Comparison Between Soccer and Basketball of Bone Bruise and Meniscal Injury Patterns in Anterior Cruciate Ligament Injuries

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Background: The varying effectiveness of anterior cruciate ligament (ACL) injury prevention programs between soccer and basketball may be due to differences in sport-specific injury mechanisms. Bone bruise patterns may provide information regarding injury mechanisms.

Purpose: To compare bone bruise and meniscal injury patterns for ACL injuries sustained in soccer versus basketball.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: Clinical notes, operative reports, and magnetic resonance imaging scans were reviewed for patients who sustained a noncontact ACL rupture while playing soccer or basketball between August 2016 and August 2018. The presence, location, and signal intensity of bone bruises on the tibia and femur were documented, and patterns were classified according to the location of the bone bruise in the lateral-medial direction. The meniscal and bone bruise injury patterns and the specific bone bruise locations were compared between the soccer and basketball groups.

Results: Overall, 138 patients were included (56 with soccer-related and 82 with basketball-related ACL injury). No significant difference between the groups was observed in bone bruise patterns ($P = .743$) or meniscal injury patterns ($P = .952$). Bone bruise on the lateral side only of both the femur and the tibia was the most common pattern in both soccer (41.9%) and basketball (47.0%) groups; the most common meniscal injury type was an isolated lateral meniscal injury in both soccer (50.0%) and basketball (45.0%) groups. For patients with bone bruises on both the lateral and the medial sides of both the femur and the tibia (BF+BT), the bone bruise signal intensity on the lateral side of the femur ($P < .001$) and tibia ($P = .009$) was significantly higher than that on the medial side for both groups. The bone bruises on the lateral side of the femur ($P < .001$) and tibia ($P = .002$) were significantly more anterior than those on the medial side for patients with the BF+BT pattern.

Conclusion: No significant differences in bone bruise location or meniscal injury type were detected when comparing ACL injuries sustained during soccer versus basketball. The study results suggest a similar biomechanical loading pattern for ACL injuries in these sports.

Keywords: anterior cruciate ligament; magnetic resonance imaging; bone bruise; sport-specific

Anterior cruciate ligament (ACL) rupture is one of the most common sports-related knee injuries. Although surgical techniques and rehabilitation programs have been highly developed to restore knee stability and function, ACL injury still causes particular concern to many patients and physicians owing to factors such as long rehabilitation period, high cost, and long-term health consequences including chronic pain, osteoarthritis, and disability.[5,17,30]

Although much research has been conducted on preventing ACL injuries, prevention programs are not equally successful. Soccer and basketball have been found to account for the majority of all ACL injuries, and the relative risk of ACL injury has been reported to be highest in basketball and soccer.[10] Studies have reported that current prevention programs are effective for soccer but ineffective for basketball.[24] Agel et al[1] found that the ACL injury rate remained stable in basketball across a 13-year study period, whereas it significantly decreased for soccer players. The limited success of these prevention programs suggests that basketball and soccer players demonstrate different biomechanical profiles. Previous studies have reported that basketball and soccer players demonstrate different biomechanical patterns during a sidestep cutting task[13] and a jump-landing task.[9] Because injury patterns

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are associated with certain sports,[11] understanding sport-specific injury mechanisms is important to design more personalized and effective ACL injury prevention programs.[28]

Bone bruises seen on magnetic resonance imaging (MRI) are thought to represent a footprint of the impact that occurs at the time of injury; they may therefore provide insight into injury mechanisms.[25] Previous studies have investigated the association between bone bruise patterns and ACL and meniscal injuries.[21,29,31] Based on the most common lateral compartment bone bruise patterns observed in ACL injuries, researchers have found valgus loading to be an important risk factor.[21,25] Studies have also reported that anterior tibial translation may be a primary ACL injury mechanism based on observed bone bruises on the posterior tibia and the anterior femur.[2,29,31,33]

The purpose of this study was to evaluate the bone bruise and meniscal injury patterns in ACL injuries sustained during basketball and soccer to aid in the design of more effective and targeted prevention programs for these sports. We hypothesized that these patterns would be different between soccer and basketball. We also hypothesized that no significant difference between soccer and basketball would be found regarding bone bruise location in the lateral-medial and anterior-posterior directions.

METHODS

Institutional review board approval was obtained before we proceeded with this study. All patients read and signed the informed consent. Patients who had undergone ACL reconstruction were identified by review of the electronic medical database of our institution between August 2016 and August 2018. Clinical notes, operative reports, and MRI scans of adult patients younger than 40 years of age who had sustained noncontact unilateral ACL rupture during soccer (soccer group) or basketball (basketball group) were reviewed to determine the detailed injury information. Patients were excluded from this study if MRI had been performed more than 4 weeks after injury or if they had previous trauma or surgery in the affected knee, associated ligament injuries, or poor-quality MRI scans. The time from injury to MRI was determined by reviewing the collected clinical notes, which included the date of injury reported by the patient. Information about medial and lateral meniscal injury was collected from the operative notes and arthroscopic findings by sports medicine orthopaedic surgeons (Z.L. and Y.A.).

All patients underwent MRI using a standard protocol for the injured knee. MRI was acquired using a 1.5-T scanner (Signa; GE Healthcare) with a 3.5-mm slice spacing and 512×512 matrices providing assessment in 3 planes. Image sequences in the sagittal and coronal planes were used to determine bone bruise location in the lateral-medial and anterior-posterior directions, respectively.

A bone bruise is defined as an increased signal intensity on T2-weighted images.[20] MRI scans were read by 2 orthopaedic researchers (1 orthopaedic surgeon [Z.L.] and 1 physiotherapist [H.S.]). The patients were first classified based on whether they had bone bruises. For patients with bone bruises, the bone bruise borders were traced using the freehand region-of-interest (ROI) function of ImageJ software (National Institutes of Health). The maximum gray value of the pixel and area of the bordered region were measured using ImageJ. A higher gray value within 1 image sequence represented a more severe bone concussion. The slice that showed the maximum gray value was considered to indicate the area where the bones experienced impact. In cases where different slices in 1 bone bruise showed the same maximum gray value, the areas of bone bruises were used to further determine the slice where the bones experienced impact. Bone bruise location in the lateral-medial direction was first determined using the sagittal image sequence (Figure 1A); the location in the anterior-posterior direction was determined using the coronal image sequence (Figure 1B). This method has been detailed previously in the literature.[26]

The bone bruise locations in the lateral-medial and anterior-posterior directions of the tibia and femur were recorded separately using the same method. We used the lateral-medial direction as an example to describe the specific method. The precise bone bruise locations in the lateral-medial direction were determined using the following equation:

$$\mathrm{LM} = \frac{M_{\max}}{M_{\text{total}}} \times 100\%,$$

where $M_{\max}$ is the number of the slice at which the gray value is maximum among all the slices in the order from lateral to medial sides in the sagittal plane, and M_{total} is the total number of slices presenting with a bone segment in the sagittal plane. LM is a measure of the location in the lateral-medial direction, and it ranges in value from 0% (closer to the lateral side of the bone) to 100% (closer to the medial side of the bone).

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Ethical approval for this study was obtained from the institutional review board of Peking University Third Hospital.

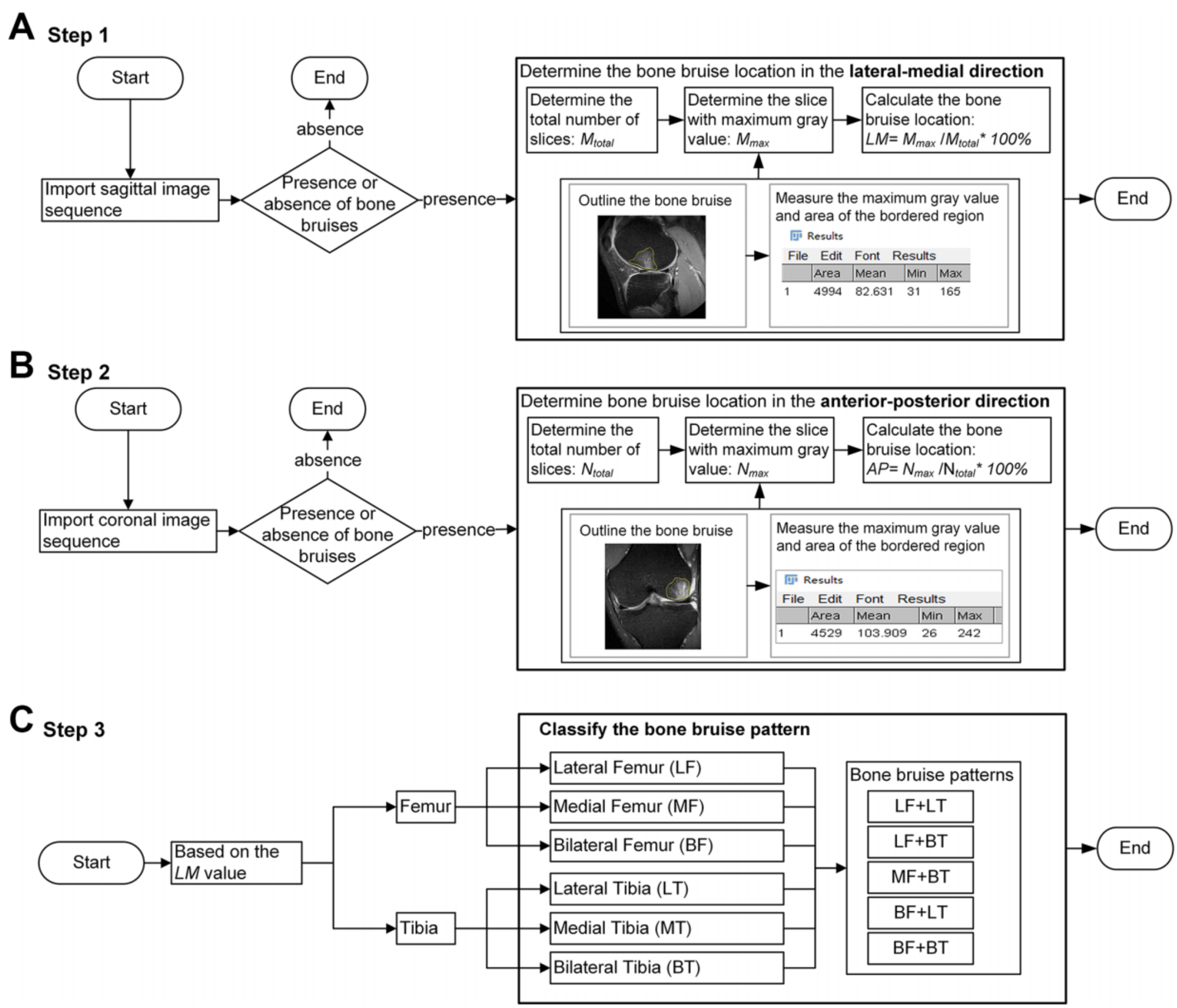

Figure 1. The workflow for determining bone bruise location. AP, anterior-posterior; LM, lateral-medial; M_{max}, the number of the slice at which the gray value is maximum among all the slices in the order from lateral to medial sides in the sagittal plane; M_{total}, the total number of slices presenting with a bone segment in the sagittal plane; N_{max}, the number of the slice at which the gray value is maximum among all the slices in the order from anterior to posterior sides in the coronal plane; N_{total}, the total number of slices presenting with a bone segment in the coronal plane.

The bone bruise patterns of the tibia and femur were further classified based on the abovementioned LM value (Figure 1C). The bone bruise location was determined as lateral (only 1 LM value that was <50%), medial (only 1 LM value ≥50%), or both lateral and medial (1 LM value <50% and another value ≥50%) parts of each bone. The bone bruise patterns were determined by combining the femoral and tibial bone bruise locations in the lateral-medial direction. This study included 5 patterns with bone bruises located on (1) both the lateral and the medial sides of both the femur and the tibia (BF+BT), (2) both the lateral and the medial sides of the femur and only the lateral side of the tibia (BF+LT), (3) only the lateral side of the femur and tibia (LF+LT), (4) only the lateral side of the femur and both the lateral and the medial sides of the tibia (LF+BT), and (5) only the medial side of the femur and both the lateral and the medial sides of the tibia (MF+BT).

To determine normalized signal intensity of the bone bruise, the signal to noise quotient (SNQ) was calculated using the following equation[7]:

$$\mathrm{SNQ} = \frac{V_{\max} - V_{\mathrm{normal}}}{V_{\mathrm{background}}},$$

where $V_{\max}$ is the maximum gray value of the bone bruise; V_{normal} is the mean gray value of the same bone without

TABLE 1
Characteristics of Patients With Bone Bruises (N = 109)[a]

	Soccer Group (n = 43)	Basketball Group (n = 66)
Age, y	30.3 ± 6.4	26.7 ± 6.0
Time from injury to MRI, d	15.5 ± 6.5	18.7 ± 7.1
Sex, male/female	41/2	60/6
Meniscal injury location		
No injury	19	26
Medial only	7	13
Longitudinal/radial/complex tear	4/2/1	11/1/2
Meniscectomy/repair	3/4	4/9
Lateral only	12	18
Longitudinal/radial/complex tear	3/7/2	3/9/6
Meniscectomy/repair	11/1	15/3
Both medial and lateral	5	9
Longitudinal/radial/complex tear, medial meniscus	4/0/1	7/0/2
Longitudinal/radial/complex tear, lateral meniscus	0/4/1	4/5/0
Meniscectomy/repair, medial meniscus	1/4	3/6
Meniscectomy/repair, lateral meniscus	3/2	6/3

[a]Data are reported as mean ± SD or number of cases. MRI, magnetic resonance imaging.

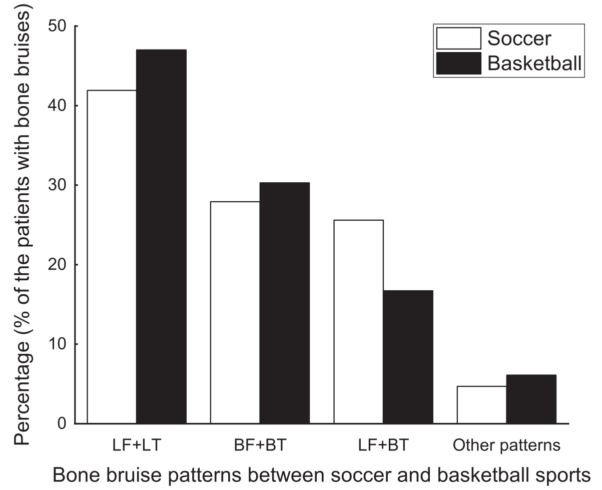

Figure 2. Bone bruise patterns in soccer and basketball players with anterior cruciate ligament injuries. LF+LT, bone bruises on the lateral side only of both the femur and the tibia; BF+BT, bone bruises on both the lateral and medial sides of both the femur and the tibia; LF+BT, bone bruises on the lateral side of the femur and both sides of the tibia.

bruise, which was the reference bone; and $V_{background}$ is the mean gray value of the background. Circular ROIs 5 mm in diameter were evaluated to measure the signal of the reference bone and the background. The background ROI was placed approximately 1 cm anterior and 1 cm distal to the joint line. The reference bone ROI was located at the middle of the proximal femur and of the distal tibia.

Statistical Analysis

The bone bruise pattern and meniscal injury pattern between soccer and basketball players were compared using chi-square analysis. The sex distribution was also compared between basketball and soccer groups using chi-square analysis. A 2 × 2 analysis of variance (ANOVA) with a mixed design was performed to compare the specific bone bruise locations in the lateral-medial direction in patients with the LF+LT pattern, between groups (soccer and basketball groups) and between bones (femur and tibia), for the tibia and the femur. A 2 × 2 ANOVA with a mixed design was performed to compare the specific bone bruise location in the anterior-posterior direction in patients with the BF+BT pattern, between groups (soccer and basketball groups) and between compartments (lateral and medial sides), for the tibia and the femur, respectively. A 2 × 2 ANOVA with a mixed design was performed to compare the bone bruise severity (SNQ) in patients with the BF+BT pattern, between groups (soccer and basketball groups) and between compartments (lateral and medial sides), for the tibia and the femur, respectively. All statistical analyses were performed using the SPSS statistical package (Version 16; SPSS).

RESULTS

The 138 noncontact ACL injuries included 56 injuries that occurred during soccer and 82 injuries that occurred during basketball. A total of 66 (80.5%) of the 82 patients who were injured during basketball had bone bruises identified on MRI scan, and 43 (76.8%) of the 56 patients who were injured during soccer had bone bruises identified on MRI scan. No significant difference was observed for the presence of bone bruises between soccer and basketball groups (P = .672). The soccer group was significantly older than was the basketball group (P = .005). The time from injury to MRI was shorter in the soccer group compared with the basketball group (P = .019). No significant difference was found in the sex distribution between soccer (95.3% male) and basketball (90.9% male) groups (P = .476). The characteristics of patients who had bone bruises are shown in Table 1.

No significant difference in the bone bruise patterns was observed between soccer and basketball groups (P = .743). LF+LT was the most common bone bruise pattern in both soccer (41.9%) and basketball (47.0%) groups (Figure 2). The other 2 common bone bruise patterns for both soccer and basketball groups were BF+BT and LF+BT. Meniscal injuries were present in 55.8% of the soccer group with bone bruises and 60.6% of the basketball group with bone bruises, with no significant difference between groups (P = .450). In both groups, the most common type of meniscal injury was an isolated lateral meniscal injury, with no

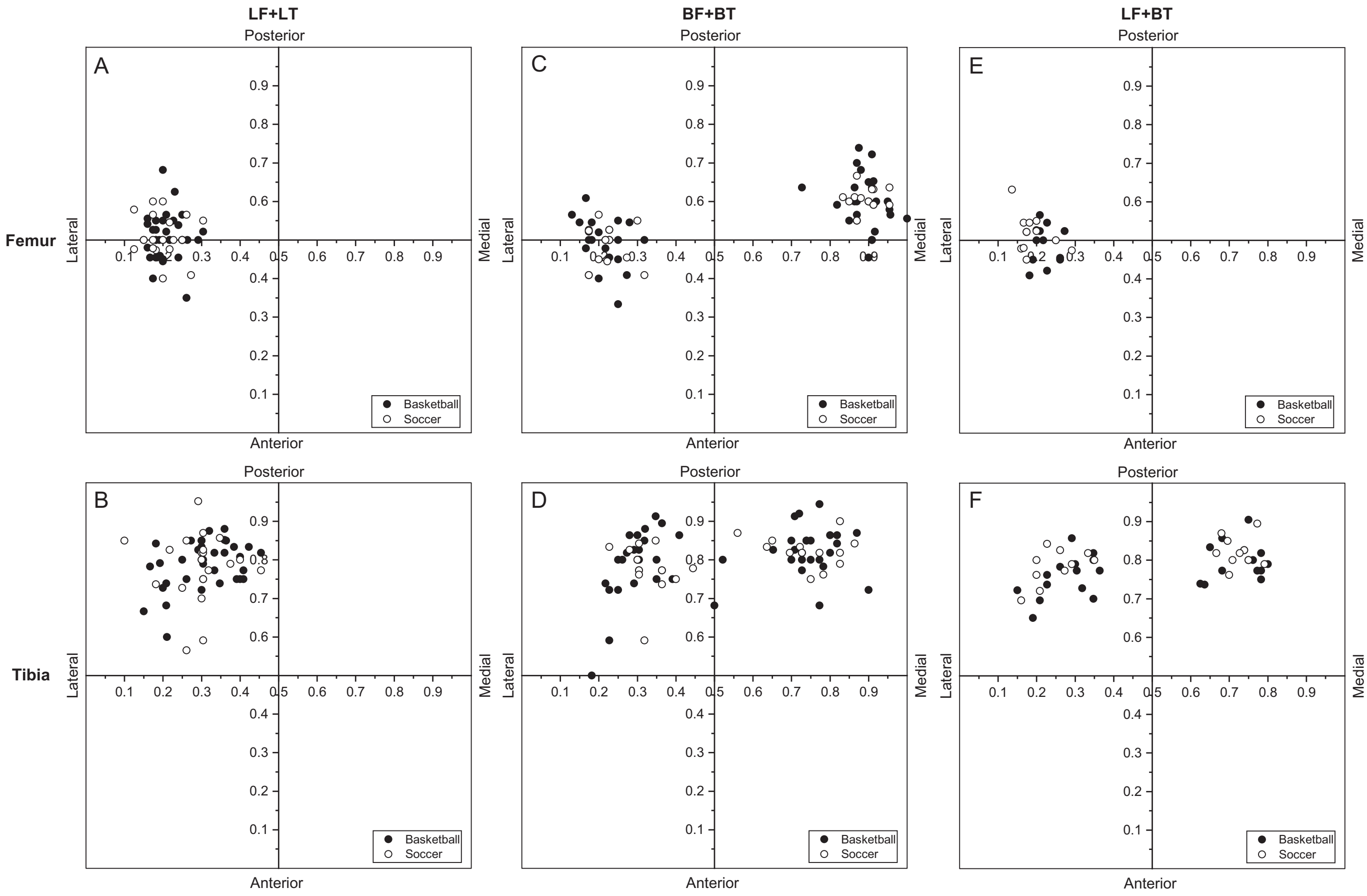

Figure 3. Femoral and tibial bone bruise locations in the 3 most common patterns. (A) Femoral bone bruise locations in the LF+LT pattern; (B) tibial bone bruise locations in the LF+LT pattern; (C) femoral bone bruise locations in the BF+BT pattern; (D) tibial bone bruise locations in the BF+BT pattern; (E) femoral bone bruise locations in the LF+BT pattern; (F) tibial bone bruise locations in the LF+BT pattern. LF+LT, bone bruises on the lateral side only of both the femur and the tibia; BF+BT, bone bruises on both the lateral and medial sides of both the femur and the tibia; LF+BT, bone bruises on the lateral side of the femur and both sides of the tibia.

significant difference between groups (50.0% in the soccer group and 45.0% in the basketball group; $P = .952$).

For the most common pattern, LF+LT, no interaction effects of group and bone were detected for bone bruise location in the lateral-medial direction ($P = .947$) or the anterior-posterior direction ($P = .516$). Main effects for bone showed that the bone bruise location on the femur was more lateral ($P < .001$) and more anterior ($P < .001$) than that on the tibia in both soccer and basketball groups (Figure 3). No main effects for group were observed for bone bruise location in the lateral-medial direction ($P = .561$) or the anterior-posterior direction ($P = .792$).

For the patients with pattern BF+BT, no interaction effects of group and compartment were detected for bone bruise location in the anterior-posterior direction for the femur ($P = .385$) or the tibia ($P = .924$). The main effects for compartment showed that the bone bruise locations on the lateral side of the femur ($P < .001$) and the tibia ($P = .002$) were more anterior than those on the medial side in patients with pattern BF+BT in both soccer and basketball groups (Figure 3). No main effects for group were observed for the variable of the femur ($P = .755$) or the tibia ($P = .978$).

For the patients with pattern BF+BT, no interaction effects of group and compartment were detected for bone bruise signal intensity of the femur ($P = .402$) or the tibia ($P = .116$). The main effects for the compartment showed that the bone bruise signal intensity on the lateral side of the femur ($P < .001$) and the tibia ($P = .009$) was significantly higher than that on the medial side in patients with pattern BF+BT. No main effects for the group were observed for the variable of the femur ($P = .596$) or the tibia ($P = .864$).

DISCUSSION

This study used bone bruise analysis to compare injury patterns between soccer and basketball players who had sustained ACL injuries; the analysis revealed that the bone bruise patterns and meniscal injury patterns were similar in soccer and basketball players. For both sports, the LF+LT pattern was the most common bone bruise pattern, followed by the BF+BT pattern. For the second most common pattern, bone bruises on the lateral side of the femur and tibia were more severe than those on the medial side in both groups. In both soccer and basketball groups, the most common meniscal injury pattern was isolated lateral meniscal injuries. Bone bruises could reflect the femoral and tibial impact that occurs at the time of injury and provide valuable clues about the mechanism of ACL rupture.[25] The similar bone bruise patterns in the present study suggested that the mechanism of ACL injury may be not different between soccer and basketball from a biomechanical perspective. According to the bone bruising observed in the present study, ACL injuries are likely to occur as a result of the valgus moment and external rotation moment in combination with an anterior translation of the tibia relative to the femur for both groups.

Contrary to the original hypothesis, we did not observe sport-specific bone bruise patterns in ACL injuries between soccer and basketball groups. The results of this study showed that the most common bone bruise distribution pattern was LF+LT for both groups. The bone bruise patterns in ACL injuries observed in this study were consistent with those in reports in the literature. Although previous investigators did not directly compare bone bruise patterns between soccer and basketball players, they reported a significantly higher proportion of bone bruises located on the lateral side of the femur and the tibia compared with the medial side of the femur and the tibia.[23,29,32] The similar bone bruise pattern in both soccer and basketball might be explained by the similar ACL loading pattern. Although some studies have reported that ACL injury occurred in different situations (eg, during tackling or cutting in soccer[4] vs landing or cutting in basketball[18]), the essential loading mechanism of ACL injuries may be similar for these situations. For example, from a biomechanical perspective, the cutting maneuvers that occur in both soccer and basketball involve a valgus load.[19] Videos have shown that valgus loading was a contributing factor for ACL injuries not only in basketball players[16] but also in soccer players.[12] Therefore, despite the different movements and sports environments in soccer and basketball, soccer and basketball players may experience similar damaging forces. In addition, for the most common bone bruise pattern, LF+LT, the impact forces during ACL injury might occur at the lateral side of the tibia and the femur, which could be caused by valgus loading. The present study combined with previous studies indicated that both soccer and basketball players had an injury pattern whereby impact forces occurred at the lateral side of the tibia and the femur during ACL injury, which might be affected by valgus loading.

In the current study, the second most common bone bruise pattern was BF+BT for both soccer and basketball groups, and the bone bruises on the lateral side of the femur and the tibia were relatively more severe based on the higher gray value compared with those on the medial side. Similarly, previous researchers have found that a bone bruise in the lateral compartment was more severe than that in the corresponding medial compartment.[15,31] The relatively more severe bone bruise on the lateral side suggests that the impacts on the lateral side were more severe than those on the medial side. This bone bruise pattern may have resulted from the contrecoup forces in the medial compartment at the resolution of the valgus forces.[15] These results suggest that valgus loading in the coronal plane was an essential risk factor for ACL injury during both soccer and basketball based on the LF+LT and BF+BT patterns observed in the current study.

Regarding the bone bruise location in the lateral-medial and anterior-posterior directions, the current study showed that for both soccer and basketball groups, tibial bone bruises occurred in the posterior section, whereas femoral bone bruises occurred in the anterior and central sections, which suggested an anterior tibial translation relative to the femur during ACL injury.[8,29] Moreover, the results also showed that both soccer and basketball groups demonstrated more lateral bone bruising on the femur than on the tibia in patients with the LF+LT pattern. The resulting bone bruise pattern suggested that the injuries may occur when a valgus load is applied to the knee combined with external tibial rotation.[25] These data agree with the results from a video analysis that reported ACL injuries occurred with knee valgus and tibial external rotation.[22] These results taken together suggest that for both soccer and basketball players, ACL injury may occur as a result of anterior translation of the tibia relative to the femur in combination with external tibial rotation.

The results of this study did not support our hypothesis that meniscal injury patterns in ACL injuries would differ between soccer and basketball players. The current results showed that the meniscal injury patterns in patients with ACL injury were similar for soccer and basketball, and the most common type of meniscal injury was the lateral meniscal injury only in both groups. Granan et al[11] recorded injury patterns during ACL reconstruction surgery and found that participation in basketball was more likely to result in cartilage and lateral meniscal injuries compared with participation in soccer. The findings of the current study appear to be inconsistent with those in the previous literature with regard to the meniscal injury pattern. However, the sport-specific ACL injury patterns reported by Granan et al were based on the overall group of patients with ACL injuries, and those investigators did not separately analyze ACL-injured patients with bone bruises. In the current study, the meniscal injury patterns were compared between soccer and basketball players based on the patients who had bone bruises. Because studies have demonstrated a relationship between bone bruises and meniscal injuries,[3,6,14,27,32] it is possible that ACL-injured patients with and without bone bruises have different meniscal injury patterns.

The results of this study, combined with the literature, demonstrated that a comprehensive injury prevention program should focus not only on biomechanics but also on the characteristics of the sport in question. Previous studies have reported that prevention programs were more effective for soccer players[24] and that the ACL injury rate significantly decreased for soccer players across a 13-year study period, whereas it remained stable in basketball.[1] The present study found that soccer and basketball players demonstrated similar bone bruise patterns, which suggests that the ACL loading mechanisms during these sports were similar from a biomechanical perspective. Thus, the unequal effectiveness of prevention programs might not be due to a sport-specific biomechanical injury mechanism, based on the results of this present study. The characteristics of different sports in question include movement strategies, activity demands, and responses to injury prevention programs. A combination of these characteristics could place the players in varied injury situations, which might account for the discrepancy in effectiveness of ACL injury prevention programs between sports. Thus, although training programs designed to improve or modify biomechanical risk factors are essential to reduce the risk of ACL injuries, the other modifiable characteristics in different sports should also be considered and need to be personalized.

The major limitation of this study was that we investigated only those patients who underwent ACL reconstruction based on a retrospective review of the medical records. In the current study, we did not detect any statistically significant differences between soccer and basketball groups for bone bruise patterns or meniscal injury locations. It is possible that patients who did not go on to have ACL surgery may have demonstrated different clinical characteristics and bone bruise patterns. Further studies should include both operatively and nonoperatively treated patients with an ACL injury. Another limitation of this study was that sex-specific bone bruise pattern was not determined because of the small proportion of women among the included patients. Previous researchers have not observed any significant differences between sexes for bone bruise locations and meniscal injury patterns; however, the sex-specific mechanism of ACL injury is always an essential issue in ACL injury prevention research and clinical practice, given reports that the ACL injury rate is higher for women than for men in both basketball and soccer. Future studies should be done to compare bone bruise patterns between sexes in both soccer and basketball.

CONCLUSION

No significant differences in bone bruise locations or meniscal injury patterns were detected between soccer and basketball players with ACL injuries. LF+LT was the most common bone bruise pattern in both soccer and basketball players with ACL injuries. An isolated lateral meniscal injury was the most common meniscal injury pattern in both soccer and basketball players. This study suggests a similar biomechanical loading pattern of ACL injuries in soccer and basketball players.

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