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Design and Finite Element Analysis of a New Kirschner Wire for Fixing Bone Fractures in Orthopedic Surgery

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Keywords

Salter Harris Type 3

A New Kirschner Wire Design

Finite Element Method

Fracture

Abstract

In this study, a new Kirschner wire (K-wire) design was performed to fix bone fractures in orthopedic surgery. The numerical analyses were completed based on the finite element method (FEM), using Deform-3D software. In this kind of numerical analyses using the FEM, friction, material model, the load and boundary conditions must be defined correctly. It has been seen that the new design is more advantageous in terms of implant failure or stability of fracture fixation. In addition, a good compatibility was found between the experimental results and the finite element analysis (FEA) results. This confirmed the accuracy of the finite element model. Therefore, this finite element model can be used reliably in drilling processes. We believe that with the use of new design investigated may have the role on the patients taking away from recurrent anesthesia and orthopaedic surgical risk.

Cite

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1. INTRODUCTION

In our daily life, some injuries and bone fractures can occur in our musculoskeletal system due to any accidental trauma. These bone fractures can be treated by surgeons with conventional or surgical procedures depending on the condition of the fracture. If the treatment process of the fracture requires a surgical procedure after the bone fractures are reduced, they are fixed with plates using screws. First, bone drilling operations are performed with surgical drill bits suitable for screw sizes. During bone drilling, a heat is released due to the friction caused by the contact between the bone and the surgical drill bit. This heat causes undesirable conditions by increasing the temperature levels of the bone and surrounding soft tissues. This heat damage is known as necrosis. With necrosis, the bone remains bloodless. This situation reduces the success of implantation. The threshold value of this temperature level, which causes thermal damage, varies between 47°C and 55°C in the literature (Eriksson et al., 1984; Hillery & Shuaib, 1999; Augustin et al., 2008). The use of fluid to remove heat from the drilling site is undesirable due to the risk of infection (Hillery & Shuaib, 1999; Sezek et al., 2012).

There are existing studies in the literature. Most of these studies used surgical drill bits or K-wires and were related to temperature or necrosis caused by bone models. Some studies are concerned with optimum drilling parameters. According to Gok et al. (2015a) developed a new driller system to prevent osteonecrosis and performed optimization of drilling processing parameters of bone models (Gok et al., 2014a). Some studies have analyzed bone drilling with K-wire or surgical drill bits with FEA and compared them with experimental studies (Yuan-Kun et al., 2008; 2009; 2011; Alam et al., 2009). We can also see other studies in the literature.

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These are fatigue behaviors of schanz screws, optimization processes, biomechanical effects of different configurations of K-wires (Gok et al., 2014b; Gok, 2015, Inal et al., 2019). In this study, a new K-wire design was performed to fix bone fractures in orthopedic surgery. A new K-wire design has been applied to Salter Harris (SH) type 3 epiphyseal fracture of distal femur and performed the FEA analyses (Figure 1).

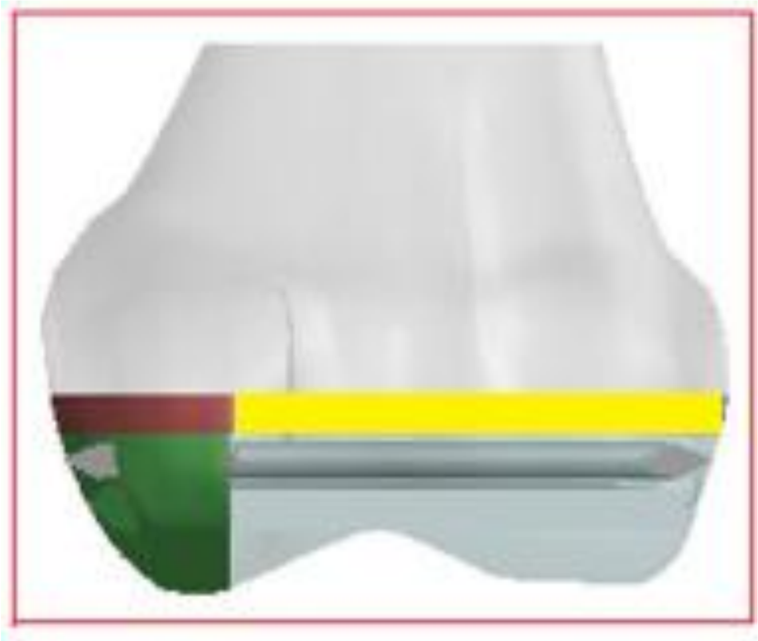


Figure 1. *K-wire with fracture model*

2. COMPUTER AIDED DESIGN AND FINITE ELEMENT ANALYSIS

In this study, three dimensional (3D) models of K-wires were created by SolidWorks and FEA analyses were performed in DEFORM-3D. The 3D models of K-wires were illustrated in Figure 2.

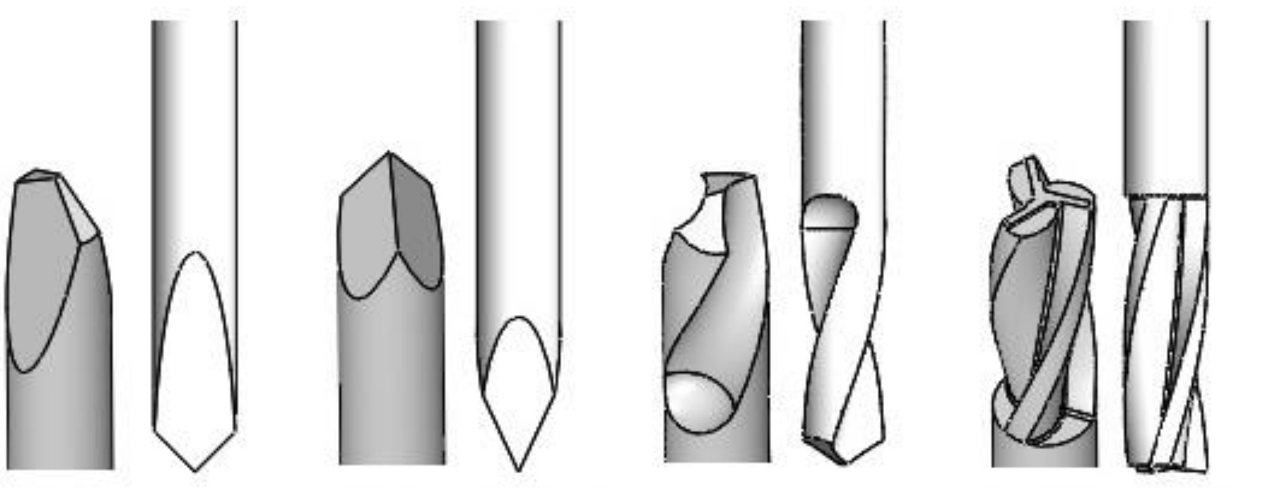


Figure 2. *The 3D models for K-wires*

2.1. Loading and Boundary Conditions

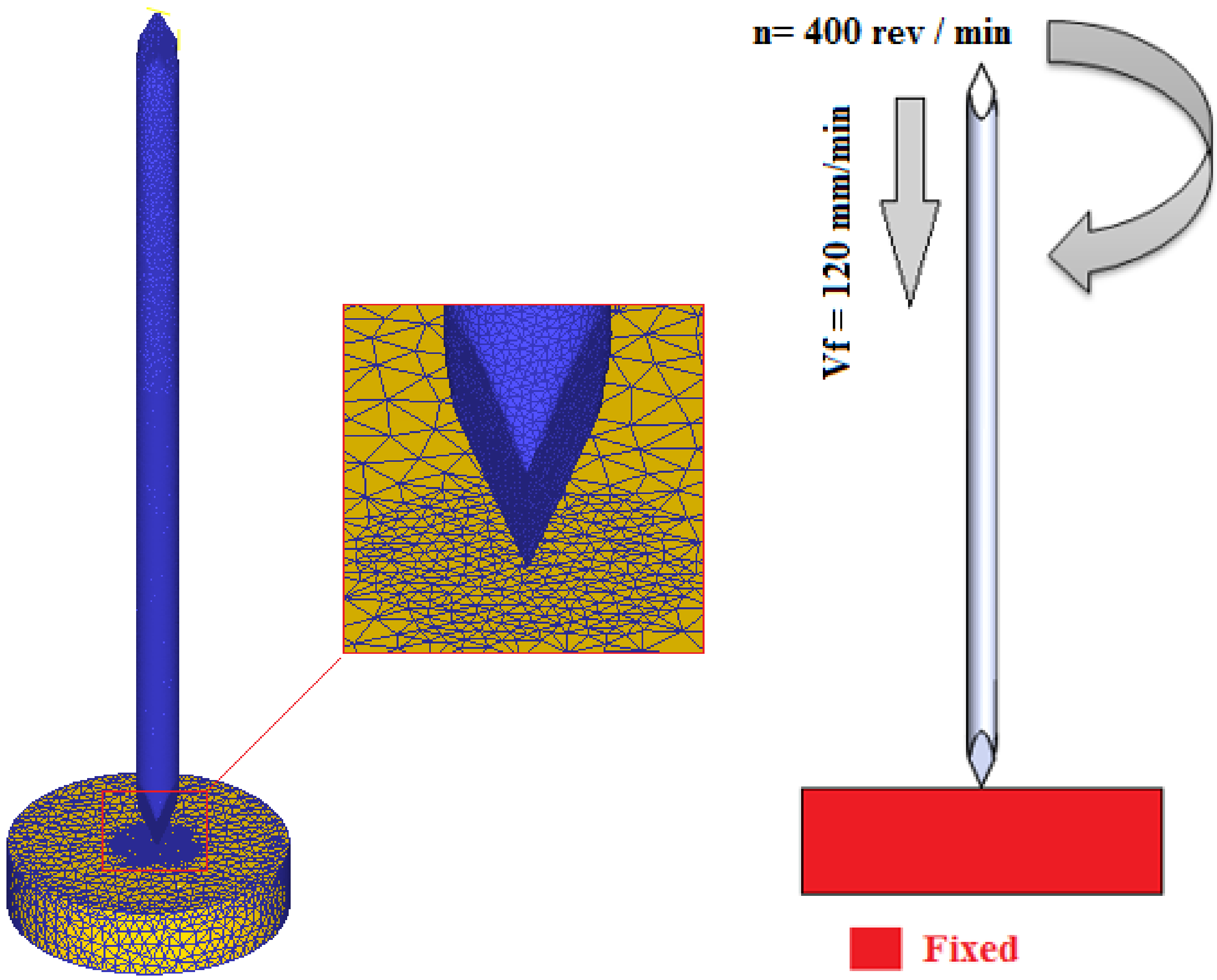
In mesh process (tetrahedral element), bone model has 21498 elements and 4853 nodes, K-wire has of 22958 elements and 5742 nodes. Boundary Conditions are illustrated in Figure 3a. The frictional contact type were defined and friction coefficient is 0.53 (Gok et al., 2015b). The bone model model was fixed from its outer surfaces. While the spindle speed was defined as 400 rpm and feed rate was set as 120 mm/min bit as seen in Figure 3b.

2.2. Material Model

While bone material properties were defined from , the stainless steel (AISI 304) was defined as K-wire from Deform-3D software (Deform_Material_Library, MatWeb, 2022). The flow stress curves McElhaney & Byars (1965) of bone models material model were given in Figure 4. The flow stress $(\bar{\sigma})$ was given in Equation (1). The effective plastic strain is $\bar{\varepsilon}$, the effective strain rate is $\dot{\bar{\varepsilon}}$, and temperature is T.

Drill bit used in orthopaedic procedures are not required to be as corrosion-resistant as implant materials, since they are not in contact with body fluids or tissues for long periods of time. It is much more important that they retain their cutting edge and withstand repeated sterilization scycles in an autoclave at temperatures of up to 135 °C (Hillery & Shuaib, 1999). However, since the K-wires stay in the fracture area throughout the fracture healing process, they must be resistant to reaction (corrosion) as a result of body fluids. Therefore, corrosion resistant and biocompatible stainless steel types are preferred.

$$\bar{\sigma} = (\bar{\varepsilon}, \dot{\bar{\varepsilon}}, T) \tag{1}$$



(a) (b)

Figure 3. *Finite element model,* ***a)*** *mesh,* ***b)*** *the boundary conditions*

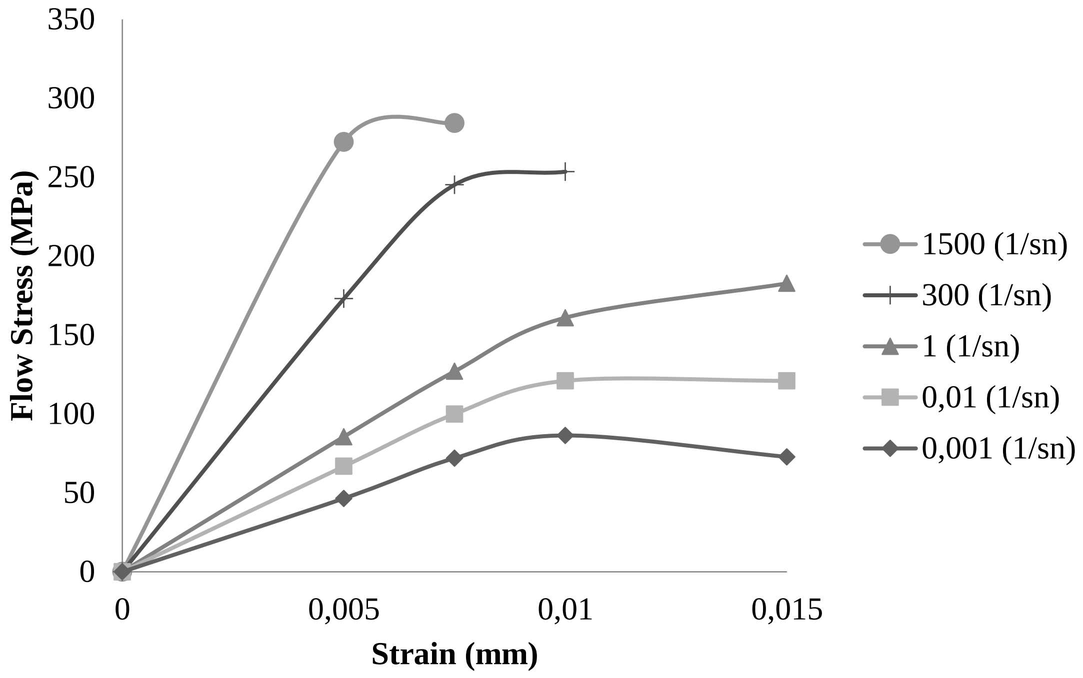


Figure 4. *Flow stress curves of bone models McElhaney & Byars (1965)*

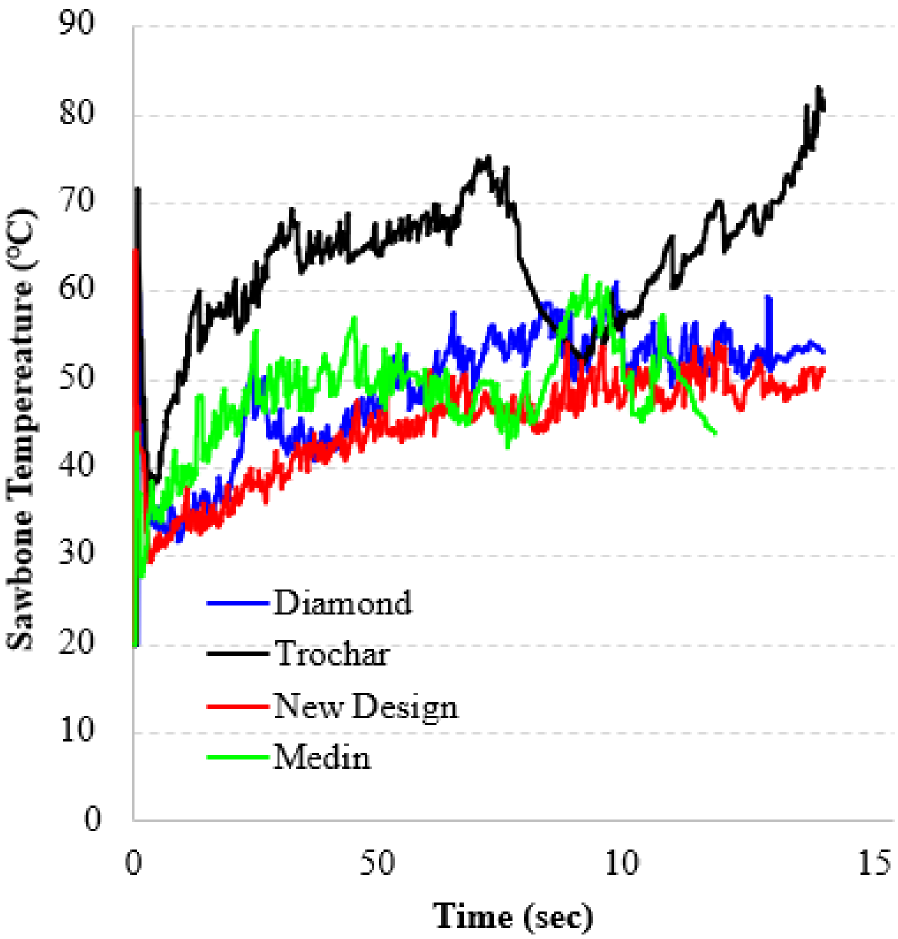
3. RESULTS AND DISCUSSION

In orthopedic bone drilling, bone temperature levels are very important in terms of bone necrosis. The threshold value of this temperature has been determined as 47°C in the literature, otherwise, if the bone temperature level exceeds this value, permanent damage may occur in the bone and surrounding tissues. As illustrated in Figure 5, we have shown that the temperature graph obtained from drilling operations using K-wire designed such as milling cutter (new design) is lower than the others. The multi-edged of the K-wire increases the performance of the drilling process. Thus, it prevents the reaching of the critical temperature value (47ºC) which causes necrosis in the bone (Eriksson et al., 1984; Hillery & Shuaib, 1999; Augustin et al., 2008). Necrosis is a result of friction between the bone and the K-wire. This situation is not desired by surgeons too much. There are several methods to prevent this temperature. One of them is to choose the optimum cutting parameters. The other is to cool the drill bit, cutting tool or K-wire internally or externally. This work concentrated on developing the new K-wire design and performed drilling simulations on bone model samples using the K-wire.

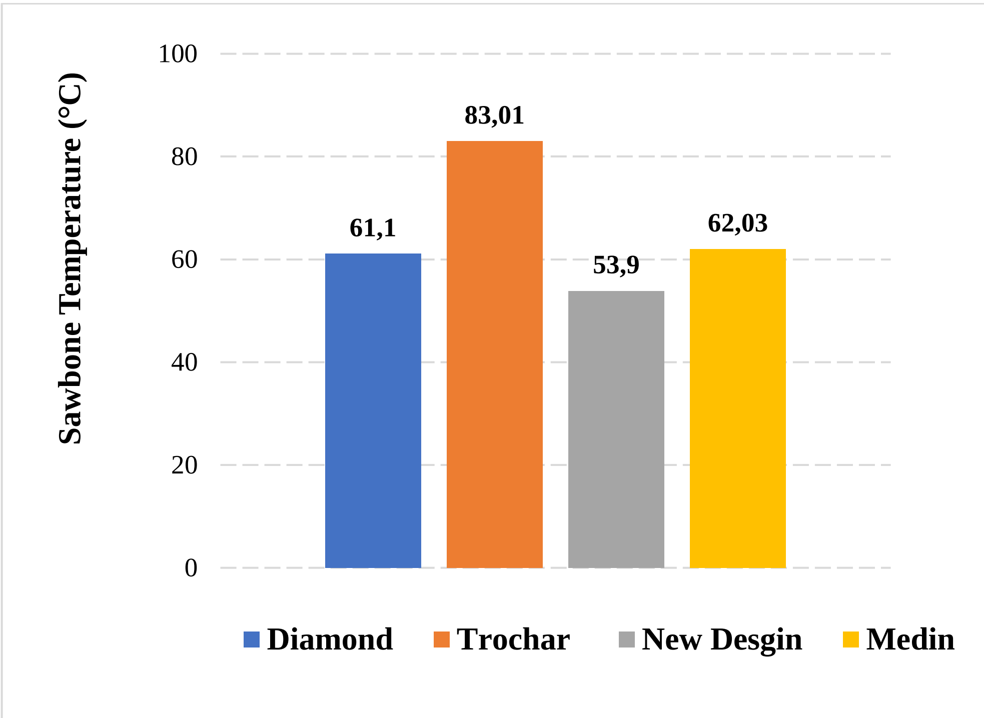
Although the biomechanical behavior of different materials used in the implants could affect the stability, the design of drill bits or K-wires is also the other determinant factor in terms of thermal necrosis. The failure of implants can lead the patients to recurrent operations, and this also increases the anesthesia induced mortality and morbidity especially in older patients (Cottrell, 2008; Pignaton et al., 2016; Blaise Pascal et al. 2021; Çömez & Demirkıran, 2021). Globally, there were 178 million new fractures in 2019, with 455 million cases of common acute or long-term fracture symptoms reported. 25.8 million of them is mentioned as “years lived with disability of fractures” Wu et al. (2021). For this reason, successful fracture management becomes more important issue as many factors are related like fixation material designs for the stability.

Tool wear and damage mechanisms are critical to machining costs. Slower wear of tool tips extends tool life and reduces service costs. In addition, it is of high importance in terms of size and dimension tolerance of the processed material. In this respect, tool life is the most common criterion in terms of cutting tool performance and material machinability Stephenson & Agapiou (2018).

As result of drilling simulations, bone model temperatures were calculated as 61.1 (diamond type), 83.01 (trochar type), 53.90 (new design), 62.03 (medin), respectively. It was also illustrated in Figure 6, tool wear values were calculated for each K-wires. The crater wear occurred in k-wire was illustrated in Figure 7.



(a)



(b)

Figure 5. *Temperature changes in bone model as a result of drilling with different K wire models,* ***a)*** *variation to time,* ***b)*** *the highest temperature*

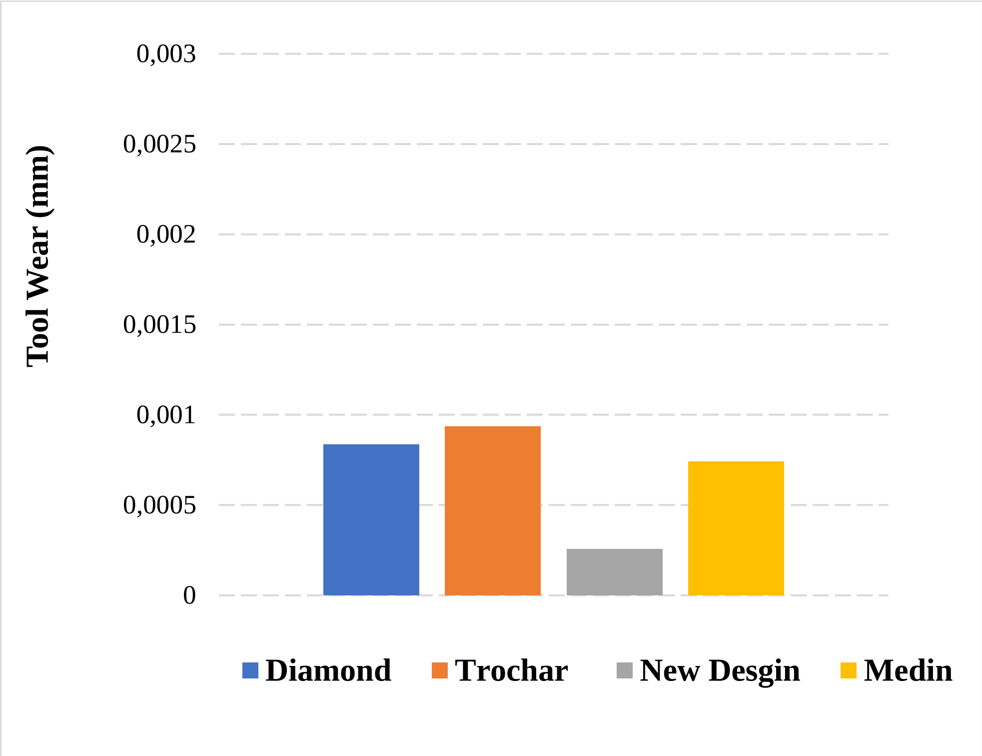


Figure 6. *The wear values occurred in K-wire*

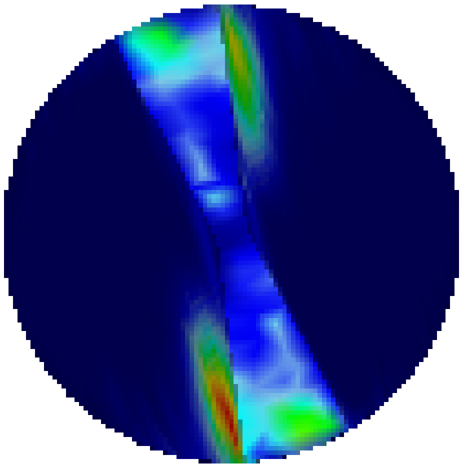


Figure 7. *The crater wear occurred in K-wire*

4.CONCLUSIONS

A new K-wire design used for stabilization after reduction of SH type 3 epiphyseal fractures of distal femur was developed and performed the FEA analyses. The results of the study indicate a significant solve for calculate to bone temperatures in drilling processes with K-wire. This model is likely to help in limiting the experiments required to determine of the bone temperatures during the drilling with K-wire. We believe that design of such implants must be investigated with more details in terms of thermal necrosis for fracture stability or others to prevent the patients from recurrent risk of anesthesia and orthopedic.

CONFLICT OF INTEREST

There is no conflict of interest

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