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CAN OSTEOCHONDRAL GRAFTING BE AUGMENTED WITH MICROFRACTURE IN AN EXTENDED SIZED LESION OF ARTICULAR CARTILAGE

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Abstract

BACKGROUND—Both microfracture and osteochondral autografting procedures have been useful in treating osteochondral lesions.

HYPOTHESIS—Combining microfracture and osteochondral autografting procedures can extend the size of lesions which can be treated with either technique.

STUDY DESIGN—Descriptive laboratory study.

METHODS—Eight adult goats underwent osteochondral autograft transfer of a 4.5mm femoral trochlea plug into an 8mm full thickness chondral defect in the weight bearing portion of the medial femoral condyle. In the gap region surrounding the autograft, microfracture was performed. The animals were allowed normal activity until the end of the experiment at 6 months, at which time the knees were harvested. At harvest the knees were assessed grossly, and then evaluation was performed by histology and histomorphometry, biochemistry and biomechanics. One animal died at 6 wks from gastroenteritis.

RESULTS—The osteochondral plugs healed well, with integration of the bone and preservation of the chondral cap. The chondral gap between the host site articular cartilage and the transferred plug had decreased from 3 mm at implant to less than 0.1 mm. Histological analysis demonstrated regions of variable cartilage repair, with integration of the cartilage layer at some sites but incomplete healing at others. Histomorphometry demonstrated filling of the chondral gap to 75–85% of the normal volume. Biochemical analysis revealed greater than 90% type II collagen at most sites with some areas containing 80% type II collagen. Biomechanical indentation testing, indicated that the repaired area had variable thickness and stiffness, with a trend of increased stiffness in the bulk graft and decreased softness at the proximal microfracture interface site.

CONCLUSIONS—The performance of a combined microfracture and osteochondral autograft transfer (OATS) procedure to resurface a large chondral defect appears promising. Transferred cartilage tissue can successfully be incorporated into a large recipient defect, and microfracture of

the surrounding bone can lead to a repair process which remains variable. Attempts need to be made to improve consistency of the repair process. This is a potential treatment option for large chondral defects which does not require a large area of autogenous tissue to be harvested.

CLINICAL RELEVANCE TO SPORTS MEDICINE—This combined technique shows promise for treatment of large chondral defects with a single operative procedure with autogenous tissue which is safe, and potentially would have a shorter period of rehabilitation, similar to that of osteochondral transfers and microfracture in a cost effective setting.

Keywords

Articular cartilage repair; osteochondral allograft; microfracture; knees

INTRODUCTION

Articular cartilage repair and regeneration continues to be an area of controversy, as there have been many treatment options proposed to resurface defects of various areas and sizes. None of these treatment options has received universal acceptance as a cost-effective treatment option to provide reliable long term function similar to hyaline cartilage. A global approach has been advocated in assessing cartilage restoration, as resurfacing procedures are now being combined with adjunctive procedures such as osteotomy³⁶ to correct abnormal biomechanical forces which would cause premature failure of the cartilage restorative procedure.

Partial-thickness defects are principally treated with debridement and lavage, with removal of unstable articular cartilage flaps.⁷ Further treatment of these partial-thickness defects, however, is sometimes necessary due to failure of the initial debridement or lavage procedures, and at that time treatment of these partial-thickness defects mirrors the dilemma of full-thickness defects.

Treatment of full-thickness defects has undergone many changes over time, with debridement being offered for small defects with stable edges. Additional options for treating small full-thickness cartilage defects less than 2 cm² have proliferated. Abrasion arthroplasty was a popular treatment initially,^{8,16} but does not appear to have the same enthusiasm as when initially proposed, and its use was more widespread. Steadman et al. have popularized the use of microfracture, and long-term studies have shown that good long-term function can be obtained in patients less than 45 years of age.^{3,33,34} Other authors, however, have demonstrated that the results of microfracture are inferior in higher demand patients and the results deteriorate over time.^{11,24} Optimal defects are those that are smaller with intact shoulders, which appear to help protect the regenerative tissue. For this reason, microfracture is usually limited to defects that are less than 2 cm².^{11,24}

Osteochondral autograft transfers have been shown to provide excellent function, either with transfer of a single plug or with a combination of multiple plugs in a mosaicplasty pattern, in greater than 90% of patients.^{6,14,15} The limiting factor for resurfacing large defects in these instances is the lack of available donor articular cartilage, as it is harvested from the edges of the patellofemoral joint, the peri-notch area or the sulcus terminalis. Due

to difficulty matching the topography of matching recipient and donor joint surfaces, the amount of tissue that can be successfully transferred in most surgeons' hands is limited to less than 2 cm². This is part of the reason these larger lesions have been treated with allograft tissue, as one can obtain resurfacing with hyaline cartilage but the limitation of donor tissue is no longer present. This raises the issues of availability of allograft tissue, disease transmission and cost of the graft. In the United States, allograft tissue has been readily available and has become a popular method of treating larger defects.^{4,5}

Autologous cell implantation is the other major treatment available for larger defects and, similar to allograft, has been shown to be effective in creating a hyaline-like articular surface which matures over a two-year period and develops functions similar to normal articular cartilage.^{29,30}

Algorithms have been developed which have characterized these treatment modalities, and the dividing size between large and small lesions has been set at approximately 2 cm². In reviewing these guidelines, it is noted that few treatment options are available for the larger defects, and these treatment options can be limited by the availability of donor tissue or by cost as allograft tissue is not available on a universal basis. The cost of autologous cell implantation can limit the ability to be used in certain clinical situations.

As a result, we elected to study a new treatment possibility in which two treatment modalities are used which combine advantageous characteristics of the two different techniques: 1) Osteochondral autograft transfer system (OATS) procedures are very effective in producing a joint surface with relatively normal joint biomechanics, but are limited in the amount of tissue that can be transplanted. 2) Microfracture is limited by type of lesion, as it is most effective in defects which have good shoulders and are relatively smaller due to a lower capacity to resist compressive forces. The combination of these two techniques could therefore potentially combine methods which could compensate for the deficiencies of the other. The osteoarticular transfer would allow a normal area of cartilage to be transplanted into a larger chondral defect, and a microfracture of the surrounding area may allow hyaline-like cartilage to form and resurface tissue, potentially allowing healing of the edge of the plug to the surrounding microfracture tissue with integration into normal articular cartilage. This could be done with a minimum amount of tissue transferred, and could allow larger defects to be resurfaced in this combination technique rather than by either method alone.

MATERIALS AND METHODS

Surgical procedure

Eight mature goats were used for this study. All procedures conformed to the guidelines of our University's Animal Subjects Committee and the American Association for Accreditation of Laboratory Animal Care. After a period of habituation, the animals underwent general anesthesia with intubation, were given perioperative antibiotics, and a unilateral arthrotomy of the right hindlimb stifle joint was performed.

The medial femoral condyle and femoral trochlea were exposed and an 8 mm in diameter chondral defect was created from the central aspect of the medial femoral condyle using a curette. The articular cartilage was removed down to and including the calcified cartilage layer. The size of the defect was approximately 50% of the width of the medial femoral condyle, which measured between 16–20 mm in these animals.

A 4.5 mm in width Mosaicplasty set (Smith and Nephew, Andover MA) was used to harvest an osteochondral core from the lateral aspect of the femoral trochlea. The osteochondral plug was approximately 10–12 mm in length. After harvest it was maintained in sterile gauze, soaked with saline, until implantation into the medial femoral condyle. After measuring the length of the plug, the 4.5 mm drill from the mosaicplasty set was used to create a central bone defect in the area of the chondral defect in the medial femoral condyle of the same depth. A tamp was used to ensure the osteochondral plug would fit, and the graft then transferred to the recipient site. Minimal force was applied to insert this into the recipient socket. The donor site in the lateral aspect of the femoral trochlea was left open following harvest of the osteochondral plug.

Following successful seating of the osteochondral plug in the recipient site, six sites were chosen in a circular pattern around the osteochondral plug to penetrate the subchondral bone plate with a 0.62 K wire (Figure 1). The area was inspected to determine if bleeding occurred following the microfracture technique.

At the end of the operative procedure, the joint was irrigated and the arthrotomy site repaired. Perioperative antibiotics were continued and postoperative analgesia was provided. The goats were maintained in a small cage for two weeks and were kept in a modified Schroeder-Thomas splint (non-weight bearing) for two weeks, thereafter were allowed a free-range environment for six months.

Six months following the operative procedure, the animals were sacrificed (one died during the study due to a gastrointestinal infection) and the knee joint harvested. All knee joints were inspected for gross evaluation of the articular cartilage and synovium. Grading of the articular cartilage surfaces was done, evaluation of the integration of the osteochondral plug into the medial adjacent cartilage area in the medial femoral condyle was performed, and integrity of the microfracture tissue was also evaluated.

All joints were assessed grossly for repair of the defect and for integration of the donor/recipient osteochondral plug. Following gross assessment, the joints of all sacrificed animals were divided for qualitative and quantitative analysis. Three joints were evaluated both histologically (toluidine blue for glycosaminoglycan and McNeal's for cellular detail) and histomorphometrically, to assess the contour of the recreated medial femoral condyle and filling of the defect. Biochemically we assessed two joints for types of collagen (i.e. types I and II) from the filling tissue in the defect (i.e. trochlea and femur). Tissue was obtained from the central part of the plug as well as adjacent tissue. Biomechanical studies on two joints were also performed by indentation testing.

Histological procedure

The cartilage/bone specimens sized to 4 cm × 2.2 cm × 1 cm (thickness) were placed in 10% buffered neutral formalin with 1% Cetylpyridinium Chloride at the time of harvest. The specimens remained in the fixative for 96 hours. After the cartilage/bone was completely fixed the specimens were dehydrated with ascending alcohol grades: 70% (2 changes), 95% (3 changes) and 100% (3 changes). The specimens were then embedded in a three-step MMA process: Step 1 is 100% MMA; Step 2 is 95% MMA with 5% n-butyl Phthalate; and Step 3 is 95% MMA with 5% n-butyl Phthalate and .5% Perkadox 16. After polymerization, the excess MMA was trimmed from the specimens. Sectioning was on the sagittal plane at 1.0 mm per slice on a Buehler Isomet slow speed saw. Two sections per specimens were cut and then glued to a translucent Plexiglas slide using Loctite® 495. The slides were allowed to dry at room temperature, and the sections were then ground down and polished to approximately 50 µm on a Buehler Isomet III grinder. The sections were stained with McNeal's tetrachrome stain and toluidine blue. Hematoxylin and eosin will not stain tissue embedded in methacrylate; therefore, McNeal's tetrachrome stain was used instead. Bone was stained a reddish/purple, nuclei was stained blue, cartilage was stained a blue/purple, and connective tissue was stained pinkish/red. Toluidine Blue stain was used to demonstrate glycosaminoglycans: bone and cartilage were stained blue, glycosaminoglycans were stained deep violet.

Histomorphometric procedure

Surface profiles of the articular cartilage surface and subchondral bone contour were studied from histologic samples; a computer program was used to calculate the ideal profile for the femoral condyle area.¹³

Biochemical procedure

Quantitative collagen typing analysis was performed on tissue specimens following removal of proteoglycan with guanidine hydrochloride and partial hydrolysis of the residue with cyanogens bromide as follows.² Freshly dissected tissue was washed in water overnight and lyophilized. Three mg of dried tissue was suspended in 4 M guanidine-HCl and digested overnight at 4° C. The contents were centrifuged and the undissolved pellet washed with water and suspended in 5 ml of 70% formic acid. Cyanogen bromide was then added and digestion carried out with stirring at 35–40° C for 5 hours. Water was added to the digest and the diluted solution lyophilized. After lyophilization the digest was desalted on a column of Bio-Gel P-2 to remove non-protein molecules. HPLC separation and quantitation of the cyanogen bromide peptides was accomplished by gel filtration HPLC. Peptide peaks were monitored by absorbance at 220 nanometers. Purified types I and II collagen isolated from goat tendon and articular cartilage, respectively, were utilized as standards of comparison.

Biomechanical procedure

Indentation biomechanical testing was performed *in situ* on the distal medial femoral condyle using methods similar to those described previously.^{7,28} but at multiples sites. Briefly, a 0.4 mm diameter plane-ended indenter was positioned at the center of the

osteocondral core as a reference. Indentation was then performed at 0.5 mm intervals in the proximal-distal and medial-lateral axes to positions 2 mm outside of the repair region (Figure 2). At each site, a set of three 100 μ m indentations were applied. Sites at analogous locations were tested on the contralateral control knees. Along each axis (medial-lateral, proximal-distal), 19 sets of three measurements were made for each knee. Three sites were typically outside of the experimentally created defect on the adjacent host cartilage (AHC), one site was in the microfracture interface region, and a set of sites were at the bulk of the transplanted osteochondral core (OC). Throughout the testing, each knee was kept moist with phosphate buffered saline supplemented with proteinase inhibitors. After indentation testing, osteochondral cores containing the repaired area were isolated, split in half, and imaged, and the cartilage thickness of each region was determined by digital imaging. At each location (AHC, microfracture, OC), the peak load was determined, and then normalized to the applied 100 μ m indentation and the thickness to obtain a normalized indentation stiffness (MPa).

RESULTS

Gross Morphology

One goat was sacrificed at nine weeks post-surgically due to a gastrointestinal malady; the joint was harvested and evaluated. The joint did not show significant degeneration, and there was partial filling of the area around the osteochondral transfer. The donor site had filling of the defect in the femoral trochlea.

The remaining goats were evaluated six months following the cartilage repair procedure. One of the joints demonstrated mild degenerative changes, and the remaining knees showed no significant degenerative changes. All the experimental knees had evidence of healing at both the femoral and trochlear surgical sites, with restoration of the articular surface in the femoral trochlea where the osteochondral plug was harvested. The subchondral bone had reformed and fibrocartilage covered the area. The recipient site of the osteochondral transfer/microfracture showed healing of all plugs with rigid fixation into the subchondral plate. The cartilage cap remained in place, with no evidence of delamination or loss of articular cartilage thickness. One of the knees showed complete reformation of the area surrounding the osteochondral core. With a fibrocartilage layer filling the entire volume of the cartilage defect, five of the knees had partial repairs. Some of the 3 mm gaps had healed with normal fibrocartilage height; other areas had decreased tissue volume repair. No area was seen to be completely devoid of articular cartilage in the gap between transferred plug and surrounding host cartilage (Figure 3).

Histology

Histological assessment showed healing of the subchondral bone at six months post-sacrifice, normal-appearing subchondral plate and no evidence of nonunion. Articular cartilage showed partial healing of the osteochondral transfer cartilage to the microfracture fibrocartilage and into adjacent host cartilage (toluidine blue stain); clefts were noted in some areas, with a gap $\sim$ 0.04–0.17 mm (Figure 4A–D). In some adjacent host cartilage there was some loss of GAG content adjacent to the repair site. The trochlear defect healed well,

with integration of the host cartilage into the fibrocartilage repair of the defect (Figure 5A,B).

Histomorphometry

Histomorphometry on two knees assessed reformation of the femoral condyle contour. Seventy-five to 80 percent of the defect between the 4.5 mm osteochondral transfer and the edge of the 8 mm chondral defect was filled with cartilage, showing that a substantial amount of cartilage had re-grown in the defect (Figure 6).

Biochemistry

Biochemical evaluation was performed of the tissue at the center, periphery and outside the operative sites in both the femoral condyle repair site and trochlear donor site. Collagen typing was performed on the cartilage tissue. In one knee, 90% of the cartilage had type II collagen in all sites. In the other knee, 80–90% type II collagen was found. In both trochleas outside the donor sites and the trochlear peripheries, >90% type II collagen was found. In one knee, the trochlear center of the donor site showed 80% type II collagen and 20% type I collagen, while the other knee showed 90% type II collagen. Both knees showed >90% type II collagen in the medial femur outside the donor site and in the medial femoral periphery of the donor site. The medial femoral center of the repair site on one knee showed 80% type II collagen and 20% type I, while the other showed >90% type II collagen.

Biomechanics

The thickness and indentation material stiffness of the cartilage and repair tissue varied with region. The thickness of articular cartilage of the central OC region was 0.66 ± 0.19 mm, substantially less than the 1.18 ± 0.09 mm of native tissue in that region (Figure 7A). The thickness of the cartilaginous tissue in the microfracture region also appeared to be less than normal (0.72 ± 0.44 mm and 1.20 ± 0.19 mm).

The indentation material stiffness also varied with region (Figure 7B). In the experimental knees, the stiffness of the AHC region (5.2 ± 3.0 MPa) tended to be lower than that in region-matched control knees (7.7 ± 2.7 MPa), as well as that from the microfracture and OC regions of the control knees (8.7 ± 3.1 MPa and 9.1 ± 2.0 MPa, respectively). The material stiffness of the microfracture region (3.4 ± 2.3 MPa) tended to be lower than all experimental and control regions, while the central OC region (9.0 ± 4.0 MPa) appeared similar to that of control cartilage. When individual regions were further analyzed, the material stiffness of the AHC and microfracture regions appeared to have location-associated variations. In the AHC of the control knees, the material stiffness appeared to be highest in the lateral and proximal regions, and lowest in the medial and distal regions (Lat: 9.3 ± 2.5 MPa, Prox: 9.1 ± 3.9 Pa, Med: 5.7 ± 3.2 MPa, Dist: 6.8 ± 1.2 MPa). In the experimental knees, the material stiffness appeared to be highest in the medial and lateral regions, and lowest in the proximal region (Lat: 6.3 ± 0.1 MPa, Prox: 2.9 MPa, Med: 6.4 ± 5.1 MPa, Dist: 4.9 ± 0.9 MPa). In the microfracture region, the material stiffness appeared to be lowest in the proximal region (0.3 MPa) and highest in the distal (5.7 ± 0.4 MPa).

DISCUSSION

This study has proposed and evaluated a new possible treatment option for larger articular cartilage lesions. Paradigms for resurfacing chondral defects have been developed empirically, with different treatment alternatives for lesions greater than and less than 2–2.5 cm² in area. The larger lesions are primarily treated with allograft resurfacing or autologous cell implantation. Both treatments can provide a durable repair surface with good clinical results in long-term follow up,^{4,5,10,20,21,22,26,30,31,35} but there are significant concerns with both treatments.

Allograft resurfacing is limited by the availability of fresh tissue. This is procured from young donors, and the amount of tissue is limited. There is also a concern about potential disease transmission including hepatitis, AIDS and bacterial infections.²⁷ For this reason, the FDA has mandated that all allografts undergo testing after harvest, and this has delayed the time in which the grafts can be implanted.^{1,19,32} As a result, the viability of chondrocytes in the graft has diminished, and this has led to studies as to the maximal amount of time that can transpire before the implants need to be placed to obtain a good result. In addition, due to the scarcity of these grafts, it can be difficult to find a correct size match for some sites. The use of allograft requires the patient to undergo an initial surgery for evaluation, with a second surgery for implantation of the graft.

Autologous cell implantation with cultured chondrocytes is the other option, usually reserved for treatment of the large chondral defects. The major drawback procedure is the cost for growth and culturing of the chondrocytes. This requires a minimum of two surgeries; the first surgery for joint assessment and harvesting of the chondral tissue which is then cultured, and a second surgery for implantation. There is approximately a 25–50% incidence of secondary surgical procedures requiring a third operative procedure.³⁶ In addition, rehabilitation can take up to 1–2 years to return to full activity.

The treatment of large lesions is not performed as successfully as in smaller lesions due to various reasons. Microfracture, successful in treating small lesions,³⁴ does not have good success in treating larger lesions. This may be due to lesions having less containment, and greater joint compressive forces are placed on the regenerative tissue because there is less native tissue to stress-shield the defect site due to its increased size. The biomechanical properties and collagen makeup of this regenerative tissue is not able to withstand the biomechanical forces, and this tissue long-term is noted to fail with increasing symptoms within five years.^{3,9,17,23,25,26}

Osteochondral autogenous transplantation has proven to be effective, as this provides normal hyaline cartilage and the biomechanics are closer to normal.^{11,12,14} There is, however, a limitation of donor tissue that can be obtained, which has relegated this treatment to smaller defects.

The present study provides preliminary evidence suggesting a repair procedure with the beneficial properties of both autogenous osteochondral transplantation and microfracture. Use of autogenous osteochondral plugs provides a solid structural support for the structural defect. The combination of OATS may benefit microfracture by allowing offloading of the

microfracture tissue. In addition, a relatively small amount of tissue is harvested with this technique compared to the size of the defect.

Evaluation of this study has shown that transferring an osteochondral plug into an area with no surrounding supporting articular cartilage does not appear to jeopardize the functional restoration by the cartilage-topped bone plug. We were concerned that the cartilage tissue might delaminate or fail in the animal study, but it was shown to remain intact with normal biomechanical parameters resembling that of OATS repairs in this model system. Thus the OATS procedure could be considered for somewhat larger defects and may not need surrounding host articular cartilage to support the transferred cartilage cap if intrinsic repair can be adequately stimulated.

The extent of cartilage repair in the present study addresses a defect of approximately 50% of the width of the medial femoral condyle. We have been able to approximate the overall contour of the medial femoral condyle by covering 40% of the defect area with an autogenous osteochondral plug with microfracture tissue, covering 35–40% of the defect. Although microfracture may have stimulated some repair, filling of the gap region was incomplete, being 75–80% of the defect. The regenerative tissue was noted to be type II collagen in greater than 90% of the tissue.

It was noted in a prior study¹⁸ that the edges of the OATS plug do not heal, and integrate into the surrounding tissue, whereas the areas in which a defect is left open (such as the femoral trochlea) seem to develop a smooth continuous articular surface. The addition of the microfracture was also postulated to allow improved integration of the OATS plug into the adjacent host cartilage. Healing of the interface partially occurred in all the specimens but was not complete. Therefore, further refinement of the technique will be necessary to try to improve complete integration of the chondral cap into the surrounding host cartilage. Long-term function of this combined chondral resurfacing procedure is needed to be able to appropriately assess the value of this combined technique.

Some limitations of the present study include the fact that a limited number of procedures were done and a goat model was used, which is different than the human knee in several ways. The goat subchondral bone is denser, and when the microfracture was performed, there was less bleeding noted than would be seen in a similar procedure in a human knee. This would suggest that there might be a difference in the quality of the microfracture tissue compared to that seen in a human knee. Longer term follow-up with more animals is also needed to assess the durability of the regenerative tissue construct. We also do not know the optimal ratio needed to fill a portion of the defect with autogenous transplant tissue. Further research is needed to evaluate optimization of the integration of the matrix generated by the stem cell from the microfracture, and the hyaline cartilage from the autogenous plug.

In summary, this combined technique shows promise for treatment of large chondral defects with a single operative procedure with autogenous tissue which is safe, and potentially would have a shorter period of rehabilitation, similar to that of osteochondral transfers and microfracture in a cost-effective setting.

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Figure 1.
Repair of an osteochondral defect with a hybrid OATS/microfracture approach.

Figure 2.
Indentation testing across the host cartilage, the microfracture site, and the osteochondral core.

Figure 3.
Six month post-operative repair of the medial femoral condyle.

Figure 4. Histological assessment of cartilage integration

A. Post surgery

B. Harvest at 6 months

C. Toluidine blue staining

D. High-resolution histology with gap measurement

Figure 5.

Trochlear defect:

A. Intra-operative (left unfilled)

B. Six-month harvest (defect filled)

Figure 6.
Histomorphometry profile

Figure 7.
Biomechanical results:
A. Thickness
B. Indentation stiffness