Hoffmann Half-Frame External Fixation Rigidity and Its Relationship to Universal Joint Slippage

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Hoffmann half-frame external fixation device configurations often fail under minimal loads secondary to joint slippage. In these experiments improved universal joints that were developed in an earlier study were tested on Hoffmann half-frame assemblies. The rigidity of selected half-frame configurations was tested in four modes (axial compression, torsion, medial-lateral and anterior-posterior four-point bending). These results were compared to those of an earlier, similar study looking at the standard Hoffmann half-frame. No changes in overall rigidity were noted, but significant increases in yield loads and loads to frame failure were achieved. Such improvements will increase the reliability and usefulness of the Hoffmann device to the orthopaedic community.

Keywords—Fixator, Frame rigidity, Joint slippage, Frame failure.

INTRODUCTION

The use of external fixation devices in severe fractures of the lower limb is often considered a primary indication (2,12,17,18,24). Due to the severity of these fractures, there is often little bony continuity to help maintain limb length. Thus, the external fixation frame (fixator) must be relied upon solely to maintain reduction (alignment) of the fracture. It must protect the fracture against disruption from both internal muscular forces and any external forces. Once healing begins and the pain stimulus decreases so that the patient can ambulate, this could mean that the fixator may be called upon to withstand the loads of weight bearing (2,12,18,24). Thus the need for a reliable and reasonably rigid frame becomes self-evident.

The exact rigidity required for the frame is controversial (8). Certain orthopaedists prefer very rigid systems (18) while others prefer less rigid or "elastic" systems as they are commonly known (6). Most tend to think a minimal controlled amount of move-
ment at the fracture site leads to faster and more effective healing (6,8,14). Elastic systems of fixation allow for this controlled movement through cyclic deformation of the frame. The elastic response of the frame is, of course, proportional to its overall structural rigidity. Thus, the amount of motion occurring at the fracture site is controlled by the variation of the frame rigidity (13,16,19,22).

Frame rigidity is influenced by a number of factors such as configuration design, the material type of the fixator’s constituent parts and the arrangement of these same parts in relation to the configurations used; for example, half-frame rigidity can be influenced by adjusting the pins’ spacing (3,9,13,19,22,29). Equally important is the ability of the fixator to maintain rigid connections between each of these parts when the frame is assembled. If these connections are not rigid then the frame will deform permanently rather than elastically under applied loads. The universal joints of fixators are used to maintain the rigid connection between the pins and sidebars. These joints, however, have often been observed to slip (4,13,22,29). Finlay et al. (13) noted in their paper that half-frame configurations of the Hoffmann device could fail secondary to joint slippage under axial loads of only 10 kg. Vossoughi et al. (29) noted similar behavior, and claimed by increasing the torque on the Hoffmann clamping device frame failure could be better controlled. Previous work (11,22) had shown such increased tightening to have minimal effect on increasing slippage resistance (as will be explained in a later section). Simple modification of the joint, however, significantly increased slippage resistance (11) and thus, this study sought to look at the effect of these improved joints on overall frame behavior.

THE MECHANICS OF REDUCING JOINT SLIPPAGE

Classic mechanics demonstrates that slippage resistance is determined by the following equation (Fig. 1):

\[ RF = N\mu \]  \hspace{1cm} (1)

where

- \( RF \) = resistive force,
- \( N \) = the Normal force, and
- \( \mu \) = the static coefficient of friction.

The clamping force, \( Q \), on the joint, directly affects the value of the Normal force, \( N \), which acts at the various joint interfaces. Thus \( Q \) directly affects the resistive force, \( RF \). The force \( Q \) is determined by the following formula (28) (see Fig. 2):

\[ Q = 2T \times (2\pi r_t - \mu_t \text{psec}(x)) / (((p + 2\pi \mu_t r_t \sec(x)) \times 2r_t) + \mu_c 2r_c \times (2\pi r_t - \mu_t \text{psec}(x))) \]  \hspace{1cm} (2)

where

- \( T \) = the torque exerted on the fastener,
- \( x \) = the angle of the threads of the fastener,
- \( r_t \) = the radius of the fastener’s threads,
- \( r_c \) = the radius of the fastener head’s collar,