Preoperative Tibial Subchondral Bone Marrow Lesion Patterns and Associations With Outcomes After Isolated Meniscus Allograft Transplantation

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Background: The association between preoperative tibial subchondral bone marrow lesion (BML) patterns and outcomes after isolated meniscus allograft transplantation (MAT) are unknown.

Purpose: To determine (1) if a superior classification means exists (ie, high interrater reliability [IRR]) for grading tibial subchondral BML before isolated MAT and (2) whether quality and/or severity of preoperative tibial subchondral BML patterns was associated with clinical outcomes and/or failure rates after isolated MAT.

Study Design: Cohort study; Level of evidence, 3.

Methods: All patients who underwent isolated MAT with a single surgeon between October 2006 and February 2017 were identified. Three means were evaluated to quantify the degree of subchondral BML in the affected tibial-sided compartment: Welsch et al, based on maximum diameter of the lesion; Costa-Paz et al, based on appearance and location of the lesion; and Filardo et al, based on severity of findings. IRR was generated and compared among the 3 classifications. The preoperative magnetic resonance imaging (MRI) subchondral BML grading scheme with the highest IRR was then used to assess for associations with postoperative outcomes for those patients with >2-year follow-up, per a Spearman correlation matrix with each reviewer's grades.

Results: In total, 60 MRI scans were available for subchondral BML grading. Grader 1 identified the presence of subchondral BML in the tibia of the affected compartment in 40 (66.7%) of the available MRI scans, as compared with 38 (63.3%) for grader 2. The calculated IRRs with the Welsch et al and Costa-Paz et al classifications were rated ''strong/almost perfect'' agreement. A significant correlation was demonstrated between grader 1 with the Welsch et al grading scheme and outcome measures of KOOS pain (Knee injury and Osteoarthritis Outcome Score; negative correlation, $P = .05$), WOMAC pain (Western Ontario and McMaster Universities Osteoarthritis Index; positive correlation, $P = .026$), and Marx Activity Rating Scale (negative correlation, $P = .019$). A significant correlation was demonstrated between grader 2 with the Costa-Paz et al grading scheme and postoperative satisfaction (positive correlation, $P = .018$). There were no significant differences in survivorship based on gradings.

Conclusion: Nearly two-thirds of patients who undergo isolated MAT have subchondral BML on preoperative MRI. Our findings suggest that increasing BML size (Welsch et al) is correlated with worse postoperative pain measures (KOOS pain, WOMAC pain) and worse activity ratings (Marx Activity Rating Scale). Additionally, increasing disruption or depression of the normal contour of the cortical surface, with or without lesion contiguity with the subjacent articular surface (Costa-Paz et al), is correlated with greater postoperative satisfaction.

Keywords: meniscus allograft transplantation; bone marrow lesion; bone marrow edema; bone; marrow; meniscal; transplant

The menisci play a critical role in the biomechanical health of the tibiofemoral joint; loss of meniscal tissue through injury or surgical debridement can lead to chondral degeneration, knee instability, and progression of osteoarthritis.[11]

To avoid these consequences of meniscal deficiency and improve associated pain and functional losses, meniscus allograft transplantation (MAT) has become a viable surgical option for certain patients. Indications for the procedure include age <50 years and pain in a meniscectomized compartment but otherwise normal or correctable articular cartilage, ligamentous stability, and coronal/sagittal alignment.[11] Overall, studies suggested good clinical outcomes from the procedure, with acceptable failure rates averaging about 10% in the mid- to long-term follow-up.[6,13]

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Subchondral bone marrow lesion (BML) involves an increased signal in the bone marrow on magnetic resonance imaging (MRI), and it has been implicated in chondral loss and pain in the knee.[8,15] The presence of subchondral BML in relation to original knee injury patterns and outcomes after surgical intervention in the knee has been a topic of recent interest and in-depth discussion. The subchondral bone is thought to play a key role in the joint environment after surgery. Authors found that the size of BML is related to knee pain with activity.[25] Some studies established the role of subchondral BML with respect to the development of osteoarthritis or osteonecrosis (including cartilage degeneration after anterior cruciate ligament reconstruction [ACLR]),[1,12,15,17] knee function after autologous chondrocyte implantation (ACI),[18] and long-term clinical outcomes after ACLR. Other studies, however, failed to demonstrate a clinical outcome correlation with the presence of BML after ACI,[19] matrix-assisted autologous chondrocyte transplantation,[5,9] or ACLR.[4,12,16]

To date, the association between preoperative tibial subchondral BML patterns and outcomes after isolated MAT is unknown. However, unlike that for cartilage restoration (predominantly ACI procedures), there is no standardized or widely agreed-on means by which to evaluate MRI scans for subchondral BML patterns in the case of noncartilage restoration surgery—in this study, MAT. The purpose of this study was thus to evaluate a surgeon's cohort of patients with isolated MAT and the predictive value of preoperative subchondral tibial BML in the affected compartment. Specifically, we sought to determine (1) if a superior classification means exists (ie, high interrater reliability [IRR]) for grading tibial subchondral BML before isolated MAT and (2) whether quality and/or severity of preoperative tibial subchondral BML patterns was associated with outcomes and/or failure rates after isolated MAT. Our hypotheses were (1) that a single classification scheme for grading subchondral BML among these patients would be superior to others and with high IRR and (2) that increasing severity of subchondral tibial BML in the affected compartment would be predictive of poor outcomes and increased failure rates after isolated MAT.

METHODS

Patient Cohort

Following Institutional Review Board approval, all patients who underwent isolated MAT with a single surgeon (B.J.C.) between October 2006 and February 2017 were retrospectively identified from a database of prospectively collected data. Exclusion criteria were revision MAT, concurrent surgical procedures (ligament reconstruction, contralateral meniscus, cartilage restoration, osteotomy), and incomplete preoperative data in terms of clinical or MRI analysis.

Preoperative MRI Analysis of BML

MRI examination for BML was performed with a 1.5- or 3.0-T superconducting magnet. All available sequences (T1 or T2 weighted) and cuts (sagittal, axial, and coronal plane imaging) were reviewed, as the BML grading schemes are not specific to a particular cut or sequence. MRI scans were calibrated to allow measurements on the picture archiving and communication system. The time between preoperative MRI and MAT surgery was recorded.

We evaluated 3 means of qualifying and/or quantifying the degree of subchondral BML in the affected compartment (medial/lateral) on the tibial side. In addition, all imaging was graded in binary format (yes/no) for the presence of subchondral BML in the affected tibial compartment. The first classification scheme was based on Welsch et al[26] for the maximum measured diameter of subchondral BML: small (<1 cm), medium (<2 cm), large (<4 cm), and very large (>4 cm) (Figure 1). The second classification, by Costa-Paz et al,[4] was a 3-level grading system on the appearance and location of subchondral BML: type I, diffuse signal with change of medullary component, often reticular and distant from the subjacent articular surface; type II, localized signal with contiguity to the subjacent articular surface (often crescentic lesions with varying thickness); type III, disruption or depression of the normal contour of the cortical surface, often associated with a type II lesion (Figure 2). The third grading scheme, by Filardo et al,[9] was a 3-tiered grading system guided by increasing severity of findings: grade 0, no edema; grade 1, small edema or slightly hyperintense; grade 2, large edema or highly hyperintense (Figure 3). Two authors (B.M.S., G.L.C.)—both senior-level orthopaedic surgery residents trained in reading musculoskeletal MRI scans—independently reviewed and graded all patient imaging for subchondral BML patterns in a blinded fashion. IRR was generated and compared for each of the 3 aforementioned classification schemes. The identified superior grading classification was then used to analyze for associations with postoperative outcomes.

Patient Demographic, Intraoperative, and Postoperative Data Collected

The following demographic and preoperative data were recorded for patients with >2-year clinical follow-up: age at time of surgery; sex; body mass index; smoking status

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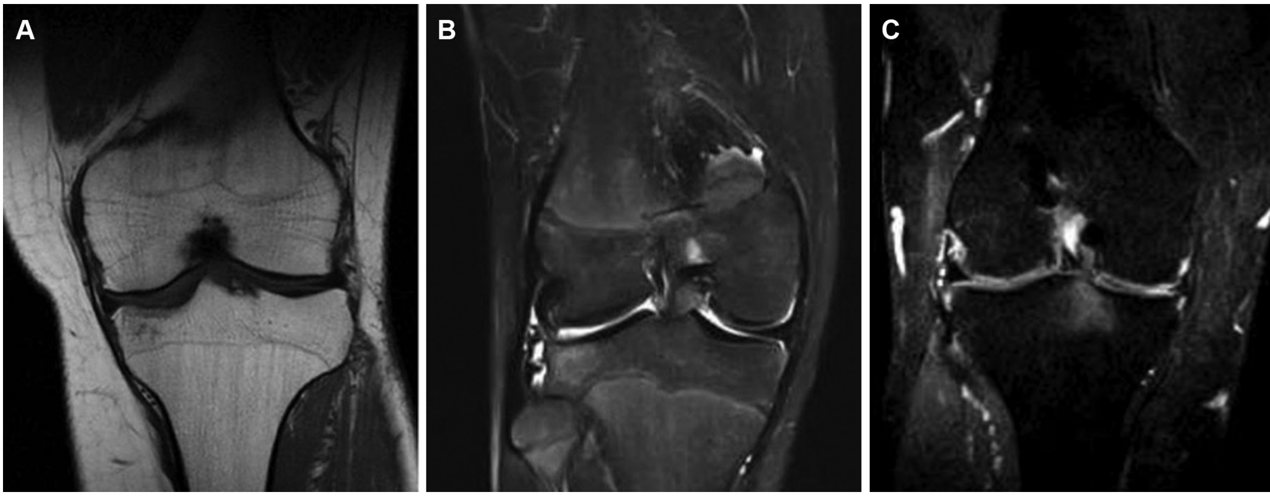

Figure 1. The Welsch et al[26] subchondral BML classification gradings based on the maximum measured diameter of subchondral BML: no edema; (A) small (<1 cm) (coronal T1-weighted image with edema in medial tibial plateau); (B) medium (<2 cm) (coronal T2-weighted image with edema in lateral tibial plateau); (C) large (<4 cm) (coronal T2-weighted image with edema in medial tibial plateau); and very large (>4 cm). BML, bone marrow lesion.

Figure 2. The Costa-Paz et al[4] subchondral BML classification gradings based on a 3-level system of subchondral BML (arrows) per appearance and location: no edema; (A) type I, diffuse signal with change of medullary component, often reticular and distant from the subjacent articular surface (coronal T2-weighted image showing bone bruise in the lateral tibial plateau); (B) type II, localized signal with contiguity to the subjacent articular surface, often crescentic lesions with varying thickness (coronal T1- and T2-weighted images showing bone bruise of the lateral femoral condyle); (C) type III, disruption or depression of the normal contour of the cortical surface, often associated with a type II lesion (sagittal T1-weighted image of lesion on femoral articular surface). BML, bone marrow lesion. Reproduced with permission from Costa-Paz et al (Elsevier Publishing).

(yes/no); workers' compensation claim (yes/no); athlete status (yes/no), level of athletic competition (recreational, high school, college, professional), and sport; and prior surgical intervention (including number, intervention [ie, ligament reconstruction, meniscal debridement, chondroplasty, cartilage restoration], and duration between most recent surgery and index isolated MAT). The following intraoperative characteristics were documented: date of surgery, knee laterality, and compartment of MAT (lateral/medial). Postoperative data included length of clinical follow-up; return to sport (yes/no), at what level (same/higher/lower), and in what period; permanent restrictions (yes/no); subsequent surgical intervention and timing (nonfailure related); and failure occurrence and timing. Failure was defined as a requirement for revision meniscal transplantation surgery, total meniscectomy, or conversion to arthroplasty. Preoperative radiographs within 6 months of surgery date were graded with the Kellgren-Lawrence scale. Of note, 2 patients did not have preoperative radiographs within our imaging database, and 1 patient had poorly developed radiographs that could not be accurately assessed.

Patient-reported outcome measures were obtained preoperatively and at >2 years postoperatively (per the inclusion criteria for the outcomes-based portion of the analysis) and included the following: Lysholm, International Knee Documentation Committee (IKDC), Knee injury and Osteoarthritis Outcome Score (KOOS) and subscales (symptom, pain, activities of daily living, sport, quality of life), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) and subscales (pain, stiffness, function,

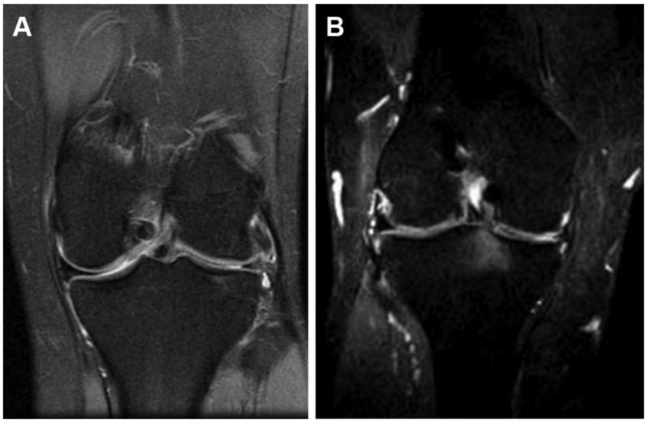

Figure 3. The Filardo et al[9] subchondral bone marrow lesion classification gradings based on a 3-tiered system guided by increasing severity of findings: grade 0, no edema; (A) grade 1, small edema or slightly hyperintense (coronal T2-weighted image of edema in lateral tibial plateau); (B) grade 2, large edema or highly hyperintense (coronal T2-weighted image of edema in medial tibial plateau).

total), overall score (0-10; an additive score based on patient complaints of stiffness, function, and pain), and SF-12 physical and mental scores (12-item Short Form Health Survey). Postoperatively, patients were asked if they would have the isolated MAT procedure again, if given the opportunity in a similar situation, and if they were satisfied with the procedural outcome (0-10, with 10 being completely satisfied); they were also asked to provide a visual analog scale pain score (0-10, with 10 being worst pain) and Single Assessment Numeric Evaluation score (0-100).

Surgical Technique and Postoperative Rehabilitation

All MAT procedures were performed by the senior author (B.J.C.). Patient donor allograft meniscus measurements were obtained according to the radiograph-sizing methods described by Pollard et al.[22] Meniscal transplant technique was the bone-bridge technique in all settings.[7,23,24]

Patient rehabilitation followed a 3-phase protocol. For the first postoperative 6 weeks, the patient is partial weightbearing in a hinged knee brace with immediate range of motion from full extension to 90° of flexion, with mobilization performed via heel slides, quad sets, and straight-leg raises. For postoperative weeks 6 to 12, the knee brace is discontinued, and patients are allowed full range of motion and weightbearing status. Postoperative weeks 12 to 18 focus on increased intensity of exercises, including single-legged hops, sports-specific drills, jogging, and plyometrics.[2,3,23]

Statistical Analysis

To calculate and compare the IRR of the MRI subchondral BML grading schemes, Cohen kappa was used with 2 raters. The analysis was performed in 2 ways: first, it was weighted with a squared term that assumes that the distance between groups is not equal (ie, the distance grows or shrinks as one goes through the levels); second, a linear weighting term was utilized that assumes equal distance.

Initially, a paired *t*-test analysis was performed to assess for an effect of surgical intervention (isolated MAT) on the reported outcome variables. The preoperative MRI subchondral BML grading scheme with the highest IRR was then used to assess for associations with postoperative outcomes, based on Spearman correlation with each reviewer's gradings. (As the scales are ordinal data, taking an average of the 2 reviewers to get 1 value for the BML grading scheme would not provide an actual value on the scales and would rather act as a surrogate variable without any real meaning.)

In addition, a Kaplan-Meier survival analysis was performed to generate survival statistics at postoperative 60 months for the overall patient cohort and by the highest IRR BML grading classification scheme and each "grade" from grader 1 and grader 2. A log-rank test was performed for the survivorship curves to assess for significant differences in survivorship by grade within each classification scheme and for each grader. Kellgren-Lawrence grades for preoperative radiographs were evaluated with chi-square analysis for association with failure rates after isolated MAT. Results were considered significant if $P \leq .05$, and values are reported as mean ± SE. Statistics were conducted in SPSS Statistics (v 23.0; IBM).

RESULTS

Preoperative MRI Subchondral BML Grading and IRR

In total, 60 MRI scans were available for subchondral BML grading (32 right knees, 28 left knees; 37 medial compartments, 23 lateral compartments), which were performed at 308 ± 280 days before surgical intervention. Grader 1 (G.L.C.) identified the presence of subchondral BML in the tibia of the affected compartment in 40 (66.7%) MRI scans, as compared with 38 (63.3%) for grader 2 (B.M.S.). Table 1 presents the overall gradings by classification scheme. For those patients with the presence of subchondral BML, most were graded "medium" per Welsch et al,[26] "type II" per Costa-Paz et al,[4] and "grade 1" per Filardo et al.[9] The calculated IRR demonstrated "strong/almost perfect" agreement with the Welsch et al and Costa-Paz et al classifications versus "average" for the Filardo et al method (Table 2). There was no significant effect of the duration from MRI scan performance to surgical intervention and the presence or absence of subchondral BML. Additionally, there was no effect of prior surgery on the degree of subchondral BML in the preoperative MRI scans.

Patient Outcomes and Subchondral BML Analysis

In total, there were 136 consecutive knees (135 patients) that underwent isolated MAT during the study period, of which 60 (59 patients) had preoperative MRI of the affected knee available for review and were included in

TABLE 1
Magnetic Resonance Imaging Findings With Subchondral Bone Marrow Lesion Gradings by Classification Scheme[a]

	Binary		Welsch et al[26]					Costa-Paz et al[4]				Filardo et al[9]		
Grader	Yes	No	None	Small	Medium	Large	Very Large	None	Type I	Type II	Type III	Grade 0	Grade 1	Grade 2
1	40 (67)	20 (33)	20 (33)	5 (8)	28 (47)	7 (12)	0 (0)	20 (33)	14 (23)	23 (38)	3 (5)	20 (33)	35 (58)	5 (8)
2	38 (63)	22 (37)	22 (37)	4 (7)	26 (43)	8 (13)	0 (0)	22 (37)	12 (20)	25 (42)	1 (2)	22 (37)	29 (48)	9 (15)

[a]Values are presented as No. (%) for 60 knees (59 patients).

TABLE 2
Calculated Interrater Reliability by Subchondral Bone Marrow Lesion Classification Schemes

	Kappa Weights					
	Square			Linear		
Scheme	Kappa	*Z*	*P* Value	Kappa	*Z*	*P* Value
Welsch et al[26]	0.943	7.32	<.001	0.885	8.64	<.001
Costa-Paz et al[4]	0.904	7.03	<.001	0.835	8.2	<.001
Filardo et al[9]	0.798	6.25	<.001	0.749	7.59	<.001

the initial MRI subchondral BML grading and IRR testing. For evaluation of clinical outcomes, 54 knees (53 patients) were >2 years postsurgery. Only 40 knees (39 patients) had >2-year follow-up (74.07%) and were available for inclusion in the final clinical analysis to evaluate associations between preoperative MRI patterns of subchondral BML and postoperative outcomes.

Age at time of surgery was 26.10 ± 9.30 years, and body mass index was 25.49 ± 5.16 kg/m^2. Of the 39 patients, 19 (47.50%) were male, and 19 (47.50%) identified as athletes (most commonly recreational: 63.16%, 12 of 19). The majority of patients had evidence of osteoarthritis on preoperative radiographs: Kellgren-Lawrence grade 1 (54.90%, 28 of 51 available films) or grade 2 (31.37%, 16 of 51 available films). There was no significant difference in failure rates based on preoperative Kellgren-Lawrence grades (P = .272). Prior surgical intervention was performed for all patients, and nearly all (98.15%, 39 of 40) underwent prior meniscectomy. Most MATs (67.50%, 27 of 40) were performed in the medial compartment. Table 3 presents the complete list of patient variables.

Postoperative Outcomes and Subchondral BML Analysis

At final follow-up (58.82 ± 27.59 months), postoperative visual analog scale for pain was 1.15 ± 1.69, and Single Assessment Numeric Evaluation score was 79.00 ± 19.36. Of the 27 patients who responded to the question regarding having the procedure again and level of satisfaction with the clinical outcome, 22 (81.48%) reported that they would have the procedure again, and patient satisfaction was 8.41 ± 2.72. Sixteen patients (84.21%) returned to sport, with 14 of 19 athletes (74%) returning at the same level. The time to full return to sport was 15.75 ± 7.43 months after surgery. There were 4 failures (2 total meniscectomies, 1 conversion to total knee arthroplasty, and 1 revision MAT), which occurred at postoperative 30.84 ± 16.80 months. Kaplan-Meier survival analysis demonstrated 95% graft survival at 24 months and 87% graft survival at 60 months (Figure 4). Eleven patients (27.50%) underwent revision surgery and reoperation, including partial meniscectomy (n = 4), total meniscectomy (n = 2), revision medial meniscal transplant (n = 1), plica excision (n = 1), debridement of articular cartilage followed by osteochondral allograft transplantation (n = 1), DeNovo NT (n = 1), and synovectomy (n = 1). The time to subsequent surgery was 16.30 ± 14.28 months. Significant improvements in patient-reported outcomes from presurgery to postoperative ≥2 years were noted in IKDC, KOOS pain, and SF-12 physical, with effects nearing the value of significance for KOOS quality of life and WOMAC total. Table 4 presents a complete description of all patient-reported outcome scores.

Table 4 additionally dictates the findings of the Spearman correlation matrix on the 2 BML classification grading schemes with the highest IRR. A significant correlation was demonstrated between 1 grader (G.L.C.) with the Welsch et al[26] grading scheme and outcome measures of KOOS pain (negative correlation, P = .05), WOMAC pain (positive correlation, P = .026), and Marx Activity Rating Scale (negative correlation, P = .019). Of note, a lower KOOS pain score and a higher WOMAC pain score represent more extreme postoperative pain. A significant correlation was demonstrated between 1 grader (G.L.C.) with the Costa-Paz et al[4] grading scheme and postoperative satisfaction (positive correlation, P = .018). No other postoperative outcomes correlated with the preoperative subchondral BML gradings classifications. There was no significant effect of the duration from MRI scan performance to surgical intervention and any of

TABLE 3
Characteristics of Patients With >2-Year Clinical Follow-up (n = 40)

Variable	Data[a]
Age at surgery, y	26.10 ± 9.30
Male	19 (47.50)
Smoker	1 (2.50)
Body mass index	25.49 ± 5.16
Follow-up time, mo	58.82 ± 27.59
Workers' compensation claim	10 (25.00)
Athlete status	19 (47.50)
Level of sport	
Recreational	12 (63.16)
Competitive high school	4 (21.05)
College	3 (15.79)
Sport played	
Basketball	6 (31.58)
Volleyball	4 (21.05)
Tennis	1 (5.26)
Soccer	2 (10.53)
MMA	1 (5.26)
Swimming	1 (5.26)
Cross-country/running >3×/wk	3 (15.79)
Cycling	1 (5.26)
Kellgren-Lawrence grade: preoperative radiographs	51 available films
0	6 (11.76)
1	28 (54.90)
2	16 (31.37)
3	1 (1.96)
4	0 (0)
Prior intervention	40 (100)
Prior interventions	2.22 ± 1.06[b]
Time from most recent intervention, mo	23.07 ± 37.63
Prior malalignment procedure	0 (0)
Prior MAT	0 (0)
Prior debridement	12 (30)
Prior meniscectomy (ipsilateral compartment)	39 (98)
Prior ACLR	8 (20)
Prior cartilage procedure	2 (5)
Prior osteotomy	0 (0)
Laterality	
Right	21 (52.50)
Left	19 (47.50)
Tibiofemoral compartment	
Medial	27 (67.50)
Lateral	13 (32.50)

[a]Values are presented as mean ± SE or No. (%), unless noted otherwise. ACLR, anterior cruciate ligament reconstruction; BMI: body mass index; MAT, meniscus allograft transplantation; MMA, mixed martial arts.

[b]Mean ± SD.

the reported outcome measures. Small sample size and/or variability was seen in the results on return to sport, failure, reoperation, and whether patients would do surgery again and thus did not allow for Spearman correlation performance and analysis.

Figure 5 demonstrates the Kaplan-Meier survival analysis based on the Welsch et al[26] and the Costa-Paz et al[4] grading schemes for grader 1 (G.L.C.) and grader 2 (B.M.S.). There were no significant differences in survivorship based on the grades within either classification scheme or by either grader (Welsch et al, grader 1: P = .619; Welsch et al, grader 2: P = .872; Costa-Paz et al, grader 1: P = .497; Costa-Paz et al, grader 2: P = .628).

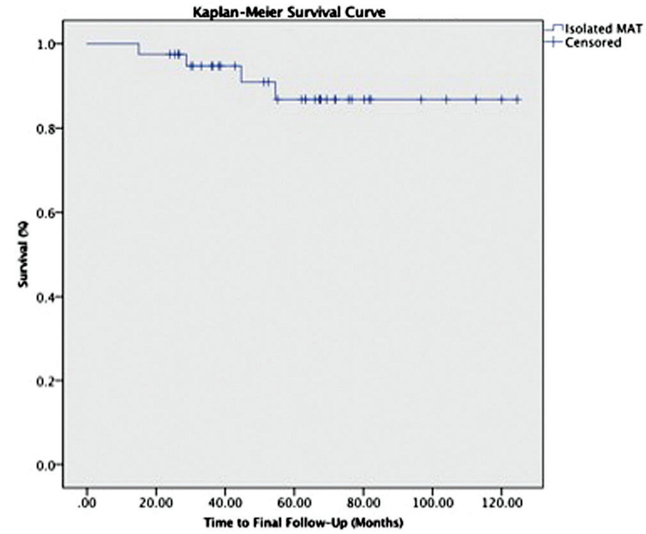

Figure 4. Kaplan-Meier survival curve was generated with 4 patients considered failures (10%) at postoperative 30.84 ± 16.80 months. The analysis demonstrated 95% graft survival at 24 months and 87% graft survival at 60 months. MAT, meniscus allograft transplantation.

DISCUSSION

The results of this study suggest that nearly two-thirds of patients who undergo isolated MAT have subchondral BML on preoperative MRI. While several patient-reported outcomes demonstrate significant improvement after isolated MAT, the Welsch et al[26] preoperative classification scheme, based on quantifiable size of the BML, has a strong IRR and finds that increasing BML size is correlated with worse postoperative pain measures (decreased KOOS pain and increased WOMAC pain) and worse activity ratings (decreased Marx Activity Rating Scale). Additionally, the Costa-Paz et al[4] preoperative classification scheme, based on relation to articular surface and diffuseness of BML, has a strong IRR and finds that increasing disruption or depression of the normal contour of the cortical surface, with or without lesion contiguity with the subjacent articular surface, is correlated with greater postoperative satisfaction. However, there are no significant differences in survivorship related to these grading scales.

Subchondral BML is a common finding before and after cartilage treatment, but the role that this plays in outcomes of these chondral procedures is still being considered. Filardo et al[9] reported on 116 patients after matrix-assisted autologous chondrocyte transplantation treatment in the knee and found that BML was present within the first 2 years after treatment, markedly reduced at 2 to

TABLE 4
Patient-Reported Outcome Measures[a]

Measure	Mean ± SE (No.) Preoperative	Mean ± SE (No.) ≥2 y Postoperative	P Value[c]	Spearman Correlation With BML Pattern (P Value)[b] Welsch et al[26]	Spearman Correlation With BML Pattern (P Value)[b] Costa-Paz et al[4]
IKDC	45.00 ± 15.59 (22)	66.53 ± 17.89 (21)	**.044**	–0.195 / –0.076 (>.1)	0.153 / 0.201 (>.1)
KOOS					
Pain	56.75 ± 17.19 (28)	76.48 ± 17.07 (21)	**.015**	**–0.369** / –0.174 (**.05**)	0.058 / 0.059 (>.1)
Symptoms	57.86 ± 19.08 (28)	71.96 ± 14.17 (21)	.226	–0.208 / –0.062 (>.1)	0.287 / 0.114 (>.1)
ADL	73.46 ± 19.66 (28)	86.78 ± 15.53 (21)	.226	–0.311 / –0.235 (.085)	–0.016 / 0.009 (>.1)
Sports	31.96 ± 22.04 (28)	53.81 ± 30.37 (21)	.341	–0.331 / –0.202 (.072)	–0.089 / 0.071 (>.1)
QOL	26.79 ± 20.94 (29)	50.02 ± 28.77 (21)	.079	–0.309 / –0.103 (.086)	–0.046 / –0.024 (>.1)
WOMAC					
Pain	6.57 ± 3.81 (28)	4.86 ± 4.04 (21)	.360	**0.428** / 0.236 (**.026**)	0.130 / 0.090 (>.1)
Stiffness	2.97 ± 1.61 (29)	2.43 ± 1.60 (21)	.535	0.258 / 0.169 (>.1)	–0.202 / 0.025 (>.1)
Function	18.30 ± 13.41 (27)	8.33 ± 8.96 (21)	.140	0.262 / 0.207 (>.1)	–0.030 / –0.056 (>.1)
Total	27.78 ± 17.46 (27)	13.00 ± 11.50 (18)	.091	0.255 / 0.183 (>.1)	–0.100 / –0.096 (>.1)
SF-12					
Physical	38.36 ± 5.20 (22)	46.37 ± 9.49 (18)	**.010**	–0.341 / –0.289 (.083)	0.114 / 0.183 (>.1)
Mental	51.36 ± 11.66 (22)	52.45 ± 11.62 (20)	.738	0.096 / 0.154 (>.1)	0.200 / –0.065 (>.1)
Marx	—	5.00 ± 5.70 (14)	—	**–0.556** / –0.458 (**.019**)	–0.293 / –0.293 (>.1)
Satisfaction	—	8.41 ± 2.72 (27)	—	0.228 / 0.257 (.098)	0.017 / **0.405** (**.018**)
VAS pain	—	1.15 ± 1.69 (26)	—	–0.091 / –0.067 (.330)	0.139 / –0.097 (.245)
SANE	—	79.00 ± 19.36 (25)	—	0.192 / 0.218 (.147)	–0.217 / 0.057 (.148)
Time to RTS	—	15.75 ± 7.43 (16)	—	–0.309 / –0.049 (.122)	–0.201 / –0.375 (.076)

[a]Dash (—) indicates not applicable. Bold indicates $P \leq .05$. ADL, activities of daily living; BML, bone marrow lesion; IKDC, International Knee Documentation Committee; KOOS, Knee injury and Osteoarthritis Outcome Score; QOL, quality of life; RTS, return to sport; SANE, Single Assessment Numeric Evaluation; SF-12, 12-item Short Form Health Survey; VAS, visual analog scale; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.
[b]Grader 1 / grader 2.
[c]Pre- to postoperative change.

3 years, and increased again into the medium/long-term follow-up. However, they found no correlation between BML and clinical outcome. Niethammer et al[19] evaluated 38 circumscribed full-thickness cartilage defects in 30 patients who underwent third-generation ACI (Novocart 3D). The authors evaluated standardized MRI at postoperative 1.5, 3, 6, 12, 24, and 36 months and observed subchondral BML in 78.9% of defects over the postoperative course. However, clinical patient outcomes did not correlate with the presence of BML at any period. Similarly, Ebert et al[5] reported no association between the severity of preoperative subchondral BML and postoperative patient-reported knee symptoms, pain, or MRI-evaluated graft repair among 56 patients undergoing matrix-induced ACI at postoperative 60 months.

Some studies, however, demonstrated a prognostic factor of subchondral BML and outcomes after cartilage restoration surgery. Niemeyer et al[18] evaluated 67 patients treated with ACI for cartilage defects of the knee joint; the 13 patients in their cohort with preoperative grade 4 edema ("severe") showed inferior results to those with gradings of "absent," "mild," or "moderate" edema per IKDC and Lysholm scores at postoperative 6 and 12 months.

BML lesions were additionally evaluated in relation to ACLR with conflicting findings. Gong et al[12] enrolled 54 patients with acute anterior cruciate ligament (ACL) tear and graded BML lesions with the Whole-Organ Magnetic Resonance Imaging Score. They noted BML lesions in 42 injured knees (77.8%) and found that while BML patterns in these patients resolved rapidly over time after ACLR, it was an independent predictor for faster cartilage degeneration during the 2-year follow-up period. However, the association between BML lesions and KOOS scores was not statistically significant. Similarly, Costa-Paz et al[4] used their 3-level grading system to evaluate BML in the setting of ACL ruptures and found no correlation between clinical scores obtained from patients with resolved lesions in the postoperative period and those with osteochondral sequelae. Lattermann et al[16] echoed these findings in their study of 81 patients with ACL tear and reconstruction, in whom neither bone bruise volume nor severity was associated with inferior postoperative outcomes. Filardo et al,[10] by contrast, identified BML presence after ACL tear in 55.2% of patients, which gradually decreased over time but correlated in severity and size with clinical prognosis, including return to sport. Illingworth et al[14] investigated whether a relationship existed between the size of bone bruise volume after acute ACL rupture and the presence of intra-articular lesions, and the authors demonstrated a statistically significant relationship between femoral bone bruise volume and the presence of meniscal tears in ACL injury. Other pathologic conditions, including patellar tendinopathy, demonstrated inferior functional outcomes and delayed return to sport for patients with simultaneous preoperative BML and intrapatellar fat pad

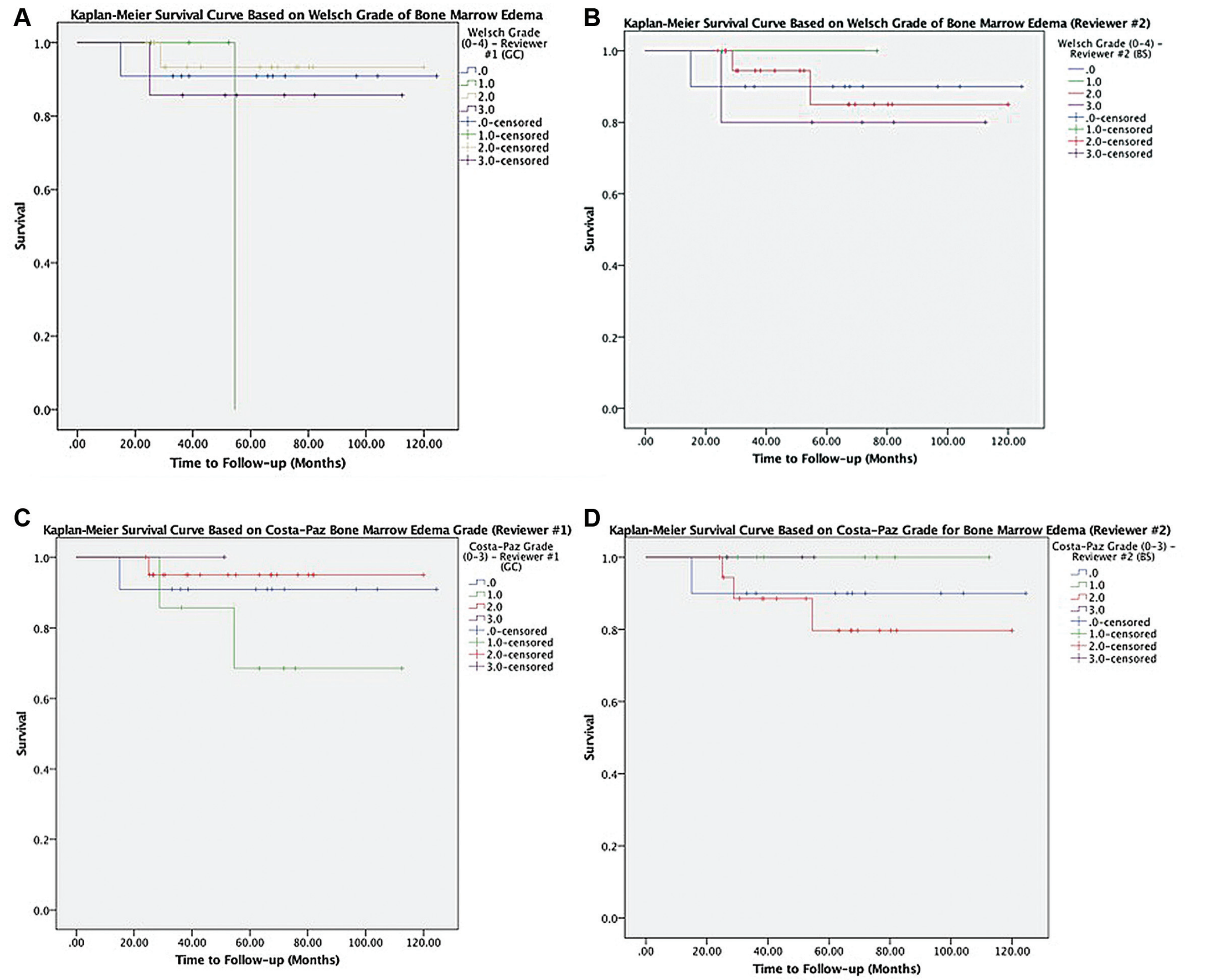

Figure 5. Kaplan-Meier survival analysis based on the Welsch et al[26] and the Costa-Paz et al[4] grading schemes for grader 1 (G.L.C.) and grader 2 (B.M.S.).

edema on preoperative MRI before undergoing arthroscopic treatment.[20]

While ACI, matrix-assisted autologous chondrocyte transplantation, and other surface cartilage procedures may have more generally agreed-on means in the literature of grading BML preoperatively or postoperatively—such as the Whole-Organ Magnetic Resonance Imaging Score[21] or MOCART scoring system—no such unified classification scheme exists for MAT. Certainly, MAT surgery does not lend itself to the utilization of such grading means, given the inclusion of a bony allograft component with the allograft meniscus and the absence of any articular cartilage component. Thus, these findings are important going forward in standardizing further research efforts on BML gradings in the context of MAT surgery to allow for comparison of findings.

Furthermore, the results of our study propose an avenue for research and possibly therapeutic targets regarding the relationship between preoperative subchondral BML and outcomes after isolated MAT. As BML was present in the majority of patients before surgery and a relationship was identified between increasing BML size and greater postoperative pain measures and worse activity ratings, translation of this research into the clinical setting could mean attempts to focus preoperative efforts on reducing edema in the affected tibiofemoral compartment (through unloading, offloading, or 1 of many oral or injection therapeutics currently receiving clinical attention) in an effort to reduce patients' postoperative pain. Moreover, the finding that increasing disruption or depression of the normal contour of the cortical surface is correlated with greater postoperative satisfaction suggests a potentially useful MRI finding—one that identifies those patients who have more aggressive disease processes preoperatively and thus will be more satisfied with operative intervention (vs those who have less severe disease preoperatively). This is not necessarily surprising, as the bony component of the meniscal allograft replaces this irregularly contoured region of bone, thereby eliminating the particular region of injury through surgery. These findings additionally may serve as an opportunity to better counsel patients on postoperative expectations based on preoperative MRI findings.

Limitations

This study is not without limitations. First, our sample size is relatively small and likely underpowered to detect potentially significant findings. We are limited as well by the number of patients completing follow-up data measures. Given the paucity of literature on the topic of BML and MAT surgery, however, the presentation of this cohort remains valuable. Additionally, there is a range of time between patients' preoperative MRI and surgical intervention, and it is possible that subchondral BML patterns could have changed per patient if otherwise standardized to a certain time point before surgery. However, there was no significant effect of the duration from MRI scan performance to surgical intervention and the presence/absence of subchondral BML or any of the reported outcome measures in our study. Future research efforts and prospective study should focus on evaluating preoperative MRI scans at a defined time point (ie, 3 months before surgical intervention with isolated MAT) and possibly only those from patients without prior surgical intervention. The latter may be difficult, as patients who are indicated for MAT surgery have typically undergone at least 1 prior surgical intervention given the nature of the procedure. We were also potentially limited such that in our correlation analysis it was not appropriate to combine or average the ordinal data between the 2 reviewers; thus, we ran the correlation analysis for each reviewer separately. To run the correlation as an average of the reviewers' gradings would be creating a surrogate variable, with numbers that do not have real meaning in terms of the grading classification schemes. Finally, more subchondral BML grading classification schemes by MRI exist than the 3 that we chose to evaluate in our study, and it is possible that any of these others would have additionally high IRR and the potential for associations with outcome measures.

CONCLUSION

Nearly two-thirds of patients who undergo isolated MAT have subchondral BML on preoperative MRI. The preoperative classification scheme by Welsch et al,[26] based on quantifiable size of the BML, has a strong IRR, and our findings suggest that increasing BML size is correlated with worse postoperative pain measures (KOOS pain, WOMAC pain) and worse activity ratings (Marx Activity Rating Scale). A preoperative classification scheme by Costa-Paz et al,[4] based on relation to articular surface and diffuseness of BML, also has a strong IRR and finds that increasing disruption or depression of the normal contour of the cortical surface, with or without lesion contiguity with the subjacent articular surface, is correlated with greater postoperative satisfaction. However, there are no significant differences in survivorship related to these grading scales.

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