Kafkas Univ Vet Fak Derg
19 (Suppl-A): A49-A53, 2013
DOI: 10.9775/kvfd.2012.7691

JOURNAL HOME-PAGE: http://vetdergi.kafkas.edu.tr
ONLINE SUBMISSION: http://vetdergikafkas.org

RESEARCH ARTICLE

Evaluation of the Effects of Holes of Various Sizes on Fracture Rates in Sheep Femurs

Ercan OLCAY [1] Ertuğrul ALLAHVERDİ [2] Turgut GÜLMEZ [3]
Dilek OLGUN ERDİKMEN [4] Celal Şahin ERMUTLU [5] Zihni MUTLU [4]

[1] Department of Orthopaedic Surgery, Faculty of Medicine, Kafkas University, TR-36100 Kars - TURKEY
[2] Department of Orthopaedic Surgery, Kars State Hospital, TR-36100 Kars - TURKEY
[3] Department of Mechanical Engineering, Faculty of Engineering, İstanbul Technical University, TR-34437 İstanbul - TURKEY
[4] Department of Surgery, Faculty of Veterinary Medicine, İstanbul University, TR-34320 İstanbul - TURKEY
[5] Department of Surgery, Faculty of Veterinary Medicine, Kafkas University, TR-36100 Kars - TURKEY

Makale Kodu (Article Code): KVFD-2012-7691

Summary

Defects in long bones are known to lead to increased risk of pathologic fracture. Holes weaken bones and increase the risk of fracture during bending, especially on exposure to torsional forces. Here, we investigated the effect of holes of varying numbers and sizes drilled into sheep femur bones on the resistance of the bone to torsional forces. Ninety-six fresh sheep femur bones were allocated to 8 groups, which were further subdivided into 4 groups of 3 bones each. In each group, 1 to 4 holes ranging from 2 to 5.5 mm were drilled into the femurs, and the bones were subjected to a rotation test. Forces that caused fractures and the force curves were measured and recorded. The effect of the number and size of the holes drilled in the femurs on the occurrence of fractures was compared using two-way analysis of variance, and Tukey's multiple comparison test was used for multiple comparisons. $P<0.05$ was considered statistically significant. We found that the resistance of a bone to torsional forces decreased significantly with increase in the number and size of the drilled holes ($P<0.001$). The rate of fractures increased as the number and sizes of the holes increased. The resistance of the bones to torsional forces decreased as the number of holes increased. We showed that the size of a defect in a bone is extremely important for torsional resistance and is, in fact, more important than the number of defects.

Keywords: *Fracture, Rotational forces, Bone, Femur, Sheep*

Koyun Femurlarında Çeşitli Boyutlardaki Deliklerin Kırık Oranları Üzerine Etkilerinin Değerlendirilmesi

Özet

Uzun kemiklerdeki defektlerin patolojik kırığa neden olduğu bilinmektedir. Delikler özellikle torsiyonel güçlere maruz kalınca bükülme esnasında kemiği zayıflatır ve kırık riskini artırır. Buradaki çalışmamızda biz koyun femur kemiklerinde drille delinmiş çeşitli sayı ve boyutlardaki deliklerin etkilerini araştırdık. 96 tane taze koyun kemiği her biri ilaveten 3 kemiği içeren 4'lü alt gruplara bölünerek 8 gruba ayrıldı. Her bir grubta 2 mm'den 5.5 mm'ye kadar değişen 1'den 4'e kadar delikler femurlar delinerek açıldı ve kemikler rotasyon testine tabi tutuldular. Kırığa neden olan kuvvetler ve kuvvet eğrileri ölçüldü ve kayıt edildi. Delik açılan femurlarda kırık oluşturan deliklerin boyutları ve sayısının etkisi iki yönlü varyans analizi ve Tukey'in çoklu karşılaştırma testi ile mukayese edildi. $P<0.05$ istatistiksel olarak anlamlı bulundu. Dril ile delinmiş deliklerin boyut ve sayısında artma ile birlikte kemiğin torsiyonel kuvvetlere karşı direncinin önemli derecede azaldığını bulduk ($P<0.001$). Kırık oranı deliklerin sayısı ve boyutu arttıkça artmaktadır. Torsiyonel kuvvetlere karşı kemiğin direnci deliklerin sayısı arttıkça azalmaktadır. Biz bir kemik defektinin boyutunun torsiyonel direnç için oldukça önemli olduğunu ve gerçekte de defektlerin sayısının boyutuna göre daha etkili olduğunu gösterdik.

Anahtar sözcükler: *Kırık, Rotasyonel kuvvet, Kemik, Femur, Koyun*

INTRODUCTION

Defects in long bones are known to increase the risk of pathologic fractures [1-7]. When biopsy samples are taken from a bone, a weak point is formed in the biopsied region [7-9]. When osteosynthetic materials are removed fracture risk

İletişim (Correspondence)
+90 532 3232848
ercanolcay@superonline.com

increases [10,11], and this risk is particularly high within the first few months after the removal of osteosynthetic materials [8]. It is well known that a hole drilled into a bone weakens the bone and increases the risk of fracture during bending, especially on exposure to torsional forces. Any hole less than 30% of the bone diameter of the bone increases the risk of fracture by weakening the bone [8].

Bones are typically exposed to several forces in vivo. Under normal conditions, a bone is subjected to cyclical loading, which is a combination of axial and torsional forces [4]. Metastatic defects appear as transcortical holes in long bones, and such defects lead to the formation of pathologic fractures, thereby decreasing the capacity of bones to carry torsional loads [12]. In this study, we investigated the effect of holes with various numbers and sizes drilled into sheep femur bones on the resistance of the bone to torsional forces.

MATERIAL and METHODS

The bones used for testing in this study were taken from the slaughterhouse, and this process did not violate animal rights in any way. In the present study, we used 96 fresh sheep femurs cut into equally sized pieces (75 mm), ensuring that the internal and external diameters of the bones were similar. The bones were divided into 8 groups, each of which was further subdivided into 4 groups (1-4 holes in the range of 2.0 to 5.5 mm. with a 0.5 mm difference between each group) were drilled in the bones. The holes were drilled in the middle of the bones at 0.5 cm intervals. The ends of the bones were fixed into a device when they were subjected to rotation tests. Torsion tests were carried out on a Tec equipment SMS21 model torsion testing machine, and the bones were securely gripped in a special grip arrangement *(Fig. 1A, 1B)*. The tests were carried out at a torsional speed of 30°/min. The torque and the corresponding torsion were continuously measured during the tests by appropriate devices attached to torsion testing machine, and the obtained values were transferred to a computer; software was used to evaluate the results. The test endpoint was partial or complete fracture of the bone identified by a drop in torque. During the application of simultaneous torsional forces, which were increased evenly in each test group, the magnitudes of the forces leading to fracture and their angles were recorded. Statistical analysis was carried out using NCSS 2007 software (NCSS).

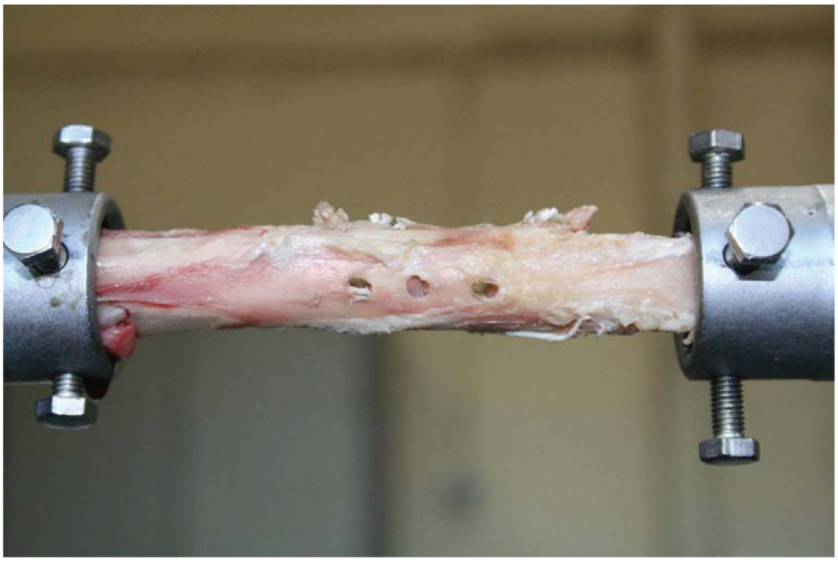

Fig 1A. The equipment used to fix the femur bones before the torsion test

Şekil 1 A. Torsiyon testinden önce femur kemiklerini tespit için kullanılan sistem

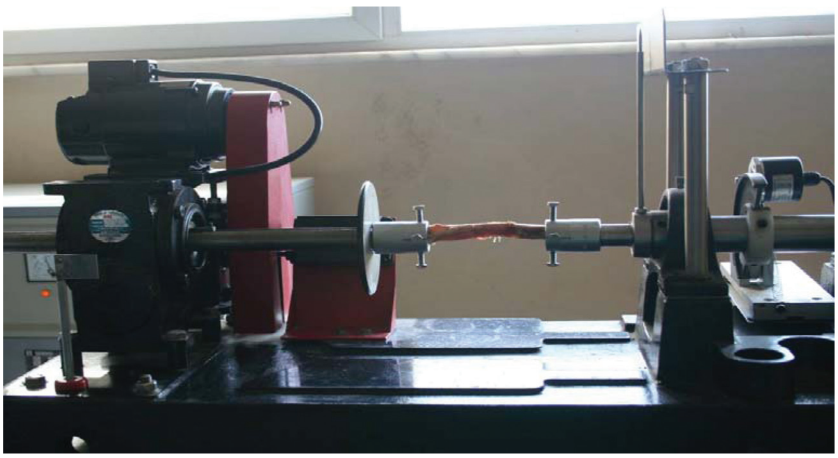

Fig 1B. The equipment used for the torsion test

Şekil 1B. Torsiyon testi için kullanılan cihaz

Descriptive statistical methods (mean±standard deviation [SD]) were used for data analysis. The effect of the number and sizes of holes drilled in the femurs on the occurrence of fractures was compared using two-way analysis of variance (ANOVA); for multiple comparisons, Tukey's multiple com-parison test was used. P<0.05 was considered statistically significant.

RESULTS

In the present study, we investigated whether the number and size of holes drilled into the bone had any effect on the development of fractures. Two-way ANOVA *(Table 1)* showed a statistically significant difference in the occurrence of fractures with different mean hole sizes (P=0.0001). Increasing the hole size resulted is progressively decreasing bone endurance for each hole size (*Table 1* and *2*). Additionally, increasing the number of holes per hole size, also decreased bone endurance *(Fig. 2)*.

Tukey's multiple comparison test was used to evaluate the differences between the groups with varying numbers and sizes of drilled holes *(Table 3)*.

Statistical evaluation for hole number related fracture rates showed significant differences between all the groups analyzed , except 3 versus 4 holes (P: 0.143) *(Table 3)*.

Table 1. *Significant differences in the mean values (± SD) of drilled hole diameters in bones*

Tablo 1. *Kemiklerde açılan deliklerin çaplarının ortalama değerlerinde (± SD) önemli farklılıklar*

Source	Type II Sum of Squares	df	Mean Square	F	*P* value
Corrected Model	517.83	31	16.70	926.94	0.0001
Intercept	1960.23	1	1960.23	108775.98	0.0001
mm	380.75	7	54.39	3018.34	0.0001
Hole	79.81	3	26.60	1476.15	0.0001
mm Hole	57.277	21	2.73	151.35	0.0001

Table 2. *The mean values (± SD) of drilled hole diameters sheep femurs*

Tablo 2. *Koyun femurlarında açılan deliklerin çaplarının ortalama değerleri (± SD)*

Diameter of Holes	1 Hole	2 Holes	3 Holes	4 Holes
2 mm	8.3±0.2	7.867±0.058	7.7±0.2	7.4±0.1
2.5 mm	7.833±0.153	7.1±0.1	5.433±0.153	5.1±0.1
3 mm	7.8±0.2	6.433±0.153	2.333±0.208	1.933±0.058
3.5 mm	6±0.1	5.767±0.058	5.4±0.2	4.9±0.2
4 mm	5.9±0.1	5.433±0.153	4.5±0.1	2.733±0.153
4.5 mm	5.6±0.1	3.133±0.153	2.6±0.1	2.267±0.153
5 mm	3±0.1	2.967±0.058	2.633±0.153	2.267±0.058
5.5 mm	1.567±0.058	1.233±0.153	0.8±0.1	0.667±0.058

Table 3. *The relationship between the number of drilled holes and fracture rate*

Tablo 3. *Açılan delik sayısı ile kırık oranı arasındaki ilişki*

Tukey's HSD Test	*P* Value for Fracture Rate (Nm)
1 Hole vs. 2 Holes	0.011
1 Hole vs. 3 Holes	0.0001
1 Hole vs. 4 Holes	0.0001
2 Holes vs. 3 Holes	0.0001
2 Holes vs. 4 Holes	0.0001
3 Holes vs. 4 Holes	0.143 (NS)

NS: *not significant*

DISCUSSION

Empty screw holes in bones are known to increase stress in the involved region [3,11,13-15]. Forming a stress riser, these regions render the bone susceptible to torsion and tension [16]. These defects may appear radiologically for 6 or more months after removal of screws from the bone, and fractures may occur along these defects [3]. It has been observed that the torsional force of bones with residual screw holes decreases by 55% in dog femurs in which 2.6 mm and 3.6 mm holes are drilled [14]. Radiologically, metastatic defects also appear as transcortical holes in long bones. These defects decrease the capacity of

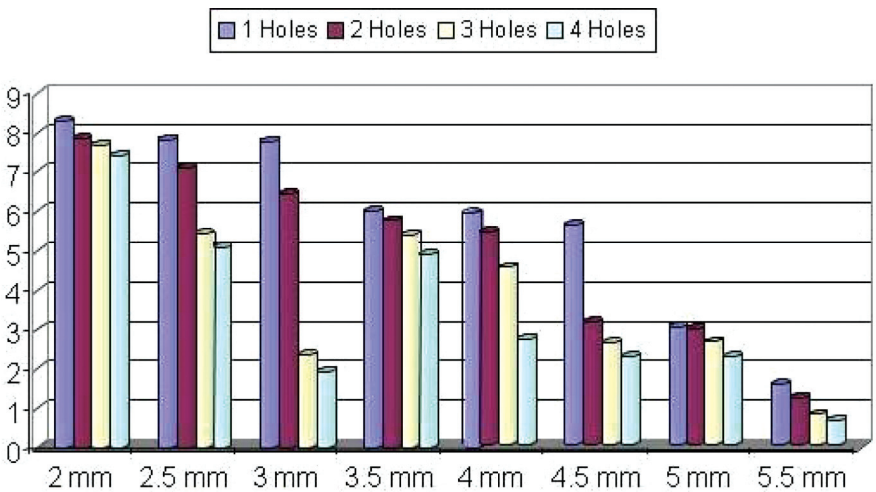

Fig 2. The relationship of the number and diameter of holes with the resistance against torsional forces

Şekil 2. Torsiyonel güçlere karşı oluşan direnç ile birlikte deliklerin çapları ve sayısının ilişkisi bones to endure torsional force, thus producing pathological fractures [4,17].

In the present study, we demonstrated that when torsional forces were applied on bones, the rate of bone fractures was influenced by the size of the drilled holes. In addition, as the number of holes in the bone increased, even lower torsional forces could cause a fracture (*Table 1* and *2*; *Fig. 2*). By using Tukey's multiple comparison test, we investigated the relationship between the sizes of holes and the fracture rate. Increasing the size of the drilled hole was significantly correlated to increased rate of fracture *(Table 2)*. Therefore lower forces were sufficient to induce bone fracture. As the number of holes increasing fracture rate also increase *(Table 3)*. As the increase in the number and size of holes would increase the risk of fracture in long and weight-bearing bones, the significant increase in the occurrence of fractures observed in our study is of clinical importance. However, there was no difference in the rate of fracture between bones with 3 and 4 drilled holes. This may be explained by rotational forces leading to fractures having comparable values in the 3 and 4-hole groups. According to our study results, the presence of more than 1 drilled hole and, more importantly, a large size hole, increased the risk of fracture significantly in long bones. Hopper et al. established that 9.5 mm hole drilled in an equine radius bone had a significantly lower endurance to torsional forces as compared to 6.35 mm hole drilled. However, they found no significant relationship between endurance and the number of holes drilled [18].

Usually, redrilling the holes following screw removal eliminates fibrous tissue membranes and is an important surgical procedure for accelerated bone healing. Such procedures prevent the formation of regions of stress concentration in their in vitro study of sheep femurs demonstrated that transcortical drill holes decreased endurance against torsional forces [16,19]. It is known that in humans, the thickness of the cortical wall decreases with age [4]. Hipp et al. also emphasized the importance of the diameter of the transcortical bone and determined that a bone with a thinner cortex has lower endurance against torsional forces than the one with a thicker cortex. In long bones with transcortical defects, the importance of cortical wall thickness has been evaluated by obtaining the ratio of the endosteal diameter to the periosteal diameter; the mean value was found to be 0.653 in sheep femurs [4]. Various studies have shown that fractures do not generally occur with small holes, indicating that the effect of stress concentration increases with an increase in the size of the hole. In addition, when the geometry of round holes is compared with that of non-round holes, a decrease in stress concentration is observed [19].

Both osteolytic and osteoblastic metastatic lesions occur around areas of density change in the bone [7,12]. In our opinion, drilling is especially risky for osteolytic lesions and can lead to pathologic fractures. In tumor surgery, cortical destruction involving 50% of the cortex requires prophylactic stabilization [7,19]. Osteoporosis can significantly reduce the cortex endurance and deteriorate weight bearing capacity. Such defects, but larger than those of similar cross-section is less than the rotational forces of resistance have been reported [19,20]. However, cortical atrophy has a graeter impact on bone weakness than residual screw holes , following removal of plates and/or screws. Drilling is especially risky for osteolytic lesions (Osteoporotic patients) and can lead to pathological fractures [11,21-23].

In conclusion, the fracture risk in a bone depends not only on the geometry of the lesion but also on other factors, including the quality of bone, tumor biology (if any), and the physical activity of the patient [5]. As observed in our study, any defect in a long bone may reduce the endurance of the bone to biomechanical torsional forces. The size of the defect is extremely important in such endurance; in fact, the size is more important than the number of defects, particularly in cases with metastasis, after biopsy, and after the removal of plates and/or screws.

REFERENCES

1. Damron TA, Heiner JP, Freund EM, Damron LA, McCabe R, Vanderby R: A biomechanical analysis of prophylactic fixation for pathological fractures of the distal third of the humerus. *J Bone Joint Surg Am,* 76 (6): 839-847, 1994.

2. Damron TA, Rock MG, Choudhury SN, Grabowski JJ, An KN: Biomechanical analysis of prophylactic fixation for middle third humeral impending pathologic fractures. *Clin Orthop Relat Res,* 363, 240-248, 1999.

3. Hidaka S, Gustilo RB: Refracture of bones of the forearm after plate removal. *J Bone Joint Surg Am,* 66 (8): 1241-1243, 1984.

4. Hipp JA, Edgerton BC, An KN, Hayes WC: Structural consequences of transcortical holes in long bones loaded in torsion. *J Biomech,* 23 (12): 1261-1268, 1990.

5. Keyak JH, Kaneko TS, Rossi SA, Pejcic MR, Tehranzadeh J, Skinner HB: Predicting the strength of femoral shafts with and without metastatic lesions. *Clin Orthop Relat Res,* 439, 161-170, 2005.

6. Keyak JH, Kaneko TS, Tehranzadeh J, Skinner HB: Predicting proximal femoral strength using structural engineering models. *Clin Orthop Relat Res,* 437, 219-228, 2005.

7. Mirels H: Metastatic disease in long bones: A proposed scoring system for diagnosing impending pathologic fractures. *Clin Orthop Relat Res,* 249, 256-264, 1989.

8. Brooks DB, Burstein AH, Frankel VH: The biomechanics of torsional fractures. The stress concentration effect of a drill hole. *J Bone Joint Surg Am,* 52, 507-514, 1970.

9. Clark CR, Morgan C, Sonstegard DA, Matthews LS: The effect of biopsy-hole shape and size on bone strength. *J Bone Joint Surg Am,* 59 (2): 213-217, 1977.

10. Anderson LD, Sisk D, Tooms RE, Park WI 3rd: Compression-plate fixation in acute diaphyseal fractures of the radius and ulna. *J Bone Joint Surg Am,* 57 (3): 287-297, 1975.

11. Rosson J, Egan J, Shearer J, Monro P: Bone weakness after the removal of plates and screws. Cortical atrophy or screw holes? *J Bone Joint Surg Br,* 73 (2): 283-286, 1991.

12. Hipp JA, Springfield DS, Hayes WC: Predicting pathologic fracture risk in the management of metastatic bone defects. *Clin Orthop Relat Res,* 312, 120-135, 1995.

13. Chauhan SK, Singh VR: Loss of strength in drilled bone in orthopaedic surgery. *Biomed Mater Eng,* 1 (4): 251-253, 1991.

14. Remiger AR, Miclau T, Lindsey RW: The torsional strength of bones with residual screw holes from plates with unicortical and bicortical purchase. *Clin Biomech,* 12 (1): 71-73, 1997.

15. Ho KW, Gilbody J, Jameson T, Miles AW: The effect of 4 mm bicortical drill hole defect on bone strength in a pig femur model. *Arch Orthop Trauma Surg,* 130 (6): 797-802, 2010.

16. Burstein AH, Currey J, Frankel VH, Heiple KG, Lungsth P, Vessely JC: Bone strength. The effect of screw holes. *J Bone Joint Surg Am,* 54 (6): 1143-1156, 1972.

17. Robertson DD, Beck TJ, Chan BW, Scott WW, Sharma GB, Maloney WJ: Torsional strength estimates of femoral diaphyses with endosteal lytic lesions: dual-energy X-ray absorbtiometry study. *J Orthop Res,* 25 (10): 1343-1350, 2007.

18. Hopper SA, Schneider RK, Ratzlaff MH, White KK, Johnson CH: Effect of pin hole size and number on *in vitro* bone strength in the equine radius loaded in torsion. *Am J Vet Res,* 59 (2): 201-204, 1998.

19. Edgerton BC, An KN, Morrey BF: Torsional strength reduction due to cortical defects in bone. *J Orthop Res,* 8 (6): 851-855, 1990.

20. Strothman D, Templeman DC, Varecka T, Bechtold J: Retrograde nailing of humeral shaft fractures: A biomechanical study of its effects on the strength of the distal humerus. *J Orthop Trauma,* 14 (2): 101-104, 2000.

21. Perren SM: The concept of biological plating using the limited contact-dynamic compression plate (LC-DCP) scientific background, design, and application. *Injury,* 22 (Suppl 1): 1-41, 1991.

22. Tepic S, Perren SM: The biomechanics of the PC-Fix internal fixator. *Injury,* 26 (Suppl 2): 5-10, 1995.

23. Tepic S, Remiger AR, Morikawa K, Predieri M, Perren SM: Strength recovery in fractured sheep tibia treated with a plate or an internal fixator: An experimental study with a two-year follow-up. *J Orthop Trauma,* 11 (1): 14-23, 1997.