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Comparison of non-compression and compression interlocking intramedullary nailing in rabbit femoral shaft osteotomy model

Tavşan femur cisim osteotomisi modelinde kompresyonsuz ve kompresyonlu kilitli intramedüller çivilemenin karşılaştırılması

Mehmet Emre Baki, MD.,[1] Cengiz Aldemir, MD.,[2] Fatih Duygun, MD.,[2] Ali Doğan, MD.,[2] Gökçen Kerimoğlu, MD.[3]

[1]Department of Orthopedics and Traumatology, Medical Faculty of Karadeniz Technical University, Trabzon Turkey
[2]Department of Orthopedics and Traumatology, Antalya Training and Research Hospital, Antalya, Turkey
[3]Department of Histology and Embryology, Medical Faculty of Karadeniz Technical University, Trabzon Turkey

ABSTRACT

Objectives: This study aims to compare non-compression and compression intramedullary nailing in an experimental femoral shaft osteotomy model in terms of radiological, histological, and biomechanical aspects.

Materials and methods: Twenty-four white New Zealand rabbits (average weight 4.3 kg; range 4 to 4.8 kg) were divided into three groups. A right femoral osteotomy was performed in all rabbits and all femurs were fixed with titanium compression interlocking intramedullary nail. After locking of nails, no compression was performed in group 1 while 0.5 mm and 1 mm compressions were performed in group 2 and 3, respectively. All rabbits were sacrificed four weeks after operation. Fracture sites were examined histologically and radiologically. Finite element analyses were performed.

Results: Radiological scores of groups 2 and 3 were significantly higher than group 1. There was no significant difference between groups 2 and 3 radiologically. Best histological scores were achieved in group 2. According to finite element analyses, osteotomy site in group 2 was exposed to 1240 N of load and 34.5 MPa of mean stress.

Conclusion: Compression interlocking intramedullary nailing provides faster fracture healing than non-compression interlocking intramedullary nailing. Best histological fracture healing scores were obtained with 0.5 mm compression performed at the fracture site.

Keywords: Femoral fracture; finite element analysis; intramedullary nail.

ÖZ

Amaç: Bu çalışmada deneysel femur cisim osteotomisi modelinde kompresyonsuz ve kompresyonlu intramedüller çivileme radyolojik, histopatolojik ve biyomekanik açıdan karşılaştırıldı.

Gereç ve yöntemler: Yirmi dört beyaz Yeni Zelanda tavşanı (ort. ağırlık 4.3 kg; dağılım 4-4.8 kg) üç gruba ayrıldı. Bütün tavşanlara sağ femur osteotomisi uygulandı ve tüm femurlar titanyum kompresyonlu kilitli intramedüller çivi ile tespit edildi. Çivilerin kilitlenmesinden sonra grup 1'e kompresyon uygulanmazken grup 2 ve 3'e sırasıyla 0.5 mm ve 1 mm kompresyon uygulandı. Cerrahiden dört hafta sonra bütün tavşanlar sakrifiye edildi. Kırık bölgesi histolojik ve radyolojik olarak incelendi. Sonlu eleman analizleri uygulandı.

Bulgular: Grup 2 ve 3'ün radyolojik skorları grup 1'e kıyasla anlamlı derecede daha yüksekti. Grup 2 ve 3 arasında radyolojik olarak anlamlı farklılık yoktu. En iyi histolojik skorlar grup 2'de elde edildi. Sonlu eleman analizlerine göre grup 2'de osteotomi bölgesi 1240 N yüke ve 34.5 MPa ortalama basınca maruz kalmıştı.

Sonuç: Kompresyonlu kilitli intramedüller çivileme, kompresyonsuz kilitli intramedüller çivilemeden daha hızlı kırık iyileşmesi sağladı. Histolojik olarak en iyi kırık iyileşmesi skorları kırık bölgesine uygulanan 0.5 mm kompresyon ile elde edildi.

Anahtar sözcükler: Femur kırığı; sonlu eleman analizi; intramedüller çivi.

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- Correspondence: Mehmet Emre Baki, MD. Karadeniz Teknik Üniversitesi Tıp Fakültesi Ortopedi ve Travmatoloji Anabilim Dalı, 61080 Trabzon, Turkey. Tel: +90 462 - 377 56 60 e-mail: bakiemre61@yahoo.com

Intramedullary nailing (IMN) is a surgical method of treating long bone fractures. The function of IMN is to stabilize the fracture fragments and to transfer load across the fracture site while maintaining the anatomical integrity of the bone.[1] High rates of fracture union, low complication rates, and excellent return of limb function make this technique the gold standard treatment of femoral shaft fractures.[2,3]

Interlocking compression nails (ICNs) generate interfragmentary compression at the fracture site. Active compression at the fracture site can enhance fracture healing by minimizing the fracture gap by forcing the bone fragments against each other.[4,5] These devices also provide more axial and torsional stability in transverse or oblique fractures, where fragments have sufficient cortical contact.[6] Therefore, ICN is not only suitable for the treatment of acute fractures but also for orthopedic procedures such as corrective osteotomies, arthrodesis, and pseudoarthrosis treatment.[7]

In this study, we aimed to compare non-compression and compression IMN in an experimental femoral shaft osteotomy model in terms of radiological, histological, and biomechanical aspects.

MATERIALS AND METHODS

The study was conducted at the Karadeniz Technical University Faculty of Medicine Department of Orthopaedics and Traumatology between September 2015 and November 2015 and included a total of 24 skeletally mature white New Zealand rabbits (average weight 4.3 kg; range 4 to 4.8 kg). The study protocol was approved by the Karadeniz Technical University Animal Ethics Committee. The study was conducted in accordance with the principles of the Declaration of Helsinki. All rabbits were placed individually in cages where they could access water and food, and then quarantined for 14 days under the supervision of a veterinarian. Rabbits were randomly divided into three groups (groups 1, 2, and 3), each consisting of eight rabbits.

Anteroposterior (AP) and lateral radiographs of a rabbit femur were provided. The length and intramedullary width of the femur were measured for designing the intramedullary nail.

Surgical technique

The rabbits were anesthetized by intramuscular injection of 40 mg/kg ketamine and 5 mg/kg xylazine. The right leg of the rabbit was shaved and prepared with povidone-iodine solution. A longitudinal skin incision was made on the lateral aspect of the middle third of the femur across the greater trochanter. The muscles were bluntly dissected, and the diaphysis of the femur was exposed. A femoral osteotomy was performed with an oscillating saw at 4 cm below the tip of the greater trochanter. Later, the femur was reamed retrogradely with a wire and the proximal entrance point of the nail was prepared. A custom-made titanium ICN (Hipokrat, İzmir, Turkey; Figure 1) for a rabbit femur was applied to the osteotomized femur. This nail allows 0.5 and 1 mm compression to the fracture site by using an external proximal compression device. Distal locking was performed according to the bone alignment technique described by Aldemir et al.[8]

After the placement of proximal and distal locking Kirschner wires (K-wire), the ICN was locked without compression in group 1, locked with application of 0.5 mm compression to the fracture site in group 2, and locked with application of 1 mm compression to the fracture site in group 3. The osteotomy site was washed with sterile saline solution, and the skin was closed with 3-0 polyglycolide suture. The wound was cleaned with povidone-iodine solution and a single dose of a first-generation cephalosporin (Cefamezin 50 mg/kg) was administered intramuscularly. All rabbits were permitted unrestricted weight bearing as soon as they recovered from anesthesia. Rabbits were allowed to move freely in their cages for four weeks. At four weeks after operation, all rabbits were sacrificed and the right femurs were excised.

Radiological examination

Anteroposterior and lateral radiographs of the right femurs were acquired after the excision of the femurs. Two independent observers rated the radiographs according to the Lane-Sandhu[9] scoring system. Accordingly, fracture healing was assessed as four different stages as follows: grade 0, no healing; grade 1, callus formation; grade 2, beginning of bone union; grade 3, beginning of the disappearance of the fracture line; and grade 4, complete bone union.

Histological examination

After the completion of the conventional radiological assessment and excision of the intramedullary nails, the femurs were fixed in

Figure 1. Compression interlocking intramedullary nail.

TABLE I

Material properties

Material	Young's modulus (GPa)	Poisson's ratio
Cortical bone	20	0.15
Titanium alloy	96	0.36
Kirschner wire	200	0.30

10% buffered formalin solution for 24 hours. On the next day, soft tissues were removed without damaging the callus. After decalcification with 10% formic acid solution, the samples were embedded in paraffin blocks and cut in slices of 5 microns by using a microtome. Specimens were stained with hematoxylin-eosin and Safranin O fast green. Each sample was examined blindly by a histologist under a light microscope. The degree of fracture healing was graded according to Huo et al.[10]

Finite element analyses

Finite element (FE) modelling and analyses were performed by using ANSYS® 16.2 (NASDAQ: ANSS). The entire right femur of a rabbit was scanned with 1 mm slice thickness by using computed tomography for developing a three-dimensional model. The FE model of bone, ICN, and K-wires were constructed. The material properties assigned to the bone, titanium ICN, and K-wire were summarized in Table I.

A femoral osteotomy was simulated at 40 mm below the tip of the greater trochanter. Finite element analyses were performed under 0.5 and 1 mm compressions to the fracture site. The FE model presented in this study was used as a quantitative tool for understanding the stress and pressure distributions on the cortical bone at the fracture site.

Statistical analysis

Statistical analyses were performed using the IBM SPSS Statistics version 22.0 software (IBM Corp., Armonk, NY, USA). Percentage, average, and standard deviation were used as descriptive statistics. The compliance of the quantitative data with normal distribution was evaluated by using the Kruskal-Wallis test. The parametric circumstance bearing data was compared with Student's t test. The non-parametric circumstance bearing data were compared with the Mann-Whitney U test. *P* values of <0.05 were considered statistically significant.

RESULTS

At the surgery phase, proximal femoral fracture occurred in three rabbits during the implementation of the ICN. These rabbits were excluded from the study. Three new rabbits were added to the groups. Neither infection at the surgery site nor implant failure was detected. All rabbits survived the study period.

TABLE II

The radiological scores of the samples according to Lane-Sandhu scoring system

Rabbit number	Group 1	Group 2	Group 3
1	1	2	3
2	1	3	3
3	2	3	4
4	2	4	2
5	1	2	2
6	2	3	3
7	2	3	3
8	3	3	2
Mean value	1.75	2.87	2.75

Assessment scores of AP and lateral radiographs at four weeks after surgery are presented in Table II. The mean radiological scores were 1.75 points in group 1, 2.87 points in group 2, and 2.75 points in group 3 (Figure 2). The radiological scores in groups 2 ($p=0.009$) and 3 ($p=0.019$) were statistically significantly higher compared with those in group 1. No statistically significant difference was detected between groups 2 and 3 ($p=0.68$).

The mean histological fracture healing scores were 5.37 in group 1, 7.87 in group 2, and 6.62 in group 3 (Table III, Figure 3). Groups 2 and 3 had statistically

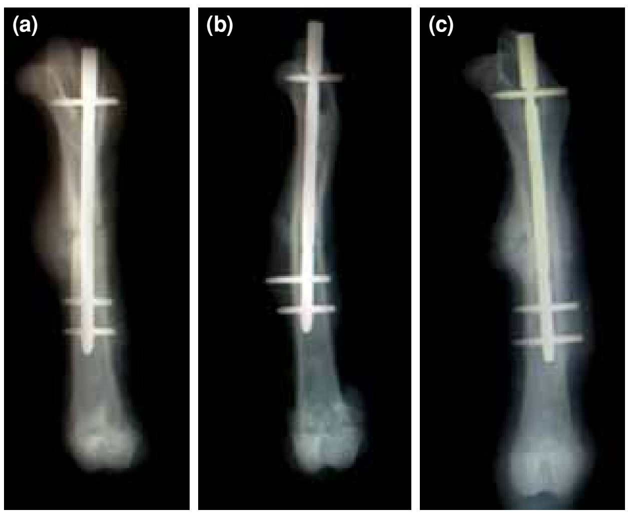

Figure 2. Anteroposterior radiographs of femurs four weeks after surgery. Groups **(a)** 1, **(b)** 2, and **(c)** 3.

TABLE III
The histological scores of the samples according to Huo et al.[10]

Rabbit number	Group 1	Group 2	Group 3
1	5	7	6
2	5	8	7
3	5	8	7
4	6	7	6
5	5	9	8
6	6	8	6
7	6	8	7
8	5	8	6
Mean value	5.37	7.87	6.62

significantly higher histological scores (p=0.001 and p=0.004, respectively) than group 1. Group 2 also had statistically significantly higher histological scores than group 3 (p=0.007).

The stress distributions at the osteotomy site for 0.5 and 1 mm compressions of ICN were calculated separately by using the FE model. The cortical bone at the osteotomy site remained under a 1240 N compressive load, and the mean stress value was 34.5 MPa when 0.5 mm compression was performed. Cortical bone remained under a 3166 N compressive load, and the mean stress value was 88 MPa when 1 mm compression was performed to the fracture site (Figure 4).

DISCUSSION

Intramedullary nailing is an osteosynthesis technique that has become the most preferred treatment for diaphyseal fractures of the long bones. In general, IMN provides high union rates and low complication rates.[1,2] Modern interlocking techniques maintain the length and rotational alignment of the bone.[3,11] The use of ICN in the treatment of long bone fractures combines the advantages of IMN (minimal invasive application and early weight bearing) with the compression feature of plate fixation.[11,12]

In comparison to traditional static IMN, ICN significantly increases the stability of the fracture site in biomechanical studies and simultaneously reduces the rotation of the fracture site by increasing the contact pressure at the fracture ends.[5,6] Therefore, ICN is an appropriate device for the treatment of acute fractures, pseudoarthrosis, arthrodesis, and corrective osteotomies, where fragments have sufficient cortical contact.[7,11,13,14] For achieving a sufficient cortical contact, we performed a smooth femoral osteotomy by using an oscillating saw.

Appropriate axial loading has been shown to significantly increase the osteogenic response and lead to earlier and stronger callus formation.[15-17] Episodic stresses that affect fracture sites were found to have positive effects on revascularization and tissue differentiation phases of fracture healing.[18,19] On the other hand, high levels of unrestrained compression may cause bone resorption and osteonecrosis at the fracture or osteotomy site.[20] Even though various experimental studies have investigated the effect of compression on fracture healing, to the best of our knowledge, this is the first study that compares compression and non-compression IMN in an animal experimental osteotomy model.

The results of this comparison demonstrated that in the ICN groups (groups 2 and 3), the level of fracture healing was significantly better than in the non-compression IMN group (group 1) according to both histological and radiological assessments at the end of four weeks. These data were consistent with the literature that details the beneficial effects of compression on fracture healing.

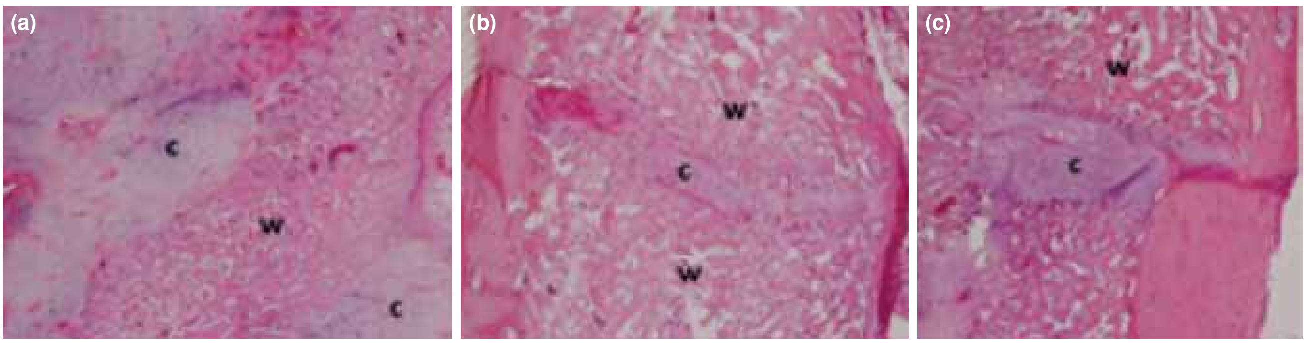

Figure 3. Histological appearance of fracture site (H-E x 40). **(a)** Domination of cartilage tissue (c) and some woven bone (w) in group 1. **(b)** Domination of woven bone (w) and lesser cartilage tissue (c) in group 2. **(c)** Equal amounts of cartilage tissue (c) and woven bone (w) in group 3.

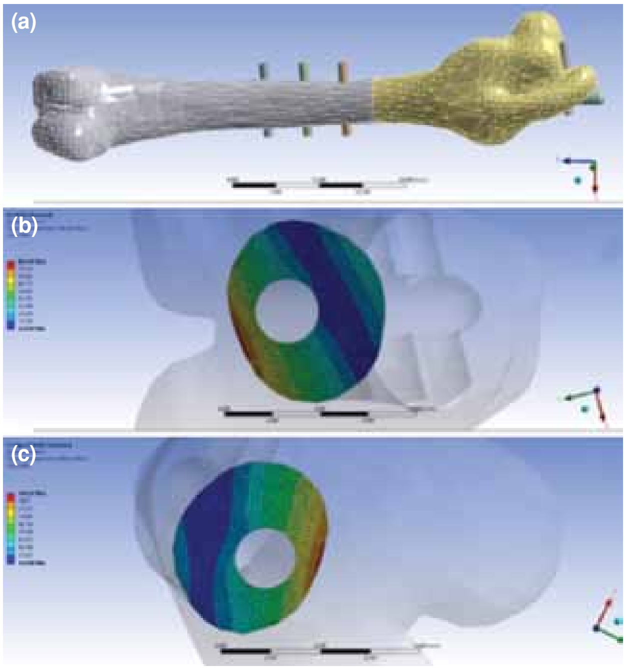

Figure 4. (a) Finite element model of rabbit femur. **(b)** Stresses on fracture site under 0.5 mm compression. **(c)** Stresses on fracture site under 1 mm compression.

Only a few clinical studies have compared compression and non-compression nailing in long bones.[21,22] The results of these studies showed that additional compression provides improved healing outcomes with less rate of non-union in transverse and oblique tibial shaft fractures.[21,22] The intended amount of compression can be achieved with ICN additive to the body weight in loaded state of walking. Active compression resists distraction forces in the unloaded state. Therefore, the fracture site will always have a baseline level of compression.[7,11] The optimal number of loading parameters to accelerate fracture healing has not been exactly defined yet. Thus, our secondary objective was to evaluate the difference between two alternative amounts of compression in terms of fracture healing.

Two different compression levels at the osteotomy site (0.5 mm and 1 mm) were simulated with the FE model. Under a 1240 N compressive load and a mean stress value of 34.5 MPa, the level of fracture healing was significantly better than a 3166 N compressive load and a mean stress value of 88 MPa according to histological scoring. These data can be explained as high levels of unrestrained compression may cause bone resorption at the fracture site. However, no significant difference was found between the radiological scores of two compression groups.

The present study has some limitations. First, more compression values could be used for ICN, but this would increase the number of rabbits. Second, micro computed tomography would have been more appropriate than plain radiography for assessing the bone architecture at the fracture site.

In conclusion, compression interlocking intramedullary nailing provides faster fracture healing than non-compression interlocking intramedullary nailing. A 0.5 mm compression at the fracture site provides the best histological fracture healing scores. Moreover, 0.5 mm compression at the fracture site provides better outcome in terms of histological healing than 1 mm compression.

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Declaration of conflicting interests

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