Experimentální Analýza Napětí 2001
Experimental Stress Analysis 2001
39th International Conference
June 4 - 6 , 2001 Tábor, Czech Republic

MONITORING TECHNIQUES OF BONE FRACTURE HEALING USING EXTERNAL FIXATORS

Danuta Jasińska-Choromańska, Igor Sadzyński

Abstract: *Long bone fractures can be healed using external fixators – devices that stiffly fix fracture fragments using parallel to the bone, attached to the bone with pins frame. This method enables to take profits both from healing and diagnostics of fracture during osteogenesis. Osteogenesis, traditionally diagnosed using X – rays methods (RTG, densitometry), can be also more precisely determined with mechanical properties like strength and stiffness inside the fracture slot. The treatment of long bone fractures by external fixators offers an unique opportunity to control the healing of the fracture by measuring the compression on the frame, that occurs under the load given to the bone and rely on the mechanical properties of the fracture. The procedure of measurement of the compression on the frame can be performed using tensometers , what is cheap and simply method, and can be performed by the patient at home. The measurement of osteogenesis gives the possibility of more precise diagnostics of the fracture, and can also be applied to the computer techniques like e.g. artificial intelligence.*

The paper presents one of the methods of the monitoring of bone fracture healing.

Key Words: External fixators, fracture healing, osteosynthesis, bone strength and stiffness

Introduction

Frequent injuries, bone fracture, an effect of load much bigger than bone can carry, can be healed using external fixators. Fracture fragments should be relatively stiffly fixed together to provide best healing condition [5,6]. To fix both parts of the broken bone external fixator provides parallel to the bone stiff frame, rigidly attached to the bone with pins (see fig.1)

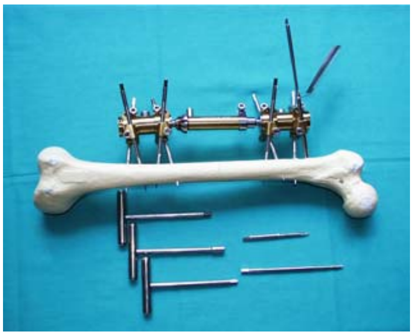


Fig.1: Fixator Dynastab Mechatronika 2000 (to long bones) with instrumentation

Danuta Jasińska-Choromańska Ph D.; Politechnika Warszawska, Wydział Mechatroniki, Instytut Mikromechaniki i Fotoniki, ul. Chodkiewicza 8, 02-525 Warszawa, Polska; e-mail: danuta@mchtr.pw.edu.pl

Igor Sadzyński M.Sc.; Politechnika Warszawska, Wydział Mechatroniki, Instytut Inżynierii Precyzyjnej i Biomedycznej, ul. Chodkiewicza 8, 02-525 Warszawa, Polska; e-mail: isadzynski@comesa.pl

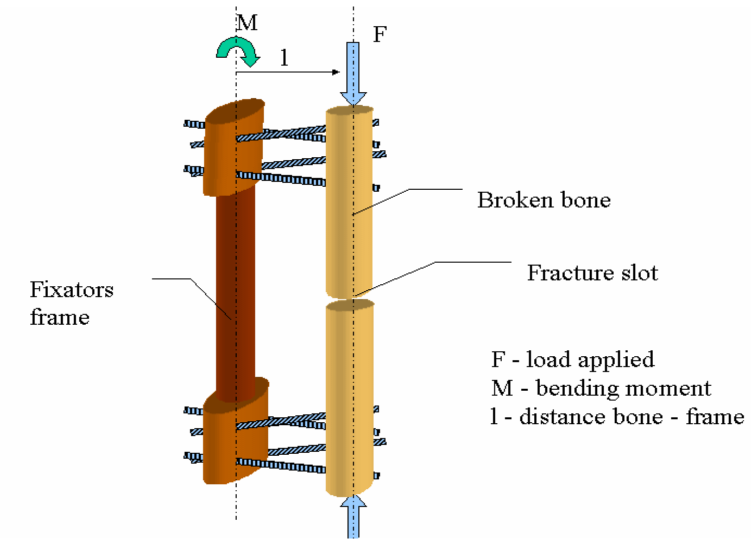
This method of fracture healing gives a unique opportunity to take profits both from healing and diagnostics during the osteogenesis (bone growth process).

Clinical and experimental observations have demonstrated that fracture healing process (osteogenesis) changes broken bone condition in a particular physiological way. Bone healing is associated with relative paucity of callus and osteonal remodelling across the fracture line. The non-invasive evaluation of fracture healing may allow more precise timing of fixation device removal, recommendation for progression from non-weight bearing to full weight bearing, and to the prediction of abnormal fracture healing such as delayed union or non-union. The common techniques include manual examination of the fracture for stability, radiographic evidence of healing, and the empirical passage of time. Traditional diagnostics methods: X-ray techniques such as radiography, radiographic densitometry, Computed Tomography give the information about mineral properties of the healed fracture and fracture site, and can describe the fracture healing as a process of calcification. It can be not enough to evaluate the real fracture condition and cause a risk of non-union or refracture. Many fractures can bear load earlier that their "empirical healing time" and are therefore immobilised for an unnecessarily long period. Others are freed too soon and may sustain refracture or develop malunion after early activity. A fracture which is sufficiently healed to allow normal activities may not have sufficient strength for strenuous work or vigorous sport.

The treatment of the fracture using external fixators enables to diagnose the healing process by measuring of mechanical properties inside the fracture slot. Direct measurement of mechanical properties of the healed bone treated by external fixators gives precise information about the fracture conditions [1,8,9]. The proposed method affords an opportunity to find a bone-healing pattern based on mechanical properties of the fracture and to propose a measure of healing of fracture, which would define stadium of healing process.

Materials and Methods

The simply measurement technique consists in measuring of the compression carried by the fixators frame under the load applied to the bone along their axis [3,9,10]. The load applied to the broken bone treated by external fixator can be divided into two parts: a load carried by healed bone and load carried by fixators frame. The load carried by the bone strictly depends on the mechanical properties inside the fracture site, so the load carried by the fixators frame also depends on the fracture conditions.



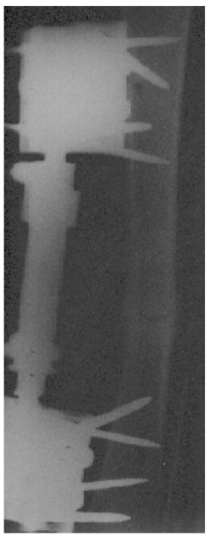


Fig.2: Diagram of external fixator showing major components and applied loading with RTG photo

The external fixation system is shown in diagrammatic form in fig. 2. excluding the biological contributions to the stiffness of the fracture from the soft tissues and surrounding muscles. These small contributions are considered to be negligible in theoretical mechanical analysis. It is also assumed that there is a rigid bond between the screws and the bone, and between the screws and the fixators frame. Idealised model of bone/fixator system (shown on fig. 3) consists of load carried by healed bone F_1, load carried by fixators frame F_2, what gives the total load applied to the system F:

$$F = F_2 + F_1 \qquad 1.1.$$

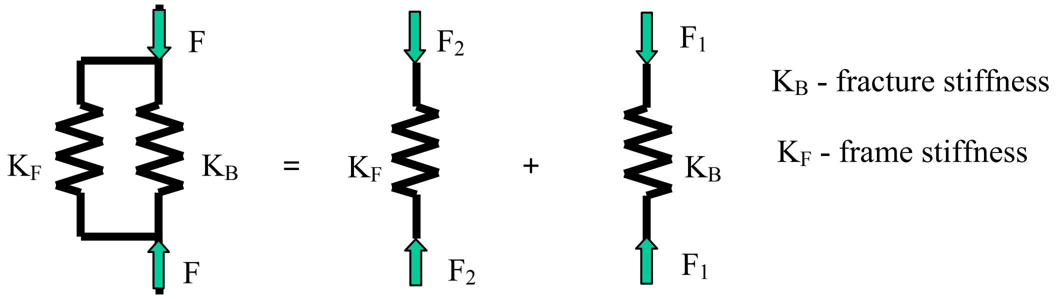


Fig. 3: Diagram of idealised fixator system as a two spring system

The load can be defined as a sum of axial compression and bending moment. The bending moment depends strictly on the length of bone screws, on bone shape and bone/fixator system configuration, which is different for each patient. The main point of the measurement technique is to exclude the influence of bending moment on the measured value of compression, and make the fracture healing measure independent of kind of fracture.
Then the fracture healing measurement value can be determined as:

$$m = \frac{F_2}{F} = \frac{F_2}{F_1 + F_2} \qquad 1.2.$$

and should tend to be zero when the fracture is successfully healed [8,9,10].

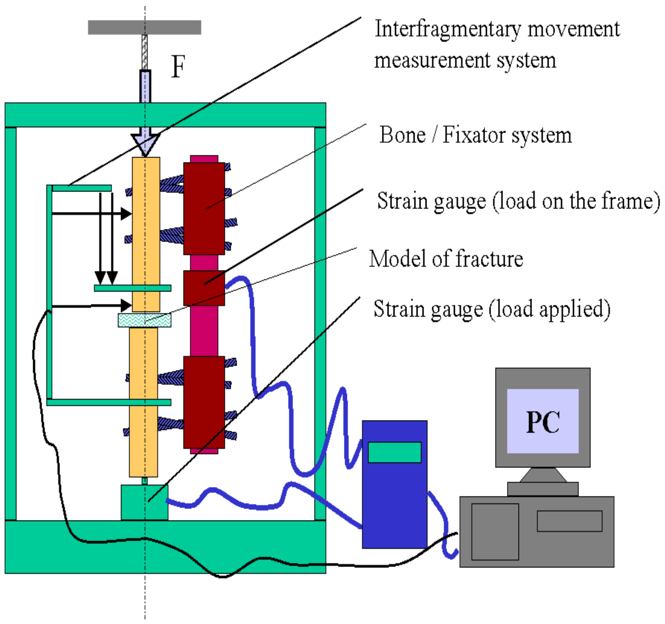


Fig.4. Diagram of test equipment and testing machine

The Dynastab fixator was used in a non-dynamic mode in all experiments. A strain gauge was placed on the frame due to measure longitudinal compression. A model of tibial bone stabilised by the fixator was placed in a testing machine due to the load (fig.4). Axial loading was applied incrementally from 26 to 500 N (26, 100, 200, 300, 400, 500 N) and then decrementally from 500 to 26 N (26 N was the weight of bone/fixator system) to achieve hysteresis loop of the frame reaction similar to the reaction for normal patients activity. To simulate the healing process and to obtain progressive strength characteristics 16 different kinds of materials with different mechanical properties were put into the fracture slot. The total load, the longitudinal compression on the frame, and interfragmentary movements were measured. The total load and compression on the frame were measured using strain gauge systems characterised in N*10 with accuracy 1 N. Interfragmentary movements were measured using 4 electromagnetic length-measuring probes characterised in mm. with accuracy 0.001mm.

Results

Result of 16 simulations of fracture with different mechanical properties described a model of healing process. Results of the measurement of the compression on the frame obtained in these simulations are partially presented in the graphs (fig. 5,6). Precise calculations and experiments performed on the bare frame showed that bending moment had a big influence on the final result of longitudinal compression measurement, and was summed up to it. The bending moment did not cause any of inaccuracies, because the dimensions and the configuration of the bone/fixator system were kept unchanged.

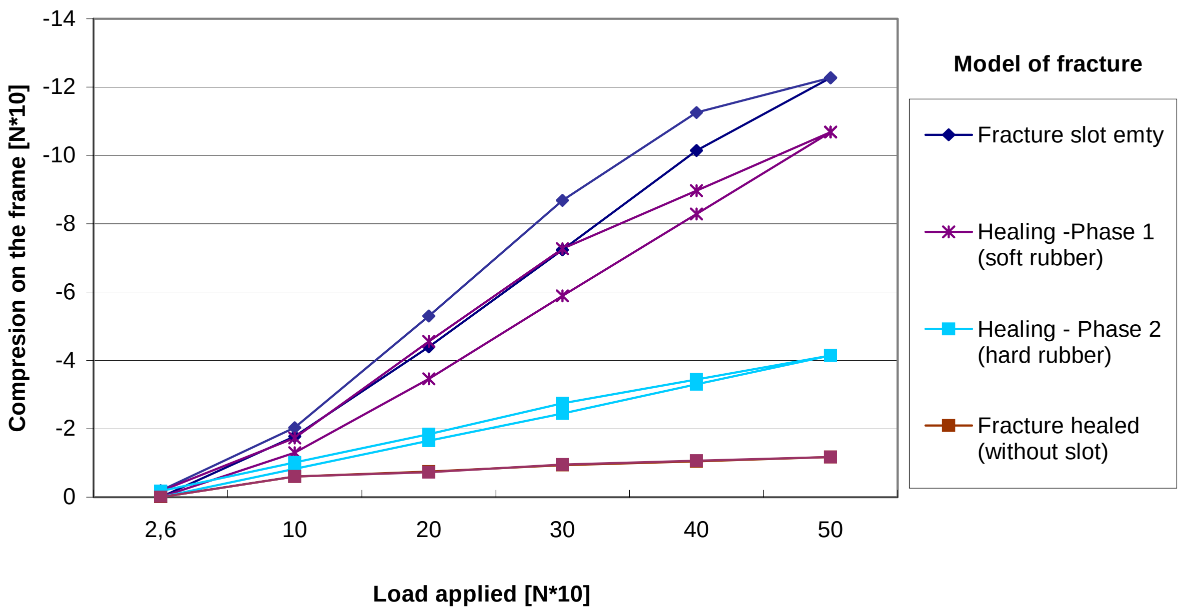


Fig. 5: Hysteresis loops of compression measured on the frame under the load applied for 4 models of fracture strength

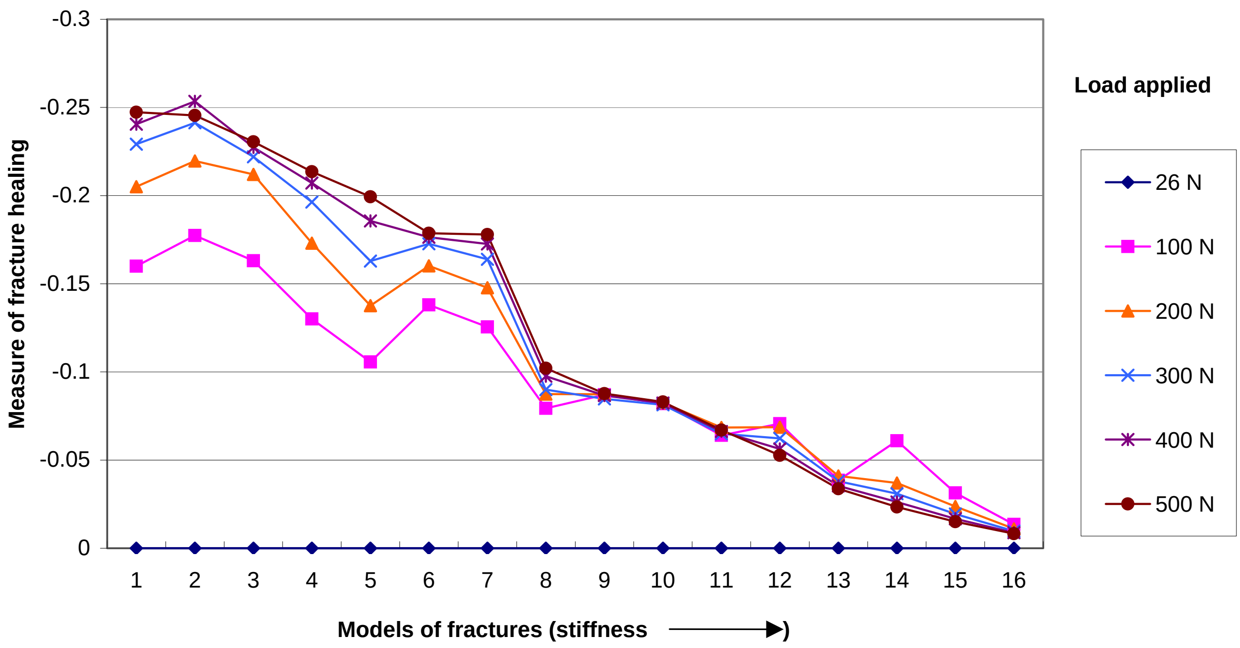


Fig. 6: A model of healing process pattern obtained under different loads applied to the bone
***NOTE**: Presented graphs of the model of healing process are not a function of time!*

Analysis of the results shows that the bigger the load and the more advanced the stadium of the fracture healing are, the more precise measurements of fracture healing can be obtained. The bigger is the load then the bigger compression on the frame is measured and the smaller inaccuracy appears. The more advanced stadium of fracture healing is examined, the smaller hysteresis loop appears.

Discussion

The noninvasive evaluation of fracture healing may allow more precise timing of fixation device removal, quantitative recommendations for weight bearing, and the prediction of abnormal fracture healing patterns.

The influence of bending moment makes the presented method of longitudinal compression measurement not repeatable for different kinds of bones and for different types of fractures, so it is not comparable between individual patients. However this method also shows that measurement of mechanical properties of the fracture slot can provide an objective quantitative measurement of fracture healing. Direct measuring of longitudinal compression on the fixators frame can more precisely describe the fracture condition. This provides a means to assess fracture healing (measure of fracture healing) and fracture healing pattern in mechanical terms. The measure of fracture healing as a result of measuring of longitudinal compression can be applied to clinical assessment.

Conclusions: The method of precise longitudinal compression measurement should be improved in order to be able to eliminate the bending moment influence on strain gauge and to be applied. The new portable strain gauge system prepared to measure only longitudinal load free from bending moments influence is now ready for trials.

The results taken from fully repeatable method of fracture healing measurement and the measure of fracture healing can be applied to the computer diagnostics technique such as artificial intelligence (neural networks etc.)

References:

1. Goodship A.E., Kenwright J., Rigby H.S., Watkins P.E.: The role of fixator frame stiffness in the control of fracture healing. An experimental study. *J. Biomech.* 1993; 1027-1035.
2. Dwyer J.S.M., Evans G.A., Kuiper J.H., Owen P.J., Richardson J.B.: Stiffness measurements to assess healing during leg lengthening. *J Bone Joint Surg. [Br]* 1996; 78-B: 286-289.
3. Cunningham J.L., Goodship A.E., Kenwright J., O'Connor B.T., Richardson J.B.: Measuring stiffness can define healing of tibial fractures. *J Bone Joint Surg. [Br]* 1994; 76-B: 389-394.
4. Chehade M.J., Nawana N., Pearcy M.J., Pohl A.P.: Clinical implications of stiffness and strength changes in fracture healing. *J Bone Joint Surg. [Br]* 1997; 79-B: 9-12
5. Aro H.T., Chao E.Y.S.: Bone healing patterns affected by loading fracture fragment stability, fracture type and fracture site compression. *Clin. Orthop.* 293, pp.8-17
6. Cunningham J.L., Kenwright J., Kershaw C.J.: Tibial external fixation, weight bearing, and fracture movement. *Clin Orthop.* 293, pp. 28-36
7. Sobolewski R., Wall A.: Badania nad wpływem sztywności zespolenia na przebieg zrostu kostnego w złamaniach goleni leczonych Zespolem w odmianie zewnętrznej. *Chir. Narz.Ruchu Ortop. Pol.* 1996, LXI, Supl. 3B, p. 23-26
8. Deszczyński J., Karpiński J.: Wykorzystanie zewnętrznych stabilizatorów ortopedycznych Dynastab z uwzględnieniem nowych metod monitorowania i komputerowego prognozowania procesu zrostu kostnego. *Chir. Narz.Ruchu Ortop. Pol.* 1996, LXI, Supl. 4B, p. 143-147
9. Jasińska-Choromańska D.: External mechatronic orthopaedic fixators – modelling, computer simulations and clinical experiences, *Journal of Theoretical and Applied Mechanics*, Vol. 38, No 3, 2000, pp. 549-572
10. Jasińska-Choromańska D.: Modelling and analysis of mechatronical external unilateral orthopaedic fixator-bone system. *Mat. 2nd International Conference MECHATRONICS AND ROBOTICS '99, Brno 6-9.09.1999*, pp. 85-90
11. Jasińska-Choromańska D.:, Deszczyński J., Karpiński J.: Komputerowa analiza wpływu przestrzennego rozmieszczenia wszczepów kostnych na stabilność zespolenia złamania. *Ortopedia, Traumatologia, Rehabilitacja* No 1, 14/1999, pp. 35-38