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A COMPARATIVE EXPERIMENTAL STUDY ON THE HUMAN AND ARTIFICIAL HIP JOINT: STRESS ANALYSIS WITH STATIC LOAD, TIME AND IMPACT LOAD.

مقارنة عملية على المفاصل الطبيعية والمفاصل الصناعية : تحليل الإجهادات تحت تأثير الأحمال الساكنة والزمن والحمل التصادمى

by

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الخلاصة :

بالرغم من أن فهم الخواص الميكانيكية للعظام والكسور بها فى تقدم مستمر ، إلا أنهـا مـازالت بعيدة عن الإكتمال. ولذلك ، فان هذا البحث يقدم دراسة عمليـة حول تـأثير كـل مـن الأحمـال السـاكنة والتصـادميـة عند ظروف مختلفة على كل من عظام ومفاصل الفخذ الطبيعية للإنسان. وقد أجريت نفس التجـارب علـى العظـام الطبيعية بعد زرعها بمفصل صناعى.

تم تصميم وإنتاج جهاز خاص لتثبيت كل من العظـام الطبيعيـة وتلـك المـزروع بهـا مفـاصـل صناعيـة مـع التأثير عليهما بحمل يماثل الأحمال المؤثرة على مفصل الإنسان من حيث المقدار والاتجاه. ثم أجريـت مقارنـة بين توزيع الإجهادات فى كلتا الحالتين باستخدام جهاز قياس الإنفعال.

وأوضحت النتائج المعملية أن الإجهادات تبدلت بعد زرع المفصل الصناعى لتصبـح أقصـى إجهادات فـى المنطقة القريبة من نهايته. كما أن عدم وجود عنق يرتكز عليها المفصل الصناعى يؤدى الى تقليل كبير فـى الإجهادات والتى قد تؤدى بدورها الى تغيرات هامة فى بناء خلايا العظام.

ABSTRACT

Although the understanding of the mechanical properties and fracture behaviour of bone is continuously improving, as yet it is far from complete. So, this paper represents an experimental study about the effect of static and dynamic loads under different parameters on intact bone and human hip joints. The same test will be applied on the human hip joints after insertion of the artificial femur component in the bone.

A special test-rig was designed in order to fix both natural and artificial implant and expose them to a state of loading similar in magnitude and direction to that encountered in the human-being. A comparison between the stress-strain distribution of the intact and artificially implanted bones were conducted by using strain gauges.

The results showed that the stresses were reversed after insertion of the artificial femoral component and the stresses were maximum at the near of the tip of the prothesis. Also, the absence of the collar-calcar causes a severe reduction of the stresses which may be due to important metabolic changes.

1. INTRODUCTION

The study of the mechanical stresses in bones is needed to develop quantitative specifications for substitute materials and to ensure effective mechanical compatibility and stability of implants and prosthetic devices which are often used to replace parts of defective or fractured bones. A mechanical mismatch, because of greatly different elastic properties of the bone and the implant, will produce a stress concentration that might lead to early failure.

One of the major mechanical problems encountered with total hip replacement was referred to the loosening of femoral component [1,2,3]. Both mechanical and biological phenomena has been proved to play a major role in this loosening process.

Many of the previous works [4,5], studied and tested the static tensile strength of fresh femurs at wet or dry conditions. Whereas, some of them [6] studied the effect of dynamic loads on the biomechanical characteristics of bones.

Also, the mechanical failiures and the fracture of the femoral component which occur after the total hip replacement were examined [7,8,9,10].

The finite element methods in both two and three dimensions were used to study the effect of some of the factors leading to eerly fatigue failure of the femoral stem in total hip prosthesis [11,12].

Three types of measurements were used to estimate stresses in the femur under load. Roftopoulos et al. [12], used theoretical analysis. Pauwels [13,14], used photo-elastic models, while more recently the stress-coat technique and strain-gauges [15] were employed for in vitro measurements.

Therefore, in the present experimental work, a test-rig was designed in which strain-gauges were utilized to measure the strain in dry and wet conditions under static and dynamic loads for intact and implanted bones.

2. TEST-RIG ARRANGEMENT

2.1. Test-rig:

A special test-rig was designed and manufactured in order to accomplish the requirements of the tests. As shown in Fig. (1-a) for static load and Fig. (1-b) for dynamic load, the test-rig consists of two half hollow cylinder welded to the base plate. They hold the femoral shaft under test vertically with the aid of the lower locking screws. In between of the femoral shaft and the two half cylinders, there is a bad of rubber to eliminate any tightening effects on the strain-reading.

The upper part of the test-rig is a mean to allow the fixation of the acetabulum, which moves vertically up and down and locked at the suitable height by using the upper locking screws. The designed test-rig was suitable to the natural and artificial implanted bones and to a state of loading similar in magnitude and direction to that encountered in the human being. Then, the signals from the strain were amplified and recorded on both a digital readout strain meter and FFT analyzer.

2.2. Materials:

A dry femur and pelvis of human cadaver were obtained free of all muscles. A sponge soaked in methanol used to clean the surface of the repeatedly.

The used bones were similar in volume, adge and time of death. The modulus of elasticity of the femur bone was considered to be 1.7×10^7 N/cm^2.

2.3. Procedure:

Three sets of experiments were performed for static and dynamic loads. The first was applied on the intact femur bone. The second was applied on the femur after implanting the artificial component with a femoral neck equal to 6 mm., while the last one applied on the implanting femoral bone without neck. The three sets of tests were carried out at:

a) Variable loads ranging from 25 to 500 N.

b) Constant load (500 N) and variable times ranging from zero to 24 hours.

c) Variable impact loads (The potential energy ranging from 392 to 7840 N.cm.).

3. RESULTS AND DISCUSSIONS

The results of the experiments may be classified according to the state of the bone under test as follows:

3.1. Results of the Intact Femoral Bone:

Fig. (2) illustrates the relation between stresses and applied load. It shows that the stresses increase rapidly with the increase of applied loads between 100 to 200 N, and decrease from the proximal to the distal of the femoral head at both concave and convex sides. Also, it is seen that the maximum tensile and compressive stresses obtained at the femoral neck, while the minimum tensile and compressive stresses were at the lower part of the measured zone of the stem.

Fig. (3) demonstrates stresses versus time. It shows that the stresses increase with the increase of time up to 6 hours, then it became constant. Also, the maximum tensile and compressive stresses were at the upper part of the measured zone of the stem, while the minimum tensile and compressive stresses were at the lower part.

The relation between stresses and potential energy, illustrated in Fig (4), shows that the compressive stress at the convex side of the femoral neck is greater than that of the tensile stress at the concave side of the femoral neck.

3.2. Results of the Femur Bone After Implanting the Artificial Component without Neck:

Fig. (5) illustrates the relation between stresses and applied load. It is obvious that the maximum tensile and compressive stresses were at the lower part of the measured zone of the stem and the minimum tensile and compressive stresses were at the upper part of the stem.

Fig. (6) demonstrates stresses versus time. It shows that the maximum tensile and compressive stresses were nearly at the lower part of the measured zone of the stem and the minimum tensile and compressive stresses were at the diagonal axis passed through the upper concave side to the lower convex side.

The relation between stresses and potential energy, demonstrated in Fig. (7), shows that the maximum tensile and compressive stresses were at the diagonal axis passed from the upper concave side to the lower convex side, while the minimum tensile and compressive stresses were at the diagonal axis passed through the other symmetrical axis.

3.3. Results of the Femur Bone After Implanting the Artificial Component with a Femoral Neck Equal to 6 mm :

Fig. (8) illustrates the relation between stresses and applied load. It is obvious that the maximum tensile and compressive stresses were nearly at the lower part of the measured zone of the stem and the minimum tensile and compressive stresses were at the upper part of the stem.

Fig. (9) demonstrates stresses versus time. It shows that the maximum tensile and compressive stresses were at the lower part of the measured zone of the stem and the minimum tensile and compressive stresses were at the upper part of the stem.

The relation between stresses and potential energy, demonstrated in Fig. (10), shows that the maximum tensile and compressive stresses were at the diagonal axis passed through the upper part of the concave side to the lower part of the convex part. while the minimum tensile and compressive stresses were at the diagonal axis passed from the upper part of the concave side to slightly above the lower part of the covex side.

CONCLUSIONS

The conclusion of this study can be summarized in the following items:

1- Stresses in the upper portion of the intact femur were the highest proximally and decreased progressively towards the middle of the diaphysis.

2- The tensile stresses resulted at convex side of the intact femoral bone and the implanting artificial component, whereas the compressive stresses resulted at the concave side.

3- The normal pattern of progressive proximal to distal decrease in stress was reversed after insertion of artificial femoral component and the stresses were maximum at the near of the tip of the prothesis.

4- With the absence of collar-calcar contact, the strain in the calcar femoral was reduced massively. The severe reduction in stresses implies that important metabolic changes my occur and suggests that extensive disuse osteoprothesis may be the results.

5- This study may have clinical application. As it suggests that coller- calcar contact may transfer load directly to the cotical bone of the calcar femoral and therefore provide more protection for the femoral stem against fatigue failure.

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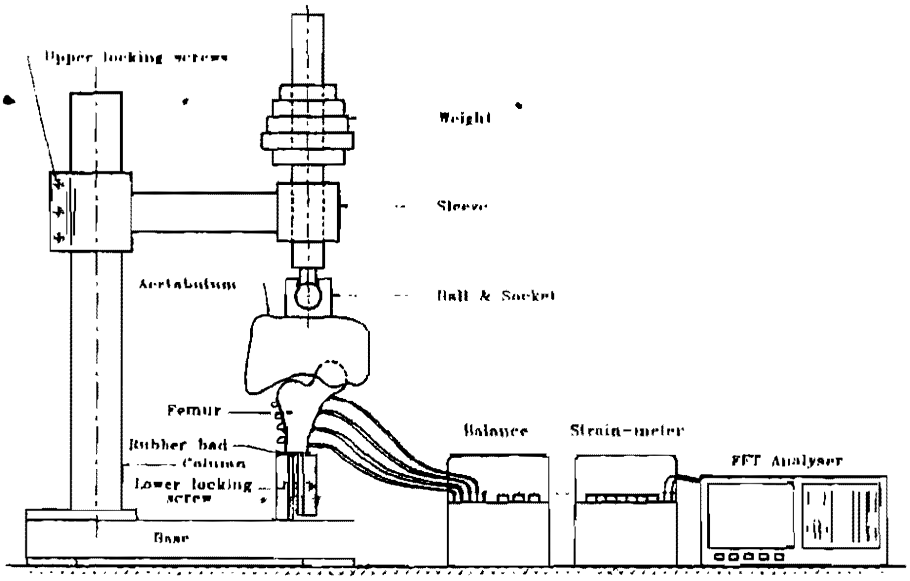

Fig. (1-a) The test-rig apparatus at static load.

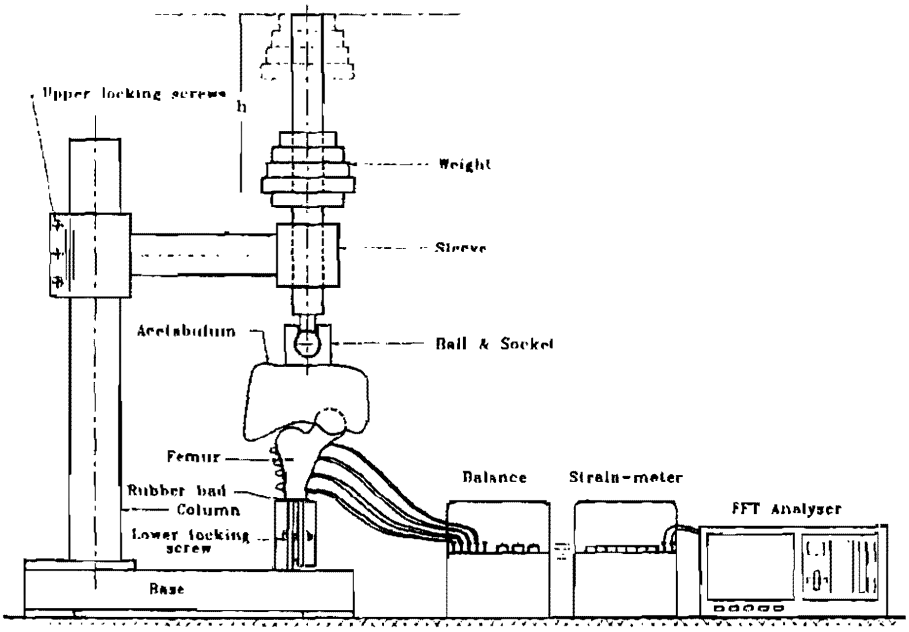

Fig. (1 b) The test rig apparatus at dynamic load.

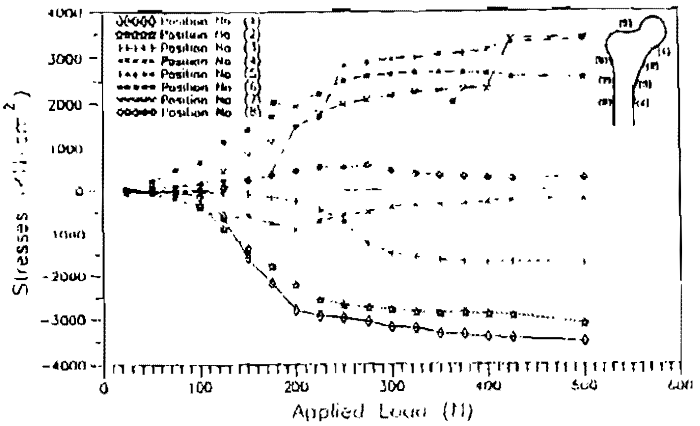

Fig. (2): The relation between stresses and applied variable loads in the intact femoral bone.

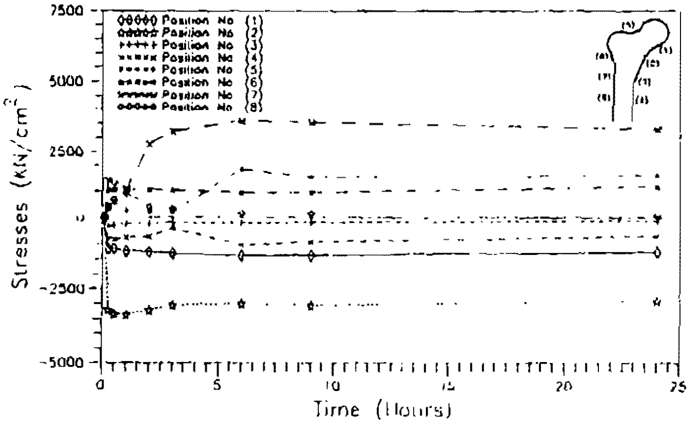

Fig. (3): The relation between the stresses versus time in the intact femoral bone "at constant load".

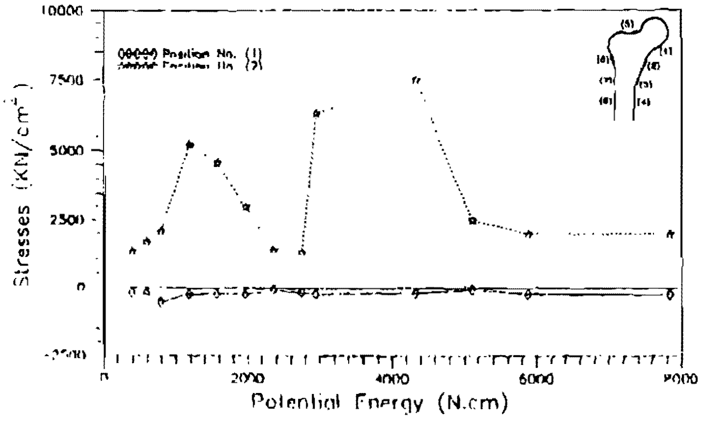

Fig. (4): The relation between stresses and potential energy in the intact femoral bone.

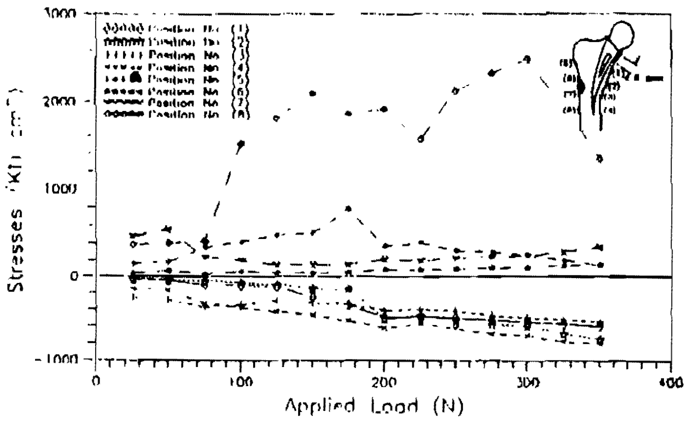

Fig. (5): The relation between stresses and applied variable loads of the implanting artifical component in the bone with a neck equal to 6 mm.

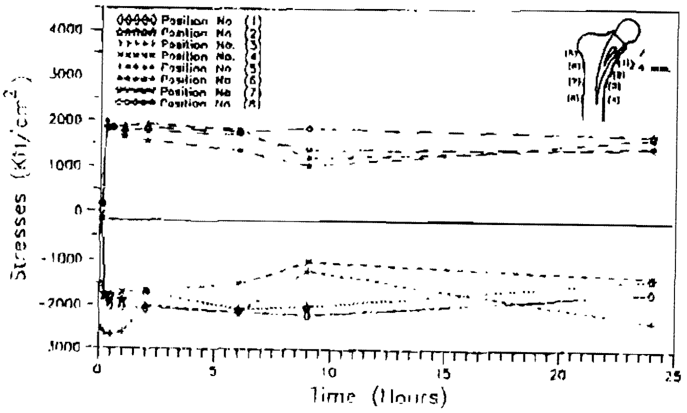

Fig. (6): The relation between the stresses versus time of the implanting artificial component in the bone with a neck equal to 6 mm. "at constant load".

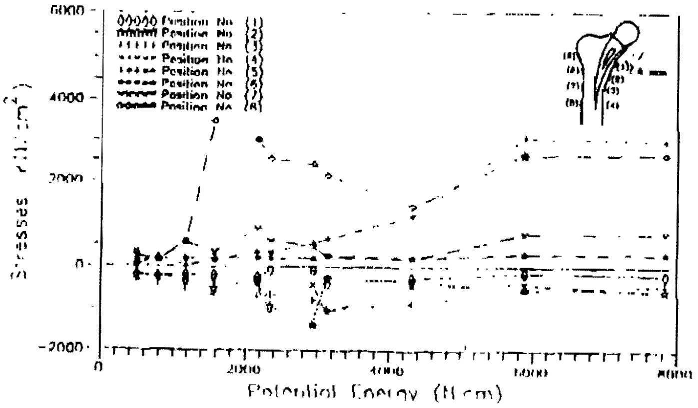

Fig. (7): The relation between stresses and potential energy of the implanting artificial component in the bone with a neck equal to 6 mm.

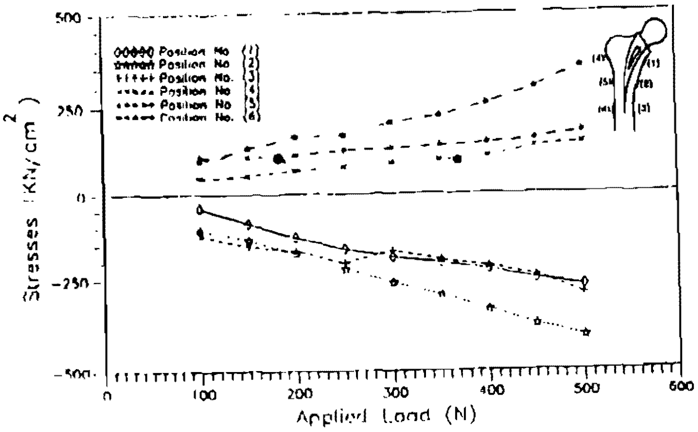

Fig. (8): The relation between stresses and applied variable loads of the implanting artificial component in the bone without neck.

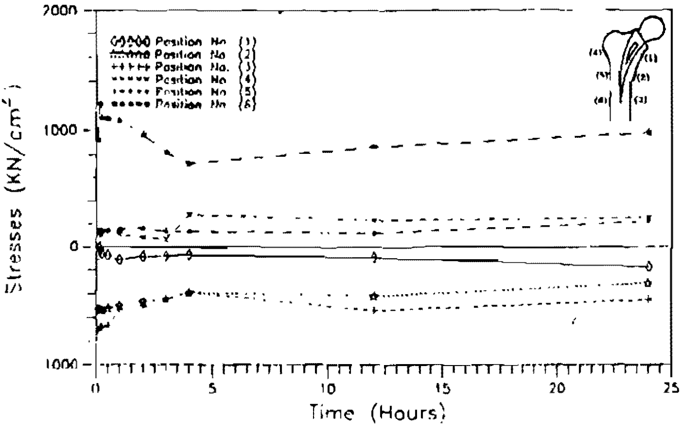

Fig. (9): The relation between stresses versus time of the implanting artificial component in the bone without neck "at constant load".

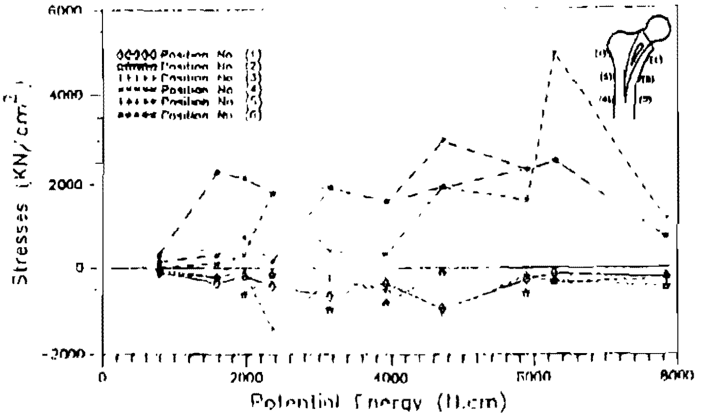

Fig. (10): The relation between stresses and potential energy of the implanting artificial componenet in the bone without neck.