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

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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 strain 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 strain 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 ($\varepsilon_{IF}$) 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 $\varepsilon_{IF}$ is:

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

Where:

$\Delta L$ = The fracture gap displacement after the body load (W) applied
$L$ = The original fracture gap length
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 gap is the combine stress from normal stress and bending stress. For normal stress (Fouad, 2011), the equation of the normal stress is Equation (2):

\[ \sigma_n = \frac{W}{A} \]  

Where:
\( \sigma \) = Normal stress or interfragmentary stress
\( W \) = Body load
\( A \) = Plate cross section area.

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

\[ \sigma_b = \frac{My}{I} \]
Where:

\[ M = \text{Bending moment} = W e \] (distance from the body load to the centroid of the plate cross section area)

\[ \sigma_b = \text{Bending stress} \]

\[ Y = \text{The distance from the centroid of the plate cross section area} \]

\[ I = \text{Moment of inertia of the plate cross section area} \]

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

\[ \sigma_{IF} = IM\varepsilon_{IF} + k \] (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 \( \Delta L \).

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 capacity                                           | 2.5 mV/V                                   |
| Non-linearity                                            | \( \pm 1\% \text{RO or better} \)            |
| Hysteresis                                               | \( \pm 1\% \text{RO or better} \)            |
| Repeatability                                            | \( \pm 1\% \text{RO or better} \)            |
| 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 \( \varepsilon_{IF} \) versus the compressive force for all cases of the distance between plate and screw is show in Fig. 4.

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

\[ \varepsilon_{IF} = aF + b \] (5)

Where:

\( a, b = \text{constant} \).

The values of \( a, b \) and \( R^2 \) are shown in Table 2.

The graph of \( \sigma_{IF} \) versus \( \varepsilon_{IF} \) 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.

Because 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, it was found that the relations of $\sigma_{IF}$ and $\varepsilon_{IF}$ are linear functions 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 other words, the stability of the plate and bone fixation is decreased by increasing the distance.

![Fig. 4. The correlation between $\varepsilon_{IF}$ and $F$.](image)

![Fig. 5. The correlation between $\sigma_{IF}$ and $\varepsilon_{IF}$.](image)
Table 2. Correlation constants for εIF

| Distance between plate and femur (mm) | a    | b    | R²  |
|---------------------------------------|------|------|-----|
| 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    | R²  |
|---------------------------------------|-----|------|-----|
| 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.

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