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Research Article

Comparison of The Two Different Patella Fracture Fixation Technique: Finite Element Analysis

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ABSTRACT

Introduction: Fractures of patella account for 1% of bone fractures and this type of injuries can lead to severe knee funciton restrictions due to its role in extansor mechanism. The most common type of fracture pattern is transverse or comminute. According to the guidelines, the most often used surgical techniques are modified tension band wiring and circumferential cercle wiring. However there is no clear information about the configuration of cerclage wiring in the tension band technique. For this purpose, a transverse fracture line was created in the patella finite element model and biomechanical comparison was made in both figure of eight and zero configurations

Material and Method: A transverse fracture line was created in patella and the k-wires were directed proximally at 90 degrees in coronal plane, perpendicular to the fracture line. A cerclage wire was wound on each finite element model in figure of zero (reference 1 model) and figure of eight (reference 2 model) configurations. These models were compared with each other in finite element model, with the knee at a 45 degree flexion angle and applying 200 Nm, 400 Nm and 800 Nm of force.

Results: When the opening amounts of reference 1 and 2 models were evaluated under 200 Nm, 400 Nm, and 800 Nm loads, it was found that there were 14%, 8%, 13% less openings in the reference 1 model, respectively. When the amount of pressure in the fracture line was evaluated under the same loads, the average pressure was 10%, 15% and 12% higher in the reference 1 model compared to the reference 2 model, respectively.

Conclusion: When the determined parameters were evaluated, although the amount of opening at the fracture line was lesser in the reference 1 model, there was no significant difference between the parameters in both models. Both fixation types allow early motion in clinical applications and help the prevention of displacement of the fracture. This paper focused on to prepare Bi_2O_3-multiwalled carbon nanotube (MWCNT) nanocomposites electrodes for supercapacitor applications with high mass loading. Nature inspired dispersing agent Celestine blue (CB), different adsorption mechanism in different materials, dispersed MWCNT and Bi_2O_3 and allowed to prepare homogenous electrode with high mass loading on a porous NiFoam current collector. The areal capacitance of 555 mF cm^{-2} was obtained from the composite electrode with 25 mg cm^{-2} active mass loading in 1M Na_2SO_4 electrolyte. Bi_2O_3/MWCNT/CB composited electrode testing results showed promising results for supercapacitor applications.

1. Introduction

Patellar fractures are infrequent, representing 1% of all fractures [1]. Despite the low incidence of this type of injury, the consequences of inadequate treatment of patellar fracture is potentially disabling, with possible development of stiffness, loss of range of motion and osteoarthritis. Indications for surgical treatment are transverse or comminuted fractures with a displacement greater than 4 mm and/or with articular step-off greater than 2 mm as well as interruptions of the extansor mechanism [2]. So, it is mostly a type of fracture that requires rigid fixation and early movement, as it plays a key role in the extansor mechanism and associated with articular surface [3]. In the literature, 10-20% displacement has been reported between the fracture parts in the modified tension band technique, which is frequently used in transvers patella fracture surgery [4, 5]. Moreover, the rates of nonunion and reoperation in these fractures are substantial [5].

In the modified tension band method used in transverse patella fracture, the distracting forces applied by the extansor mechanism are converted into compressive forces, so that the fracture ends are not displaced. In this method, cerclage wire wrapped in eight shape over k-wires which were sent at an angle of 900 to the transverse fracture are used [6]. There is literature support that k-wires passing closer to the articular surface in the sagittal plane are more stable [7]. However, there is no clear information about cerclage wire configuration.

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In this study, a transverse simple patella fracture was created and a finite element model was build up aiming to reveal the biomechanical differences between the fracture fixed with k-wires perpendicular to the transverse facture line, with both cerclage wire configuration of figure of eight and figure of zero.

2. Method and Finite Element Modelling

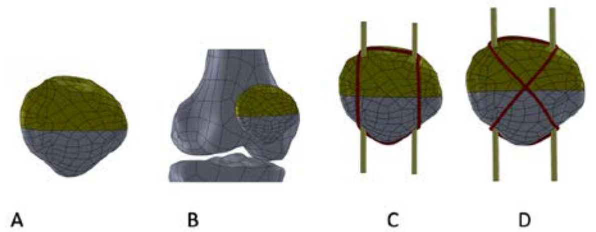
The patella geometry used in this study was obtained from computed tomography (CT) images of a 35 years old, 75 kg, healthy male because one of the most important issues for finite element analysis to give accurate results is to create correct geometry. CT images obtained by scanning at 135 kw with a apixel size of 0.255 mm and a resultion of 512x512 pixels. CT images of the patient with no previous history of surgery, trauma, osteoporosis or chromic disease were used.

Creation of the 3D model

Thin-section CT images of the patient's lower extremities and knee region were sent to MIMICS ® 12.11 (Materialize's Interactive Medical Image Control System / Materialize NV, Belgium) program in DICOM format. After the patella geometry was created in the MIMICS program, the model was converted to stereolithography (STL) format and transfered to the Geomagic Studio ® (3D Systems Inc., NC, USA) program to remove unwanted artifacts. More detailed 3D solid models were obtained with the Geomagic Studio program, which is a reverse engineering software. The resulting 3D model was transferred to SolidWorks ® (Dassault Systemes, Waltham, MA, USA) for fracture line and k-wire implantation.

A virtual transverse fracture without gap was created in the midline of the patella (AO/OTA 34-C1 classification) in SolidWorks program. First of all, k-wire of 2 mm diameter used in standard surgery was sent on the model, and then two different tension band techniques were applied to the model (Figure 1).

Figure 1: Creation of FEA model(a:AO/OTA 34C1 Fracture model, B: Finite element model, C:reference 1 model, D: reference 2 model)



Obtained models were transferred to ANSYS Workbench (v.2021; Swanson Analysis, Houston, Pennsylvania, USA) program for finite element analysis. All bone, k-wire and cerclage wires were considered homogeneous, isotropic and linear elastic. Material properties are shown in Table 1 [8-10].

Table 1: Material parameters of finite element models

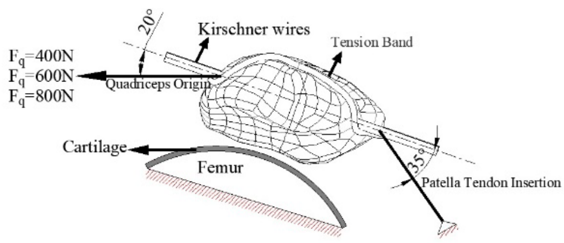
Table 1 Material parameters of finite element models		
Material Name	Elasticity modulus （MPa）	Poisson's ratio
Patella	16300	0.30
K-wire	200000	0,3

Mesh Generation

In this study, mesh convergence was achieved by adjusting the mesh size from 3 mm to 5 mm with 0.5 mm intervals for the patella and from 1 mm to 0.5 mm with 0.25 mm intervals for k-wire for mesh convergence. Appiled additional mesh improvement at the fracture line contact areas has been made. For optimum results, the most suitable element sizes were determined as 1 mm fort he patella and 0.5 mm for the k-wire.

According to the 45^0 flexion condition of the non-weight bearing knee, the force applied by the quadriceps tendon made with ana angle of 20^0 with the horizontal and a aforce of 200 N, 400 N and 800 N was applied [11-14]. The patellar tendon, on the other hand, was timulated to make. An angle of 35 with the horizontal and fixation was applied from the side of the patella (Figure 2). The same boundary conditions are applied in these two models. In addition, in the analysis, a contact definiton was made between the two materials at the fracture line and on the contact surfaces. A friction coefficient of 0.45 for bone-bone contact, 0.3 for bone to metal, and 0.3 for metal to metal contact has been defined [15, 16]. Under all these loads, the amount of displacement at the fracture line, the average amount of pressure and the Von Miss stress on the implants were calculated.

Figure 2: Boundary Conditions



Celestine blue (CB), Bismuth (III) Nitrate, citric acid (CA), nitric acid, potassium hydroxide (KOH), poly(vinyl butyral-co-vinyl alcohol-co-vinyl acetate) (PVB, average Mw = 50,000–80,000) and MWCNT (inner and outer diameter 6 and 13 nm) were purchased from Sigma Aldrich. As a current collector, Ni foam was used with 95% porosity provided by Vale Limited Company.

The synthesis of Bi_2O_3 particles were prepared as follows. Firstly, 0.97 g Bismuth (III) nitrate and 0.13 g citric acid were dissolved in 40 ml of nitric acid (1M). Then, potassium hydroxide solution (KOH, 8M) added dropwise until the pH value was 6. After 10 min well mixing, the solution was transferred into a Teflon-lined stainless-steel autoclave to

3. Results

A total of 6 scenarios were available for finite element model analysis using different cerclage wiring modifications in standart k-wire fixation, with different force applied to the fracture line. In each scenario, wire tension, cerclage tension and both tensions were measured (Table 2).

Also in total 6 scenarios, surface pressure at fracture site and widening at the fracture site measured (Table 3).

Table 2: Tensions in different force applied(Mpa: megapascal, Kn: kilonewton)

	200 Kn Maximum Tension(Mpa)			400 Kn Maximum Tension(Mpa)			800 Kn Maximum Tension(Mpa)		
	Wire	**Cerclage**	**Both**	**Wire**	**Cerclage**	**Both**	**Wire**	**Cerclage**	**Both**
Figure of Zero	246,75	96,633	246,75	406,02	72,712	0,24081	558,58	690,66	690,66
Figure of Eight	275,98	203,69	275,98	501,35	84,126	0,26404	790,14	1137	1137

Table 3: Surface Pressure at Fracture and Widening at the Fracture Line (Mpa: megapascal, mm: milimetres)

	200 Kn		400 Kn		800 Kn	
	Surface Pressure at Fracture(Mpa)	**Widening at the Fracture Line(mm)**	**Surface Pressure at fracture(Mpa)**	**Widening at the Fracture Line(mm)**	**Surface Pressure at fracture(Mpa)**	**Widening at the Fracture Line(mm)**
Figure of Zero	40,897	0,13107	72,712	0,24081	125,48	0,35222
Figure of Eight	44,073	0,15118	84,126	0,26404	159,85	0,45212

When the opening amounts of reference 1 and 2 models were evaluated under 200 Nm, 400 Nm, and 800 Nm loads, it was found that there were 14%, 8%,13% less openings in the reference 1 model, respectively. When the amount of pressure in the fracture line was evaluated under the same loads, the average pressure was 10%, 15% and 12% higher in the reference 1 model compared to the reference 2 model, respectively. When the stress on both implants was evaluated under the same loads, 11%, 19% and 47% of the reference 1 models were more stressed than the reference 2 models, respectively. (Figure 3 and 4).

Figure 3: Surface Pressure

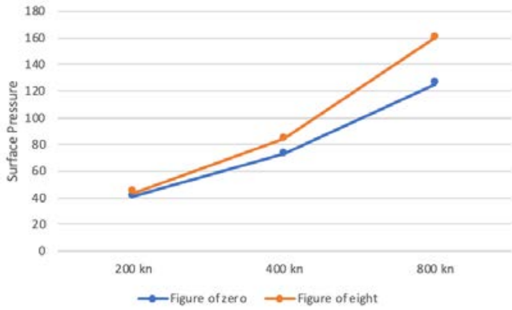
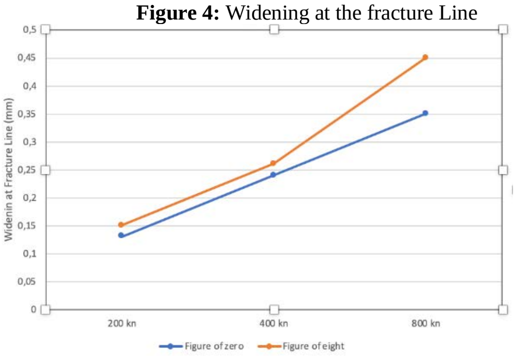


Figure 4: Widening at the fracture Line



4. Discussion

Patella is the largest sesamoid bone in human body, and is located between the quadriceps tendon and the patellar tendon. The quadriceps muscle consists of four muscles, and when the tendon of this muscle is examined, its deep layer attaches to the proximal base of patella, while the superficial fibers extend continously over the patella to the tibial tuberosity. Considering the forces acting on the patella, the vastus medialis and vastus laterealis act as oblique vectors, pulling patella proximally together with the rectus tendon, and the patellar tendon fixes the patella distally. The articular surface of the patella articulates with the femoral condyles, creating a frictional force. The main purpose of the patella in this system is the connection and the displacement of these forces (17). During flexion, it primarily acts as a lik between the quadriceps muscle and the proximal tibia. As knee moves into full extension, the patella moves the connection between the quadriceps and tibia away from the knee rotation axis, increasing the effective leverage of the quadriceps. Biomechanical studies have shown that this increases the quadriceps lever arm in full extension by up to 30%. In 450 flexion, the proximal part of the patella that covered with a thick layer of cartilage must withstand the greatest pressure (18).

Under this biomechanical framework, the management of patella fractures is of great importance. The most important consequence of a patellar fracture is the distruption of the extansor mechanism of the knee joint, resuting in insufficient active knee extension. In addition, if good joint reduction is not performed in these fracutres, it can lead to patellofemoral joint osteoarthritis. So, main goals of treatment have to aim for anatoic reduction as well as the maintanace of extansor mechanism for early rehabilitation.

In the light of this content, every unstable fracture of patella requires surgery. From a biomechanical point of wiew, surgical procedure aims to neurtalize the tension forces applied to the patella via extansor mechanism amd convert them into compression forces. According to AO principles, the most common used technique is modified tension band technique (19). In this technique, two k-wires are placed perpendicular to the fracture line and a tension band applied to secure the reduction. But figure of eight shaped cerclage wiring has higher risk of soft tissue irritation due to prominence of the metallic hardware (20).

When the literature is reviewed to evaluate complications, the most common complication after patellar fracture is decreased range of motion which is mostly caused by prolonged immobilizastion and improper rehabilitation (21). Also, loss of reduction occurs up to 20% (22). Only k-wire fixation without tension band correlates with higher failure rates. This study also explains the importance of the cerclage wire (23). If the fragments seperate more than 3 mm from each other indicates revision surgery (24).

Prominent and symptomatic implants as a result of breakage or soft tissue irritation result in hardware removal in 37% of patients (25). More attention to detail in performing tension band wiring may reduce the number of symptomatic hardware, as most of the soft tissue irritation comes from broken tension bands or bulky wire knots.

In this study, which was designed with this information, was tried to answer the question of whether there will be a difference between cerclage wire configuration and the widening at the fracture line and the fracture surface pressure. Changing configuration may help to reduce the complications, with early movemet and increased union rates. There is no biomechanic difference between figure of eight and figure of zero configuration. Both configurations can be used in the clinical practice.

5. Conclusion

Both fixation types allow early motion in clinical applications and help the prevention of displacement of the fracture. Figure of zero configuration may help to reduce complications.

Declaration of conflicting interests

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