BIOMECHANICAL EVALUATION OF FRACTURE CONSTRUCT FOR FRACTURE FIXATION OF THE TIBIA

RAJA MOHD AIZAT BIN RAJA IZAHAM

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Dedicated to

Abah (Raja Izaham Raja Iskandar) & **Mama** (Norasah Shafie),

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ABSTRACT

Plate osteosynthesis is one of the methods that can be used by surgeons to treat patients with bone fractures and irregularities. There are various osteosynthesis plates available commercially, but the most suitable implant with optimum screw configurations is highly subjective and remained a topic of debate. The aim of the study is to determine the optimum implant-screws configuration and implant designs which could maintain stability of the construct during bone healing. The tibia bone was chosen for the analyses, and has been divided into three stages – the proximal, diaphyseal and distal part of the bone. Three-dimensional (3D) bone model was reconstructed from computed-tomography (CT) datasets, and the implant models were designed using computer-aided design software. Tibial fractures and deformities were simulated with reference to the orthopaedic literatures. Finite element analysis (FEA) was used with a common loading applied at the proximal tibia. Results showed that the use of Locking Compression Plate (LCP) for fracture fixation provides better stability to the construct despite having a large stress magnitude of 45.5 MPa (p-value<0.001). In terms of screws configurations, placement near the fractured site provides a more rigid fixation. In contrast, placing the screws further away from the fractured site gives flexibility to the fracture construct which may result in callus formation. For the pylon fracture, the Medial Distal Tibial (MDT) plate significantly reduced the displacement and stress magnitudes as compared to the Anterolateral (ATL) plate (p-value<0.001).

ABSTRAK

Osteosintesis plat merupakan salah satu cara yang digunakan oleh pakar bedah untuk merawat pesakit yang mangalami kepatahan dan kecacatan pada tulang. Kini, pelbagai jenis osteosintesis plat boleh diperolehi secara komersial, tetapi jenis implan dan konfigurasi skru yang terbaik masih menjadi perkara yang subjektif dan topik ini sering dibincangkan. Tujuan kajian ini dilakukan adalah untuk menentukan konfigurasi skru-plat yang optimum dan juga reka bentuk implan yang dapat mengekalkan kestabilan konstruk semasa proses penyembuhan tulang. Tulang tibia telah dipilih untuk kajian ini dan dibahagikan kepada tiga bahagian – *proximal*, *diaphyseal* dan juga bahagian *distal* tulang. Model tulang tiga dimensi (3D) dijana daripada dataset tomografi berkomputer (CT), manakala implan telah direka dengan menggunakan perisian rekaan berpandukan komputer. Kepatahan dan kecacatan pada tulang disimulasikan berdasarkan kajian ortopedik terdahulu. Analisis unsur terhingga (FEA) digunakan dengan mengenakan beban langsung pada bahagian *proximal* tibia. Keputusan menunjukan bahawa penggunaan *Locking Compression Plate* (LCP) memberikan konstruk yang lebih stabil walaupun mempunyai magnitud tegasan yang tinggi sebanyak 45.5 MPa (*p-value*<0.001). Selain itu, penetapan yang lebih pegun boleh diperolehi dengan menempatkan skru berdekatan dengan kawasan yang patah. Sebaliknya, dengan menempatkan skru lebih jauh dari kawasan yang patah dapat memberikan lebih fleksibiliti kepada konstrak kepatahan dan seterusnya menggalakkan pertumbuhan *callus*. Bagi kepatahan *pylon*, plat *Medial Distal Tibial* (MDT) memberi kelebihan dengan pengurangan sesaran dan tegasan yang ketara berbanding plat *Anterolateral* (ATL) (p-value<0.001).

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LIST OF ABBREVIATIONS

3D	-	Three dimension
AIS	-	Abbreviated injury scale
ANOVA	-	Analysis of variance
AO	-	*Arbeitsgemeinschaft für Osteosynthesefragen*
ATL	-	Anterolateral
BMD	-	Bone mineral density
CAD	-	Computer-aided design
CT	-	Computed Tomography
CWHTO	-	Closed-wedge high tibial osteotomy
DCP	-	Dynamic Compression Plate
DISP	-	Displacement
EVMS	-	Equivalent von Mises stress
FEA	-	Finite element analysis
HTO	-	High tibial osteotomy
JOT	-	Journal of Orthopaedic Trauma
LC-DCP	-	Limited Contact Dynamic Compression Plate
LCP	-	Locking Compression Plate
LHS	-	Locking head screws
LISS	-	Less invasive stabilize system
MDT	-	Medial distal tibia
MIPO	-	Minimal invasive plate osteosynthesis
mm	-	Millimeter
MPa	-	Mega Pascal
N	-	Newton
NA	-	Neutral axis

No.	-	Number
NTrD	-	National Trauma Database
OTA	-	Orthopaedic Trauma Association
OWHTO	-	Open-wedge high tibial osteotomy
PC-Fix	-	Point Contact fixator
PC-Fix2	-	Point Contact fixator 2
USA	-	United State of America
WBL	-	Weight bearing line

LIST OF SYMBOLS

%	-	Percentage
E	-	Elastic Modulus
^{o}	-	Degree
υ	-	Poisson ratio
x, y, z	-	Rectangular coordinates
σ	-	Stress

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Trauma can be considered as one of the most common cases attends by surgeon on major medical center around the world. According to the Health Facts 2000 that being document by Ministry of Heatlh, Malaysia, trauma is the third most cases being admit to the medical center [1]. Report by National Trauma Database (NTrD) from January 2007 until December 2009 shows an increasing number of patient with trauma injury being admitted to the medical center (figure 1.1) [2-5]. Bone will fail when large external forces being applied to the bone. Risk for younger patient to experience bone fracture is different from the elderly which osteoporosis can be exclude as one of the factor. Trauma is the fifth contributing to death in Malaysia [2]. Active lifestyle of young patient is one of the factors that contributed to the statistic patient being admitted to the medical center, most of the time the patient suffers broken bones from sport activity. Besides that, accidents can happen anywhere and it also gives away some patient that will suffer some bone fracture.

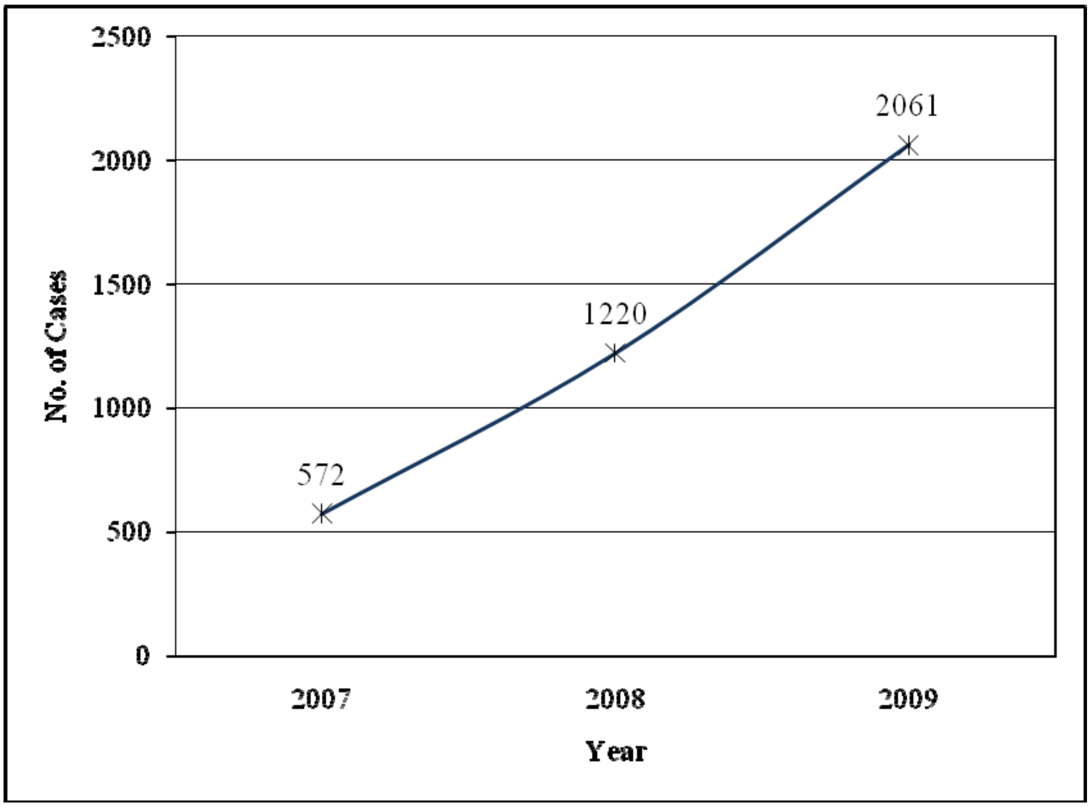

Figure 1.1 Number of cases from 2007 till 2009 based on NTrD reports

Condition of the bone also can contribute to bone fracture to occur such low bone mineral density (BMD), osteoporosis or bone cancer which gives weaken the bone and relatively easy to fracture even under a small force being apply directly to the bone. Elderly age around 60 and above are the potential group for bone fracture to occur because of osteoporosis. Gender based statistic shows that female has the tendency to experience bone fracture compared to male because of osteoporosis [6]. Caucasian female age 50 has a risk of forty percent to fracture on hip, spine or distal forearm, while thirteen percent on Caucasian male in similar age [6].

Trauma fixation depends on the severity and the complexity of the injury itself beside the surgeon familiarity and their expertise of handling the case. There are broad number of treatment and implant that can be choosing from. Most of the implant has its own advantages and disadvantages in every aspect for fracture fixation. However, a well known implant that usually being relate to the bone fracture fixation is plate osteosynthesis. Plate osteosynthesis is a method of bone fracture fixation using a plate and screws as the fixation devices and it also one of the direct method for fracture fixation. The implant will hold the fracture site by maintaining the fracture bones align together in their anatomical place until the bone heal itself. After healing process is complete without any complication, the implant will be leave in the patient body unless there is some complication cause by the implant to the patient. The whole fixation process from identifying the problem until the bone is fully heal need to be done under two separated surgical procedure. Between both surgical procedures, the stability of the implant and the expertise of the surgeon will be tested by the reaction the patient's body with the implant [7]. Stability of the fracture construct is the main aspect that needs to be considers during fracture fixation. The implant need to be able to maintain the fracture construct and endure all physical activity that being done by the patient during healing period of the bone. achieving stable fixation may become a step closer to the fracture fixation common goal which is to achieve boney union [8].

1.2 Problem statement

Since the 1960s, both the techniques and implants used for fracture fixation has evolved in order to improve healing of the bone [9]. Fracture fixation offer a lot of varieties of implant and need a proper planning by the surgeon in detail. Among things that need to be considered by the surgeon are the patient factors, the intended outcome, reduction technique, choice of implant and post operative regime [7].

Varieties choices of implant are wide from the direct to the indirect method of bone healing. Most common implant being used by the orthopedic surgeon for fracture fixation are plate system which include the locking compression plate (LCP), dynamic compression plate (DCP), less-contact dynamic compression plate (LC-DCP), point-contact fixator (PC-Fix) and less invasive stabilize system (LISS). All this plates serve the same purpose which is to achieve boney union but the approach for each of it is different [8]. Among all the plates, the LCP and DCP are usually being used for fracture fixation. The DCP also referred to as conventional plating, achieves fixation through the friction between the plate and bone [10]. The plate has to be in compression with the fragment bone in order to achieve maximum stability for the fixation [8, 11]. Meanwhile, the LCP does not require the plate to be in contact with the bone mainly because its follows the biomechanical principles of an external fixator [10]. The LCP using the locking head screws (LHS) that will maintaining the stability of the fracture construct and eliminate the need of friction between the plate and the bone. Level of stability of both type of implant in maintaining the fracture fixation is reliable but does not guarantee a correct and successful fixation can be achieved.

Despite the existing of LCP, the DCP is still be using by certain surgeon as their implant of choices even the LCP gives much more biological advantages from the fixation point of view. Comparative study between the LCP and DCP stability still an on-going research. Beside that the combination on the plate itself by manipulating the screw’s type, screw’s size, plate’s length and various combination of screw’s placement on the plate can provide a wide option to the surgeon.

1.3 Aims and Objective

Purpose of fracture fixation is to achieve boney union where the bone can function properly. As mention before, the variety of treatment are broad, therefore the correct choice must be made by the surgeon to ensure the fixed bone can achieve their purpose. Plate osteosynthesis technique is one option among all the technique available for fracture fixation. These techniques also offer very wide varieties of plate that can be used for bone fracture fixation. DCP and LCP are common being used because of the stability both implant provide.

Therefore, based from the problem statement, the objective of this study being conduct is to evaluate the fixation construct through the use of Dynamic Compression Plate (DCP) for fracture fixation of lower limb. Besides using only the DCP as the fixator, LCP also be included in this study in order to evaluate the fixation construct through the use of Locking Compression Plate (LCP) using same fracture condition. By having both implants being used for the same fracture construct, comparison between both implant can be determined based on obtained result.

Others than comparing between the different, the LCP alone can provide a different stability by changing the combination on the plate itself. Configuration of the LCP can be change by manipulation of screws numbers being used, length of the screws and the plate length. Each configuration may give stability that need by the surgeon. This study is to investigate the configuration needed by LCP to provide a sufficient stability for fracture fixation.

On the other hand, in order to investigate the effect of different plate with the same locking concept to the stability of the intra-articular fracture or also known as pilon fracture, anterolateral plate (ATL) and medial distal tibia (MDT) will be used for this task. This type of fracture is one of challenging construct to be fixed because of the involvement of multiple fragments. This study will show the effect of the stability on the fracture construct of intra-articular fracture on by using different plate.

1.4 Scope and the Importance of Research

Traumatology is a wide area which covers almost every area of bone in patient’s body that either broken or dislocate. Therefore, for this particular study, the fixation will take place on the lower limb area, more specifically the femur and tibia bone. Lower limb bear most of the weight from the body during standing and also during high load activities such as climbing, jumping and even running. This study is a three dimensional (3D) computer simulation analysis and the reason is to create more realistic approach in simulating the real condition during the fixation.

Despite the varieties of implant exist for fracture fixation, the LCP and DCP be used in this study as the implant. This study contains three different cases using three different implants. One of the study will used the straight LCP plate with combination screws hole for fixation of tibial shaft. Another cases will used the DCP claw plate that being used as fixator for peri-prosthetic fracture on the proximal femur. The last case in these thesis used the both the DCP and LCP implant concepts that being used for a high tibial osteotomy (HTO) which is the Puddu plate used the DCP concept and the Tomofix plate that using the LCP concept. All the implants created into 3D model using the existing commercially available implant.

Impact on bone can break the bone and cause the disturbance in the continuity of the bone and their alignment. Energy level of the impact, direction of the impact and the condition of the bone mineral density all where factor that contributed to the condition of the fracture bone. As in this study, two out three cases using the same type of fracture which is the oblique fracture. According to the Müller AO (*Arbeitsgemeinschaft für Osteosynthesefragen*) classification of fractures for the tibia is 42-A2 for oblique fracture and for articular multi-fragmentary fracture of 43-C3 [12].

Besides the fracture bone, bone deformity correction also being simulated and be analyze. Deformity correction also used the same principal as the fracture fixation which is to restore functionality and union of the bone. As is this thesis, the deformity correction of varus tibia using high tibial osteotomy (HTO) technique being done. With HTO, the tibia will be corrected to be in normal position of the tibia. The correction will leave a wide gap along the osteotomy line. This gap needs to be stabilized for the bone to be in a normal condition.

Analysis is done in finite element using computer simulation. Computer simulation gives the option of simulate the real condition of the bone and its surrounding. Therefore the result can be trusted and can be as references to the surgeon community for patient's treatment. Results obtain be discussed biomechanically with equivalent von Mises stress (EVMS) and displacement as the parameter to explained the stability of the fracture bone, the efficiency of the implant to maintaining the construct and the effectiveness of the implant to maintain the fracture construct in order to achieved the purpose of fracture fixation.

This study will let us know the stability of the fracture construct after fixation plate place on bone under normal loading condition. Results obtain from the study can gives an overview to surgeon in biomechanical aspect despite the clinical aspect. It also can be as one of the references to the surgeon in determines the best fixation implant that can provide a better stability to the fracture construct and give the functionality and mobility back to the patients.

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