Microdrilling Resulted in Less Subchondral Bone Destruction Than a Traditional Microfracture Awl for Articular Cartilage Defect Bone Marrow Stimulation

Lucy E. Meyer, M.D., Richard M. Danilkowicz, M.D., Zoe W. Hinton, M.D., Bryan S. Crook, M.D., Bijan Abar, M.H.S., Nicholas B. Allen, B.S., Mitchell Negus, B.S.E., Eoghan T. Hurley, M.B., M.Ch., Ph.D., Alison P. Toth, M.D., Annunziato Amendola, M.D., and Samuel B. Adams, M.D.

Purpose: The purpose of this study was to compare bone marrow stimulation using micro-computed tomography (micro-CT) analysis of an abrasion arthroplasty technique, drilling k-wire technique, traditional microfacture awl, or a microdrill instrument for subchondral bone defects. **Methods:** Eleven cadaveric distal femoral specimens were obtained and divided into 3 common areas of osteochondral defect: trochlea and weightbearing portions of the medial and lateral femoral condyles. Each area of interest was then denuded of cartilage using a PoweRasp and divided into quadrants. Each quadrant was assigned either a 1.6 mm Kirschner wire (k-wire), 1.25 mm microfracture awl, 1.5 mm fluted microdrill, PowerPick, or a curette (abrasion arthroplasty) to create 4 channels into the subchondral bone sing the same instrument. Subchondral bone and adjacent tissue areas were then evaluated using micro-CT to analyze adjacent bone destruction and extension into the bone marrow. **Results:** Overall, there was a significantly decreased area of bone destruction or compression using the microdrill (0.030 mm) as compared to the microfracture awl (0.072 mm) and k-wire (0.062 mm) ($P < .05$). Within the trochlea and the medial femoral condyle, there was significantly decreased bony compression with the microdrill as compared to the awl and k-wire ($P < .05$); however, when stratified, this was not significant among the lateral femoral condylar samples ($P = .08$). **Conclusion:** Bone marrow stimulation causes bony compression that may negatively impact subchondral bone and trabecular alignment. It is important to understand which tools used for bone marrow stimulation cause the least amount of damage to the subchondral bone. **Clinical Relevance:** This study demonstrates the decreased subchondral bony defects seen with the microdrill versus the traditional microfracture awl indicating that when performing bone marrow stimulation, the microdrill may be a less harmful tool to the subchondral bone.

A number of varying techniques and devices are used in the treatment of small, focal areas of articular cartilage defects; however, the bone marrow stimulation technique as described by Steadman et al.[1] remains a commonly performed treatment for these defects. As previously described, the bone marrow stimulation technique directly stimulates mesenchymal stem cells in the subchondral bone, leading these cells to differentiate into chondrocytes.[2-5] A number of other techniques have been described for treatment of focal articular defects including debridement, drilling, osteochondral allograft or autograft transplantation,

From the Department of Orthopaedic Surgery, Duke University Medical Center (L.E.M., R.M.D., Z.W.H., B.S.C., E.T.H., A.P.T., A.A., S.B.A.); and the Department of Mechanical Engineering and Material Science, Duke University (B.A., N.B.A., M.N.), Durham, North Carolina, U.S.A.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: A.P.T. reports personal fees from Arthrex, Breg, Mitek, Smith & Nephew, and Stryker. A.A. reports personal fees from Arthrex, Bio2, Bioventus, Bone Solutions, Conmed, Lima, Miach, and Stryker. S.B.A. reports Conventus, DJO, Exactech, Medshape, Orthofix, Regeneration, and Stryker. All other authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. Full ICMJE author disclosure forms are available for this article online, as supplementary material.

Received April 25, 2023; accepted July 17, 2023.

Address correspondence to Lucy E. Meyer, M.D., Department of Orthopaedic Surgery, Duke University Hospital, Durham, NC 27705, U.S.A. E-mail: lucy.meyer@duke.edu

2666-061X/23570
https://doi.org/10.1016/j.asmr.2023.100786

and autologous matrix-induced chondrogenesis; however, bone marrow stimulation is commonly thought of as the first-line treatment for these defects when less than 1 cm^2 in size.[6-11] Additionally, bone marrow stimulation is low in cost and minimally invasive and has low technical demands.[12]

When performing the bone marrow stimulation procedure, it is important to note that the structural and functional architecture of the subchondral bone is of the utmost importance and can play a vital role in the long-term outcome of the index bone marrow stimulation procedure, as well as on any subsequent cartilage procedure that may follow.[13,14] Although previous literature has shown good short-term outcomes in appropriately selected patients, recent literature has suggested that the outcomes of bone marrow stimulation may worsen after 5 years, primarily because of the poor quality of the fibrocartilage replacement tissue that is formed.[7,15] The size of the instrument, depth of penetration into the subchondral bone, and resulting trabecular compaction around the channel have been implicated in this fibrocartilage tissue, because it may affect the ability of the technique to cause regeneration versus degeneration.[13,16] The instruments impact the subchondral bone differently by nature. The microfracture awl was most likely to cause the most subchondral compression given its mechanism. With the k-wire acting as an unfluted drill and the microdrill acting as a fluted drill, these instruments would likely cause less subchondral bone destruction and compression than the awl.

The purpose of this study was to compare bone marrow stimulation using micro-computed tomography (micro-CT) analysis of an abrasion arthroplasty technique, drilling k-wire technique, traditional microfacture awl, or a microdrill instrument for subchondral bone defects. Our hypothesis was that larger-diameter instruments used for bone marrow stimulation would cause more subchondral bone destruction and compaction adjacent to the defect. We also hypothesized that the fluted microdrill would cause the least amount of subchondral bone destruction and compression, given the fluted nature of the instrument.

Methods

Institutional IRB in the form of research not involving human subjects was obtained, PRO00033747. Cadaveric distal femoral specimens were obtained from donor samples, including 4 trochlea, 4 lateral femoral condyle, and 3 medial femoral condylar samples, resulting in a total of 11 samples of each bone marrow stimulation tool. The specimens were dissected and thawed at room temperature before use. Inclusion criteria for cadaver specimens were <65 years old, no underlying documented bone or cartilage pathology, and no observable macroscopic cartilage degeneration. Exclusion criteria were cadaver specimens >65 years old, underlying documented bone or cartilage pathology, and observable macroscopic cartilage degeneration. No specimens were excluded. The articular surface of all specimens was inspected by 2 observers for fibrillation, fissuring, or cartilage loss

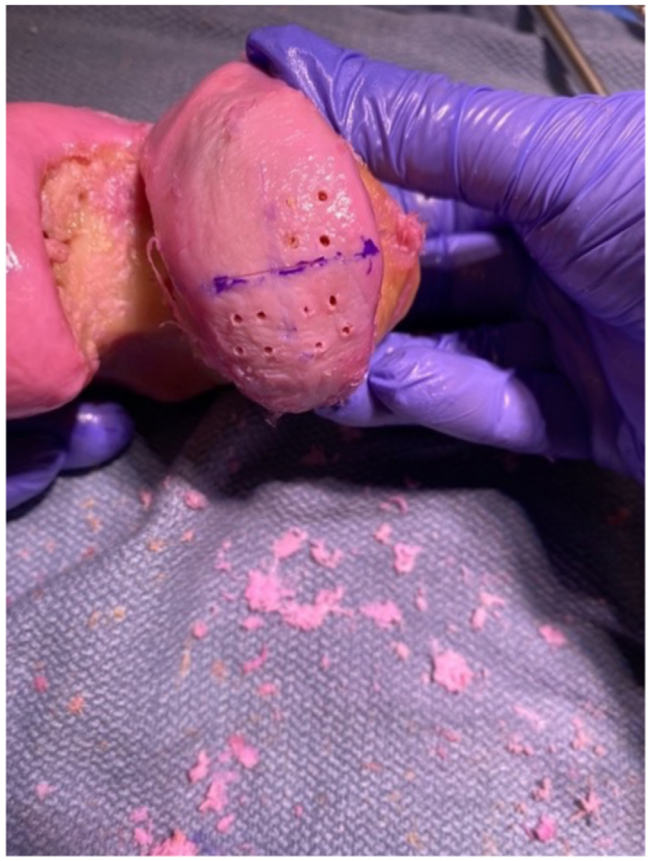

Fig 1. Demonstration of the quadrants created and bone marrow stimulation channels seen on gross femoral condylar specimens. The top left quadrant is the abrasion arthroplasty quadrant, top right quadrant relates to the microdrill, bottom left quadrant channels were made with a k-wire, and bottom right quadrant channels were made with the microfacture awl. These channels were then evaluated on micro-computed tomography.

Bone Marrow Stimulation Technique

Each area of interest was then denuded of cartilage using a 4.5 mm or 5.5 mm PoweRasp (Arthrex, Naples, FL) and divided into quadrants (Figs 1 & 2). Each quadrant was assigned either a 1.6 mm Kirschner wire (k-wire), 1.25 mm microfracture awl, 1.5 mm PowerPic (Arthrex), or a curette (abrasion arthroplasty) to create 4 channels into the subchondral bone using the same instrument. The microdrill had a set drill depth of 4 mm.

Micro-CT Analysis

The 3-dimensional structure of the femoral condyle was analyzed with a micro-CT scanner (Nikon XTH 225

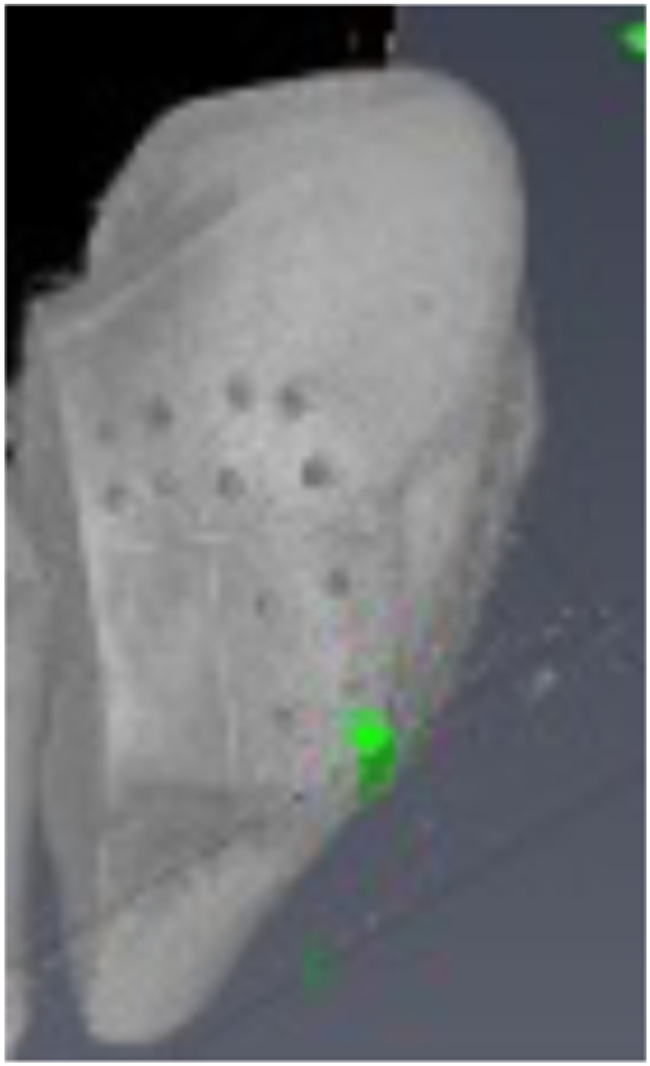

Fig 2. Quadrants as seen on the micro-computed tomography (micro-CT) analysis software. This is a depiction of all 4 quadrants, similar to those seen in Figure 1. Given how the images were collected on the micro-CT software, the top right quadrant is the abrasion arthroplasty quadrant, top left quadrant is the microdrill, bottom right is the k-wire, and bottom left is the microfracture awl.

ST; Nikon, Melville, NY). A nail was placed on the lateral surface to orientate the sample, and the condyles were secured in a plastic container in the scanner. The power of the X-rays was set to 200 kV, and the current was set to 167 uA. Two frames were captured at an exposure time of 354 ms for each of the 2000 projections. The entire sample was scanned, resulting in an effective pixel size of 80 μm. The TIFF stack was reconstructed and analyzed using AvizoLite (FEI Company, Thermo Fisher Scientific, Hillsboro, OR). Orthogonal slices were created on the XY, YZ, and XY plane. The subchondral bone and adjacent tissue areas were evaluated for adjacent bone destruction and extension into the bone marrow (Fig 3). The subchondral bone density was measured directly.

Statistical Analysis

All statistical analysis was performed using GraphPad Prism 8.3 (GraphPad, La Jolla, CA). A power analysis was conducted based on a prior investigation.[16] For all continuous and categorical variables, descriptive statistics were calculated. Continuous variables were reported as weighted mean and estimated standard deviation, whereas categorical variables were reported as frequencies with percentages. Categorical variables were analyzed using Fisher's exact or χ^2 test. The independent or paired *t*-test for normally distributed variables, or the nonparametric Mann-Whitney U test or Wilcoxon signed-rank test was performed to compare continuous variables. A value of $P < .05$ was considered to be statistically significant.

Results

All 11 cadaveric specimens were included for analysis. Overall, there was a significantly decreased area of bone destruction using the microdrill (0.030 mm) as compared to the microfracture awl (0.072 mm) and k-wire (0.062 mm) ($P < .05$). Within the trochlea and the medial femoral condyle, there was significantly decreased bony compression with the microdrill as compared to the awl and k-wire ($P < .05$ for both), however, when stratified, this was not significant amongst the lateral femoral condylar samples ($P = .08$) (Table 1). Furthermore, there was no significant difference between awl and k-wire in bony compression overall or in any anatomic area ($P > .05$). Initially abrasion arthroplasty was included, but it was excluded from the analysis because nothing could be picked up on micro-CT because it does not create channels.

Discussion

The most important finding from the current study was that with the microdrill cadaveric femoral condyles demonstrated decreased subchondral bony defects seen versus the traditional microfracture awl, indicating that when performing bone marrow stimulation, the microdrill may be a less harmful tool to the subchondral bone. Bone marrow stimulation causes bony compression that may negatively impact subchondral bone and trabecular alignment. The microdrill had a significantly decreased compressive impact on the subchondral bone as compared to traditional microfracture awl or k-wire drilling techniques. This difference was noted along all areas of articulation between the trochlea, medial femoral, and lateral femoral condyles. There was no difference in the performance of the tools between the 3 articular segments. This has potential clinical implications going forward and may improve survivorship of bone marrow stimulation because subchondral bone

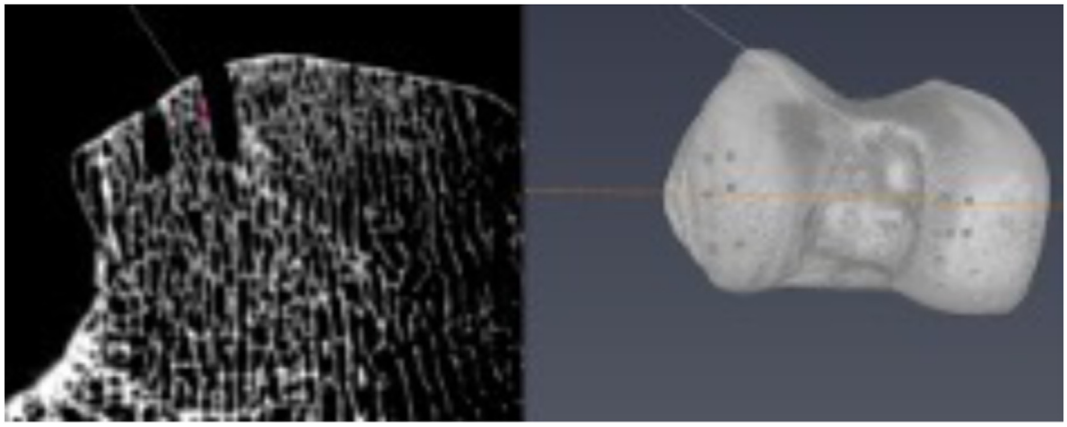

Fig 3. This is a side-by-side image depicting the micro-computed tomography analysis performed via a coronal cut through the femoral condyle on the left and the reference image on the right. The orange line in the image on the right is the reference line demonstrating the coronal cut that is shown on the left. The subchondral bone and adjacent tissue areas were evaluated for adjacent bone destruction and extension into the bone marrow. The subchondral bone density and compression were measured directly using calibrated measurement tool on the analysis software. The pink measurement on the photo to the left corresponds to a calibrated length of compressed bone that is reported in the results.

damage has been shown to result in fibrocartilage degeneration; however, further clinical studies are required to assess the impact of this.

Seow et al.[13] found in their systematic review of preclinical models that there are alterations in the subchondral bone after bone marrow stimulation. Furthermore, they advocated for refinements of bone marrow stimulation techniques that should incorporate consideration of subchondral bone damage and restoration. They also believe that further investigations were required to optimize bone marrow stimulation techniques incorporating both minimally invasive approaches and biologically augmented platforms. Zedde et al.[17] reported that nanofracture in an ovine in vivo model was superior to microfracture in that the nanofractured samples had significantly less trabecular fragmentation and compaction. In their study, nanofracture was conducted using cannulated awl and a 1 mm−thick Nitinol needle with a 9 mm perforation depth set by the awl, whereas bone marrow stimulation was conducted using a curved Steadman awl. Gianakos et al.[16] performed a study similar to our own in which they used a small microfracture awl (1.00 mm), large k-wire (1.25 mm), and large microfracture awl (2.0 mm) on cadaveric talar articular dome surfaces. Using micro-CT analysis, the authors analyzed the microfracture channels for sclerosis and marrow access and found that bone marrow stimulation techniques using instruments with larger diameters led to increased trabecular compaction and sclerosis adjacent to the area of bone marrow stimulation; however, their study was limited to talar cartilage, which has different intrinsic properties than knee articular cartilage.[16,18,19] Their results were similar to those described in our study; however, our study was able to include newer technology in the form of the microdrill, which had significantly decreased compression adjacent to the defect than the larger-diameter bone marrow stimulation instruments.[16]

Table 1. Depth of Compressed Bone Measured in mm/1000 Compared Between Groups Using One-Way Analysis of Variance

	Trochlea	LFC	MFC
Awl	0.085733	0.061348	0.06719333
K-Wire	0.068715	0.052195	0.06518667
Microdrill	0.036005	0.026845	0.02513667
P value	**.025**	.087	**.0004**

LFC, lateral femoral condyle; MFC, medial femoral condyle.
Bolded values demonstrate statistically significance.

The status of the subchondral bone architecture has been shown to play a significant role in the long-term health of the chondral surface, and as more recent evidence has shown, may have an impact on future cartilage restoration procedures.[13,14] Currently there is a lack in long-term studies that adequately target these specific questions; however, this study may serve as another piece of foundational evidence to further investigate the role that subchondral architecture has on not only native articular cartilage but also the efficacy and survival of the various restoration techniques that have been developed. Initially, the current study performed abrasion arthroplasty, but this was excluded from the analysis because it does not create bone marrow channels, and it is unclear how the cells get to the surface or how it affects the subchondral bone. Although this may play a role in denervating the surface, it is unclear how this generates a fibrocartilaginous response or whether it may cause subchondral bone

damage or even have a negative effect on a future cartilage repair/replacement procedure.

Limitations

There are several limitations and sources of bias in the study. This study used 11 specimens, which is a small number for evaluation; however, it proved to be sufficient for statistical significance with relation to our primary outcome measure. Because it was a cadaveric study, it is strictly a time-zero investigation, and it is not possible to assess remodeling after the initial procedure. Furthermore, because it is a cadaveric study, it does not include or predict patient-reported outcomes or survivorship. Unfortunately, we did not analyze the specimens before the experiment and therefore do not have initial bone density measurements.

Conclusions

Decreased subchondral bony defects were seen with the microdrill versus the traditional microfracture awl, indicating that when performing bone marrow stimulation, the microdrill may cause less damage to the subchondral bone.

References

1. Steadman JR, Rodkey WG, Briggs KK, Rodrigo JJ. The microfracture technic in the management of complete cartilage defects in the knee joint. *Der Orthopade* 1999;28:26-32.
2. Khan WS, Johnson DS, Hardingham TE. The potential of stem cells in the treatment of knee cartilage defects. *Knee* 2010;17:369-374.
3. Mithoefer K, Williams RJ 3rd, Warren RF, et al. The microfracture technique for the treatment of articular cartilage lesions in the knee. A prospective cohort study. *J Bone Joint Surg Am* 2005;87:1911-1920.
4. Mithoefer K, Williams RJ 3rd, Warren RF, et al. Chondral resurfacing of articular cartilage defects in the knee with the microfracture technique. Surgical technique. *J Bone Joint Surg Am* 2006;88:294-304 (Suppl 1 Pt 2).
5. Shapiro F, Koide S, Glimcher MJ. Cell origin and differentiation in the repair of full-thickness defects of articular cartilage. *J Bone Joint Surg Am* 1993;75:532-553.
6. Erggelet C, Vavken P. Microfracture for the treatment of cartilage defects in the knee joint—A golden standard? *J Clin Orthop Trauma* 2016;7:145-152.
7. Angele P, Zellner J, Schroter S, Flechtenmacher J, Fritz J, Niemeyer P. Biological reconstruction of localized full-thickness cartilage defects of the knee: A systematic review of level 1 studies with a minimum follow-up of 5 years. *Cartilage* 2022;13:5-18.
8. Pareek A, Reardon PJ, Maak TG, Levy BA, Stuart MJ, Krych AJ. Long-term outcomes after osteochondral autograft transfer: A systematic review at mean follow-up of 10.2 years. *Arthroscopy* 2016;32:1174-1184.
9. Assenmacher AT, Pareek A, Reardon PJ, Macalena JA, Stuart MJ, Krych AJ. Long-term outcomes after osteochondral allograft: A systematic review at long-term follow-up of 12.3 years. *Arthroscopy* 2016;32:2160-2168.
10. Pareek A, Carey JL, Reardon PJ, Peterson L, Stuart MJ, Krych AJ. Long-term outcomes after autologous chondrocyte implantation: A systematic review at mean follow-up of 11.4 years. *Cartilage* 2016;7:298-308.
11. Melugin HP, Bernard CD, Camp CL, Saris DBF, Krych AJ. Bipolar cartilage lesions of the knee: A systematic review of techniques, outcomes, and complications. *Cartilage* 2021;13:17S-30S.
12. Zamborsky R, Danisovic L. Surgical techniques for knee cartilage repair: An updated large-scale systematic review and network meta-analysis of randomized controlled trials. *Arthroscopy* 2020;36:845-858.
13. Seow D, Yasui Y, Hutchinson ID, Hurley ET, Shimozono Y, Kennedy JG. The subchondral bone is affected by bone marrow stimulation: A systematic review of preclinical animal studies. *Cartilage* 2019;10:70-81.
14. Cogan CJ, Friedman J, You J, et al. Prior bone marrow stimulation surgery influences outcomes after cell-based cartilage restoration: A systematic review and meta-analysis. *Orthop J Sports Med* 2021;9:23259671211035384.
15. Kraeutler MJ, Belk JW, Purcell JM, McCarty EC. Microfracture versus autologous chondrocyte implantation for articular cartilage lesions in the knee: A systematic review of 5-year outcomes. *Am J Sports Med* 2018;46:995-999.
16. Gianakos AL, Yasui Y, Fraser EJ, et al. The effect of different bone marrow stimulation techniques on human talar subchondral bone: A micro-computed tomography evaluation. *Arthroscopy* 2016;32:2110-2117.
17. Zedde P, Cudoni S, Giachetti G, et al. Subchondral bone remodeling: Comparing nanofracture with microfracture. An ovine in vivo study. *Joints* 2016;4:87-93.
18. Makitsubo M, Adachi N, Nakasa T, Kato T, Shimizu R, Ochi M. Differences in joint morphology between the knee and ankle affect the repair of osteochondral defects in a rabbit model. *J Orthop Surg Res* 2016;11:110.
19. Henak CR, Ross KA, Bonnevie ED, et al. Human talar and femoral cartilage have distinct mechanical properties near the articular surface. *J Biomech* 2016;49:3320-3327.