American Journal of Applied Sciences 11 (3): 356-361, 2014
ISSN: 1546-9239

doi:10.3844/ajassp.2014.356.361 Published Online 11 (3) 2014 (http://www.thescipub.com/ajas.toc)

STUDY OF THE INTERFRAGMENTARY STRAIN AND THE INTERFRAGMENTARY MODULUS WITH CHANGING THE DISTANCE BETWEEN PLATE AND FEMUR

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Received 2013-12-17; Revised 2013-12-21; Accepted 2013-12-28

ABSTRACT

For several years the distance between plate and femur has been studied for preventing the damage to the blood supply by the contact pressure between plate and femur. The Limited Contact Dynamics Compression Plate (LC-DCP) is normally used to create the distance by using the locking screws. However, increasing of the distance between plate and femur affects the interfragmentary stain and the interfragmentary modulus. The interfragmentary strain is the main factor of femur-fractured healing. While the interfragmentary modulus is the new interesting factor of the stability of the femur and plate. This research proposes a study of the effect of the distance between plate and femur on the interfragmentary stain and the interfragmentary modulus. The interfragmentary strain is increased when the distance increases while the interfragmentary modulus is decreased by increasing the distance.

Keywords: Interfragmentary Strain, Interfragmentary Modulus, LC-DCP, Femur Fracture

1. INTRODUCTION

When fractures of the human femur occur, there are many ways for treatment, e.g., external close reduction and spica cast immobilization, external fixation, internal fixation. For internal fixation, plate fixation is a main choice to heal the femur fractured (Wahnert *et al*., 2012). The Dynamics Compression Plate (DCP) is used to fix a femur with the conventional screws. Because the conventional screw cannot lock with the DCP hole, DCP and femur will be fixed by compressive force from the conventional screw (Kanchanomai *et al*., 2008; Field *et al*., 2004; Kabak *et al*., 2004; Gao *et al*., 2011). But the periosteal blood supply to femur may be compressed by DCP and may cause femur harming (Haasnoot *et al*., 1995; Ahmad *et al*., 2007). The LC-DCP is developed to solve this problem (Borgeaud *et al*., 2000; Field *et al*., 2004; Kabak *et al*., 2004; Miller and Goswami, 2007; Kumar *et al*., 2013). It can use the locking screws with LC-DCP holes. The distance between LC-DCP and femur helps the periosteal blood supplying femur more easily. In addition, LC-DCP can use the conventional screw as DCP.

However, the stability of plate and femur is the main problem. How about the stability of plate and bone if the distance between plate and femur increases? There are many research papers studied about effect of the distance between plate and bone on the plate and bone stability and it has been found that increasing of the distance decreased the stability of plate and bone (Haasnoot *et al*., 1995; Ahmad *et al*., 2007).

The interfragmentary strain (ε_{IF}) is defined as the ratio of the fracture gap displacement after the body load applied and the original fracture gap as shown in **Fig. 1**. The Equation 1 of ε_{IF} is:

$$\varepsilon_{IF} = \frac{\Delta L}{L} \tag{1}$$

Where:
ΔL = The fracture gab displacement after the body load (W) applied
L = The original fracture gap length

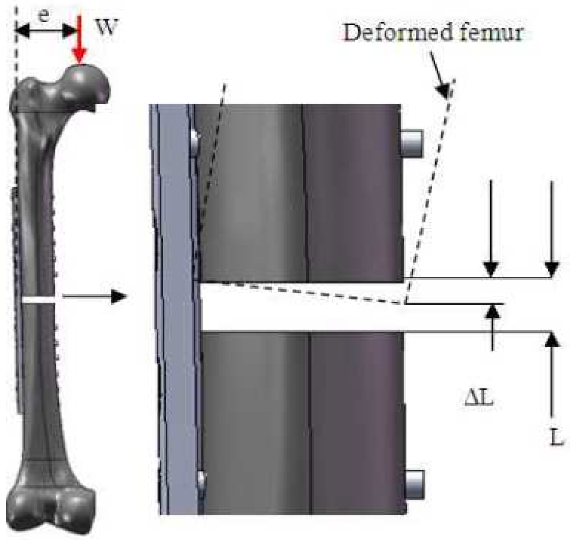

Fig. 1. The deformation of the fractured femur

Fig. 2. The experiment setup on the compressive testing machine

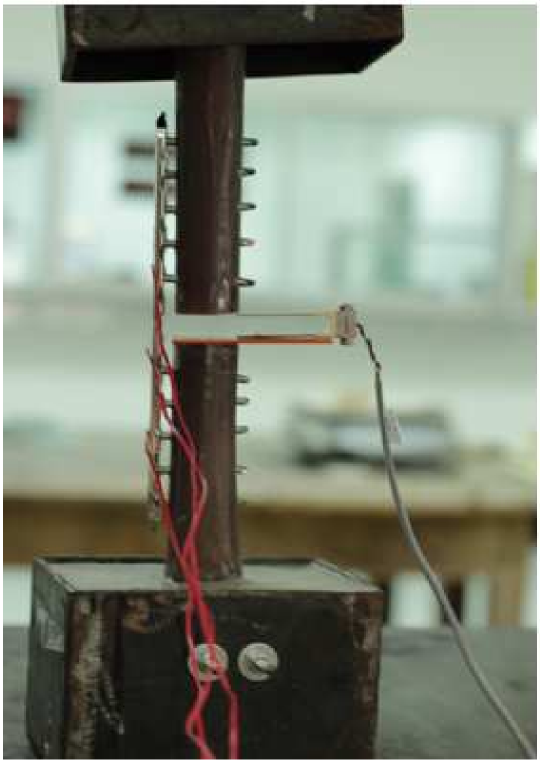

Fig. 3. The setup of the distance of plate and femur

The best IFS ranges from 2-10% (Perren, 1979; Kim *et al*., 2010).

The physician will cut the fracture and form a gap of 1-10 mm when the fracture occurs at the middle part of the femur.

The normal stress in the plate at fracture gab is the combine stress from normal stress and bending stress. For normal stress (Fouad, 2011), the equation of the normal stress is Equation (2):

$$\sigma_{IF} = \frac{W}{A} \quad (2)$$

Where:

σ = Normal stress or intefrgragmentary stress
W = Body load
A = Plate cross section area.

The equation of the bending stress is Equation (3):

$$\sigma_b = \frac{My}{I} \quad (3)$$

Where:

M = Bending moment = We (e = distance from the body load to the centroid of the plate cross section area)

σ_b = Bending stress

Y = The distance from the centoid of the plate cross section area

I = Moment of inertia of the plate cross section area

The Interfragmentary Modulus (IM) is defined as the slope of the graph between σ_{IF} and ε_{IF} if the graph is linear (Wongchai, 2012). The equation of the infragmentary modulus. The equation of σ_{IF} and ε_{IF} is Equation (4):

$$\sigma_{IF} = IM\varepsilon_{IF} + k \quad (4)$$

where, k is constant value.

In general compressive testing of bone and plate fixation, several research papers interest the relation between the compressive load and the deformation of bone (Haasnoot *et al*., 1995; Ahmad *et al*., 2007). But they do not test the interfragmentary strain of the bone and plate.

In the present work, the interfragmentary strain is the goal to test by varying the distance between plate and femur.

2. MATERIALS AND METHODS

The 3406 large left fourth generation femur of Pacific Research Lab and the 12-holes LC-DCP from synthes, Inc. with the locking screws are used in the present work. The Pacific research laboratories bone are usually used in biomechanics research (Greer and Wang, 1999; Stoffel *et al*., 2003; Ahmad *et al*., 2007).

The 10-mm gap is generated at the middle point of the femur as shown in **Fig. 2 and 3**. The Kyowa DTC-A-5 clip-type displacement transducer with specification listed in **Table 1** is used to measure ΔL.

The lowest of the femur is fixed with epoxy resin while the femur head is fixed by one screw as shown ub **Fig. 2**. The jig at the femur head can rotate about this screw and touch the femur head for transferring the compressive force from the compressive testing machine.

The force and displacement signals are converted to digital signals by the Kyowa PCD-300A. the PCD-300A control software is used for data recording and exporting excel files.

Table 1. Displacement transducer specification

Rated capacity	5 mm (mounting groove interval 4 to 9 mm)
Rated output	2.5 mV/V (5000×10^{-6} strain)
Non-linearity	$\pm$ 1%RO or better
Hysteresis	$\pm$ 1%RO or better
Repeatability	$\pm$ 1%RO or better
Recommended bridge voltage	2 to 4 V, AC or DC
Safe bridge voltage	10V, AC or DC
Input resistance	$350\,\Omega \pm 2\%$
Output resistance	$350\,\Omega \pm 2\%$

The distances between and plate are 0, 1, 3 and 5 mm as show in **Fig. 3** and the compressive force F is applied from 0 to 300 N.

3. RESULTS

The graphs of ε_{IF} versus the compressive force for all cases of the distance between plate and screw is show in **Fig. 4**.

The relations between ε_{IF} and F are generated by using the linear regression in Equation (5):

$$\varepsilon_{IF} = aF + b \quad (5)$$

Where:

a, b = constant.

The values of a, b and R^2 are shown in **Table 2**.

The graph of σ_{IF} versus ε_{IF} is shown in **Fig. 5** for all distances with the slope of IM. **Table 3** shows the values of IM, k and R^2.

4. DISCUSSION

From **Fig. 4**, it can be seen that the slope of the graph is increased by increasing the distance between plate and femur. Because the high slope graph has the interfragmentary strain more than the low slope graph at the same compressive force, the interfragmentary strain is increased when the distance between plate and femur increases.

Becuase the femur, the plate and the screws are the linear materials, the results from **Table 2** show that the graphs of the interfragmentary strain are linear with high R^2. However, all graphs in **Fig. 4** are not linear near the start durations.

From **Fig. 5 and Table 3** found that the relations of σ_{IF} and ε_{IF} are linear function with high R^2. From the Equation (4), IM is the slope of the graph. It is decreased when the distance between plate and femur increases. On the otherwords, the stability of the plate and bone fixation is decreased by increasing the distance.

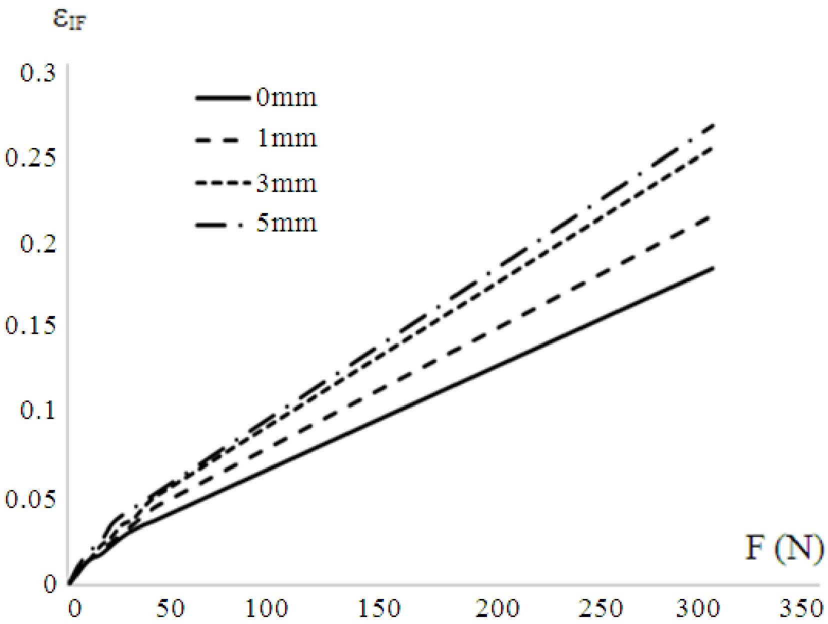

Fig. 4. The correlation between ε_{IF} and F

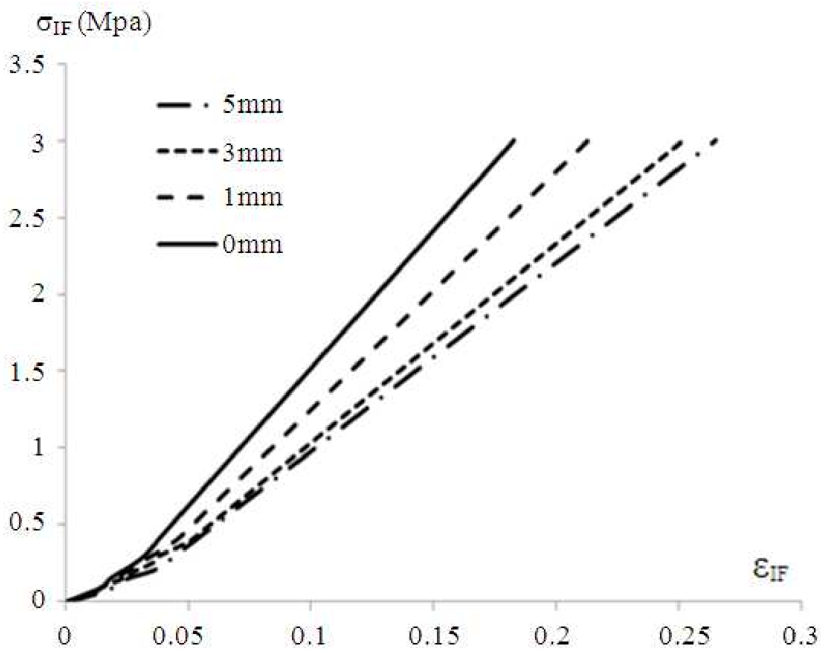

Fig. 5. The correlation between σ_{IF} and ε_{IF}

Table 2. Correlation constants for εIF

Distance between plate and femur (mm)	a	b	R^2
0	0.00559	0.1500	0.998
1	0.00646	0.1923	0.997
3	0.00773	0.2002	0.997
5	0.08160	0.1955	0.998

Table 3. IM and k

Distance between plate and femur (mm)	IM	k	R^2
0	17.48	-0.216	0.998
1	14.96	-0.221	0.997
3	12.55	-0.191	0.997
5	12.01	-0.201	0.998

From **Fig. 5**, IM can be used for compressive testing of plate and femur fixation as young modulus on material testing.

However, the graphs in **Fig. 5** do not perform linearly near the origin point.

5. CONCLUSION

- The interfragmentary strain is increased when the distance between plate and femur increases
- The interfragmentary modulus is decreased by increasing the distance between plate and femur
- The interfragmentary modulus can be used for compression testing of plate fixation on the femur as young modulus in material testing

6. ACKNOWLEDGEMENT

The researcher is grateful to Kasetsart University, Si Racha Campus and the Center for Advanced Studies in Industrial Technology for the research grants.

7. REFERENCES

Ahmad, M., R. Nanda, A.S. Bajwa, J. Candl-Couto and S. Green *et al*., 2007. Biomechanical testing of the locking compression plate: When does the distance between bone and implant significantly reduce construct stability? Injury, 38: 358-364. DOI: 10.1016/j.injury.2006.08.058

Borgeaud, M., J. Cordey, P.F. Leyvraz and S.M. Perren. 2000. Mechanical analysis of the bone to plate interface of the LC-DCP and of the PC-FIX on human femora. Injury. DOI: 10.1016/S0020-1383(00)80029-7

Field, J.R., R. Edmonds-Wilson and R.M. Stanley, 2004. An evaluation of interface contact profiles in two low contact bone plates. Injury, 35: 551-556. DOI: 10.1016/S0020-1383(03)00215-8

Fouad, H., 2011. Assessment of function-graded materials as fracture fixation bone-plates under combined loading conditions using finite element modelling. Med. Eng. Phys., 33: 456-463. DOI: 10.1016/j.medengphy.2010.11.013

Gao, M., W. Lei, Z. Wu, D. Liu and L. Shi, 2011. Biomechanical evaluation of fixation strength of conventional and expansive pedicle screws with or without calcium based cement augmentation. Clin. Biomechanics, 26: 238-244. DOI: 10.1016/j.clinbiomech.2010.10.008

Greer, B. and E.L. Wang, 1999. Solid model in IGES format.

Haasnoot, E.V.F., T.W.H. Miinch, P. Matter and S.M. Perren, 1995. Radiological sequences of healing in internal plates and splints of different contact surface to bone. (DCP, LC-DCP and PC-Fix). Injury, 26: B28-B36. DOI: 10.1016/0020-1383(95)96896-C

Kabak, S., M. Halici, M. Tuncel, L. Avsarogullari and S. Karaoglu, 2004. Treatment of midclavicular nonunion: Comparison of dynamic compression plating and low-contact dynamic compression plating techniques. J. Shoul. Elbow Surgery, 13: 396-403. DOI: 10.1016/j.jse.2004.01.033

Kanchanomai, C., V. Phiphobmongkol and P. Muanjn, 2008. Fatigue failure of an orthopedic implant-A locking compression plate. Eng. Failure Anal., 15: 521-530. DOI: 10.1016/j.engfailanal.2007.04.001

Kim, S.H., S.H. Chang and H.J. Jung, 2010. The finite element analysis of a fractured tibia applied by composite bone plates considering contact conditions and time-varying properties of curing tissues. Comp. Struct., 92: 293-2118. DOI: 10.1016/j.compstruct.2009.09.051

Kumar, V., D. Mehrotrab, S. Mohammadc, R.K. Singhb and V. Singhd *et al*., 2013. Anchor lag screw vs conventional lag screw in mandibular fractures: A series of 30 cases. J. Oral Biol. Craniofacial Res., 3: 15-19. DOI: 10.1016/j.jobcr.2013.01.002

Miller, D.L. and T. Goswami, 2007. A review of locking compression plate biomechanics and their advantages as internal fixators in fracture healing. Clin. Biomech., 22: 1049-1062. DOI: 10.1016/j.clinbiomech.2007.08.004

Perren, S.M., 1979. Physical and biological aspects of fracture healing with special reference to internal fixation. Clin. Orthopeadics Related Res., 138: 175-196.

Stoffel, K., U. Dieter, G. Stachowiak, A. Gachter and M.S. Kuster, 2003. Biomechanical Testing of the LCP-how can stability in locked internal fixators be controlled? Injury, 34: 11-19. DOI: 10.1016/j.injury.2003.09.021

Wahnert, D., J.H. Lange, M. Schulze, S. Lenschow, R. Stange *et al*., 2012. The potential of implant augmentation in the treatment of osteoporotic distal femur fractures: A biomechanical study. Injury, 44: 808-812. DOI: 10.1016/j.injury.2012.08.053

Wongchai, B., 2012. Interfragmentary modulus. Am. J. Applied Sci., 9: 372-375. DOI: 10.3844/ajassp.2012.372.375