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Hexagonal grafts in mosaicplasty: Biomechanical comparison of standard cylindrical and novel hexagonal grafts in calf cadaver model

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ABSTRACT

Objective: Cylindrical grafts are currently used to cover defected area in mosaicplasty. However, there are some difficulties with cylindrical grafts, such as potential dead space between grafts and insufficient coverage. Hexagonal graft (honeycomb model) was created and evaluated in this biomechanical study. Hypothesis was that harvesting grafts with hexagonal shape, which has the best volume geometry characteristics in nature, would be biomechanically advantageous and provide superior pull-out strength.

Methods: Total of 24 fresh calf femurs were divided into 3 equal groups. In the first group, 1 cylindrical and 1 hexagonal graft were compared. Second group consisted of 3 cylindrical and 3 hexagonal grafts. Third group was designed to evaluate effect of graft depth; hexagonal graft implanted at 5 mm depth was compared with 20-mm-deep hexagonal graft. All specimens were subjected to pull-out test. Friction field and graft surface area were also evaluated.

Results: Pull-out strength comparison of 15-mm-deep triple cylindrical grafts and 15-mm-deep triple hexagonal grafts in second group revealed statistically significant difference in favor of hexagonal grafts ($p < 0.05$). Surface area of cylindrical graft with 9-mm diameter was calculated to be 50.27 mm^2, while hexagonal graft surface area was 55.425 mm^2. Volume ratio of cylindrical and hexagonal grafts was 753.98 mm^3 and 831.375 mm^3, respectively.

Conclusion: This biomechanical study demonstrated that graft geometry, especially in multiple graft applications, is a factor that influences stability. Hexagonal grafts appear to be more stable than cylindrical grafts in multiple applications, and they may be used to cover a larger defected area.

The treatment of injuries to articular cartilage, which has very low potential for spontaneous repair, is a challenging problem for orthopedic surgeons.[1] Several techniques, including abrasion arthroplasty, drilling, and microfracture, have been described to repair articular defects in weight-bearing areas of the knee.[2–4] However, these techniques have led to fibrocartilage formation rather than normal articular hyaline cartilage.[5] As a result, new procedures for hyaline cartilage transplantation and grafting techniques have been developed, such as autologous chondrocytes, osteochondral allografts, and mosaicplasty (i.e., autologous osteochondral transplantation).[6,7]

Satisfactory results can be obtained with autologous osteochondral transplantation, especially in combined injuries associated with subchondral bone. In this technique, described by Hangody, grafting is performed by transferring 1 or more cylindrical osteochondral autografts from low weight-bearing area of the knee to defective weight-bearing site.[8] Along with alignment of the affected lower extremity, age of the patient, and size and location of defect, filling rate of defected area also plays an important role in long-term outcomes.[9] This is a technically demanding procedure; matching size and radius of curvature of cartilage defects can be difficult, and some problems may arise due to complications, such as creating potential dead space between grafts and insufficient covering of defected area.[10–12] Several technical or surgical problems have been pointed out in the literature regarding clinical and experimental use of autologous osteochondral transplantation with cylindrical grafts, including poor or inadequate graft fixation and graft movement (suggesting

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poor fit), depending on graft diameter and dilation, as well as multiple grafting,[13] joint instability, donor host-graft size mismatch, and contour incongruence.[14]

To overcome such complications, hexagonal grafts (honeycomb model) can be used instead of standard cylindrical grafts. Aim of the present study was to evaluate and compare hexagonal grafts and standard cylindrical grafts in terms of graft stability and capacity to fill potential dead spaces. Hypothesis of the study was that use of hexagonal grafts in mosaicplasty would provide enhanced graft stability as result of having best occupying area and volume geometry characteristics in nature.

Patients and methods

Experiments were performed using standard cylindrical osteochondral autograft transfer system and hexagonal graft system on 24 fresh, left distal femora with both condyles obtained from calves weighing between 200 kg and 400 each. None of the samples had macroscopic cartilage injury, and soft tissues were cleaned. Samples were divided into 3 groups, each consisting of 8 distal femora (Fig. 1). Hexagonal graft receivers and tunnel-opening tubes were prepared. For each cylindrical graft, 8-mm-diameter cylindrical tunnel was prepared using tunnel-opening tubes on the medial condyle load-bearing area at desired depth as described below. Similarly, 8-mm-diameter hexagonal tunnel on lateral condyle load-bearing area was also prepared for each hexagonal graft. Grafts were harvested from peripheral and superior aspects of each femoral condyle and not from the trochlea. During hexagonal graft harvesting, hammer was used to push chisels into bone to desired depth and bone plug was detached at its base with axial turning of the chisel 45° clockwise and counterclockwise. No bony bridge was maintained between grafts. Cylindrical grafts were harvested with 90° axial turns in both directions. Graft was then inserted into recipient defect directly from donor chisel. The 3 study groups used to compare results were as follows:

First group: One cylindrical graft from lateral anterior articular surface, and 1 hexagonal graft from medial anterior articular surface of the trochlea were harvested, each 15 mm deep and 9 mm in diameter. Cylindrical graft was transplanted to medial condyle load-bearing area, and hexagonal graft was applied to lateral condyle load-bearing area in each femur (Fig. 2).

Second group: Triple cylindrical grafts from lateral anterior articular surface and triple hexagonal grafts from medial anterior articular surface of the trochlea were harvested, each 15 mm deep and 9 mm in diameter. Cylindrical grafts were transplanted to medial condyle load-bearing area and hexagonal grafts were transplanted to lateral condyle load-bearing area in each femur (Figs. 3 and 4).

Third group: A 5-mm-deep hexagonal graft from lateral anterior articular surface and 20-mm-deep hexagonal graft from medial anterior articular surface of trochlea were harvested, each 9 mm in diameter. Hexagonal graft from 5-mm-deep site was implanted to medial condyle load-bearing area and hexagonal graft from 20-mm site was applied to lateral condyle load-bearing area in each femur.

Grafts in each group were harvested from non-weight-bearing area of lateral anterior articular surface and medial anterior articular surface of the trochlea. Nine-mm-diameter cylindrical grafts were transplanted press fit to 8-mm cylindrical tunnels. Similarly, 9-mm-diameter hexagonal grafts were applied press fit to 8-mm hexagonal tunnels.

After application of the grafts, screw hooks of 5 mm in length and 2 mm in diameter were manually anchored in center of grafts after creating entry point with 2-mm Kirschner wire. Hooks were then subjected to pull-out test at rate of 20 mm/min using computer-assisted Shimadzu Autograph AGS-X 10 Kn universal testing machine (Shimadzu Corp., Kyoto, Japan) (Fig. 5). Three evaluations were conducted:

1) Pull-out data of cylindrical and hexagonal grafts in the 3 groups were compared. In the second group, test was conducted for only 1 of the 3 grafts. Additionally, pull-out data of 15-mm-deep single cylindrical graft in first group and 5-mm-deep single hexagonal graft in third group were compared.
2) Cylindrical and hexagonal grafts in first and second groups were compared in terms of friction field, which was obtained with geometrical calculation of lateral and base area of each geometric shape. Influence of friction field on stability was evaluated.

   For cylindrical grafts, calculation used was:

   Height (h): 15 mm, diameter (d): 8 mm
   Lateral surface area: $2\pi rh$: 376.99 mm^2
   Surface (or base) area: $2\pi r2$: 50.27 mm^2
   Lateral surface area + base area (total friction surface): $2\pi rh + 2\pi r2$: 376.99 + 50.27: 427.26 mm^2
   Volume: base area × h: 753.98 mm^3

   And for hexagonal grafts:

   Height (h): 15 mm, length of 1 edge (a): 4.618
   Lateral area: 6ah: 415.692 mm^2
   Surface (or base) area: 6 (ah/2): 55.425 mm^2
   Lateral area + base area (total friction surface): 6ah + 6 (ah/2): 471.117 mm^2
   Volume: base area × h: 831.375 mm^3
3) Graft surface area (cartilage surface) of cylindrical and hexagonal grafts in first and second groups was evaluated by calculating base area and volume of each geometrical shape as described. Coverage ratio of defected area was assessed by comparing volume of each graft to surface area.

Statistical analysis

Mann–Whitney U test was used to evaluate significance of differences between groups using SPSS statistical software (version 15.0; IBM Corp., Armonk, NY, USA).

Results

Pull-out strength comparison between 15-mm-deep cylindrical graft and 15-mm-deep hexagonal graft in the second group revealed significant difference in favor of triple hexagonal grafts ($p < 0.05$). Differences between first and third groups were statistically insignificant ($p > 0.05$) (Table 1).

In the first and second groups, surface area (cartilage surface) and volume ratio of cylindrical and hexagonal grafts were calculated to evaluate coverage of defected space. Surface area of 15-mm cylindrical graft was 50.27 mm^2, while 15-mm hexagonal graft surface area was calculated to be 55.425 mm^2. Respectively, volume ratio of cylindrical and hexagonal grafts was 753.98 mm^3 and 831.375 mm^3 (Table 2).

Discussion

In the present study, multiple hexagonal grafts were found to be stable as result of ability to cover larger defects without dead space between grafts. Our results demonstrated that hexagonal grafts are biomechanically superior to cylindrical grafts, particularly in