Original Research

Relationship Between Bone Bruise Volume and Patient Outcomes After ACL Reconstruction

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Background: Subchondral bone injuries, or bone bruises, are commonly observed on magnetic resonance imaging (MRI) after anterior cruciate ligament (ACL) injury. The current relationship between bone bruise volume and postsurgical outcomes remains poorly understood.

Purpose: To examine the influence of bone bruise volume on self-reported and objective functional outcomes at the time of return to play and 2 years following ACL reconstruction.

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

Methods: Clinical, surgical, and demographic data were obtained for a sample of convenience utilizing a single-surgeon ACL database (n = 1396). For 60 participants, femoral and tibial bone bruise volumes were estimated from preoperative MRI. Data obtained at the time of return to play included International Knee Documentation Committee (IKDC-2000) score, ACL–Return to Sport after Injury (ACL-RSI) score, and performance on an objective functional performance battery. Two-year follow-up data included graft reinjury rate, level of return to sport/activity, and self-reported knee function using the Single Assessment Numeric Evaluation (SANE). The forward stepwise linear regression was used to determine the relationship between bone bruise volume and patient function.

Results: The distribution of bone bruise injuries was as follows: lateral femoral condyle (76.7%), lateral tibial plateau (88.3%), medial femoral condyle (21.7%), and medial tibial plateau (26.7%). Mean total bone bruise volume of all compartments was 7065.7 ± 6226.6 mm^3. At the 2-year follow up, there were no significant associations between total bone bruise volume and time of return to play ($P = .832$), IKDC-2000 score ($P = .200$), ACL-RSI score ($P = .370$), or SANE score ($P = .179$).

Conclusion: The lateral tibial plateau was the most frequent site to sustain bone bruise injury. Preoperative bone bruise volume was not associated with delayed time to return to sport or self-reported outcomes at time of return to play or at 2 years postoperatively.

Registration: NCT03704376 (ClinicalTrials.gov identifier).

Keywords: bone bruise; return to sport

Subchondral bone injuries, also known as bone bruises, are frequently associated with anterior cruciate ligament (ACL) injuries due to the corresponding contact forces imparted to the tibiofemoral joint by the subluxation moment.[10,14,18,29] Bone bruises are defined as a type of bone marrow or subchondral lesion resulting from microtrabecular fractures[2,3,5,10,12,14,18,27] and are observed as a high-intensity signal on magnetic resonance imaging (MRI).[1,10,14,19,22,24,29] In the setting of ACL injuries, these lesions are pathognomonic, with prevalence rates up to 80%,[12,15,20] and they are commonly localized at the lateral tibial plateau (LTP) and femoral condyle.[2,15,17,19,22,24,29] Despite knowledge of the frequency and location of bone bruises, little is known about the potential influence that these lesions may have on functional recovery and long-term joint integrity after ACL injury.

The relationship between bone bruises and long-term articular cartilage health is of particular concern, as previous work has indicated that these lesions are associated with degenerative chondral changes at 5 years after ACL

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reconstruction.[14] Research suggests that bone bruising may alter subchondral blood supply to the adjacent articular cartilage thereby potentially accelerating degenerative arthritic changes within the tibiofemoral joint.[3] Furthermore, bone bruise healing or resorption does not appear to be associated with improvements in the articular cartilage health.[15] This relationship is supported by the prevalence rates of posttraumatic osteoarthritis (PTOA) observed within the ACL population upon long-term follow-up. Specifically, it has been estimated that between 40% and 50% of individuals present with irreversible chondral joint changes as early as 2 to 5 years after the initial ACL injury.[15]

Clinically, individuals with bone bruising have reported increased knee joint effusion and increased pain affecting the time to restore symmetrical gait and knee range of motion.[6,7,13] Authors suggest that the volume of bone bruising found on MRI is associated with poorer outcomes, including increased pain and lower reported scores on the Knee injury and Osteoarthritis Outcome Score.[26] However, Lattermann et al[15] found that neither bone bruise volume or severity alone was associated with decreased self-reported outcomes, highlighting the inconsistency and lack of understanding surrounding the impact of bone bruises.

While existing studies have examined self-reported outcomes for patients sustaining concomitant bone bruising and ACL injuries, these results are mixed, and few studies have explored the long-term outcomes. Moreover, an existing gap within the literature is whether bone bruise volume affects functional performance, return to sport rates, and the time to return to play. Therefore, the purpose of this study was to quantify preoperative bone bruise volume and examine the relationships between preoperative bone bruise volume and objective functional performance, time of return to play, and self-reported function at 2 years for patients following an ACL reconstruction. We hypothesized that larger volume bone bruises would correlate with decreased objective functional performance, increased time to return to play, and poorer self-reported outcomes at 2 years following ACL reconstruction.

METHODS

Study Design

A retrospective study was completed in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology guidelines using a single-surgeon (W.R.L.) database of 1396 patients who underwent ACL reconstruction between 2014 and 2019. Verbal and written consents were obtained, and the study was approved by our institutional review board and was registered with ClinicalTrials.gov (NCT03704376). Included were patients between the ages of 15 and 50 years who underwent a preoperative MRI scan within 2 months of injury. Patients were excluded if they underwent revision ACL reconstruction or had a chronic ACL injury, concomitant ligamentous injuries, occult fracture, or meniscal allograft or osteochondral transplantation.

Baseline patient demographics were obtained for all patients including age, sex, height, weight, body mass index, and preinjury activity level (Marx score).[16] In addition, descriptive surgical data were gathered for all patients and included graft type, concomitant injuries, and meniscal involvement. All patients followed a standardized rehabilitation protocol based upon surgeon discretion at time of surgery. Preoperative MRI and objective self-reported and functional outcomes data at the time of return to play were extracted for the purposes of data analysis. In addition, 2-year injury surveillance and self-reported function were obtained.

Bone Bruise Volume

Bone bruise frequency, distribution, and volume were estimated using preoperative proton density-weighted MRI with standard knee sequences (coronal and sagittal). All MRI scans were reviewed by the primary investigators (C.G., H.W.) and a fellowship-trained musculoskeletal radiologist (M.K.) on an independent picture archiving and communication system via Centricity (GE Healthcare Systems). Based on previous research, bone bruise volume was calculated by obtaining the total cross-sectional area of the lesion multiplied by image slice thickness.[5,15,26] This method is consistent with work by Lattermann et al[15], in which the region interest of the hyperintense signal area was traced using the picture archiving and communication system software toolkit for each image (Figure 1). The resulting area traced for each slice was then summed to provide the sum of slices (mm^2). The sum was then multiplied by the slice thickness to provide the total volume for the single bone bruise (mm^3). This described procedure was performed on the lateral femoral condyle (LFC), LTP, medial femoral condyle (MFC), and medial tibial plateau (MTP) if bone bruising was present (Figure 1). The bone bruise volumes calculated from each location were then aggregated to provide the total bone bruise volume (mm^3) about the tibiofemoral joint.

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Ethical approval for this study was obtained from the University of Texas Health Sciences Center (ref No. HSC-MH-14-0734).

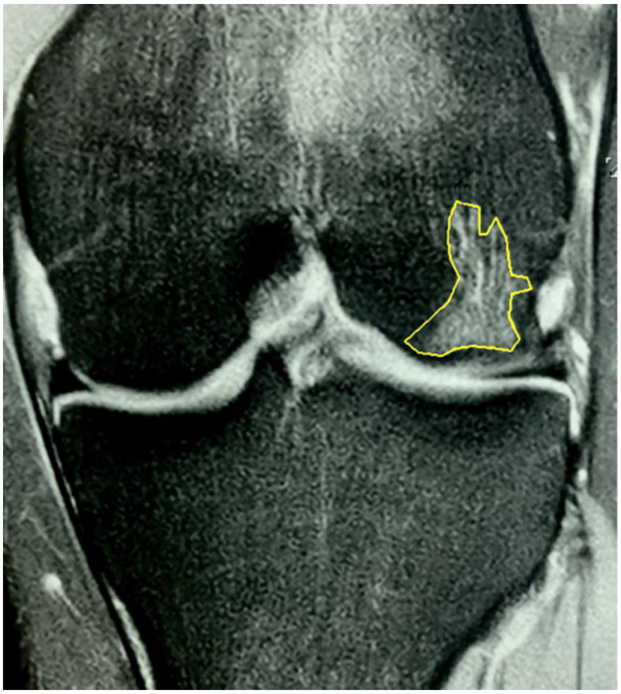

Figure 1. Proton-density coronal magnetic resonance imaging scan showing hyperintense region of interest (outlined in yellow) for the lateral femoral condyle.

Inter- and intrarater reliabilities for the measurements were completed by the primary investigators on 10 patients. The sum of slices, total volume for each region (LFC, LTP, MFC, MTP), and the total volume for each patient's MRI scan were recorded and calculated by each investigator on the same group of 10 patients. Two separate measurements were performed and separated by at least 24 hours for each investigator, to limit any bias.

Outcome Measures

Patients completed the International Knee Documentation Committee subjective knee evaluation form and ACL–Return to Sport after Injury scale at time of return to play.[11,28] Objective functional performance was assessed via a functional battery including passive knee range of motion, isometric hip abduction strength,[9] single-leg balance,[8] 4 single-leg hop tests,[21] and change of direction testing.[25] Three trials were completed for involved and uninvolved limbs, and the limb symmetry index was calculated for each test.

Injury surveillance was conducted via an electronic survey at 2 years and included graft reinjury, return to sport rates, and current level of sports participation.[4] In addition, the Single Assessment Numeric Evaluation (SANE) score was obtained to assess self-reported knee function.[23] The SANE score is a valid and reliable method for reporting knee symptoms following ACL reconstruction.[23] A total of 3 email attempts and 3 subsequent telephone call attempts were made to minimize the loss to follow-up for the 2-year self-reported outcome measures.

TABLE 1
Patient and Surgical Demographics (N = 60 Patients)[a]

Variable	Value
Age, y	23.4 ± 10.6
Male sex	29 (48.3)
Height, cm	172.0 ± 12.5
Weight, kg	65.0 ± 2.7
Body mass index	25.2 ± 5.7
Marx score (range, 0-16)	12.5 ± 2.4
Graft type, n	
Patellar tendon	54
Hamstring	4
Quadriceps tendon	2
Associated chondral injury	
No injury	52 (86.7)
≤5 mm	4 (6.6)
6-10 mm	2 (3.3)
11-15 mm	1 (1.7)
16-20 mm	1 (1.7)
Meniscal injury	40 (67.0)
Meniscal injury location	
Isolated medial meniscus	10 (16.7)
Isolated lateral meniscus	12 (20.0)
Both menisci	18 (30)
Medial meniscal treatment	
Meniscectomy	2 (3.3)
Repair	26 (43.3)
No. of medial meniscal repair sutures	3.4 ± 2.1
Lateral meniscal treatment	
Meniscectomy	1 (1.7)
Repair	29 (48.3)
No. of lateral meniscal repair sutures	2.8 ± 1.4
Rehabilitation protocol (n, % accelerated)	44 (73.3)

[a]Data are reported as mean ± SD or n (%) unless otherwise indicated.

Statistical Analysis

Descriptive statistics were calculated for all baseline and surgical demographic data. A total of 49 patients were estimated to be needed to achieve a power of 0.80 with an alpha level of .05 for linear regression modeling. The interclass correlation coefficients (ICCs) was used to assess inter- and intrarater reliability for bone bruise volume estimates. A forward stepwise linear regression was completed to determine the relationship between bone bruise volume and the dependent variables. Bone bruise volume data were assessed for normality via the Kolmogorov-Smirnov test. An a priori alpha of .05 was selected to determine statistical significance. All statistical analyses were performed using SPSS Version 23 (IBM Inc).

RESULTS

Of the 138 patients meeting the study criteria, 60 were included in the final analysis. Baseline patient and surgical demographics are listed in Table 1. Both intrarater ($ICC_{2,1}$, 0.89-0.99; $P < .05$) and interrater ($ICC_{2,1}$, 0.95-0.99; $P < .05$) reliability were good to excellent for estimating total bone bruise volume.

TABLE 2
Distribution and Volume of Bone Bruise Injuries[a]

Bone Bruise Location	Distribution, n (%)	Volume, mm^3, mean ± SD
LTP	53 (88.3)	4056.6 ± 3759.6
LFC	46 (76.7)	3582.5 ± 3550.7
MTP	16 (26.7)	1474.4 ± 1389.3
MFC	13 (21.7)	2051.1 ± 2054.3
Total	128 (100.0)	7065.7 ± 6226.6

[a]LFC, lateral femoral condyle; LTP, lateral tibial plateau; MFC, medial femoral condyle; MTP, medial tibial plateau.

TABLE 3
Outcomes at Time of Return to Play[a]

Outcome	Mean ± SD
Time of medical release, months	8.1 ± 1.7
IKDC-2000 score (range, 0-100)	91.7 ± 10.9
ACL-RSI score (range, 0-100)	71.4 ± 18.3
Extension ROM deficit, deg	1.5 ± 1.8
Flexion ROM deficit, deg	3.0 ± 2.6
Single leg balance deficit, cm	1.9 ± 2.5
Single leg hop, LSI	94.6 ± 6.8
Triple hop, LSI	93.7 ± 7.6
Crossover hop, LSI	91.9 ± 8.3
6 m timed hop, LSI	96.2 ± 4.3
Pro agility test	99.7 ± 1.2

[a]ACL, anterior cruciate ligament; ACL-RSI, ACL–Return to Sport after Injury; IKDC-2000, International Knee Documentation Committee; LSI, limb symmetry index (involved limb/uninvolved limb); ROM, range of motion.

TABLE 4
Functional Outcomes at 2-Year Follow-up[a]

Outcome	Mean ± SD or n (%)
SANE score (range, 0-100)	92.5 ± 8.3
Graft reinjury	2 (3.3)
Return to sport	57 (95.0)
Level of sport at return	
Level 1	38 (63.3)
Level 2	11 (18.3)
Level 3	8 (13.3)
Did not return	3 (5.0)
Reason for not returning	
Knee symptoms	1 (1.7)
Fear of reinjury	2 (3.3)

[a]SANE, Single Assessment Numeric Evaluation.

The distribution of bone bruise injuries was as follows: LTP (88.3%), LFC (76.7%), MTP (26.7%), and MFC (21.7%) (Table 2). A total of 57 (95%) patients demonstrated bone bruising in ≥1 location. Table 2 highlights the bone bruise volume by location, with the total calculated volume of bone bruising being 7065.7 ± 6226.6 mm^3.

Functional test performance at time of return to play (8.1 ± 1.7 months) is shown in Table 3, with subjective function at 2-year follow-up shown in Table 4. There were no significant relationships between total bone bruise volume and time of return to play (P = .832), International Knee Documentation Committee (P = .200) and ACL–Return to Sport after Injury scores at time of return to play (P = .370), and 2-year SANE score (P = .179).

DISCUSSION

The purpose of this study was to quantify preoperative bone bruise volume and examine the relationships between preoperative bone bruise volume and objective functional performance, time to return to play, and self-reported function at 2 years after ACL reconstruction. Overall, there were no significant relationships between bone bruise volume and patient function at return to play or at 2 years. These findings are in accordance with previous research reporting no association between preoperative bone bruise volume and self-reported outcome measures.[15] This study confirms the existing body of evidence, as our data did not indicate significant relationships between bone bruise volume and objective functional performance, graft failure rates, or level of return to sport participation. Our results do support previous studies indicating that the highest frequency of bone bruises associated with ACL injury are distributed to the lateral compartment,[2,15,19,22,24,27,29] with the LTP exhibiting the highest frequency (88.3%) and the MFC demonstrating the lowest frequency (21.7%) with ACL injury.[2,15]

This study is among the few to assess the relationship of objective functional performance and the presence/magnitude of preoperative bone bruise volume following ACL injury.[3,5,13] Furthermore, our cohort demonstrated a high return to sport rate (95%), with 81.7% of patients participating in a level 1/2 (cutting and pivoting) sport at the 2-year assessment. The results of our study suggest that patients may not have a protracted recovery or limitations in return to sport participation following an ACL injury with concomitant bone bruising. Without significant evidence of early clinical implications associated with bone bruise volume, adaptations of postoperative rehabilitation guidelines or timelines for medical clearance may not be warranted.

Research indicates that meniscal and articular cartilage injuries in the setting of ACL reconstruction are linked to the development of PTOA.[14,15] A total of 67% of patients in the current study sustained a concomitant meniscal injury and 13% sustained an associated chondral injury, suggesting that this phenomenon may be multifaceted in nature or that the outcome measures were assessed too early in the recovery phase to detect the influence of PTOA. The results of the current study align with work by Lattermann et al,[15] who suggested that posttraumatic arthritis may not be solely due to subchondral edema but instead may be due to a variety of factors (condition of menisci and articular cartilage, residual laxity, activity level, etc). In contrast, Kia et al[14] discovered that significant signs of PTOA were observable 5 years after ACL reconstruction, suggesting that self-reported function at 2 years may be too early or not sensitive enough to detect these degenerative changes.

Limitations

A primary limitation of this study is its retrospective design. In addition, the outcome measure data collection occurred only at time of return to play (mean, 8.1 ± 1.7 months) and 2 years following ACL reconstruction when a previous study suggests that bone bruising has resolved.[15] It is plausible that stronger relationships would exist between self-reported and objective functional outcomes at earlier phases of recovery. This theory is supported by the work of Davies[5] and Johnson[13] who detected increased postoperative joint effusion, pain, and poorer gait mechanics in the presence of bone bruises after ACL reconstruction. As a result, we recommend future investigations include more acute outcome measures when assessing the relationships between bone bruise volume and function. An additional limitation to the current study is the lack of preoperative laxity measurements and long leg radiographs. Further, objective postoperative imaging was not performed to objectively quantify the potential presence of PTOA. Considering how the subchondral bone supports the local healing environment of the articular cartilage and the documented prevalence rates of PTOA associated with ACL reconstruction, early radiographic markers may serve as a more sensitive outcome measure within this patient population.

CONCLUSION

Preoperative bone bruise volume was not associated with self-reported outcomes, objective functional performance, graft failure rates, or level of return to sport when assessed at return to play and 2 years after ACL reconstruction. As a result, we do not recommend adaptations to postoperative rehabilitation protocols based on the presence of bone bruise volume alone; however, more study is warranted to determine the acute influence of this concomitant injury in ACL-deficient patients undergoing surgical reconstruction.

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