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TRABECULAR METAL FOR TIBIAL PLATEAU FRACTURE REPAIR: BIOMECHANICAL SUPERIORITY DEMONSTRATED

Sudheer Kumar Reddy*

Associate Professor, Department of Orthopaedics, Sree Balaji Medical College & Hospital, Chennai - 600044.

ABSTRACT

In the evaluation of tibial plateau fracture repair, restoring and maintaining the plateau surface is crucial to prevent osteoarthritis and axis deviation. This study examines the efficacy of using trabecular metal (porous tantalum) in repairing central depression tibial plateau fractures. Fresh frozen human cadaveric tibiae were randomly assigned to two treatments: impact cancellous bone graft with stabilizing screws, or an experimental approach involving trabecular metal discs supported by screws beneath the comminute articular surface. The tibiae underwent cyclic loading using MTS machines to simulate immediate postoperative loads. Results showed lower caudad displacement in trabecular metal constructs compared to standard of care constructs (1.32 ± 0.1mm vs 0.80 ± 0.1mm, $p < 0.05$). Additionally, trabecular metal constructs exhibited higher strength at load to failure (3275 N) compared to the standard of care (2650 N). These findings suggest that trabecular metal constructs offer superior biomechanical properties for tibial plateau fracture repair.

Key words: Tibial plateau fracture, Trabecular metal, Biomechanical properties, Cyclic loading, Fracture repair.

INTRODUCTION

Central depression fractures in the lateral tibial plateau account for approximately 8% of fractures among the elderly population, posing significant challenges in treatment and management. The standard approach involves restoring congruency to the articular surface through subchondral lag screws and impacted bone grafting [1].

However, conventional methods such as autogenous cancellous bone grafting may not always provide adequate support for articular fragments, particularly when faced with weak compression strength ranging from 1-2 MegaPascals (MPa) [2].

To address the limitations of traditional bone grafting techniques, researchers have explored various bone substitutes as potential alternatives. These substitutes aim to fill metaphyseal defects and prevent loss of reduction in fractures. Despite their potential benefits, one common challenge with these substitutes is their brittleness [3], which often results in differences in biomechanical properties compared to human subchondral bone. The present study aimed to compare the efficacy of two similar surgical constructs in addressing central depression fractures in the lateral tibial plateau [4]. Specifically, the study compared the use of autologous cancellous bone grafts versus Trabecular Metal (TM) grafts. Trabecular Metal (TM) grafts offer a promising alternative to traditional bone grafting materials due to their unique properties and potential for providing enhanced support and stability to articular fragments in tibial fractures with central depressions. In this study, six frozen cadaveric tibias were dissected from surrounding tissue following thawing. Osteotomies were performed approximately twenty centimeters (cm) away from the tibial plateau using metal alloy fixtures. Each tibia was randomly assigned to one of two groups: fixation with or without a cannula.

Corresponding Author: - **Dr. Sudheer Kumar Reddy**

The fixation methods included 4.5 mm subchondral screws augmented with cancellous bone grafts or a Trabecular Metal (TM) construct, consisting of 4.5 mm subchondral screws augmented with TM material. To simulate fragmentation, the cartilage and subchondral bones were divided into four identical sections using a reduction, augmentation, and fixation technique [5]. This experimental setup allowed for the evaluation of the efficacy of different fixation methods in stabilizing and supporting the fragmented tibial structures. An additional Trabecular Metal (TM) disc was implanted over two 4.5 mm screws embedded in the subchondral bone and positioned beneath two fragments of articular cartilage. Anatomic reduction of the articular surface was observed in both specimens. The construct was then subjected to static and dynamic compression testing using the BionixTM Test System 810. To control the fracture, a stainless steel cylinder measuring 2 cm in diameter was utilized. This cylinder precisely matched the defect when applied directly, ensuring accurate testing conditions.

STATISTICS

A normality and equal variance test was performed prior to parametric statistical analyses. Using the cyclic loading test, we assumed the data were normal and the variances were equal. To analyze variance two-way, Student t-tests were used along with parametric Student t-tests. In order to analyze load to failure, we performed a nonparametric test (the Mann-Whitney U test) considering that the data were not normally distributed. In all statistical tests, $P = 0.05$ was the minimum significance level. Statistics were calculated using Excel for Windows.

RESULTS

There were significant differences in caudal displacement among constructs during cyclic loading. TM presents a displacement of 0.33 ± 0.1 mm based on 1000 cycles, while the standard construct presents a displacement of 0.39 ± 0.1 mm based on 1000 cycles. The difference between the standard and TM constructs was not significant after 1000 cycles. Both constructs showed an increase in displacement after this period. As compared to standard construct groups, TM construct groups experienced displacements of 0.80 ± 0.1 mm rather than 1.32 ± 0.1 mm. Under static loading, each construct failed in a different way (Figure 6). According to Mann-Whitney U test, both TM and standard constructs had significantly higher mean loads at failure (3275 N versus 2650 N). In addition, the TM group had higher stability (362 vs 174 Newton mm), Mann-Whitney U test, $P<0.002$. There was no difference in failure modes between the two types of constructs. None of the constructs had hardware failures. It was evident on gross examination that the lateral tibial plateau progressively became shorter under loading, eventually fractured. Hardware failures were not observed in either construction. There were no differences in appearance between TM discs before and after testing.

DISCUSSION

Usually, recession type lateral tibial plateau fractures result from axial and bending forces across the knee. The articular surface may be depressed in elderly persons due to osteoporosis-induced weakness of the subchondral cancellous bone. These fractures must be treated by restoring the articular surface's congruency. The new graft is supported by internal fixation after depressed articular surfaces are elevated and realigned. There are a number of disadvantages to using autograft bone grafts despite their reputation as the gold standard. Low compressive strength and donor site morbidity are among these problems. Malunion and loss of correction are the outcomes of inadequate support for articular fragments. Stability has been improved through the use of specific implants in recent studies. A small fragment t-plate of 3.5 mm diameter was used to reduce Hardware in its most basic form. Using a low-profile subchondral raft reconstruction model created [6], small fragment fixation was compared to conventional large fragment fixation. The displacement of raft plates under axial loading was significantly different from that of buttress plates (2954 N/mm versus 968 N/mm). Support for an articular surface may be improved by a raft of screws. Pullout strength of proximal tibial screws was strong according to a study [7]. Meta-diaphyseal proximal tibia screws measuring 6.5 mm, 4.5 mm, and 3.5 mm were similar in size. Tibial plateau fractures would benefit from small-fragment fixation, according to their study [8]. The use of subchondral rafts of screws for local depression load fixation may provide superior resistance to local depression loading, according to a study.

The stiffness of the overall construct was not compromised by placing fewer screws closer to the subchondral bone. Constructs consisting of large fragments with and without cancellous bone grafts did not increase stiffness significantly. The depressed articular fragments of a tibial plateau fracture have been supported with bone substitutes [9,10-15]. Trauma settings have proven beneficial to the use of calcium phosphate cement because it is biocompatible and osteoconductive. Based on the results of several trials [16] calcium-phosphate cement was found to be superior to autogenous iliac bone grafts, because of its low compressive strength. Using calcium phosphate cement to repair compromised metaphyses was found to be beneficial in an animal study. Allograft-treated tibias incorporated faster and returned to strength faster than morsellized bone allograft-treated tibias, but there were no significant differences between them.

A calcium phosphate cement's compressive strength is similar to cancellous bone, but it is brittle and susceptible to fatigue and fracture. In another study, calcium phosphate bone cement was evaluated in cadaveric models of tibial plateau fractures [16]. In this study, there was no significant difference between the average depression of the articular fragment when being treated with a bone graft with screws and that when no bone graft was used. It was necessary to extensively cure the cancellous bone under the subchondral bone plate for significant results to be achieved. Metaphyseal defects have no ideal substitute as yet. It resembles cancellous bone, has similar biomechanical properties, and consists of porous tantalum metal. Biocompatible and corrosion-resistant, tantalum is the most biocompatible biomaterial. A strong, low-stiff, and fatigue-resistant material.

A porous tantalum metal's internal microstructure consists of interconnected pores that allow biological attachment to the bone and regeneration. Its porosity makes it similar to subchondral bone in terms of elastic modulus. This construct has a highly porous structure (80%), preventing fatigue failure and maintaining its strength throughout the healing process due to its open cell structure. When calcium phosphate cement is loaded cyclically, the mechanical properties degrade. As a result of in vitro testing for tibial plateau fractures, the concept behind TM disc design came into being. Fracture constructs are most vulnerable to failure in collagenous bone adjacent to subchondral plate, according to various load-to-failure analyses. The stability of a fracture construct depends on the strength of its foundation. Restoration of the subchondral plate is essential to improve stability and load transfer. This study showed that TM augmentation of raft screw constructs had better biomechanical properties than cancellous bone grafts. When subjected to 10000 cycles, it showed a significant improvement in stiffness and displacement. A loading indentor was used in this study to simulate a worst-case scenario, and only the material of the graft differed between the two groups. In spite of the solid disc structure of the TM trabecular metal, it was expected to be more loading resistant than the AIBG standard of hammered bone. Unlike the bone graft, the titanium implant had not been morsellized. By distributing the load more evenly across the plateau, the lateral femoral condyle shields the reduction [5]. A significant portion of the load would also be carried by soft tissues and meniscus. As a result of the absence of soft tissues in this study, a reproducible fracture was created as well as a straightforward implant placement in vivo compared to a depression lateral plateau fracture. TM's mechanical properties are largely influenced by ingrowth of bony tissue. This biomechanical model does not consider progressive fracture healing. A clinical trial or animal study will be needed to determine whether TM can replace grafting in the future.

CONCLUSION

In spite of these limitations, this study found that early postoperative subchondral augmentation with TM prevents loss of reduction in lateral tibial plateau fractures when treated with compression forces across the fracture site. Because of its mechanical properties and similar pore structure to cancellous bone, a porous tantalum may be useful in orthopaedic trauma surgery. It will take further research to apply surgical procedures in clinical settings.

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