Contralateral Lateral Femoral Condyle Allografts Provide an Acceptable Surface Match for Simulated Classic Osteochondritis Dissecans Lesions of the Medial Femoral Condyle

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Background: Osteochondral allograft transplantation is an effective technique for repairing large lesions of the medial femoral condyle (MFC), but its use is limited by graft availability.

Purpose/Hypothesis: The present study aimed to determine whether contralateral lateral femoral condyle (LFC) allografts can provide an acceptable surface match for posterolateral MFC lesions characteristic of classic osteochondritis dissecans (OCD). The hypothesis was that LFC and MFC allografts will provide similar surface contour matches in all 4 quadrants of the graft for posterolateral MFC lesions characteristic of OCD.

Study Design: Controlled laboratory study.

Methods: Ten fresh-frozen recipient human MFCs were each size-matched to 1 ipsilateral medial and 1 contralateral LFC donor (N = 30 condyles). After a nano–computed tomography (nano-CT) scan of the native recipient condyle, a 20-mm circular osteochondral "defect" was created 1 cm posterior and 1 cm medial to the roof of the intercondylar notch (n = 10). A size-matched, random-order donor MFC or LFC plug was then harvested, transplanted, and scanned with nano-CT. Nano-CT scans were then reconstructed, registered to the initial scan of the recipient MFC, and processed in MATLAB to determine the height deviation (d_{RMS}) between the native and donor surfaces and percentage area unacceptably (>1 mm) proud (%A_{proud}) and sunken (%A_{sunk}). Circumferential step-off height (h_{RMS}) and percentage circumference unacceptably (>1 mm) proud (%C_{proud}) and sunken (%C_{sunk}) were measured using DragonFly software. The process was then repeated for the other allograft plug.

Results: Both MFC and LFC plugs showed acceptable step-off heights in all 4 quadrants (range, 0.53-0.94 mm). Neither allograft type nor location within the defect had a significant effect on step-off height (h_{RMS}), surface deviation (d_{RMS}), %A_{proud}, or %A_{sunk}. In general, plugs were more unacceptably sunken than proud (MFC, 13.4% vs 2.4%; LFC, 13.2% vs 8.1%), although no significant differences in %C_{sunk} were seen between allograft types or locations within the defect. In LFC plugs, %C_{proud} in the lateral quadrant (28.0% ± 26.1%) was significantly greater compared with all other quadrants ($P = .0002$).

Conclusion: The present study demonstrates that 20-mm contralateral LFC allografts provide an acceptable surface match for posterolateral MFC lesions characteristic of OCD.

Clinical Relevance: With comparable surface matching, MFC and LFC allografts can be expected to present similar stresses on the knee joint and achieve predictably positive clinical outcomes, thus improving donor availability and reducing surgical wait times for matches.

Keywords: osteochondral allograft transplant; osteochondritis dissecans; knee articular cartilage; allografts

Osteochondritis dissecans (OCD) of the knee is a common musculoskeletal injury in young patients characterized in its more advanced stages by the separation of an area of cartilage and subchondral bone from the surrounding bone. OCD occurs in an estimated 15 to 29 per 100,000 patients and appears most commonly in the medial femoral condyle (MFC) of the knee.[17] In the event of complete osteochondral detachment (type IV lesion), surgical intervention is typically required.[4,10,11] When the unstable fragment is not repairable, there are numerous options for surgical management, including microfracture,[13,14,39] autologous chondrocyte implantation with a sandwich technique,[6,23,33,35]

The Orthopaedic Journal of Sports Medicine, 8(1), 2325967119898413
DOI: 10.1177/2325967119898413

autologous matrix-induced chondrogenesis,[2] osteochondral autograft transplant,[14,27,28,35] and osteochondral allograft transplant.[4,11,12,38] However, no singular treatment plan is preferred for all cases.[32] For lesions greater than 4 cm^2, allograft transplantation of a size- and location-matched donor graft has been found to be an effective approach, with 91% survivorship of the transplant at 5 years and 87% survivorship at 10 years.[7,11,26,36-38] Inadequate graft availability has unfortunately limited the use of osteochondral allografts. The number of osteochondral allograft procedures performed in the United States has increased considerably,[25] and MFC grafts are in particularly high demand. According to the Joint Restoration Foundation (JRF), 80% of osteochondral allografts requested are for MFC grafts, while there is 30% more availability for the lateral femoral condyle (LFC) grafts (JRF Ortho, oral personal communication, April 2017). Furthermore, many potential donor grafts are unusable because the MFC is a common site for joint injury. MFC defects outnumber LFC lesions by as much as 6-fold.[8,34,41] The discordance between the requests for MFC allografts and their availability effectively results in delayed treatment for patients as they wait for an acceptable donor.

To address this problem, recent studies[29,42,45,46] have evaluated the utility of using contralateral (nonorthotopic) condyle grafts for osteochondral defects. Contralateral LFC allografts have shown an excellent surface contour match when compared with MFC grafts for defects of 20 mm in diameter.[29] Yanke et al[42,45,46] have corroborated these findings with computer modeling, concluding that LFC allografts provide an acceptable topography match for 20-mm MFC defects, but the ability to match the topography decreases as the graft size increases to 25 mm. With a good surface topography match, acceptable clinical outcomes can be achieved.[18,30] Specifically, articular surfaces recessed by 1 mm or less were shown to be acceptable, while grafts that are 0.5 to 1 mm proud increase the contact pressure by 50% and lead to degenerative changes in the knee.[15,20-22,43]

Although progress has been made in achieving surface contour matches, current models of articular damage position the defect in the center of the MFC, where the curvature is consistent and concentric.[29,40] More than 70% of OCD lesions, however, are located in the lateral aspect of the MFC near the intercondylar notch,[19] where the radius of curvature increases abruptly. This difference in curvature near the intercondylar notch was proposed by Mologne et al[29] to be more challenging to match and was noted as one of the limitations in their study of central 20-mm defects. It therefore remains unknown whether LFC allografts can adequately replicate the native MFC geometry in this location. The purpose of this study was to determine whether LFC allografts could demonstrate an acceptable surface contour match compared with MFC allografts for "classic" OCD lesions in the lateral region of the MFC along the intercondylar notch. It was hypothesized that there would be no differences in step-off height or surface contour match between LFC and MFC allografts in all 4 quadrants of the graft.

METHODS

Thirty fresh-frozen human femoral condyles (20 MFC and 10 LFC) were provided by JRF Ortho, and exempt status was obtained from the institutional review board of our university. Donor age ranged from 14 to 35 years and the donors were 77% male. Ten of the MFCs were identified as the recipient and were size-matched (based on condyle width and length) with 10 ipsilateral MFCs and 10 contralateral LFCs. This resulted in 10 groups of condyles that included 1 donor MFC, 1 donor LFC, and 1 recipient MFC. The condyles within each group exhibited a length difference of no more than 3 mm and a width difference of no more than 2 mm.[1] Each condyle was stored in a proprietary medium.

Allograft Transplantation and Computed Tomography Scanning

Before initial nano–computed tomography (nano-CT) scanning of the recipient condyles, the site of the osteochondral "defect" was marked with the recipient sizer from a 20-mm Arthrex MegaOATS instrument set. The sizer was positioned perpendicular to the condylar surface with its most anterior edge 1 cm posterior and 1 cm medial from the roof of the intercondylar notch. This location was chosen to represent a "classic" OCD lesion, with the most lateral edge of the "defect" located at the perimeter of the cartilage surface along the intercondylar notch with the lateral edge unshouldered by 2 to 3 mm (Figure 1). To facilitate future data set registration, four 1-mm drill holes were placed approximately 3 mm outside and around the marked "defect." These holes were placed in standard locations to allow reproducible identification of the condyle orientation

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Final revision submitted October 6, 2019; accepted October 9, 2019.

One or more of the authors has declared the following potential conflicts of interest or source of funding: Research reported in this publication was supported by the National Institute of Arthritis and Musculoskeletal and Skin Diseases of the National Institutes of Health under award number P30 AR069620. JRF Ortho provided the grafts/specimens and paid for personnel time and nano–computed tomography scanning for this study. J.A.G. has received research funding from Aesculap Biologics, Arthrex Inc, and JRF Ortho, educational support from Pinnacle, consulting fees from JRF Ortho, and hospitality payments from Aesculap Biologics, Ossur, and Smith & Nephew. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

Ethical approval for this study was waived by the Medical School Institutional Review Board at the University of Michigan (study ID HUM00131484).

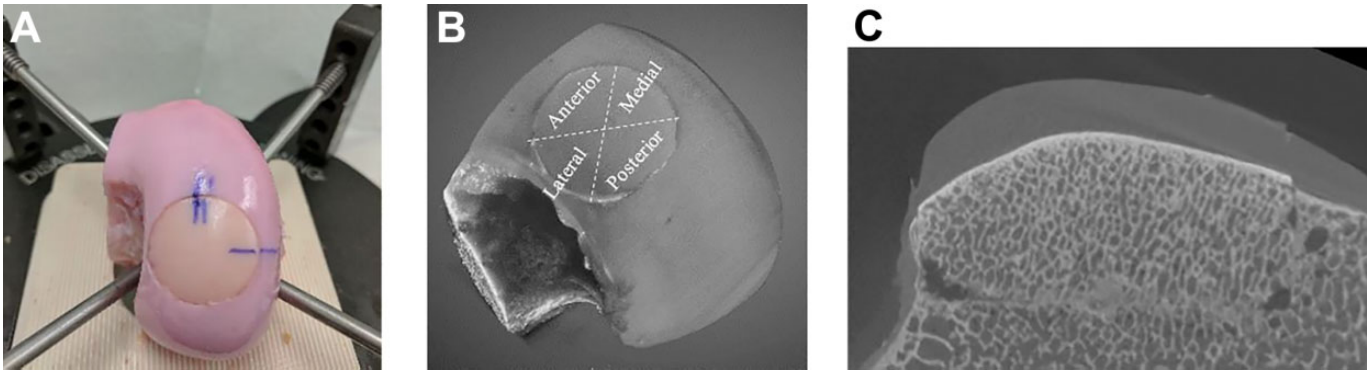

Figure 1. (A) Transplanted osteochondral allograft adjacent to the intercondylar notch. The anterior edge of the plug was positioned 1 cm medial and 1 cm posterior from the roof of the notch. (B) 3-dimensional reconstruction of a nano–computed tomography (CT) scanned medial femoral condyle showing the 4 regional quadrants of the allograft considered in this study. (C) Nano-CT image demonstrating the location of the transplant relative to the wall of the intercondylar notch.

after nano-CT scanning. Once drilling was complete, the condyle was scanned to obtain the cartilage thickness and surface map of the native condyle.

Individual condyles were coated with a silicone lubricant and scanned using a Nanotom S nano-CT with Phoenix Datos|x 2 Acquisition, version 2.3.2 (Phoenix Radiograph, GE Inspection Technologies). Scan settings of 90 kV, 250 μA, mode 0, 3 frames averaged, 1 skip, 1000-ms exposure time, 1000 images per scan, a diamond-coated tungsten target, and a 0.5-mm aluminum filter were used. Scans were reconstructed at 25-μm voxel size using Phoenix Datos|x 2 reconstruction v 2.2.1-RTM (Phoenix Radiograph, GE Inspection Technologies).

After scanning of the recipient MFC, the sizer was repositioned to the location of the defect. The condyle cartilage was scored, bored to a depth of approximately 10 mm, and dilated. Depth measurements were taken in duplicate at all 4 quadrants of the recipient socket and recorded.

Within each set of condyles, the donor MFC and LFC condyles were assigned using a random-number generator to be implanted first or second. This was done to avoid bias from any circumferential cartilaginous deformation that may occur upon inserting and removing the first plug as well as any added experience gained from performing additional procedures.

Similar to the recipient condyles, each donor condyle was marked with a 20-mm Arthrex MegaOATS sizer positioned to match the recipient "defect" (anterior edge 1 cm posterior and 1 cm medial to the roof of the intercondylar notch on the condylar surface). The orientation was marked at 12 o'clock and 3 o'clock on the donor surface. The plug was removed with an appropriately sized coring trephine and an oscillating saw. The donor plug thickness was then adjusted to match the depth of the recipient defect in all 4 quadrants. Once the depths were consistent, the bony edges were chamfered, the plug was press-fit into the recipient socket (Figure 1A), and then the condyle was scanned with nano-CT. After scanning, the plug was removed, and the procedures for plug insertion were repeated for the other donor plug.

Data Set Registration and Surface Mapping

Reconstructed nano-CT scans of the native and transplanted condyles were uploaded into DragonFly Version 3.0 (Object Research Systems) software. The 2 objects were registered based on mutual information acquired through rotation, translation, and linear interpolation (Figure 1B).[17] The registered objects were cropped to isolate the location of the osteochondral defect/plug and then exported for further processing using a custom MATLAB (Mathworks) program.

In MATLAB, sagittal slices of the native MFC surface and transplanted osteochondral plug surface (Figure 2A) were used to create 3-dimensional plots of the cartilaginous surface (Figure 2B). Previous registration of the 2 condyles in DragonFly allowed for these surfaces to be plotted on the same set of axes ($R^2 = 0.99 \pm 0.004$). Using these plots, a tangent plane was identified, and the perpendicular distances from over 3000 points on the native condyle to the surface of the transplanted plug were calculated (Figure 2C). The surface deviation was measured as the perpendicular distance between the native and transplanted surface at each of these points. These deviations were then summarized as a color map showing deviations in height between the 2 surfaces (Figure 2D). The number of included points varied depending on the angle of curvature of each condyle. Scanning difficulties with the initial nano-CT scan of one of the native recipient condyles prevented the determination of surface height deviation measurements for 1 group, resulting in n = 9 for this analysis.

Each surface map was divided into anterior, lateral (intercondylar notch side), medial, and posterior quadrants to allow for comparisons to be made within each quadrant across the 2 donor conditions (Figure 1B). In each quadrant, the root mean square (RMS) of the difference in height between the 2 surfaces (ie, surface deviation; d_{RMS}) was calculated. The RMS method was used to determine the mean height deviation (regardless of being sunken or proud) across the whole area of interest without having sunken values (–) cancel out the proud values (+).[29] Similarly, based on prior work,[5,10,11,36,38] the percentage area unacceptably proud (>1 mm; $\%A_{\mathrm{proud}}$) and unacceptably

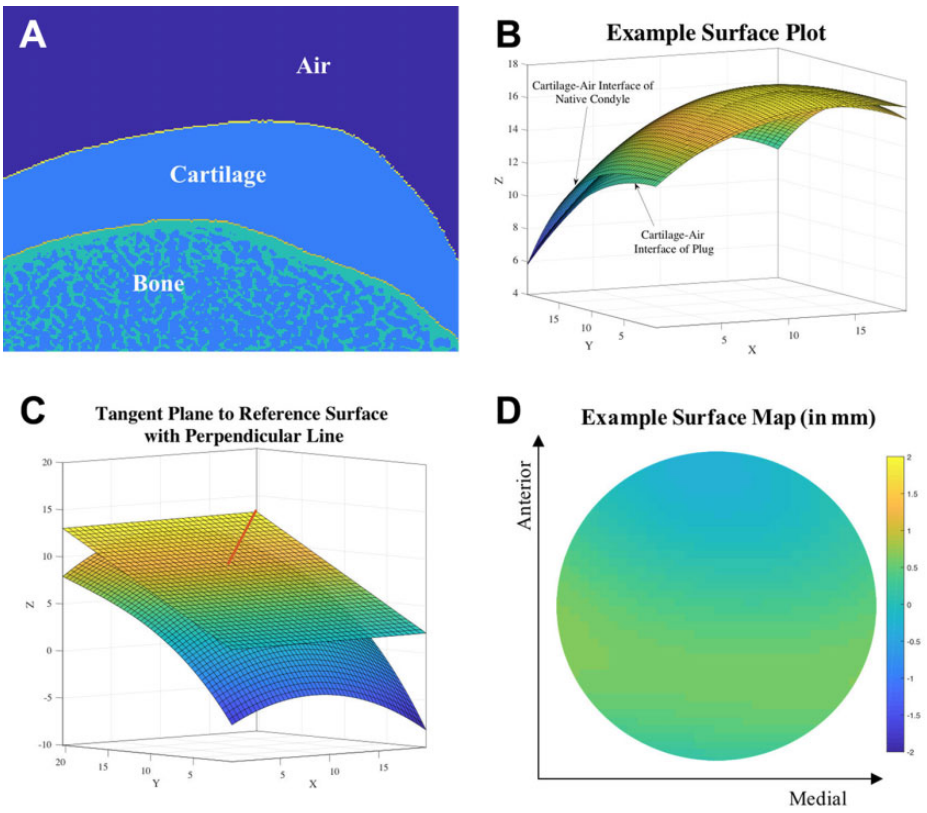

Figure 2. (A) The bone-cartilage interface (highlighted in orange) and the cartilage-air interface (highlighted in yellow) of a native medial femoral condyle. (B) 3-dimensional surface plots for the cartilage-air interface of the plug and native condyle. (C) Example of the tangent plane used to determine the surface deviations. (D) An example surface map of the difference in surface height between the native condyle cartilage surface and the transplanted plug surface.

sunken (>1 mm; $\%A_{\text{sunk}}$) was calculated for each sample and used to compare MFC and LFC plugs. Previous laboratory and finite-element analysis work has suggested that donor plugs that are only 0.5 mm proud result in increased local forces.[9,22,44] While it may be challenging to measure and achieve this level of accuracy intraoperatively, the $\%A_{\text{proud}}$ and $\%A_{\text{sunk}}$ were also calculated using the 0.5-mm threshold on an exploratory basis.

Step-off Height Measurements

Reconstructed nano-CT scans of the recipient condyle with the transplanted MFC and LFC osteochondral plugs were blinded and randomized, then uploaded into the DragonFly software. By defining a plane transverse to the bored socket of the recipient condyle, the central axis of the plug was determined. A longitudinal plane was then rotated about this central axis, allowing the measurement of step-off heights at 3-degree increments around the plug. The difference in the height of the plug cartilage compared with the adjacent surrounding native cartilage was measured (Figure 3). These measurements were then categorized as acceptably proud (≤1 mm), unacceptably proud (>1 mm), acceptably sunken (≤1 mm sunken), and unacceptably sunken (>1 mm sunken). The RMS step-off height for the whole circumference (h_{RMS}), percentage of circumference

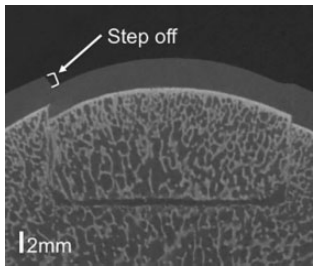

Figure 3. Example nano-computed tomography scan of a sunken plug; step-off height was measured between the plug and native cartilage surfaces (white arrow).

unacceptably proud ($\%C_{\text{proud}}$), and percentage of circumference unacceptably sunken ($\%C_{\text{sunk}}$) for each sample were also calculated and compared between groups. These measurements were calculated for the whole plug as well as by quadrant. As in the analysis of surface height differences described above, the $\%C_{\text{proud}}$ and $\%C_{\text{sunk}}$ were also calculated using the 0.5-mm threshold on an exploratory basis.

Statistical Analysis

All continuous data were evaluated using descriptive statistics and boxplots to assess for normality. Unpaired

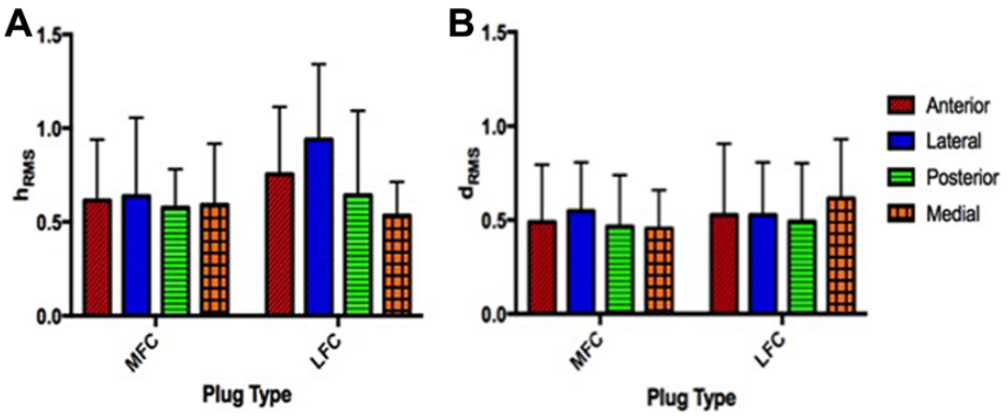

Figure 4. Root mean square of the (A) step-off height (h_{RMS} [mm], mean ± SD) and (B) surface deviation (d_{RMS} [mm], mean ± SD) for anterior, lateral, posterior, and medial quadrants of medial femoral condyle (MFC) and lateral femoral condyle (LFC) allografts.

Student t tests ($\alpha < 0.05$) were used to compare the RMS circumferential step-off height measurements (h_{RMS}) and the total RMS surface height differences (d_{RMS}) between MFC and LFC donor plugs. For the surface maps, a 2-way analysis of variance with Sidak post hoc comparisons was used ($\alpha < 0.05$). The goal of this comparison was to determine whether donor plug type (MFC or LFC) and/or location within the plug (anterior, posterior, medial, and lateral) had an effect on the difference in the cartilage height between the native and donor surfaces. Interactions were also evaluated.

To determine the sample size, a plug was considered to have acceptable geometry if it was no more than 1 mm proud or sunken. A previous comparable study[29] reported the standard deviations of RMS step-off height to be 0.24 to 0.31 mm. Given our defect location closer to the intercondylar notch with an increase in the expected variability of the surface morphology, a more conservative standard deviation of 0.5 mm was used. A clinically relevant difference of at least 0.75 mm (slightly less than the acceptable 1 mm step-off) between groups was used with a power of 0.8 in a 2-tailed test ($\alpha < 0.05$) to determine a sample size of 7 condyles per group. To provide a safety factor, 10 condyles per group were planned.

RESULTS

Step-off Height

Allograft type (MFC or LFC) did not have a significant effect on step-off height (h_{RMS}) (Figure 4A), the percentage of the circumference unacceptably proud ($\%C_{proud}$), or the percentage of the circumference unacceptably sunken ($\%C_{sunk}$) (n = 10). The percentage of the circumference unacceptably proud ranged from 0% to 21% (mean ± SD, 8% ± 7%) for the LFC donor and was consistently 0% for the MFC donor. The percentage of the circumference unacceptably sunken ranged from 0% to 42% for the LFC donor (mean, 13% ± 14%) and was 0% to 25% (mean, 9% ± 9%) for the MFC. Location, however, did have a significant effect on $\%C_{proud}$ (Table 1). The lateral quadrant (intercondylar notch side) was found to be significantly more unacceptably proud than the 3 other quadrants, but only with LFC condyle grafts ($P = .0002$). On average, 28% of the circumference in the LFC lateral quadrant was unacceptably proud with an average h_{RMS} for the whole quadrant of 0.94 mm, not far from the acceptable threshold of 1 mm. Location did not have significant effect on $\%C_{sunk}$, although the transplanted condyles were generally more sunken than they were proud. Approximately 13% of the whole circumference was unacceptably sunken in MFC and LFC allografts, while less than 9% of the circumference of MFC and LFC grafts were unacceptably proud.

Surface Deviation

The cartilage surface deviation of the plug from the native MFC surface (d_{RMS}), the percentage area of the plug that was unacceptably proud ($\%A_{proud}$), and the percentage area of the plug that was unacceptably sunk ($\%A_{sunk}$) were not significantly affected by plug type or location (n = 9) (Table 2). The percentage of the surface area that was unacceptably proud ranged from 0% to 30% (mean ± SD, 6.1% ± 10.6%) for the LFC donor and was 0% to 14% for the MFC donor (mean, 3.2% ± 5.3%). The percentage of the surface area that was unacceptably sunken ranged from 0% to 27% for the LFC donor (mean, 6.1% ± 12.1%) and was 0% to 23% (mean, 3.6% ± 7.9%) for the MFC. In general, d_{RMS} was in an acceptable range for MFC and LFC condyles (Figure 4B), with unacceptable height differences being at least 1 SD from the average d_{RMS} at all locations. The $\%A_{proud}$ was found to show an interaction between MFC and LFC, with a significant post hoc difference between medial quadrants of both condyles. Color maps were used to summarize the surface deviation data (Figure 5).

DISCUSSION

Limited allograft donor availability for osteochondral lesions of the MFC remains a significant clinical problem.[17]

TABLE 1
Step-off Height Measurements (h_{RMS}) for Anterior, Medial, Posterior, and Lateral Quadrants and the Total Circumference of the MFC and LFC Allografts[a]

MFC	Anterior	Medial	Posterior	Lateral	Overall
h_{RMS}, mm	0.62 ± 0.33	0.59 ± 0.33	0.58 ± 0.20	0.64 ± 0.42	0.63 ± 0.24
$\%C_{proud(1)}$	0.00 ± 0.00	0.00 ± 0.00	1.67 ± 5.30	11.30 ± 27.00	2.42 ± 7.64
$\%C_{proud(0.5)}$	2.33 ± 7.38	2.00 ± 4.50[d]	14.33 ± 28.24	21.00 ± 31.66[e]	9.92 ± 13.02
$\%C_{sunk(1)}$	18.00 ± 27.9	17.70 ± 31.9	7.00 ± 15.30	11.00 ± 24.70	13.40 ± 17.90
$\%C_{sunk(0.5)}$	43.67 ± 39.32	52.23 ± 43.69[f]	33.00 ± 33.86	27.33 ± 41.60	39.08 ± 25.96
LFC	**Anterior**	**Medial**	**Posterior**	**Lateral**	**Overall**
h_{RMS}, mm	0.76 ± 0.36	0.53 ± 0.18	0.64 ± 0.45	0.94 ± 0.40	0.74 ± 0.12
$\%C_{proud(1)}$	2.00 ± 5.26[c]	1.33 ± 4.22[c]	0.00 ± 0.00[c]	28.00 ± 26.10[b]	8.08 ± 6.89
$\%C_{proud(0.5)}$	11.00 ± 14.23	25.33 ± 33.27[d]	1.67 ± 5.27	43.00 ± 25.11[e]	20.25 ± 14.25
$\%C_{sunk(1)}$	26.00 ± 33.10	3.67 ± 7.77	16.70 ± 36.0	4.67 ± 7.06	13.20 ± 14.50
$\%C_{sunk(0.5)}$	41.00 ± 40.16	17.67 ± 22.28[f]	48.67 ± 36.42	9.00 ± 12.07	29.08 ± 16.85

[a]Values are expressed as mean ± SD. The percentage of the circumference (C) unacceptably proud and sunken is also listed with a 0.5 or 1 mm cutoff for acceptability. LFC, lateral femoral condyle; MFC, medial femoral condyle; RMS, root mean square.

([b]) is significantly different from ([c]) when comparing across the quadrants within the LFC donor ($P = .0002$).

The medial quadrant of the MFC donor had a significantly lower $\%C_{proud}$ at the 0.5 mm level compared with the LFC donor ([d]$P = .0002$). The medial quadrant of the MFC donor had a significantly lower $\%C_{proud}$ at the 0.5 mm level compared with the LFC donor ([e]$P = .0005$). The medial quadrant of the MFC donor had a significantly greater $\%C_{sunk}$ at the 0.5 mm level compared with the LFC donor ([f]$P = .0007$).

TABLE 2
Surface Height Deviations (d_{RMS}) for Anterior, Medial, Posterior, and Lateral Quadrants and the Total Area of the MFC and LFC Allografts[a]

MFC	Anterior	Medial	Posterior	Lateral	Overall
d_{RMS}, mm	0.49 ± 0.30	0.45 ± 0.21	0.47 ± 0.27	0.55 ± 0.26	0.51 ± 0.22
$\%A_{proud(1)}$	4.38 ± 13.20	0.00 ± 0.00[b]	0.00 ± 0.00	7.12 ± 11.80	3.16 ± 5.28
$\%A_{proud(0.5)}$	22.44 ± 41.97	15.42 ± 28.18	17.84 ± 28.13	30.72 ± 37.93	21.58 ± 29.71
$\%A_{sunk(1)}$	2.42 ± 7.25	2.20 ± 5.96	9.41 ± 28.20	1.32 ± 3.97	3.63 ± 7.94
$\%A_{sunk(0.5)}$	23.16 ± 35.41	17.69 ± 30.36	18.77 ± 34.31	10.60 ± 25.26	16.43 ± 21.88
LFC	**Anterior**	**Medial**	**Posterior**	**Lateral**	**Overall**
d_{RMS}, mm	0.53 ± 0.38	0.61 ± 0.31	0.49 ± 0.31	0.53 ± 0.28	0.57 ± 0.25
$\%A_{proud(1)}$	2.21 ± 4.52	15.1 ± 23.10[c]	3.88 ± 11.70	5.06 ± 15.20	6.12 ± 10.60
$\%A_{proud(0.5)}$	16.18 ± 32.19	42.31 ± 43.42	12.78 ± 25.74	29.78 ± 36.82	25.62 ± 29.36
$\%A_{sunk(1)}$	9.48 ± 28.10	2.11 ± 4.82	10.1 ± 30.20	5.18 ± 10.50	6.08 ± 12.10
$\%A_{sunk(0.5)}$	20.51 ± 40.12	9.54 ± 19.97	18.07 ± 33.58	14.00 ± 27.83	14.64 ± 27.96

[a]Values are expressed as mean ± SD. The percentage of the surface area (A) unacceptably proud and sunken is also listed with a 0.5 or 1 mm cutoff for acceptability. LFC, lateral femoral condyle; MFC, medial femoral condyle; RMS, root mean square.

([b]) is significantly different from ([c]) when comparing MFC and LFC allografts ($P < .05$).

The present study aimed to determine whether contralateral LFC allografts could match the surface topography of the native MFC as effectively as MFC allografts in the "classic" location of OCD lesions. Using an ex vivo cadaveric model of OCD, this study builds on previous work investigating the use of contralateral LFC allografts for more centrally located defects of the MFC.

Allograft type (medial or lateral condyle) did not have a significant effect on surface deviation (d_{RMS}) or step-off height (h_{RMS}), suggesting that MFC and LFC allografts can equally replicate the native MFC surface topography. Prior work has found that while flush plugs show no differences in peak pressure compared with the original surface,[9] plugs >0.5 mm proud or sunken can result in significantly greater stresses on the joint.[22] The clinical implications of these increases in peak pressure require further research, but current studies in animal models have found that plugs >2 mm proud can contribute to degenerative changes in the knee,[18] while depressions <1 mm can still promote acceptable cartilage healing.[30] The average overall h_{RMS} and d_{RMS} values for MFC and LFC plugs were all found to be between 0.5 and 1 mm, suggesting that acceptable clinical outcomes are possible. Based on the limited previous basic science work suggesting increased local pressures with

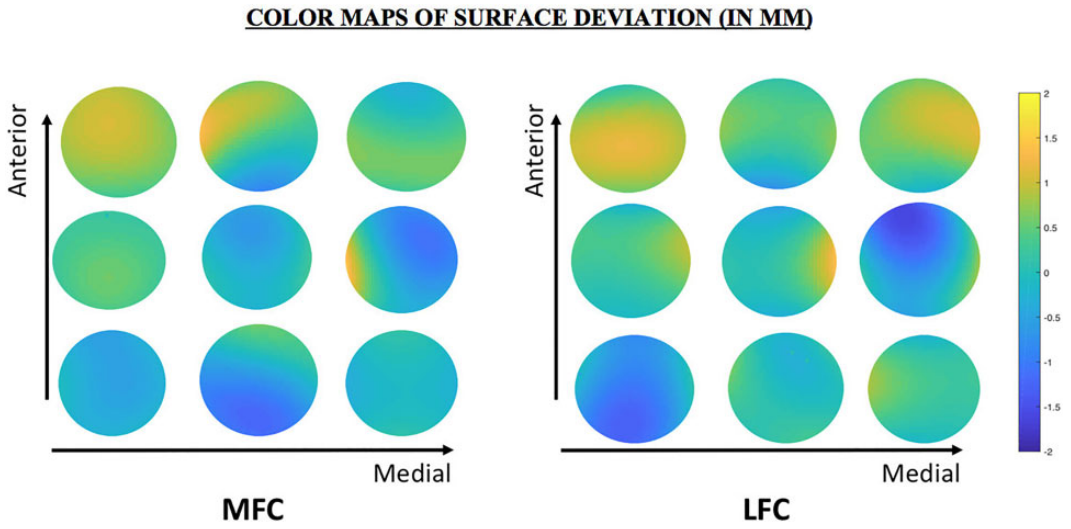

Figure 5. Color maps showing the surface deviation of medial femoral condyle (MFC) and lateral femoral condyle (LFC) transplants relative to the native MFC (in mm, n = 9).

even 0.5 mm of elevation,[9,22,44] further basic science and clinical research is required to evaluate how a 0.5-mm height threshold, which may be hard to appreciate clinically during a transplant, will translate into clinical outcomes and graft survival.

The percentage of plug circumference that was unacceptably proud ($\%C_{\text{proud}}$) or sunken ($\%C_{\text{sunk}}$), as well as the percentage of the plug surface area unacceptably proud ($\%A_{\text{proud}}$) or sunken ($\%A_{\text{sunk}}$), was not significantly affected by allograft type. As a result, LFC plugs can be expected to produce joint contact pressures and clinical outcomes similar to orthotopic MFC plugs.[18,22,30] One possible explanation for this outcome is the nearly identical average mean principle curvature of medial and lateral femoral condyles.[16] With similar curvatures, well-placed MFC or LFC plugs can be expected to have similar surface topographies and thus minimal differences in surface deviation.

Overall, step-offs were more unacceptably sunken than proud for both MFC and LFC transplants. The $\%C_{\text{sunk}}$ was approximately 13% for both allograft types, with an average minimum value of –1.24 mm. Clinically, sunken grafts are believed to be favorable to proud grafts. While proud grafts create regions of stress concentration,[43] sunken step-offs create an unloaded zone approximately 3 times the height of the step-off.[24] In addition, patients with depressed plugs were found to be asymptomatic 2 to 4 years postoperatively, and second-look arthroscopy showed depressed areas covered with fibrocartilage-like tissue and a resultantly smooth joint surface.[30]

The present study corroborates the results of previous work investigating the use of nonorthotopic allografts for osteochondral lesions of the MFC. For MFC defects that are more centrally located, Mologne et al[29] similarly found that step-off height and surface deviation are not significantly affected by allograft type.[29] The extent to which the plugs were proud was comparable between theirs and the current study.

The significant increase in $\%C_{\text{proud}}$ in the lateral quadrant of LFC plugs compared with other quadrants reflects small regional differences in topography between the LFC plug and the native MFC condyle. Unlike centrally located defects, where the curvature is approximately symmetric, the lateral portion of the MFC borders the intercondylar notch where the surface curvature suddenly increases. As a result, step-off height in this region depends on the location and extent of the surface curvature. If the curvature of the plug is slightly less than that of the native condyle, the lateral portion of the plug will be positioned relatively higher, resulting in a higher step-off height. The inverse is also true for plugs with higher curvature. Step-off height values along the lateral aspect of the plug (0.94 ± 0.40 mm), although not significantly different from MFC, still neared the threshold for unacceptability. While the clinical implications of this prominence need further evaluation, the lateral portion of the MFC bears substantially less weight compared with the center of the condyle,[3] likely lowering the risk for subsequent osteochondral degeneration in vivo.

The current study has some limitations. First, a single surgeon performed all osteochondral transfer procedures. We therefore did not account for variations in surgeon experience and technique. Second, only 20-mm defects were investigated. Prior work[42,45,46] has shown that LFC allografts for 25-mm centrally located lesions do not replicate the native surface geometry as well as for 20-mm lesions. However, since 75% of harvested MFCs are $<$25 mm in the mediolateral direction (JRF Ortho, oral personal communication, April 2017), larger lesions tend to extend more in the anteroposterior direction. These lesions, therefore, may be treated with multiple round plugs (snowman or mastercard configuration) or a single oval-shaped plug for which the instrumentation has only recently become clinically available. As a result, for any defect larger than 20 to 25 mm, a different clinical model may be required.

A third limitation is that the current study was performed ex vivo and as such cannot describe the biochemical and biomechanical postsurgical changes in the tissue. Prior work in a rabbit model has shown that stiffness returned to normal values, subchondral bone healing occurred, and cartilage thickness was maintained after osteochondral allograft surgery in a centrally located defect.[31] These results, however, remain unknown for the more eccentrically located lesion. Furthermore, clinical outcome measures such as graft survivorship, patient satisfaction, and reoperation need to be evaluated using this approach. Given the relatively low volume of these transplants that are performed in any single surgeon's practice, researchers will need to harness the power of cartilage transplant registries, such as the one hosted by the International Cartilage Regeneration & Joint Preservation Society, to provide this clinical information.

CONCLUSION

Contralateral LFC osteochondral allografts for characteristic OCD lesions located eccentrically near the MFC intercondylar notch restored native tissue topography just as effectively as MFC allografts. Although regional differences in step-off were found around the plug, these changes were concentrated near the intercondylar notch, where joint forces are lower.[3] The current study suggests that contralateral LFC allograft transplantation into an eccentric, "classic OCD-type" MFC defect may produce joint topography fit similar to that of MFC donors. This finding has the potential to address delays in allograft procurement by supporting the use of LFC allografts, which are more readily available than orthotopic MFC grafts. This will reduce the time patients must wait for a size-matched allograft, allowing them shorter waits for surgery and therefore less delay in regaining their mobility and quality of life.

ACKNOWLEDGMENT

The authors thank Jaron Scott and Andrea Clarke for their assistance with nano-CT scanning and computer analysis.

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