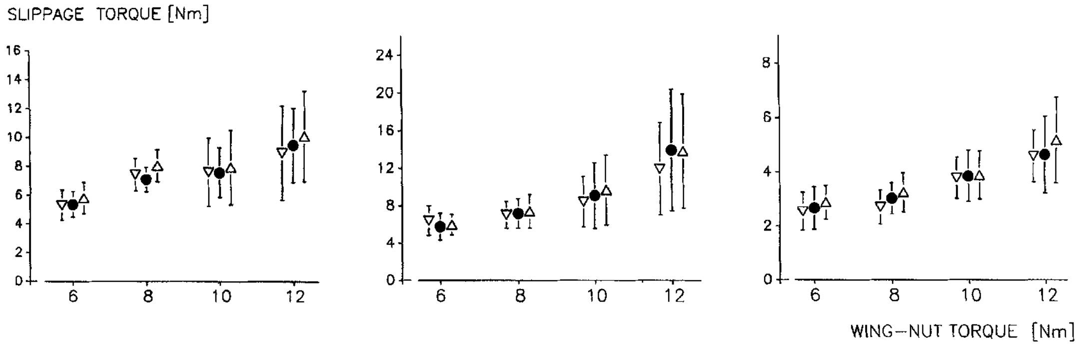

Figure 3. Slippage tests conducted on all three interfaces of the Hoffmann universal joint: (right) Rod/Clip torsional interface, (center) Cheek/Clip interface, and (left) Cheek/Bowl interface. Rates were ▽ 1°/sec, ● 10°/sec, and △ 100°/sec.

Discussion

From an engineering standpoint, the results of this experiment are not unreasonable. The initial resistive force to slippage is directly proportional to the product of the normal force and the static coefficient of friction (Equation 1), neither of which are rate dependent.

$$RF = \mu N \quad (1)$$

where RF = resistive force, N = the normal force, and μ = the static coefficient of friction.

The stick-slip phenomenon that can occur after slippage is rate dependent, in that it will not occur if the displacement of the two bodies over each other is too rapid (Ludema 1984). In our study, however, despite the fact stick-slip was often evidenced at the lower rate of testing, it did not increase the joint's resistance to slippage.

Thus, although there may be a common-sense impression that the fixation device will be less likely to slip if loads are applied slowly, our experiment did not support the notion. What is more likely is that when a patient treats his fractured extremity with care, that is, walks quietly, he/she only partially loads the frame. Cunningham et al. (1989), for example, have shown in their study of tibial fracture treated with external fixation devices that patients seldom bore greater than 20 kg of vertical load on the injured limb, despite encouragement to bear their full weight freely.

With only such minimal loads, the frame is, of course, less likely to slip or for the slippage to be as noticeable clinically as would occur should a patient rapidly apply full body weight on a damaged limb. The difference is clearly in the amount of load applied and not the rate at which it is applied.

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