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EXPERIMENTAL STUDY

Microfracture for chondral defects: assessment of the variability of surgical technique in cadavers

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Abstract
Purpose The purpose of this study was to assess the variability of the microfracture technique when performed by experienced knee arthroscopy surgeons.
Method Four surgeons were each asked to perform microfracture on six preformed cartilage defects in fresh human cadaveric knees. Surgeons were instructed on penetration depth, inter-hole distance, and to place the holes perpendicular to the subchondral surface. Micro-computed tomography was used to calculate depth error, inter-hole distance error, and deviation of penetration angles from the perpendicular.
Results All surgeons misjudged depth and inter-hole distance, tending to make microfracture holes too deep (depth error 1.1 mm ± 1.9) and too close together (inter-hole distance error: −0.8 mm ± 0.4). Fifty-one per cent of holes were angled more than 10° from the perpendicular (range 2.6°–19.8°). Both depth and distance errors were significantly lower in the trochlear groove than on the femoral condyle ($p < 0.05$). Surface shearing was associated with both penetration depth >4 mm and angles >20°. Inter-hole infraction occurred in holes closer than 2.5 mm to each other.
Conclusion Even experienced knee arthroscopy surgeons demonstrate inconsistency in surgical technique when performing microfracture. While further research will be required to demonstrate that these variations in surgical technique are associated with poorer clinical outcomes after microfracture, surgeons should attempt to minimizing such variations in order to prevent surface shearing and inter-hole infraction.

Keywords Microfracture · Surgical technique · Variability · CT

Introduction

Full-thickness chondral defects in the knee have a limited capacity for repair and often become progressively

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symptomatic if left untreated [17]. As a result, there has been an emphasis on determining the most favourable surgical technique for the management of such injuries. Of the various techniques available including autologous chondrocyte implantation and mosaicplasty, microfracture is commonly utilized technique as a first-line treatment. The majority of the literature regarding the outcome of microfracture surgery is based upon single surgeon case series, with some level I evidence comparing microfracture with other cartilage regeneration techniques, rather than against controls [13–15, 18, 19].

Microfracture was introduced by Steadman [21] in the late 1980s. One of the major advantages of this technique is that microfracture can be performed with readily available equipment at minimal cost, making it one of the most common cartilage repair procedures. In the original description of the microfracture technique, Steadman [21] described microfracture holes 2–4 mm deep (in order to allow leakage of blood and fat droplets from the marrow cavity), 3–4 mm apart [so that holes are as close together as possible without breaking into each other (infraction)], and perpendicular to the surface of the exposed bone. Whether this is the optimal technique for achieving the best patient outcome is unknown, as there is no high-level evidence investigating variations in microfracture technique, and relating these variations to clinical outcomes.

While the results of microfracture have been generally good, there is a significant variation in reported outcomes—a systematic review in 2009 identified a range in the reported incidence of good outcomes in both the short term (75–100 %) and long term (67–86 %) [13, 20]. Multiple factors may account for this difference, including lesion size, location, patient age, weight, activity level, post-operative rehabilitation, as well as variation in surgical technique [9–11, 14, 16]. Given that microfracture is often used as a control group in randomized trials investigating novel cartilage regenerative therapy [1, 7, 8], the variability associated with this surgical procedure should be minimized. To our knowledge, no previous study has examined the variability of the microfracture technique.

The purpose of this study was to assess the variability of the microfracture technique, when performed by surgeons experienced in knee arthroscopy. The hypothesis was that experienced arthroscopic knee surgeons would be highly accurate with regard to the depth, angulation, and inter-hole distance of microfracture holes.

Materials and methods

Four experienced arthroscopic knee surgeons (over 100 knee arthroscopic surgeries per year, with a minimum of 5 years of clinical experience) who regularly perform microfracture (>10 times per year) as part of their surgical practice were asked to perform arthroscopic microfracture in fresh human cadaveric knees. A full-thickness chondral defect with a size of 2 cm^2 was created on either the femoral condyle or the trochlear groove of 24 knees (12 matched pairs). Using a standard arthroscopy set-up, with 30° arthroscope and angled microfracture awls, each surgeon performed a microfracture on six defects (three on the femoral condyle and three on the trochlea groove), beginning with the trochlea defect in each knee. Specific instructions in terms of penetration depth (3 mm), inter-hole distance (4 mm), and angulation (perpendicular to subchondral bone) were given for each defect.

All soft tissue was then removed from each distal femur, and micro-computed tomography (micro-CT) (GE Medical Systems eXplore Locus Micro-CT Scanner, GE Medical Systems London, ON, Canada) with a nominal isotropic resolution of 45 µm at 80 kV/450 µA performed. Microview ABA 2.1.2 (GE Healthcare London, ON, Canada) was utilized for all measurements (Fig. 1). Calculations included depth errors (deviation from desired depth of 3 mm), inter-hole distance errors (deviation from desired inter-hole distance of 4 mm), and deviation from the perpendicular angle (Fig. 2). Two observers (radiologist and orthopaedic surgeon) reviewed each CT and came to a consensus on each measurement. Volumetric bone mineral content (BMC) was measured in all 24 specimens. The specimens with manifest osteoporosis (BMC <0.648 g/cm^2) were excluded from analysis. Thus, two samples were lost, leaving 22 available for analysis.

Ethics

Approval for this study was obtained from the University of Guelph Research Ethics Board, approval number 05JA014.

Statistical analysis

Statistical analysis employed Kolmogorov–Smirnov testing in order to identify Gaussian value distribution. A post hoc sample size calculation was performed to determine the sample size required to detect a difference in inter-hole distance performed on the femoral condyle and on the trochlea—using the mean of 1 mm and the standard deviation of 0.3 mm, with an expected difference of 0.5 mm, it was calculated that a total of three knees would be required in each group. The Student-*t* test and Mann–Whitney U test were used for parametric and nonparametric samples, respectively. Bonferroni testing was performed in case of multiple group comparisons. Statistical significance was defined as $p < 0.05$.

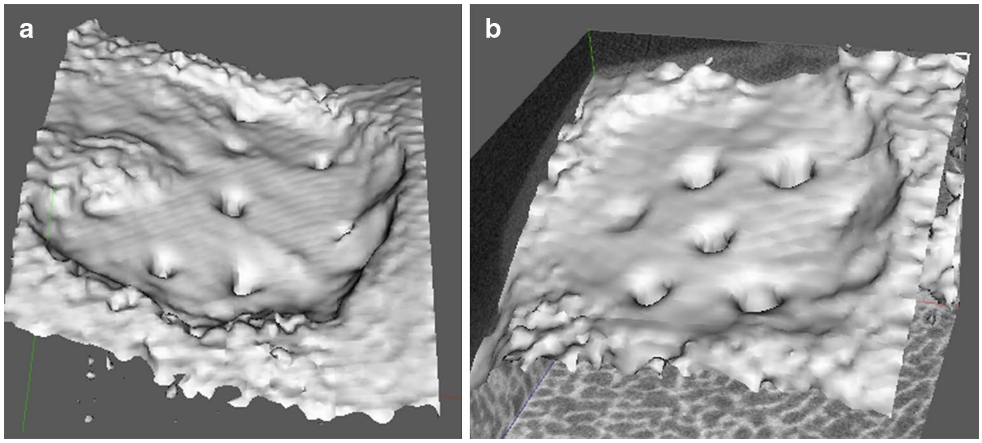

Fig. 1 **a** Example of microfracture in lesions of the trochlea and **b** the femoral condyle

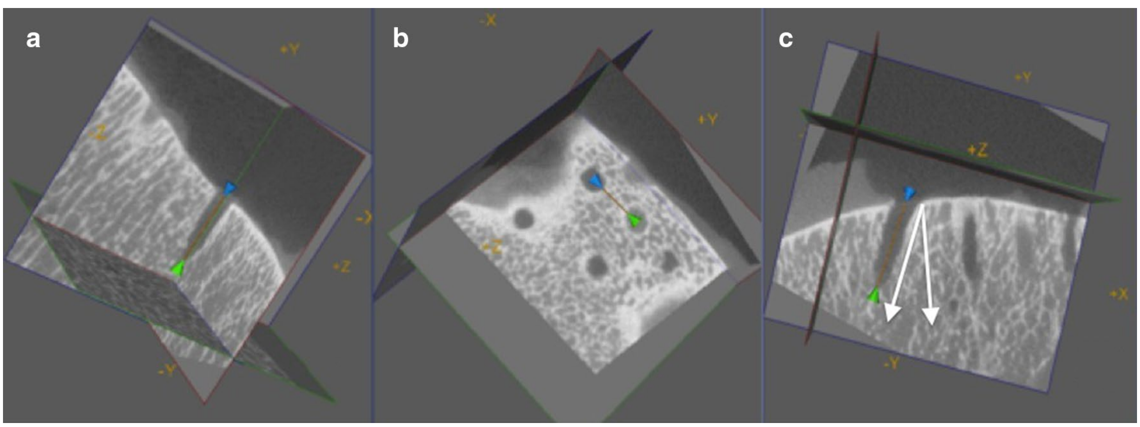

Fig. 2 3D reconstruction of micro-CT scans utilized for measurement of **a** penetration depth (trochlea), **b** inter-hole distance, and **c** penetration angle and penetration depth (femoral condyle)

Results

Depth error, inter-hole distance error, and angle deviation from the perpendicular for each surgeon were determined (Fig. 3). All surgeons misjudged depth and inter-hole distance, usually making microfracture holes that were deeper (depth error 1.1 mm, 95 % CI 0.7–1.5) and closer together (inter-hole distance error −0.8 mm, 95 % CI −0.9 to −0.6) than requested. While there was no significant difference in depth and inter-hole distance errors for three of the four surgeons, surgeon 1 was statistically more accurate in terms of depth ($p = 0.03$), but made significantly higher inter-hole distance errors ($p = 0.02$).

No significant deviation in angle of insertion error was seen between surgeons. Overall, 51 % of microfracture holes deviated more than 10° from the perpendicular (range 2.6°–19.8°). Of the remainder, 36 % of holes deviated between 10° and 20° from the perpendicular, while 5 % deviated more than 20°. While defect localization (femoral condyle and trochlea) had no influence on the accuracy of microfracture hole angles ($p = 0.25$), both depth and inter-hole distance errors were significantly reduced on the trochlear groove than on the femoral condyle (Table 1).

Two additional findings were documented during micro-CT analysis: surface shearing and inter-hole infraction (Fig. 4). Surface shearing was associated with penetration depth >4 mm and angles >20°, while inter-hole infraction was seen when microfracture holes were placed closer than 2.5 mm to each other ($p < 0.05$).

Discussion

The main finding of this study is that experienced knee arthroscopy surgeons display variation in regard to microfracture hole depth, inter-hole distance, and angular deviation when performing microfracture. These errors can lead

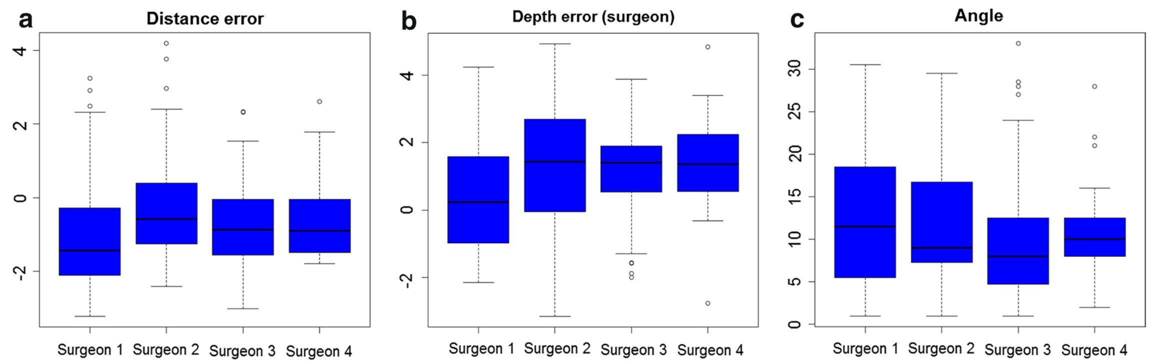

Fig. 3 **a** *Boxplot* demonstrating distant errors for each surgeon. Surgeons were directed to create microfracture holes 4 mm apart—the distance error is the distance (closer as negative and further as positive) from this 4-mm distance. **b** *Boxplot* demonstrating depth errors for each surgeon. Surgeons were directed to place the microfracture holes 3 mm deep—the depth error is the deviation (shallower as negative and deeper as positive) than the directed 3 mm. **c** *Boxplot* demonstrating angle errors for each surgeon, measured as the deviation in degrees from perpendicular to the surface of the defect

Table 1 Error analysis with regard to localization of treated defects

Parameter	Femoral condyle	Trochlear groove	*p* value
Mean depth error (95 % CI)	1.6 mm (0.7–2.5)	0.5 mm (−0.1–1.1)	$p < 0.05$
Mean inter-hole distance (95 % CI)	−1.1 mm (−1.2 to −1.0)	−0.4 mm (−0.5 to −0.3)	$p < 0.05$
Mean angle (95 % CI)	10.6° (7.9°–13.3°)	12.3° (9.0°–15.1°)	n.s

Surgeons were more accurate with regard to microfracture depth and inter-hole distance when performing microfracture in the trochlear groove as opposed to the femoral condyle

CI confidence interval, *n.s.* nonsignificant

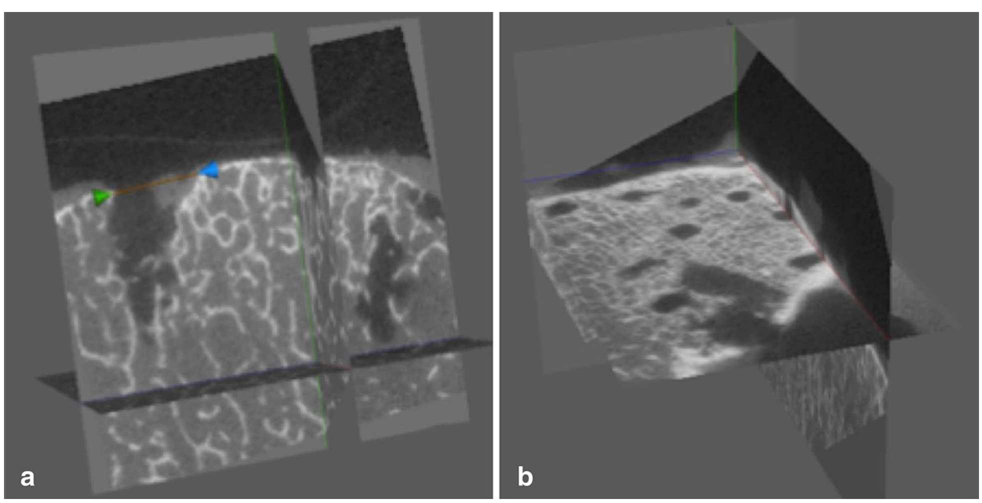

Fig. 4 Examples of **a** surface shearing and **b** infraction between neighbouring microfracture holes

to surface shearing and inter-hole infraction, especially when holes are made deeper than 4 mm and closer than 2.5 mm to each other. Further research is required to determine whether these variations are linked to clinical outcomes following microfracture procedures.

In patients with isolated osteochondral defects, Steadman et al. [20] reported good to excellent patient outcomes, with 80 % of patients still experiencing good to excellent results at 7 years post-operatively. However, Mithoefer et al. [13], systematically reviewed 28 studies, six of which were randomized clinical trials, found that there was a high variability in success rates (ranging between 67 and 86 %) at mid- to long-term follow-up. It may be that some of these technical variations identified in our study are the cause of poorer outcomes in some patients after microfracture. Certainly, there is evidence in a rabbit model that deeper drilling (6 vs. 2 mm) resulted in histological improvements in cartilage response [2].

Other than variations in surgical technique, there are many possible causes for the variable patient outcomes, especially with regard to patient selection and post-operative rehabilitation. Significantly better results have been reported in patients younger than 40 years [9], body mass index (BMI) less than 30 kg/m^2 [14], and in defects smaller than 4 cm^2 [4]. Variations in post-operative rehabilitation may also be linked to clinical outcome. While Steadman et al. [20] recommend continuous passive motion (CPM) and touch weight bearing for 6 weeks after this procedure, supported by research in animal models [6], the clinical evidence for this post-operative rehabilitation protocol in the knee is lacking [3, 11].

Theodoropoulos et al. [22] reported on a survey of 299 Canadian surgeons with regard to microfracture practice, identifying significant variations in indication (age limit and BMI), surgical technique (removal of the calcified layer and resection to stable base), and post-operative rehabilitation (weight bearing and CPM). Interestingly, the majority of surgeons felt confident in their ability to accurately create microfracture holes 3–4 mm apart, a confidence not backed up by the results of this study.

This study demonstrates that technical factors can destabilize the subchondral bone layer, potentially leading to failure of microfracture as surgical technique. While we are unable to comment on the clinical significance of these findings, the presented study is the first to evaluate the accuracy of microfracture in a cadaveric model. Further studies should be conducted to assess the depth and position of microfracture holes in patients with chondral defects, in order to determine whether there is a relationship between these factors and patient outcomes. Once the optimal technique has been determined, it may be that intra-operative templates including depth stops could be used to reduce variations in surgical technique.

This study also demonstrated that surgeons were more accurate when performing microfracture on the trochlear groove than on the femoral condyle. It seems unlikely that this finding is a result of a training effect, as surgeons performed the microfracture on the trochlea chondral defect first in every knee, before the condylar defects. While the reason for this finding is uncertain, it may be that surgeons are more able to orient themselves better in the patellofemoral joint during arthroscopy. However, it may be that performing microfracture in the patellofemoral joint is easier in the cadaveric setting than in live patients, due to decreased muscle tone and increased access to this aspect of the knee joint.

This study has some limitations. Two observers made all the measurements after reaching agreement—we are thus unable to comment on the intra- or inter-observer reliability of this measurement. However, there is literature to support micro-CT as being highly accurate [5, 12], with high intra- and inter-observer reliability [12]. It would also have been interesting to know whether less experienced surgeons display greater variability in technique compared to the experienced surgeons involved in this study. Finally, the correct depth and separation between microfracture holes are unknown; however, the targets set in this study are consistent with the literature on this surgical technique.

While the variations in surgical technique we have demonstrated require further research to determine whether these are linked to variations in clinical outcomes, surgeons should be aware that placing microfracture holes too deep and too close together can be associated with surface shearing and inter-hole infraction, respectively.

Conclusion

There is variability in microfracture hole depth, inter-hole distance, and angle of penetration when experienced knee arthroscopy surgeons perform microfracture of chondral defects. Further study is required to determine whether this variation is seen clinically and whether there is any association with patient outcomes after microfracture.

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