AN EXPERIMENTALLY VALIDATED MODEL FOR THE ILIZAROV FIXATOR CONSIDERING THE LOSS OF WIRE'S PRETENSION

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1. Introduction

The Ilizarov device was proposed in the early fifties as an alternative fracture fixation technique. Its main novelty was the use of very thin wires (instead of thicker threaded pins), which under pretension are transformed into stiff pins [1]. The purpose of this study is to assess the biomechanical performance of the device and to attempt optimization of its configuration. To achieve this goal a combined experimental and numerical scheme is adopted: The numerical model, after proper calibration and validation based on results of the experimental protocol, is used for parametric analysis of the factors, which according to clinical experience influence the efficiency of the device.

2. Experimental and numerical study

According to literature the most serious limitation of Ilizarov's technique is the gradual or abrupt loss of the pretension induced to the wires. Although the exact mechanism of the phenomenon is not as yet definitely determined it is believed that it is due to a combination of slippage of the wires and yield of their material. The loss of pretension occurs in two stages, i.e. immediately after the tensioner is removed and during loading. According to experimental studies [2] the critical axial force required to cause sliding ranges around 1018±16 N.

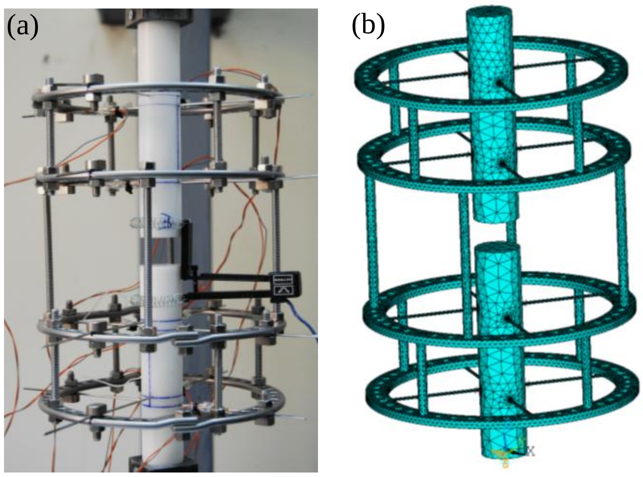

Fig. 1: The frame used for the experimental protocol (a) and for the numerical model (b).

In this study a complete frame, made up of four rings was constructed using components of the Smith and Nephew (S&N) collection. Each ring consisted of two semi-rings (diameter 150 mm, S&N 101305) hold in place with two bolt-nut pairs (tightening torque 15 Nm). The rings were connected to each other using threaded metallic bars (diameter 6 mm, S&N 102314). Four K-wires pairs (diameter 1.8 mm, S&N 102107) were used with a strain gauge (HBM 1-LY11-0.6/120) attached on each wire. The bone was simulated by two acetal bars (diameter 3 cm) with a 2 cm inter-fragmentary gap. The wires were fixed to the rings with cannulated bolts (S&N 100600). Initially only one end of each wire was fixed. The assembly was then supported on the MTS miniBionix 858 frame, the strain gauges were connected to the data logger (TML TDS-530) and the pretension (1080 N) was imposed using the S&N 103101 tensioner. Then the wires were attached to the rings, as described previously, with the same tightening torque. A suitable clip gauge was attached to the "bone's" gap (Fig.1a).

The device was submitted to axial and torsional loading-unloading loops. In Fig.2a the pretension level in each wire before loading (during the assembling stage) is plotted as represented by the axial strain. The pretension decreases by about 20% just when the tensioner is removed and then it is stabilized. What is more important, however, is the significant increase (even up to 40%) of a wire's pretension when its counterpart (i.e. the second wire of each ring) is tensioned. This behaviour, studied systematically by Ryan et al. [3] for a single-ring fixator, is attributed to the rings' elasticity. Of equal importance is the gradual degradation of the system's stiffness for increasing load level: As it is seen in Fig.2b, the minimum axial strain becomes lower for each successive loading loop.

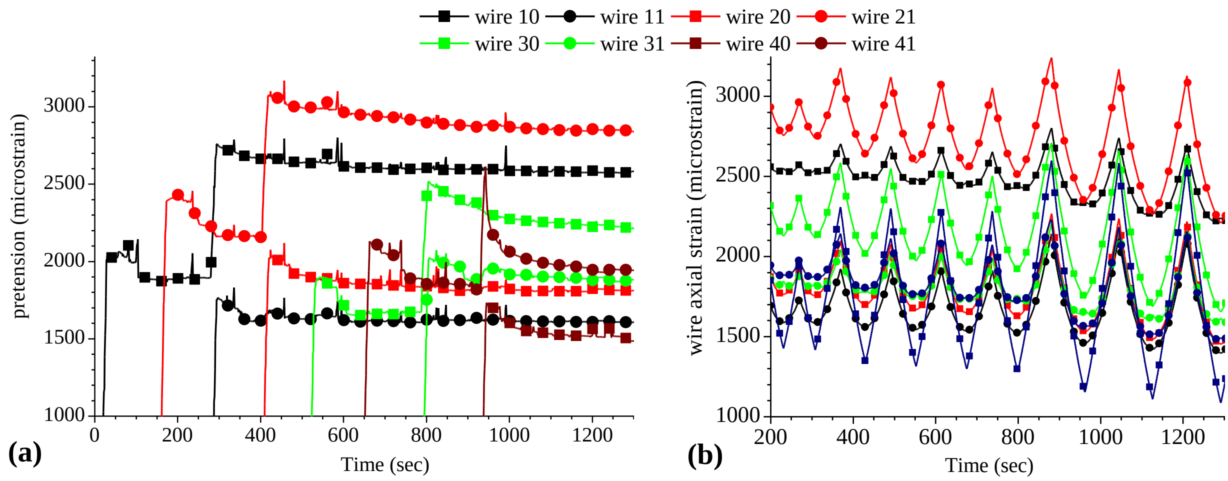

Fig. 2: Time variation of the pretension during the (a) assembling stage and (b) axial loading. The first number of each wire's index denotes the ring and the second one the succession of imposing pretension.

A numerical model was then constructed using ANSYS software (Fig.1b) with special elements permitting simulation of wire's slippage. It was calibrated using data for the strains and validated with the aid of the 'force-displacement' and the 'torque-angle' experimental curves. The results were very satisfactory for the torsional loading (see Fig.3a) and excellent concerning the axial loading.

3. Results and concluding remarks

The model was used for a thorough analysis of various parameters affecting the mechanical response of the fixator. The parameters studied were the ones which according to clinical experience can enhance the system's response, i.e. the rings' diameter, the initial pretension, the wires' diameter, the bone's location, the distance between the rings and the angle between the wires. Critical factors, concerning their influence on the system's stiffness, were proven to be the pretension (an increase of 200 N increases the torsional stiffness by 20%), the rings' diameter (an increase from 150 to 180 mm decreases the axial stiffness by 20% without increasing the torsional one) and the angle between the wires. The role of the latter is shown in Fig.3b. The influence of the remaining factors was less important.

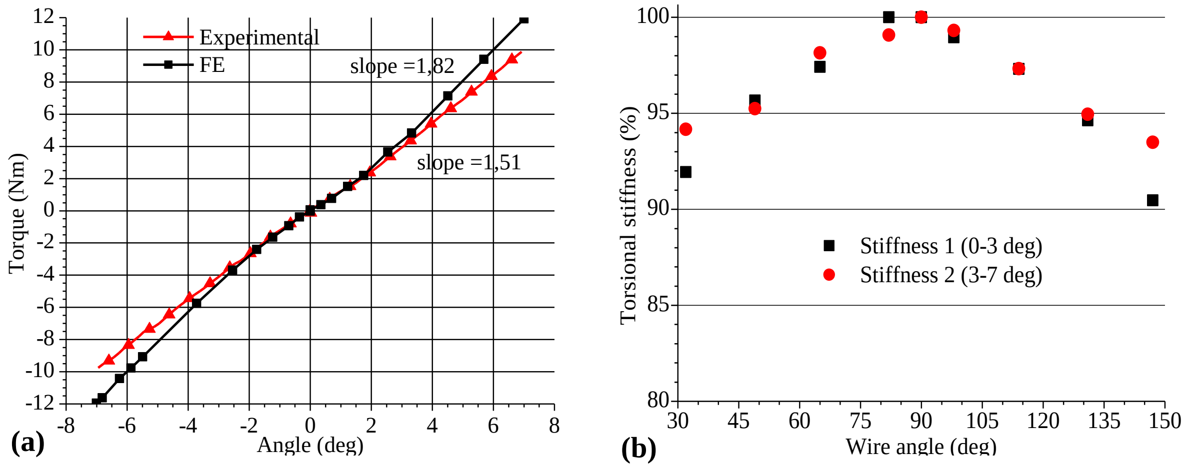

Fig. 3: (a) Validation of the model. (b) Influence of the wires' angle on the torsional stiffness.

4. References

[1] B. Fleming, D. Paley, T. Cristiansen and M. Pope (1989). A biomechanical analysis of the Ilizarov external fixator, *Clinical Orthopaedics and Related Research*, **241**, 95-105.

[2] A. S. Mitousoudis and S. K. Kourkoulis (2010). Biomechanical study of Ilizarov fixation systems' failure due to wire slippage, *Proceedings ECF18*, D. Klingbeil et al. (eds.), Paper B.11.1-5/635.

[3] S. Ryan, N. Ehrhart, K. Zuehlsdorff and S. James (2009). Comparison of alternate and simultaneous tensioning of wires in a single-ring fixator construct. *Veterinary Surgery*, **38(1)**, 96-103.