ECRONICON OPEN ACCESS

EC ORTHOPAEDICS
Research Article

In Silico of the Different Pin Size of Unilateral Tibia External Fixator: A Pilot Study

Nur Amalina Zainudin[1,2] and Muhammad Hanif Ramlee[1,2]*

[1]Medical Devices and Technology Center (MEDITEC), Institute of Human Centered Engineering (i-Humen), Universiti Teknologi Malaysia, Johor Bahru, Johor, Malaysia

[2]School of Biomedical Engineering and Health Sciences, Faculty of Engineering, Universiti Teknologi Malaysia, Johor Bahru, Johor, Malaysia

***Corresponding Author**: Muhammad Hanif Ramlee, Medical Devices and Technology Center (MEDITEC), Institute of Human Centered Engineering (i-Humen), Universiti Teknologi Malaysia, Johor Bahru, Johor, Malaysia.

Received: May 23, 2019; **Published:** October 14, 2019

Abstract

External fixator is the promising medical device that can be used for treating bone fracture of tibia. The healing process can be taken place if some parameters are considered such as biomechanical aspect. One of them is the diameter of pin. However, the information regarding the biomechanics characteristics of the different pin size is fairly limited in the literature, thus it might be difficult for medical surgeons to choose pin size. Therefore, this pilot study was conducted to study the different pin size in treating transverse fracture in order to investigate the effect of it. Three-dimensional model of tibia bone and external fixator was constructed using MIMICS and Solid works, respectively. For the analysis, finite element method was utilized to simulate a stance phase condition where 50% of body weight was applied axially on the proximal tibia. The results showed that the 6.5 mm pin size demonstrated the lowest von mises stress at the pin bone interface.

Keywords: *Transverse Fracture; Finite Element; External Fixator; Pin Diameter; Unilateral; Biomechanics*

Introduction

External fixator is a type for fixation for treating bone fractures and has many other uses like lengthening, axial correction and non-union treatment [1, 2]. The external fixator is made from either stainless steel or carbon fibre where it can be fixed into the broken bone for a several period of time in order to limit the movement. Once the healing process is taken place, the removal of the external fixator will be done by medical surgeons. The fixation method such as the number of pins, pin diameter, angle of pin, pin design, spatial configuration, distance between the rod and the bone as well as the number of connecting rods have contributed to the effect of the bone healing process at clinical sites [3-9]. The amount of literature related to the choice of external fixators and pin placements is fairly limited. Hence, a study regarding the biomechanical analysis of an tibia external fixator was conducted to determine the best configuration with regards to providing high stability and low stress to avoid any complications. For the hypotheses of the study, factors that influence a stable construct could be in various aspects such as: larger pin diameter or connecting bar, the numerous pins used, a shorter distance between connecting bar and bone as well as larger distance between pin-to-pin could provide high stability.

For the pin-bone interface, two important parameters influence interface stresses and bone hold; interference and pin diameter. Larger diameter pins have a higher resistance to sustain a bending force and has possibility to reduce the stresses at the pin-bone interface [10]. For component of the fixator, surgeons must be aware of the selection of bar diameter. It is important to note that choosing a proper diameter can reduce the weight and provides strength [11]. For example, diameter of 11 mm can provide strength but at the same time its weight can be increased. This argument should be investigated through a parametric study. Not only these two variables, it should be noted a large contribution in order to provide a stable fixator construct is the configurations. These are depending on the number of pins and the distance between the connecting bar and bone. Increasing the pin number from two to three in any segment whilst reducing the connecting bar distance to bone should be able to increase the fixator stiffness [10,12] Researchers focused on different spatial geometry and types of implants [8,9]. As to date, the information on the biomechanical characteristics of different diameter is fairly limited in the literature. In orthopaedics, there are present attempts to use 3D models in planning and supporting treatment [13]. Therefore, this pilot study was conducted to investigate the effect of different pin diameter on the biomechanical aspects.

Methodology

Three-dimensional modelling

Three-dimensional (3D) model of tibia bone was reconstructed using MIMICS software by utilizing Computed Tomography (CT) images [14]. The 3D model consists of cortical and cancellous bone where a threshold value of 700 was set to differentiate it [15]. A simple transverse fracture was constructed in order to mimicking real case scenario. External fixator was designed in the Solid works software where the pin diameter varies from 4.5 to 6.5 mm. All 3D models were then saved in STL file.

Finite element analysis

All STL files of the 3D model were then imported into Marc. Mentat software for further analysis. The convergence analysis was done in the previous study where size of 3 mm is the optimum for the bone and 1 mm for the external fixator [16]. A validation analysis of the model was done earlier [14]. From this study, the cortical bone was assigned with 16.2 GPa and the cancellous was 480 MPa modulus. For the external fixator, a value of 200 GPa was assigned as representing the stainless steel material [17]. In order to simulate stance phase, 50% of the body weight (60% is on the medial and 40% on the lateral) was applied to the proximal tibia as shown in the figure 1.

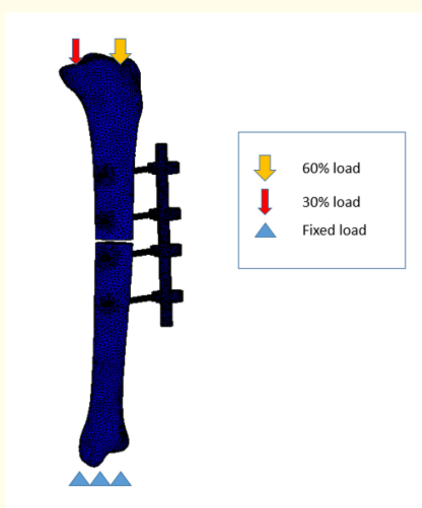

Figure 1: *Boundary condition of the stance phase condition.*

Results and Discussion

Results for equivalent von misses stress are expected to follow the hypothesis where the larger the pin diameter will provide lower the stress. First and foremost, 4.5 mm pin diameter shows the highest stress distribution of 30.1824 MPa in bone and 202.014 MPa in external fixator followed with the lowest stress distribution possess by pin diameter 6.5 mm. 6.5 mm pin diameter results in 17.2388 MPa in bone and 109.909 MPa in external fixator. In addition, 5.5 mm pin diameter which expectedly to have the most optimum and favourable pin diameter possess 21.4979 MPa in bone and 147.331 MPa in external fixator followed with 6.0 mm pin diameter which have 18.4173 MPa in bone and 129.126 MPa in external fixator which is slightly higher than 5.5 mm diameter. A part from that, 5.0 mm pin diameter results in 26.0595 MPa in bone and 160.748 MPa in external fixator which show lower stress distribution than 5.5 mm pin diameter. Value for stress for five different pin diameter shown in table 1 below.

No.	Diameter of pin (mm)	Peak Stress (MPa)	
		Tibia bone	External Fixator
1	4.5	30.1824	202.014
2	5.0	26.0595	160.748
3	5.5	21.4979	143.331
4	6.0	18.4173	129.126
5	6.5	17.2388	109.909

Table 1: *Peak von Mises stress at the bone and external fixator.*

Peak stress for five different diameter of pin in tibia bone varied only at two pin which is second and third pin. Peak stress of pin diameter 4.5 mm, 5.0 mm and 6.5 mm placed in third pin while peak stress for 5.5 mm and 6.0 mm placed at second pin. Furthermore, peak stress happened at third pin for all external fixator configuration. This shows that maximum stress happened at pin interface nearer to fracture site. In this case second and third pin have high probability to exert high stress.

Displacement that happened in tibia bone also important. Pin diameter of 4.5 mm which possess the high stress distribution displaced 2.82 mm while pin diameter of 6.5 mm which exerted the lowest stress distribution displaced 2.36 mm. 5.0 mm, 5.5 mm and 6.0 mm displaced 1.90 mm, 1.42 mm and 4.44 mm respectively. While trying to stabilize the fracture site of tibia shaft fracture, external fixator being displaced to maintain flexibility of the configuration. A non-flexible fixator will resulted in failure of configuration as the tibia bone not allowed to displace in the process of healing. Displacement for external fixator with pin diameter of 4.5 is 2.00 mm while 6.5 mm displaced for 1.60 mm. Configuration for 5.0 mm, 5.5 mm and 6.0 mm displaced 1.11 mm, 1.20 mm and 2.17 mm respectively. The value for displacement of both tibia and external fixator considered a safe displacement. Technically the displacement happened as part of healing process where the configuration is allowed to have small movement to initiate the healing process.

Conclusion

It is expected that the highest pin size will provide the lowest von Mises stress. Thus, it is suggested that medical surgeons can consider to use the bigger pin size to avoid secondary fracture at the pin-bone interface.

Bibliography

1. Bor N., *et al*. "Ilizarov method for gradual deformity". *Operative Techniques in Orthopaedics* 21.2 (2011): 104-112.
2. Nakase T., *et al*. "Distraction osteogenesis for correction of three-dimensional deformities with shortening of lower limbs by Taylor Spatial Frame". *Archives of Orthopaedic and Trauma Surgery* 129.9 (2009): 1197-1201.

3. Ou Y-J. "Kinematic adjustability of unilateral external fixators for fracture reduction and alignment of axial dynamization". *Journal of Biomechanics* 42.12 (2009): 1974-1980.

4. Huikes R and Chao EYS. "Guidelines for external fixation frame rigidity and stresses". *Journal of Orthopaedic Research* 4.1 (1986): 68-75.

5. Oni OOA., *et al*. "A finite element analysis of the effect of pin distribution on the rigidity of a unilateral external fixation system". *Injury* 24.8 (1993): 525-527.

6. Schell H., *et al*. "Mechanical induction of critically delayed bone healing in sheep: Radiological and biomechanical results". *Journal of Biomechanics* 41.14 (2008): 3066-3072.

7. Karnezis IA., *et al*. "Axial preload in external fixator half-pins: a preliminary mechanical study of an experimental bone anchorage system". *Clinical Biomechanics* 141 (1999): 69-73.

8. Bairaktari C., *et al*. "Towards a solution of the wires slippage problem of the Ilizarov external fixator". *European Journal of Orthopaedic Surgery and Traumatology* 25.3 (2015): 435.

9. Paley D., *et al*. "Mechanical evaluation of external fixators used in limb lengthening". *Clinical Orthopaedics and Related Research* 250 (1990): 50-57.

10. Huiskes R., *et al*. "Parametric analyses of pin-bone stresses in external fracture fixation devices". *Journal of Orthopaedic Research* 3.3 (1985): 341-349.

11. Behrens F and W J. "Unilateral external fixator methods to increase and reduce frame stiffness". *Clinical Orthopaedics and Related Research* 241 (1989): 48-56.

12. Briggs BT and EY C. "The mechanical performance of the standard Hoffmann-Vidal external fixation apparatus". *The Journal of Bone and Joint Surgery* 64.4 (1982): 566-573.

13. Lijing G., *et al*. "Artificial bone with personalised ordering and lase rapid prototyping based on CT image processing". *Image Processing* 57.10 (2015): 5620-566.

14. Ramlee MH SM., *et al*. "Biomechanical features of six design of the delta external fixator for treating Pilon fracture: a finite element study". *Medical and Biological Engineering and Computing* 56.10 (2018): 1925.

15. Ramlee MH., *et al*. "The effect of stress distribution and diplacement of open subtalar dislocation in using titatium alloy and stainless steel mitkovic external fixator- a finite element analysis". *Malaysian Journal of Fundamental and Applied Sciences* (2017): 477.

16. Ramlee MH., *et al*. "Biomechanical evaluation of two co mmonly used external fixators in the treatment of open subtalar dislocation- A finite element analysis". *Medical Engineering and Physics In press* 36.10 (2014): 1358-1366.

17. Ramlee MH., *et al*. "Three-dimensional modeling and analysis of a human ankle joint". *Institute of Electrical and Electronics Engineers* (2013): 74.

Volume 10 Issue 11 November 2019