Biomechanical Studies on Femoral Fracture Repair Fixed By Different Fixation Methods in Dogs

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Abstract: This work was carried out to study the influence of mechanical tension and bending fracture forces on 21 repaired femora in dogs after fixation with intramedullary pins, bone plates and screws and transkeletal fixation. Biomechanical evaluation proved that, in case of intramedullary pinning technique, there was no significant (P<0.05) difference in mechanical tension and bending force values compared with the normal values. During maximum mechanical tension, the site of the fracture lines were at the supra-condylar region and the shape was transverse and during bending forces, the fracture occurred at the mid-diaphysis with oblique fracture line. Repaired femora fixed with bone plates and screws showed a significant (P<0.05) decrease in the mean values of tension and bending mechanical forces compared with the normal values. The shape and site of the fracture patterns were observed at the sites of the screw holes either in the proximal or distal segments and the fracture lines were transverse. Repaired femora fixed with external transkeletal fixation showed no significant (P<0.05) changes in the tension force values compared with the normal values, while, there was a significant (P<0.05) decrease in the mean bending force values compared with the normal values. The shape and the sites of the fracture lines for both mechanical tension and bending forces were observed at the sites of the pin holes either at the proximal or distal bone segments and the shape of the fracture lines was transverse. In conclusion, the present study indicated that, the maximum mechanical fracture forces of the repaired femora were significantly influenced by the used fixation device. Treatment with intramedullary pinning had a better or minimal mechanical effect on the repaired femora, meanwhile, with the other two techniques, bone plates and screws as well as external skeletal fixation, the mechanical strength of the repaired femora decreased significantly. However, fixation with external skeletal acrylic fixation was better than fixation using bone plates and screws regarding the mechanical bone strength.

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1. Introduction

The femur is a long bone mostly subjected to fractures in dogs. Many reported implant systems are suitable for fracture repair .Intramedullary pins, bone plate and screws, external skeletal fixation, lag screws as well as interlocking pins are mostly used as implant devices **(Beale, 2004)**

Bone biomechanics is considered one of the most important subjects in the biomechanical research fields (**Sharir *et al.,* 2008**). Bending, tension, compression, and torsion are the basic biomechanical tests commonly used for assessing the mechanical properties of bony tissues (**Roberts *et al.,* 2005**).

The two most important mechanical properties of the bony tissue are strength and stiffness. The primary physiological forces are axial compression, axial tension, bending, shear and torsion. Each of them alone or in combination results in a complex pattern of internal stresses and strains within the bone.

Femoral fractures are fixed by different implant systems that included intramedullary pinning, bone plate and screws, external skeletal fixation, lag screws and interlocking nails (**Aithal *et al.,* 1999 and Cunningham, 2001**).

It is important to choose an implant system that is capable of adequately neutralizing all the disruptive forces at the fracture site and allowing bone healing to rapidly progress. These forces cause bending, compressive, tensile, shear, or torsional stresses to act on the fractured bone and fixation system at the same time (**Perren, 2002). **Bending test is a common method used to test the whole bone **(Sharir *et al.,* 2008).**

Fracture treatment with either external or internal fixation had some biomechanical problems as the method of fracture fixation changes the bone geometry and alters its normal mechanical strength **(Carter and Spengler, 1982**)

A large variety of mechanical factors have been identified to influence fracture healing. The most dominant factors were bone geometry and type of fracture **(Chen *et al.*, 2009)**. Bone diseases and surgical procedures reduce the strength of bone by removing bony masses which influence the internal forces to be distributed over a smaller volume of tissues as well as producing poor distribution of stresses within the bone **(Nordin and Frankel, 1989).**

The mechanical properties of the bony tissue depended on its composition and structure **(Schwarz,1991).** Mechanical assessment of the bone is essential in developing guidelines for evaluating the success of treatment (**Markel *et al.*, 1994)**

The aim of this study was to evaluate the effect of three different fixation techniques on the mechanical strength of the femur bone in dogs after fracture repair. We hypothesized that; the mechanical properties of repaired femora would change significantly following fixation with intramedullary pins, bone plates and screws and external transkeletal fixation.

2. Material and Methods

This study was carried out on 21 clinically normal mongrel male dogs. Their mean body weights were 20.3± 2.38 kg and their mean age was 18.2± 4.6 months. These animals were subjected to experimental fracture of the femur bones of the left hind limbs. Fractured bones were fixed by three different fixation techniques. The operated animals were classified into three groups according to the method of fixation.

- Group I (8 dogs): The femur bones were fixed with intramedullary pins.
- Group II (7 dogs): The femur bones were fixed with bone plates and screws.
- Group III (6 dogs): The femur bones were fixed with acrylic external skeletal fixation.

The surgical operation:

The left hind limb of each dog was prepared for aseptic surgery. The right hind limb was used as control.

All dogs were operated under the effect of general anesthesia through intravenous injection of atropine sulphate (0.05 mg/kg body weight); diazepam (1mg/kg body weight); xylazine (1mg/kg body weight) and ketamine Hcl (10mg/kg body weight). The anesthetic depth was maintained with intravenous injection of 2.5% thiopental sodium (25 mg / kg body weight).

An s shape skin incision was made over the cranial border of the femur bone from the subtrochantric area to the femoral condyles. Separation between the biceps femoris muscle caudally and the vastus lateralis was done to expose the femoral diaphysis.

A transverse mid-shaft osteotomy was made using an oscillating saw; then the experimentally induced fracture was reduced anatomically using each previously mentioned fixation technique surgically operated according to **(Hulse and Hyman, 1993)**.

To examine optimum healing, all dogs were subjected to routine clinical and radiographic evaluations. Radiology was taken before and immediately after the operation.

Biomechanical evaluation:

Collection and preparation of samples:

After 24 weeks dogs were euthanized. The right control normal and left operated femora were taken. The overlying soft tissues were removed and the bones were wrapped in saline soaked towels and stored at -20°C.

Biomechanical tests:

Tests were carried out at the department of Mechanical Design and Production at the faculty of Engineering, Cairo University.

Both mechanical tension and bending tests for the control and repaired femora were applied using a universal testing machine (AMSLER®).

The failure forces were evaluated for the maximum forces causing bone fracture in control normal and operated femora.

Statistical analysis:

All data were statistically analyzed using unpaired t-test between control and repaired femora. Analysis of variance (ANOVA) was used between different fixation methods. Significance was considered at ($P < 0.05$).

3. RESULTS

I- Clinical observation:

All the operated animals showed oedema at the site of the operation which disappeared one week postoperatively. The surgical wound was clean and completely healed after 10 days of operation in all cases.

Cases treated with intramedullary bone pinning showed full limb function on the operated limbs after 2 weeks and complete weight bearing at 3 months postoperatively.

Cases treated with bone plates and screws showed full limb function on the operated limbs after 3 weeks and complete weight bearing occurred within 3 months.

Cases treated with acrylic external skeletal fixation had full limb function at 6 weeks and complete weight bearing at 5 months.

II-Radiographic evaluation:

Radiographic studies of the fracture repair in the three fixation techniques showed progressive callus formation. Three months post-operation, the fracture gap disappeared with optimal stability. The radio-density of the callus at the fracture site was uniform with complete cortical bone union and disappearance of the fracture line completely in all cases 6 months postopertaion.

III-Biomechanical evaluation:

The mean values of the tension and bending failure forces in the control and operated healed bones treated by intramedullary bone pinning were represented in (Table 1). There was no significant ($p<0.05$) difference in the mean values of both tension and bending fracture forces between control and repaired femora.

Concerning the shape and site of the fracture pattern, after application of the tension force, there was a complete transverse supracondylar fracture line (Fig.2 A). In case of bending force, the fracture pattern was observed as a complete mid-shaft and oblique line (Figs. 1A, 2B). This appeared similar to the fracture line which occurred in the normal control limbs (Fig.1B).

-The mean values of the tension and bending failure forces in control and operated healed bones treated with bone plates and screws were represented in (Table 2). There was a significant ($p<0.05$) decrease in the mean values of tension and bending fracture forces between control and repaired femora.

The site of the fracture pattern during maximum tension and bending forces were observed at the places of the screw holes either in the proximal or distal bone segments. The shape of the fracture line was transverse in some cases and oblique in other cases (Fig.3).

-The mean values of the tension and bending forces in normal control and operated healed bones treated with acrylic external skeletal fixation were represented in (Table 3). There was a highly significant ($p<0.05$) decrease in the mean values of forces between the control and repaired femora in case of bending force, while in the tension force, there was non significant difference in the values between the normal and repaired femora.

The shape and the sites of the fracture patterns for both maximum mechanical tension and bending forces were observed at the places of pin holes either in the proximal or distal bone segments. The shape of the fracture line was transverse (Fig.4).

Table (1): The mean values of the maximal mechanical tension and bending fracture forces / KN in normal and repaired cases treated by intramedullary bone pinning.

Parameters		Mean ± SD	T-test p value
Age/ months		20.50 ± 2.97	
Body weight /Kg		20 ±1.9	
Mechanical test	Tension force /KN right control femora	1.67 ± 0.20	
	Tension force /KN left repaired femora	1.62 ± 0.20	0.7433 non significant
	bending force /KN right control femora	1.47 ± 0.18	
	Bending force /KN left repaired femora	1.22 ± 0.16	0.09070 non significant

Table 2: The mean values of the maximal mechanical tension and bending fracture forces / KN in control and repaired femora treated by bone plates and screws.

Parameters		Mean ± SD	T-test p value
Age /months		20.67 ± 2.73	
Body weight /Kg		19.67 ±1.86	
Mechanical test	Tension force /KN right control femora	2.12 ± 0.095	
	Tension force /KN left repaired femora	1.74 ± 0.16	0.0060* Significant
	bending force /KN right control femora	1.8 ± 0.14	
	Bending force /KN left repaired femora	1.350 ± 0.129	0.0033* Significant

Table 3: The mean difference in tension and bending forces / KN in control and repaired bones treated with acrylic external skeletal fixation

Parameters		Mean ± SD	T-test p value
Age /months		21 ± 2.4	
Body weight/Kg		21 ± 1.26	
Mechanical test	Tension force /KN right control femora	2.05 ± 0.19	
	Tension force /KN left repaired femora	1.76 ± 0.17	0.0659 non significant
	bending force /KN right control femora	1.8 ± 0.14	
	Bending force /KN left repaired femora	0.97 ± 0.05	0.05* highly significant

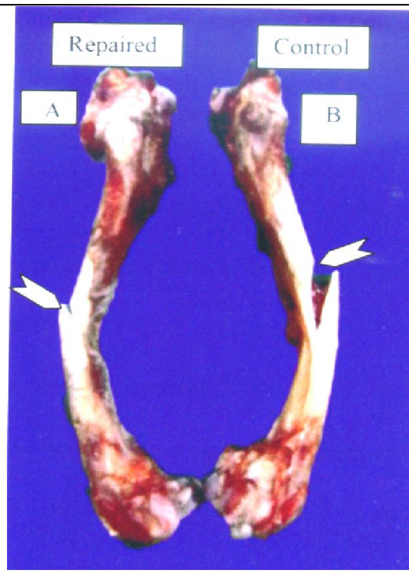

Fig. 1: Maximal mechanical bending fracture forces in repaired (A) and control contra-lateral femur (B) after intramedullary bone pinning. Note, the common sites of fractures of both femora were at the mid-diaphysis and the fracture line was oblique (arrows).

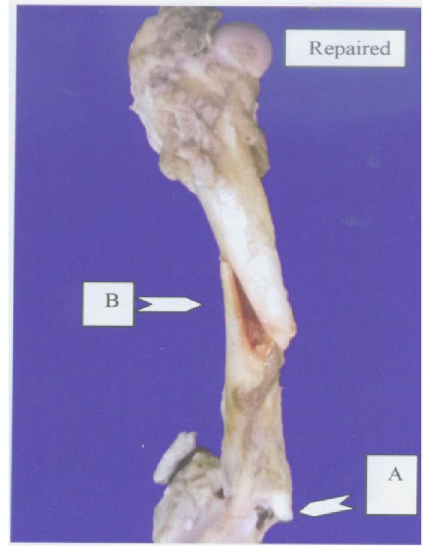

Fig. 2: Mechanical tension (A) and bending (B) fracture failure forces in a repaired femur after removal of the intramedullary pin: Note, the fracture line in case of tension was supracondylar (A) and transverse and in bending was mid-shaft and oblique(B) (arrows).

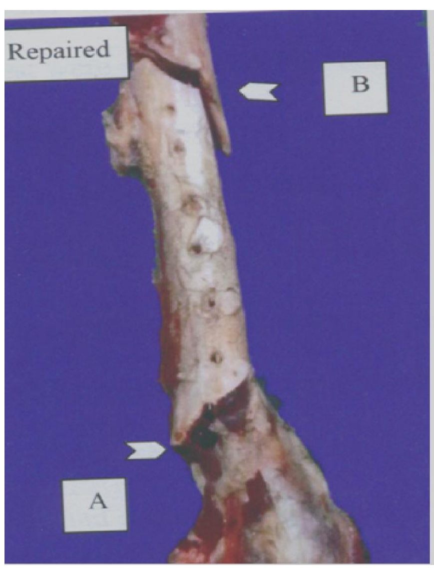

Fig. 3 Maximum mechanical tension (A) and bending (B) fracture forces in a repaired femur after bone plates and screw fixation. Note: In both tests, the sites of fractures were at the areas of screw holes (arrows).

Fig.4: Maximum mechanical tension (A) and bending (B) fracture forces in a repaired femur treated with acrylic external skeletal fixation. Note: The site of fracture was at the pin- hole interface (arrows).

4. Discussion

The goal of fracture treatment is known as the restoration of the bone structure, composition and function. The fixation technique must adequately neutralize intrinsically as well as extrinsically generated forces while the material and structural properties of the bone being restored to normal **(Hulse & Hyman, 1993; Harasen, 2003 and Beale,**

2004).

The function of the surgical implants should promote bone healing by providing stability and significantly reducing local strain at the fracture site. Very little investigations are known about the correlation between the biomechanical strength of the whole bones and the different fixation devices.

In the current study, the biomechanical evaluation after fixation with intramedullary bone pinning showed that, the mean values of the maximum mechanical tension and bending failure forces were nearly equal to the fracture failure forces of the normal bones. Therefore, the use of the intramedullary bone pinning technique had no significant influence on the biomechanical strength of the bones after fixation and repair. Similar results have been presented by many investigators who mentioned that, the intramedullary pinning technique provides excellent biomechanical stability for a fractured long bone as well as a good environment for healing (**Zimmermann and Klasen, 1983)**. The basic principle is that the nail acts as an internal splint which reduces but does not eliminate interfragmentary motion as the nail carries significant axial and bending forces.

Harasen (2003) added that, intramedullary pin fixation is effective in neutralizing bending forces as the bending support afforded by intramedullary pin depends on the load sharing between the bone and pin. Our results indicated that, intimate contact of the intramedullary pin with the endosteal surface improves the bone resistance to bending and horizontal shear forces, a fact which coincided with **(Bernarde *et al.,* 2001)** who added that bone pinning currently represents the most effective treatment for most diaphyseal fractures in the tibia and femur.

The site of fracture following the maximum mechanical tension force was supracondylar, while the site of the fracture when subjected to maximum mechanical bending fracture was located at the mid -diaplysis in both the operated and the control groups. Also, the shape of the fracture line was transverse in the tension force and oblique in bending force in both the control and healed femora . These findings agreed with **Cunningham (2001)** who reported that, the healed long bones after repairing acquire torsion and bending stiffness twice as the normal bones. The results indicated that, the clinical use of intramedullary pin fixation had no effect on the bone strength and structures of the bone after repair.

Concerning the fixation with bone plates and screws, an accurate immobilization resulted in clinical improvement at the end of the experiment which could be explained by the capability of the plate to neutralize the disruptive forces acting on the fractured bone as the compression plates prevent the dynamic movement of the fractured segments and allow primary healing. The same was also reported by **Hulse & Johnson, 1997**. Our biomechanical results indicated that, there was a significant decrease in the mean values of the maximal mechanical tension and bending fracture force failures in repaired femora compared with the normal control ones. The strength reduction was explained by the presence of the residual screw holes after removal of the plate and the bone becomes brittle due to cortical atrophy.The strength reduction after the removal of a plate is related more to the presence of residual screw holes than to the cortical atrophy. Same results were mentioned by **(Rosson *et al.,* 1991).**

The shape of the fracture pattern in both tension and bending fracture forces were transverse in some cases and oblique in other cases. Concerning the sites, in all animals, the fracture occurred at the residual screw holes of the repaired bones. These findings have been supported clinically by **(Claes, 1989)** who concluded that, bone plate and screws have been associated with a decrease in bone mineral density and occurrence of osteopenia proved histologically in other previous studies by missed interconnection in the orientation of the newly formed lamellae, collagen fibrils and new woven bones at the junction between old and new healed bony tissue at the residual holes (**Carter *et al.,* 1981, and Rand & Chao, 1981).**

Rand and Chao (1981) attributed this to the pressure stress and compromised bad visualization which are usually the main problems associated with the use of stiffness plates.

Concerning the acrylic transkeletal fixation, there was no significant differences in tension fracture failure forces between control and repaired femora. However, there was a highly significant decrease in the mean values of the bending failure forces compared with the control femora. It was mentioned that, the transkeletal fixation method had the effect of neutralization all the mechanical forces, this is accomplished through the multiple percutaneous transcortical pins that are interconnected by metallic or acrylic bars to form a rigid external frame **(Lewis *et al.,* 2001)**.

Our results indicated that, the transkeletal technique had also an influence effect on the repaired femora proved by the decrease in the mechanical strength of the repaired bones in case of application of the bending forces which proved a reduction in their biomechanical stiffness.

Recently, **O'Doherty and Butler (1995**) mentioned that, although the use of a fixator with an intact bar resulted in a significant stress protection of the underlying bone, it was found that, after 16 weeks the bone mineral content fell by 9%. In this respect in an experimental study, quantitative assessment proved that, bone resorption in the endosteal, periosteal and intra-cortical tissues occurs when external fixators have been used **(Claes *et al.*, 1980 and Korvick & Newbrey, 1989)**.

The shape and sites of the fracture patterns at both maximal mechanical tension and bending fracture forces were transverse in direction and located at the sites of the pin bone interface which represented the weakest points.

In conclusion, our results proved that, bone fixation by using intramedullary pinning had the minimal mechanical effect on the strength of the fractured bone .Meanwhile, fixation by bone plates and screws or the use of acrylic skeletal fixation results in a significant decrease in the mechanical strength of the fractured femoral bones. However, acrylic transkeletal fixation was better than bone plates and screws.

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