学 位 論 文 の 要 旨

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学位論文名　Bone Screws Have Advantages in Repair of Experimental Osteochondral Fragments

発表雑誌名　Clinical Orthopaedics and Related Research
Published online: 12 November 2011

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論 文 内 容 の 要 旨

INTRODUCTION

Intraarticular fractures may progress to secondary osteoarthritis if resurfacing of articular cartilage is not well accomplished. When intraarticular osteochondral fragments are fixed to the original site, fixation devices such as pins or screws are inserted through the articular cartilage to subchondral bone. Therefore, cartilage defects are created on the fragments at the entrance holes of the devices. Conventional fixation devices hinder repair of these defects and there is a latent risk of secondary osteoarthritis. In clinical settings, poly-L-lactic acid (PLLA) pins have been used for fixation of detached osteochondral fragments. However, several complications with PLLA pins or screws have been reported, including foreign body reaction, osteolysis, or loosening. To overcome these problems, we developed a novel fixation device system for osteochondral fragments: bone screws made of cortical bone using a precision machine. We hypothesized cartilage defects on osteochondral fragments are not well repaired when fixation devices made of PLLA are used, but in contrast, devices made of bone will improve the repair of the cartilage defects. The specific aims of this study were to compare (1) gross assessment of the surface, (2) volume and histologic quality of the repair tissue, and (3) biomechanical assessment of the tissue stiffness between PLLA and bone screws.

MATERIALS AND METHODS

We manufactured headless bone screws (2.50 ± 0.01 mm diameter, 12 mm length, 1 mm pitch) from the compact bone of male Japanese Black cattle, using a numerically controlled lathe (MTS4Q; Nano Wave, Yokohama, Japan). As control materials, we also manufactured screws of the same size and shape from PLLA cylinders. We examined gross morphology, microCT, histology, and stiffness of the repaired tissue with PLLA (Group P, n = 32) and bone (Group B, n = 32) screws in a rabbit model of osteochondral fracture, compared with normal controls (Group N, n = 16).

The gross morphologic condition of the surface of the repaired defects was evaluated according to the classification system described previously (Grades 1–4). MicroCT was performed using a TOSCANER-30900μC3 (Toshiba IT & Control Systems Corp, Tokyo, Japan). First, we measured cartilage volume (%) of the repaired tissue and surrounding cartilage in Groups P and B. Second, bone volume fraction was measured at the subchondral space of the repair site of Groups P and B. After microCT assessment, ½ of the specimens underwent histologic evaluation with toluidine blue O staining. We performed biomechanical testing on the remaining ½ of the specimens using an Instron 5565 testing machine (Instron Worldwide Headquarters, Norwood, MA, USA). The stiffness of repaired tissue and surrounding cartilage was tested on each screw hole.

RESULTS AND DISCUSSION

In gross morphologic evaluations, overt fibrillation (Grade 3) was observed in 14 of 32 from Group P and only three of 32 from Group B. Three of 32 from Group P showed erosion (Grade 4), but 0 of 32 from Group B showed erosion. The distributions of repaired scores were worse ($p = 0.0001$) in Group P than in Group B. In microCT evaluations, the repaired volume in Group P was smaller ($p < 0.0001$) in Group P than in Group B (mean, 50.3% versus 70.6%). The surrounding volume tended to be smaller ($p = 0.1494$) in Group P than in Group B, although it was not significant (mean, 80.0% versus 86.8%). Bone volume fraction at the subchondral space was lower in Group P than in Group B (mean, 20.5% versus 54.9%; $p < 0.0001$) and Group N (mean, 20.5% versus 66.2%; $p < 0.0001$). No differences ($p = 0.1628$) were found between Groups B and N. In histologic evaluations, most of the repaired tissues in Group P were composed of fibrous tissue with little subchondral bone repair, and degeneration of the cartilage layers was found in the surrounding area. Conversely, in Group B, the repaired tissues contained hyalinelike cartilage, including chondrocytes and proteoglycan matrix, and the subchondral bone tissues were almost totally regenerated. In biomechanical testing, the stiffness at the repaired tissue was lower ($p = 0.0001$) in Group P than in Group B (mean, 1.67 N/mm versus 2.63 N/mm). Although there were no differences ($p = 0.1891$) in the stiffness of the surrounding cartilage between Groups P and B (mean, 2.44 N/mm versus 2.88 N/mm), stiffness was lower ($p = 0.0046$) in Group P than in Group N (mean, 2.44 N/mm versus 3.15 N/mm), but no differences ($p = 0.6130$) were detected between Groups B and N (mean, 2.88 N/mm versus 3.15 N/mm).

Our results demonstrated that materials made of bone were more advantageous than PLLA for the repair of cartilage and subchondral bone both in quality and quantity. PLLA devices have no osteoinductive potential and their osteointegrative properties are thought to be limited, and it was reported PLLA devices were not completely replaced by bony tissue years after the operation. PLLA has other latent disadvantages, including foreign body reaction and osteolysis. These characteristics of PLLA might contribute to the limited cartilage repair observed.

In contrast, bone screws have osteoinductive potential because they include bone morphogenetic protein (BMP) in the bone matrix. Owing to this property, subchondral repair might be promoted with bone screws. As a secondary result, well-repaired subchondral bone also might help maintain repaired chondral tissue. Stiffness of the osteochondral complex with bone screws showed a value close to normal stiffness because cartilage and subchondral bone were repaired sufficiently. The suppression of degeneration of the surrounding cartilage adjacent to the defect site with bone screws was unexpected. We suggest edge effects attributable to the chondral defects were decreased because of maintenance of repaired chondral tissue at the defect site and degeneration of the surrounding cartilage tissues therefore might be prevented.

There were certain limitations to this study. It was unclear whether chondral defects at the osteochondral fragment have clinical significance because there are few clinical reports in which such a small defect was observed for a long time. However, the degenerative changes of the surrounding cartilage might imply potential osteoarthritis after several decades. Therefore, even a small defect of the cartilage theoretically should be treated.

There have been some clinical reports of the use of bone screws for osteosynthesis after mandibular correction osteotomy or osteochondral fracture. Precision machines such as the MTS4Q are available so we can easily process bone materials into screw forms. Therefore, clinical treatments using bone screws should be technically uneventful.

On the other hand, the amount of autologous bone available for harvesting is limited so it would be ideal if artificial materials could be substituted for bone materials in the future. Artificial devices containing beneficial functions, as is shown with the bone screws in our experiment, still need to be developed. Additional studies are required to clarify the essential functions supplied by bone materials. The experiments reported here show devices with biologic function can promote repair of the joint surface.

CONCLUSION

Our results show better repaired tissue was observed for quality and quantity when chondral fractures were treated with bone screws than when treated with PLLA screws. Bone screws made of cortical bone may have applications in clinical situations for the fixation of intraarticular osteochondral fragments.