

Original Article

Biomechanics analysis for the treatment of ischemic necrosis of the femoral head by using an interior supporting system

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Received December 20, 2014; Accepted March 2, 2015; Epub March 15, 2015; Published March 30, 2015

Abstract: Objective: This work aims to perform a biomechanical test to evaluate the effect of interior supporting system and tantalum rod in simulating the treatment of ischemic necrosis of the femoral head. Method: Three models were established: control group (group A), interior supporting system group (group B), and tantalum rod group (group C). Step-by-step loading was applied on the top of the femoral head until femoral head damage occurs by using the testing machine of the material test system. Strain and maximum load were applied until the femoral head collapses. The damage to the trochanteric fossa, femur calcar, and greater trochanter were compared. Results: (1) The strain on the trochanteric fossa shows the following order: group C > group A and group B ($P < 0.05$). No significant difference was observed among groups for the other parts ($P > 0.05$). (2) The maximum load in group B is larger than that in groups A and C ($P < 0.05$). No significant difference in the maximum load was observed among the three groups when the femoral head was destroyed. Conclusions: The compression strain and bearing load of the femoral head are close to normal after placement of an interior supporting system and tantalum rod. The interior supporting system helps prevent femoral head collapse.

Keywords: Femoral head, ischemic necrosis, interior supporting system, tantalum rod, biomechanics

Introduction

Adult ischemic necrosis of the femoral head is a common orthopedic and refractory disease. The use of large doses of corticosteroid in the treatment of SARS to control the inflammation caused many osteonecrosis of femoral head during year 2003 [1]. The incidence of male was 39.5% while 19.3% of female [2] and seriously affecting patient functioning and quality of life. This disease is a hotspot in the research on orthopedic clinical problems [3, 4]. Since many patients present after disease progression, primary total hip replacement is often the only reliable treatment option available [5]. Core decompression is a common surgical procedure in young patients with low degree of pathological changes. However, this procedure may lead to postoperative femoral head collapse [6]. With the development of biological

materials with unique advantages in recent years, tantalum rod is often adopted as a clinical application to treat femoral head necrosis. However, the use of tantalum rod is limited by its expensiveness and stress concentration. To this end, we develop an interior supporting system within the femoral head with the aim of supporting the femoral head or resetting the collapse of the femoral head. Thus, the cost-benefit of bisphosphonate use is clearly positive in those with osteoporosis [7]. Bone grafting was undertaken below the femoral head to surround the interior supporting system to achieve three goals: restore the mechanical properties of the femoral head and neck; bone graft fusion of the femoral neck; avoidance of future artificial joint replacement, and there's one system review showed the conclusion that the injury-to-surgery interval did not significantly affect the disease process [8].

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Materials and methods

Specimen and grouping

Fifteen femur specimens from adults aged 20 years to 50 years that were soaked in formalin within 1 year were provided by the Department of Anatomy in Xiangya Medical College of Central South University. No pathological change was found through macroscopic observation and X-ray fluoroscopy after stripping the specimens of all soft tissue. The specimens were randomly divided into three groups: the normal femoral head and neck group (group A); the interior supporting system and bone graft group (group B); and the tantalum rod and bone graft group (group C). Each group contained five specimens.

Specimens modeling

The normal model is characterized by normal specimens of the femoral head and neck.

The interior supporting system and bone graft model was established as follows. Tunnel decompression was performed, and a tunnel with 1 cm diameter was drilled. The beginning point of this tunnel was 2 cm under the femoral greater trochanter, whereas the end point was 0.5 cm under the femoral head cartilage. The direction of this tunnel was along the femur neck center. A space with 2 cm diameter was scraped by using a curette under the cartilage of the femoral head. The interior supporting system was installed in the decompression tunnel. Subsequently, the screw cap was tightened as the shore leaves were opened. Bone graft was performed under the shore leaves. To fix the interior supporting system, a turnbuckle closure was fixed into the tunnel. Finally, the bottom cover was tightened.

The same tunnel decompression method was performed for the tantalum rod and bone graft group model. Bone grafting was performed under the femoral tunnel. The tantalum rod was screwed along the tunnel.

Experimental methods and procedures

The axial compression experiments on the top of the femoral head followed the methods described by Baitner and Baril. Step-by-step loading was applied until the femur was damaged. During loading, the strain on the femur rotor nest (point 1), the femoral calcar (point 2), and under the femoral greater trochanter (point

3) were recorded and compared. The maximum stress was recorded when the femoral head collapsed and when the femoral neck was damaged.

Specimen fixation: The material test system was used to fix the femur. To simulate the state of double lower-limb standing, the femur shaft was fixed at the position of adduction 15° in the coronal plane by using an experimental machine fixture steel check.

Installation of pressure deformation strain slice: Resistive pressure deformation strain slice was posted on three points: the femur rotor nest, the femoral calcar, and under the femoral greater trochanter. Connecting wires were then used to establish a bridge to the computer.

Loading conditions: The material test system was used to continuously apply load to the top of the femoral head at a rate of 1.0 mm/min until the femur was damaged.

Experimental procedure: Step one involved the mechanical testing for the normal femoral head and neck group (group A). For group A, with five normal femoral head and neck specimens, the testing machine of the material test system was used to apply load step by step at the top of the femoral head until the femur was damaged. The pressure ranged from 0 N to 300 N. The strain on the trochanteric fossa, calcar femoral, and under the greater trochanter, as well as the maximum load, was recorded until the femoral head collapsed and was destroyed. Step two involved the mechanical testing for the interior supporting system and bone graft group (group B). Biomechanical testing was conducted on the five femoral head and neck specimens of group B by using the same method as that of group A. The values recorded in group A were also recorded in group B. Step three involved the mechanical testing for the tantalum rod group (group C). Biomechanical testing was conducted for the five femoral head and neck specimens of group C by using the same method as that of groups A and B. The values recorded in groups A and B were also recorded in group C.

Statistical analysis

Results were analyzed by SPSS18.0 statistical package. The *t* test was used for intragroup and

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Table 1. Comparison of the strain at three points of the femoral neck when loading to 300 N (n=5)

Groups	Trochanteric	Fossa calcar	Femoral under greater trochanter
A	100.27 ± 10.05	368.86 ± 30.00	123.23 ± 12.15
B	106.41 ± 10.20	428.62 ± 40.30	150.25 ± 15.10
C	181.87 ± 17.71*	365.84 ± 35.10	135.62 ± 13.20

*Comparison among groups. The strain value of C group was obviously higher than that of group A and group B, $P < 0.05$. Comparison between the other groups had no significant difference.

Table 2. Comparison of the maximum load when the femoral head collapsed and the femoral damaged

Groups	Femoral head collapse	Femoral damage
A	1783.44 ± 209.62	6536.74 ± 593.19
B	3907.50 ± 396.60*	5648.19 ± 479.04
C	2873.77 ± 319.70	5411.99 ± 503.06

Note: As to the comparison between groups when loading to femoral head collapsed, the maximum load value of B group was obviously higher than that of group A and group C, $P < 0.05$. And the comparison between groups when load to the femoral head damaged, each group has no statistical significance, $P > 0.05$.

intergroup comparisons. The statistical significance was defined as $P < 0.05$.

Results

Stress change

The stress changes on the different parts of the femoral neck varied. **Table 1** lists the strain on the trochanteric fossa, calcar femoral, and under the greater trochanter when the pressure is 300 N. The results showed that the strain value of C group was obviously higher than that of group A and group B ($P < 0.05$), and there's no difference between group A and group B. In group A, it is significantly higher than that in the femur rotor nest and big rotor ($P < 0.001$); the descending order of strain in group B is as follows: calcar femoral > under the big rotor > the femur rotor nest. The difference among the three parts is statistically significant ($P < 0.001$). The order for group C is as follows: calcar femoral > the femur rotor nest > under the big rotor.

Maximum load

Step-by-step loading was applied to the top of the femoral head until the femur was damaged.

The maximum load value of B group was obviously higher than that of group A and group C ($P < 0.05$), meanwhile, there's no difference between group A and group C (**Table 2**).

Discussion

Adult osteonecrosis of the femoral head results in partial blood circulation attributed to a number of negative factors. This condition causes further ischemia of bone cells, necrosis, bone breaks, and femoral head collapse. This disease can manifest at any age, but its highest incidence can be found within the age range 31 years to 60 years old. No gender difference was observed. In the beginning, most symptoms are associated with dull pain of the hip joint or around the joint, which increases after activity. Upon further development, the disease can result in hip dysfunction, affecting the patient's quality of life and labor capacity. The disease may cause permanent disability if left untreated.

The treatment of adult ischemic necrosis of the femoral head is mainly categorized as non-surgical and surgical treatment. Non-surgical treatment is suitable for adolescent patients because such patients have good potential ability to repair themselves during their growth and development period. As an individual grows with age, the body develops, and the pathological changes of the femoral head can often be improved to obtain satisfactory results. For adults, non-surgical treatment is suitable for patients whose pathological change is at stages I and II of Ficat [9, 10]. Non-surgical treatments mainly include drug therapy. Drug delivery methods include oral, injection, and intervention with preference for vasodilators, especially those that promote blood circulation to remove blood stasis of traditional Chinese medicine (TCM). The clinical curative effect of the treatment of femoral head necrosis aided by shock wave has recently been confirmed. Treatment of femoral head necrosis by shock wave can work instantly and can significantly reduce pain [10-14]. Hyperbaric oxygen therapy is also considered a type of noninvasive treatment. This type of therapy combined with other non-operative therapy or surgical treatment is one of the best choices of treatment of early avascular necrosis of the femoral head [15, 16]. With the development of molecular biology

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and the advancement of gene transfer technology, research on the use of various growth factors to promote angiogenesis and new bone formation in the repair process to treat ischemic necrosis of femoral head has made significant achievements; these approaches have been used in clinical treatment [17-20].

Surgical treatment is the main method for the treatment of ischemic necrosis of the femoral head. Operation methods vary, and each method has its own advantages and disadvantages. The choice of method mainly depends on the severity of the illness and the patient's age. Operating methods mainly include bone graft, bone marrow transplantation, vascular transplantation, reconstruction of the femoral head, pith decompression, and artificial hip replacement. Pith decompression is a common operating method used in the treatment of ischemic necrosis of the femoral head and is especially suitable for young patients with low degree of pathological changes. This method can effectively reduce the pressure within the femoral head, reduce hip pain, and help repair the blood supply of the femoral head without destroying the residual blood supply of the femoral head and without impeding future artificial joint replacement. Moreover, pith decompression is a simple operation with minimal trauma. However, postoperative femoral head collapse or aggravation is the main disadvantage of pith decompression [21]. Tantalum rod was used by Tsao et al to treat femoral head necrosis. Tantalum rod is a biological material with high porosity (> 80%) and has completely interlinked holes (average pore size is 430 μm). This material has high friction stability with bone and has a modulus of elasticity that corresponds to that of bone (3 GPa). The modulus of elasticity of this material can reduce stress accumulation. Tantalum rod is a structural material that is fully capable of withstanding physiological load intensity. Some clinical experiments show that the clinical effect of tantalum rod for early-stage femoral head necrosis is satisfactory. The post-operation success rate of tantalum rod is significantly higher than that of fibula graft. Moreover, tantalum rod induces less bleeding and has shorter operation and patient recovery time compared with that of fibula graft [22]. All these factors contribute to the increasing application of the tantalum rod [23-25].

Although many methods can be used for the treatment of ischemic necrosis of the femoral

head, the treatment effects are usually unsatisfactory. All patients eventually need artificial joint replacement. Considering the status quo of femoral head necrosis treatment, especially for young patients, we developed an interior supporting system within the femoral head to sustain the femoral head or reset the collapsed femoral head. To restore the mechanical properties of the femoral head and neck as well as the bone graft fusion of the femoral head and neck without interfering with future hip arthroplasty, we performed a bone graft under the femoral head to surround the interior supporting system.

This approach is a new mode of treatment for adult ischemic necrosis of the femoral head. By using a device that can cause the interior supporting system to open and close following the dowel of the heart column, we sent the interior supporting system to the position of avascular necrosis decompression via a small reduced pressure tunnel to support the femoral head or reset the collapsed femoral head. The open shore leaves of the interior supporting system, the function of which is similar to that of an open umbrella, that is, to expand the roof area of the device, will increase the support area for the femoral head. By using a triangular structure of the heart column, we performed a bone graft under the roof and beside the heart column. This system relies on the external thread of the closed set fixed in the interior supporting system to the bone tunnel, which can strengthen sinking resistance and prevent femoral head collapse. This method is a minimally invasive surgical treatment for the ischemic necrosis of the femoral head that can avoid postoperative femoral head collapse.

Fifteen normal adult femur specimens were randomly divided into three groups: control group (group A), interior supporting system group (group B), and tantalum rod group (group C). The strain and maximum load test indicates that the strain of this point when the interior supporting system and bone graft are performed is close to normal. No significant difference was observed among groups in other parts ($P > 0.05$). And so the strain differences among different groups indicate that from the perspective of strain, both the method of interior supporting system with bone graft and the tantalum rod with bone graft did not change the main anatomical structures of the femur neck. Although the normal biological mechanical per-

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formance of the femur neck cannot be recovered, both methods can recover close-to-normal function. Since the load is larger in group B than in groups A and C ($P < 0.05$), we supposed that the effect of the interior supporting system with bone graft against collapse after femoral head loading is better than that of the tantalum rod with bone graft. When the femoral head was destroyed, the maximum load of different groups was not different significantly ($P > 0.05$). This finding shows that the tunnel influences the bearing load of the femur, which functioning became close to normal after installation of the interior supporting system with bone graft and the tantalum rod with bone graft.

Conclusion

In conclusion, our study shows that the compression strain and bearing load of the femoral head are close to normal after placement of an interior supporting system and tantalum rod. The interior supporting system helps prevent femoral head collapse and provides a new method for the treatment of ischemic necrosis of the femoral head.

Acknowledgements

The study was funded by project from department of science and technology of Hunan Province, China.

Disclosure of conflict of interest

None.

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