Effect of the Screw Torque Level on the Interfragmentary Strain and the Interfragmentary Modulus

Boonthum Wongchai

Department of Mechanical Engineering, Faculty of Engineering at Si Racha,
Kasetsart University, 199 M.6, Tungsukhla, Si Racha, Chonburi, 20230, Thailand

ABSTRACT

The screw torque is applied at the screw head to fix the plate and the bone. It generates the compressive force between the plate and the bone to stabilize them. The interfragmentary strain is the main factor for healing the bone fractured. The screw torque level affects the interfragmentary strain and the stability of the fixation between the plates an the bone. The interfragmentary modulus is the new factor of the plate fixation stability and it is affected by the torque level. This research is proposed to study the effect of the screw torque level on the interfragmentary strain and the interfragmentary modulus. The interfragmentary strain and the interfragmentary modulus decrease by increasing the screw torque level.

Keywords: Screw Torque Level, Interfragmentary Strain, Interfragmentary Modulus, LC-DCP, Limited Contact Dynamics Compression Plate, Femur Fracture

1. INTRODUCTION

Internal fixation is the main method to cure the human bone fracture (Wahnert *et al.*, 2012). The plate fixation is the main choice of the internal fixation. The Dynamic Compression Plate (DCP) and the Limited Contact Dynamics Compression Plate (LC-DCP) are generally used to fix the broken bone. For the DCP, only the conventional screws are used. The conventional screws fix the plate and the bone by the compressive force that is generated by the applied torque at the screw head (Kanchanomai *et al.*, 2008; Field *et al.*, 2004; Kabak *et al.*, 2004; Gao *et al.*, 2011; Kumar *et al.*, 2013). For the LC-DCP, the locking screws are used to make the distance between plate and bone. The conventional screw can be used in the LC-DCP as the DCP.

The contact between the plate and the femur affects the periosteal blood supply to the femur (Haasnoot *et al.*, 1995; Ahmad *et al.*, 2007). The LC-DCP is developed to solve this problem by using the locking screws (Borgeaud *et al.*, 2000; Field *et al.*, 2004; Kabak *et al.*, 2004; Miller and Goswami, 2007).

However, the stability of the plate and the bone must be conscious. The plate fixation with the conventional screws has more stable than the locking screws because the locking screw cannot generates the compressive force (Haasnoot *et al.*, 1995; Ahmad *et al.*, 2007; Kumar *et al.*, 2013).

In the human bone fracture, the screw tensile force (internal force) ranges from 2000 N to 3000 N (Kim *et al.*, 2010). Ahmad *et al.* (2007) applied the screw torque of 4 N·m in their research.

The interfragmentary strain (ε_{IF}) is a main factor of femur fractured healing. It has the best ranges from 2-10% (Perren, 1979; Kim *et al.*, 2010). It 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:

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

ΔL = The fracture gab displacement after the body load (W) applied
L = The original fracture gap length (L = 10 mm for this study)

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. In this present work, a gap of 10 mm was applied.

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

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

Where:
σ_{IF} = Normal stress or interfragmentary stress
W = Body load
A = Plate cross section area

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

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

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

Wongchai (2012) has defined the Interfragmentary Modulus (IM) as the slope of the graph between σ_{IF} and ε_{IF} when the are linearity related. The relation between σ_{IF} and ε_{IF} can be written as Equation (4):

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

k = Constant value

In the present work, the interfragmentary strain and the interfragmentary modulus is the goal to study at various bone screw torques level.
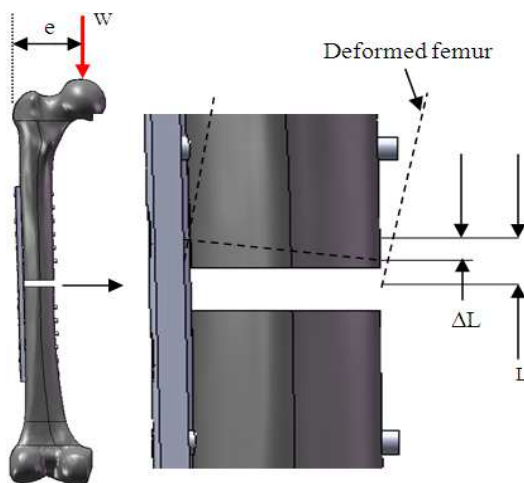
2. MATERIALS AND METHODS

The 3406 large left fourth generation femur of Pacific Research Lab is 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 12-holes LC-DCP from synthes Inc. with the ten conventional screws are attached on the femur.

The 10 mm gap is generated at the middle point of the femur. 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 bolt as shown in **Fig. 2**. The jig at the femur head can be rotated about this bolt and touched the femur head for transferring the compressive force from the compressive testing machine.

The compressive force from the compression testing machine and displacement signals are converted to digital signals by the Kyowa PCD-300A. The PCD-300A software is used for data recording.

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	±1% RO or better
Hysteresis	±1% RO or better
Repeatability	±1% RO or better
Recommended bridge voltage	2 to 4 V, AC or DC
Safe bridge voltage	10V, AC or DC
Input resistance	350 Ω ± 2%
Output resistance	350 Ω ± 2%

Fig. 1. The deformation of the fractured femur

Fig. 2. The experiment setup

Fig. 3. The bone screw torque setting

Figure 3 shows the torque applyed on the screw head. The level of the screw torque is varies from 1 to 5 N.m. The compressive force F on the femoral head is varies from 0 to 300N.

3. RESULTS

The graphs of ε_{IF} versus the compressive force for all cases of the screw torque level are shown in **Fig. 4**.

By using the Equation (2) and (4), the graphs of σ_{IF} versus ε_{IF} for all cases of the screw torque level are shown in **Fig. 5**.

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

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

Where:
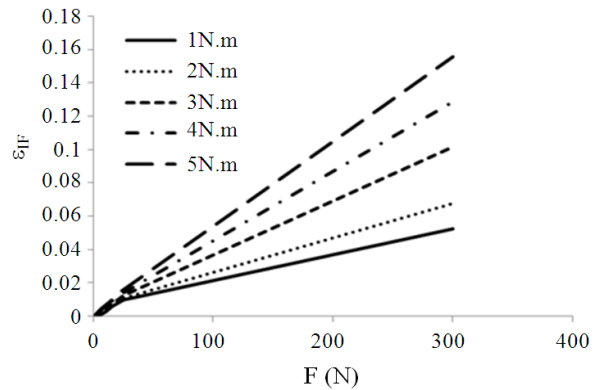a, b = Constant

The results of a and b with R^2 are in **Table 2**. By using Equation (4), IM and k are calculated and shown in **Table 3**.
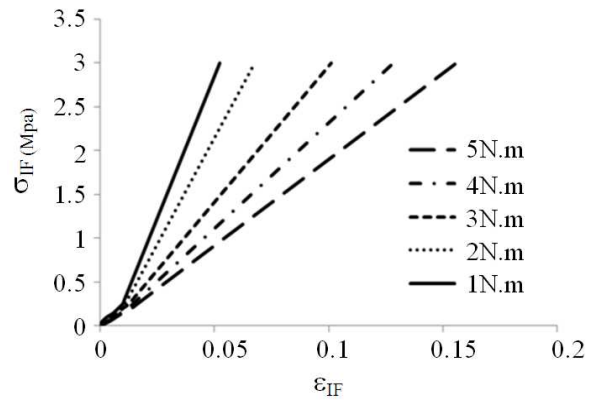
4. DISCUSSION

From **Fig. 4**, it has been found that the slopes of the graph decreased by increasing the screw torque level. In other words; for the same compressive force applied at the femoral head, the interfragmentary strain decreased when the screw torque level is increased.

From the data in **Table 2**, It has been seen that the relation between ε_{IF} and F is the linear function with high R^2 because the plate, the femur and the screws are linear materials. In the present work, the applied force at the femur head is not exceeding the elastic limit of all parts.

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

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

Table 2. Correlation constants for ε_{IF}

Bone screw torque (N.m)	a	b	R^2
1	0.00154	0.00613	0.993
2	0.00206	0.00589	0.996
3	0.00322	0.00463	0.999
4	0.00415	0.00397	0.999
5	0.00507	0.00356	0.999

Table 3. IM and k

Bone screw torque (N.m)	IM	k	R^2
1	61.88	-0.292	0.993
2	47.05	-0.216	0.996
3	36.62	-0.113	0.999
4	23.90	-0.079	0.999
5	19.62	-0.059	0.999

The graphs of the ε_{IF} and F must be stayed in the elastic zone of material (linear zone).

Table 3 shows that the relations between σ_{IF} and ε_{IF} are linear with high R^2. The slope (IM) of the graphs in **Fig. 5** decreased when the screw touque level is increased. Because the meaning of IM is the spring stiffness and the stabilliy of the bone-plate fixation. Thus, the stabilliy of the bone-plate fixation decresed when the screw touque level is increased.

5. CONCLUSION

- The interfragmentary strain decreased by increasing the screw torque level
- The interfragmentary modulus decreased by increasing the screw torque level

6. ACKNOWLEDGEMENT

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, 31. 29-36. PMID: 11052378

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. Biomech., 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. Shoulder 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 plat. 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. Compos. 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. Orthop. Relat. Res., 138: 175-196. PMID: 376198

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 and 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