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

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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 and 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 Nm in their research.

The interfragmentary strain ($\varepsilon_{IF}$) 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 length (Kim et al., 2010).

The Equation 1 of $\varepsilon_{IF}$ is:

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

$\Delta L =$ The fracture gap 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 gap 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):

$$\sigma_{IF} = \frac{W}{A}$$  \hspace{1cm} (2)

Where:
- $\sigma_{IF}$ = Normal stress or interfragmentary stress
- W = Body load
- A = Plate cross section area

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

$$\sigma_{b} = \frac{My}{I}$$  \hspace{1cm} (3)

M = Bending moment = We (e = distance from the body load to the centroid of the plate cross section area)
- $\sigma_{b}$ = Bending stress
- y = The distance from the centroid 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 $\sigma_{IF}$ and $\varepsilon_{IF}$ when the are linearity related. The relation between $\sigma_{IF}$ and $\varepsilon_{IF}$ can be written as Equation (4):

$$\sigma_{IF} = IM \varepsilon_{IF} + k$$  \hspace{1cm} (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 $\Delta L$.

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.

| Displacement transducer specification |
|--------------------------------------|
| Rated capacity                      | 5 mm (mounting groove interval 4 to 9 mm) |
| Rated output                        | 2.5 mV/V (5000x10^{-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                    | 350Ω ± 2% |
| Output resistance                   | 350Ω ± 2% |

Fig. 1. The deformation of the fractured femur

Fig. 2. The experiment setup
3. RESULTS

The graphs of $\varepsilon_{IF}$ 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 $\sigma_{IF}$ versus $\varepsilon_{IF}$ for all cases of the screw torque level are shown in Fig. 5.

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

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

Where:

$a, b = \text{Constant}$

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 $\varepsilon_{IF}$ 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.

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Table 2. Correlation constants for $\varepsilon_{IF}$

| 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 $\varepsilon_{IF}$ and $F$ must be stayed in the elastic zone of material (linear zone). Table 3 shows that the relations between $\sigma_{IF}$ and $\varepsilon_{IF}$ are linear with high $R^2$. The slope (IM) of the graphs in Fig. 5 decreased when the screw torque level is increased. Because the meaning of IM is the spring stiffness and the stability of the bone-plate fixation. Thus, the stability of the bone-plate fixation decreased when the screw torque 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

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