



# Increased lateral meniscal slope is associated with greater incidence of lateral bone contusions in noncontact ACL injury

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## Abstract

**Purpose** (1) To investigate whether an increased lateral meniscal slope measured on magnetic resonance image (MRI) would be associated with greater risk of bone contusions in noncontact anterior cruciate ligament injury, and (2) to measure the relationship between the occurrence of bone contusions and associated findings observed in ACL deficient knees such as cartilage damage, anterolateral complex injury and concomitant meniscal tears.

**Method** Patients who underwent ACL reconstruction surgery between 2013 and 2018 were retrospectively reviewed. Sixty-three patients were included in the study group (ACL + bone contusions group), 56 participants were in the control group (isolated ACL group). The presence and severity of bone contusions were determined from preoperative MRIs. The lateral meniscal slope and lateral posterior tibial slope were measured on the MRIs in a blinded fashion. The predictors of lateral bone contusions including age, sex, body mass index, lateral meniscal slope and lateral posterior tibial slope were examined by multivariable logistic regression. Associated findings including concomitant meniscal lesions, intra-articular cartilage damage and anterolateral complex injury, which were also calculated by multivariable logistic regression.

**Results** The mean lateral meniscal slope in the study group was  $6.5^\circ \pm 3.5^\circ$ , which was significantly larger than that in the control group ( $3.8^\circ \pm 2.7^\circ$ ;  $P < 0.01$ ). In addition, increased lateral meniscal slope was significantly associated with lateral bone contusions in noncontact ACL injury (Lateral femoral condyle (LFC): AOR 16.5; 95% CI 5.40–50.20;  $P < 0.01$ ; Lateral tibial plateau (LTP): AOR 31.8; 95% CI 8.68–116.7;  $P < 0.01$ ). However, lateral posterior tibial slope was not significantly associated with bone contusions. Moreover, the presence of lateral bone contusions was associated with concomitant lateral meniscal tears (OR 12.4; 95% CI 3.30–46.30) and cartilage damage (OR 2.9; 95% CI 1.04–8.18).

**Conclusion** An increased lateral meniscal slope was associated with increased risk of lateral bone contusions in noncontact ACL injury. In addition, the presence of lateral bone contusions was associated with intra-articular cartilage damage, anterolateral complex injury and concomitant meniscal tears. Hence, additional information was provided for counseling patients who have increased LMS on the greater risk of knee rotational instability and identify patients undergoing ACL reconstruction who may benefit from extra-articular tenodesis.

**Level of evidence** IV.

**Keywords** ACL injury · Bone contusions · Lateral meniscal slope · Anterolateral ligament

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## Introduction

Noncontact anterior cruciate ligament (ACL) injuries account for almost three quarters of all ACL injuries observed clinically and previous studies have proposed different theories and risk factors [2]. Several associated injuries such as anterolateral ligament (part of anterolateral complex) injury and bone contusions may help us better understand the mechanism of injury and thus optimize prevention strategies [28, 30, 31, 41].

Bone contusions are present in up to 80% of ACL ruptures [9], which are observed by MRI as trabecular bone marrow edema [3, 5, 12, 18, 37]. The most common bone bruise site is on the lateral femoral condyle (LFC) at the sulcus terminalis and posterior lateral tibial plateau (LTP) [26]. The injury results from a pivot-shift like mechanism, which is characterized by anterior subluxation of the lateral tibial plateau on the femoral condyle [19, 25]. In addition, severe bone contusions are suggested to be an indicator of early degenerative changes in the knee [23, 36]. However, the exact mechanism and risk factors for bone contusions still remain unknown.

The posterior tibial slope (PTS) of the bony tibial plateaus frequently is mentioned for its association to non-contact ACL injury. It is defined by a tangent line to the respective tibial plateau and a line perpendicular to the longitudinal axis of the tibial bone. Prior studies have suggested that in ACL ruptured knees, every 10 degree increase of PTS results in 6 mm of anterior tibial translation [7]. Song et al. [31] have shown that increased PTS was connected to high-grade pivot-shift, which is the injury mechanism for lateral bone contusions in ACL rupture. However, the relation of tibial slope and ACL rupture, together with its associated injuries remains controversial [10, 39]. This lack of consensus may be attributed to the use of bony tissue to define the tibial slope [16]. Some investigators have claimed that the assessment of meniscal slope was more accurate since it might represent the true surface of the tibia [21, 34]. Therefore, the lateral meniscal slope (LMS) will potentially be a more accurate assessment of the relationship between the tibia and the femur in the lateral compartment of the knee [8].

Thus, an increased LMS as measured on MRI is hypothesized to be correlated with the occurrence of bone contusions in noncontact ACL injury. The aim of the current study was to investigate the relationship between LMS and bone contusions in noncontact ACL ruptured knee. The secondary objective was to measure the relationship between the occurrence of bone contusions and different signs observed in ACL deficient knees such as cartilage damage, ALL injury and concomitant meniscal tears.

## Materials and methods

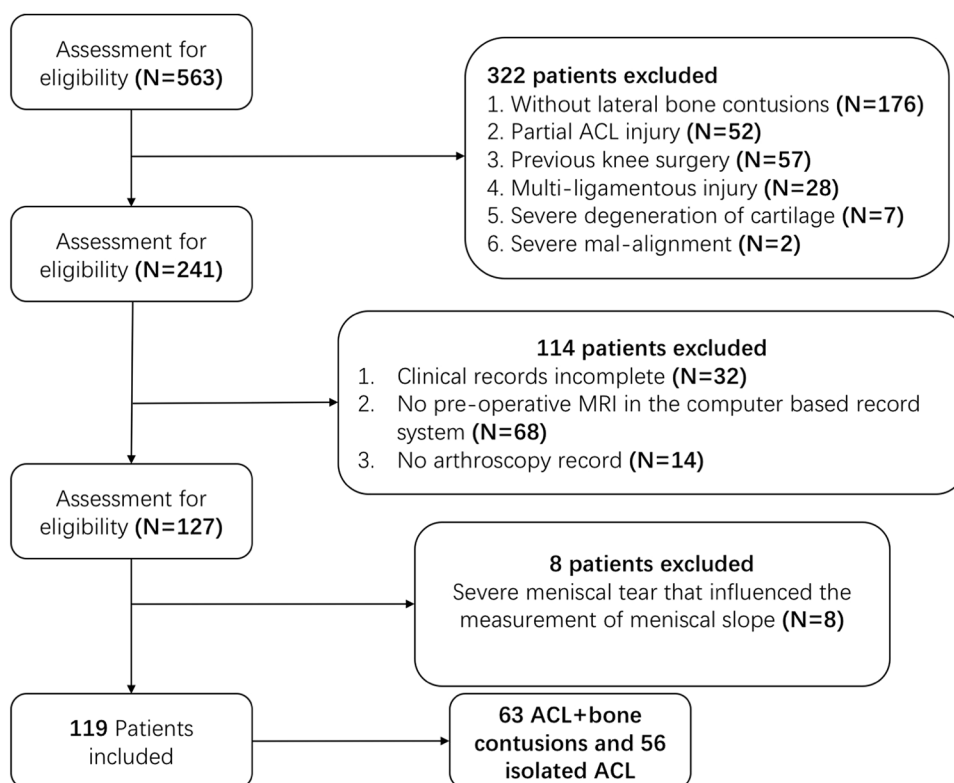
A retrospective case–control study was performed on 563 patients who underwent ACL reconstruction between 2013 and 2018. Patients were selected through our computer-based patient record system. Both medical records and operation records were reviewed to determine if inclusion criteria were present: primary ACL reconstruction relative to a lesion resulting from a noncontact mechanism. If the mechanism of injury was not described in detail in the medical records, the patient would be interviewed by telephone to obtain the required information. Patients were excluded if they (1) did not have lateral bone contusions; (2) had partial ACL injury; (3) had a history of knee surgery on the affected side; (4) had combined ligament injuries including PCL injury, MCL injury or PLC injury; (5) had severe degeneration of cartilage > grade 2 according to Kellgren-Lawrence grading system; (6) had severe malalignment of the lower limb or (7) had general joint laxity. Demographic data including gender, age, side, BMI and follow-up time were recorded. The flow chart of patient selection is presented in Fig. 1.

### Preoperative evaluation

The medical history, physical examinations, demographic data including age and sex were retrospectively reviewed. A sports medicine-trained orthopedic surgeon and a radiologist specialized in musculoskeletal imaging independently reviewed the preoperative MRI and were blinded to the results found by other observers. The sagittal, coronal and axial sequences with T1 and T2 phases of MRI were included in the protocol. Fat suppressed sequence was utilized to evaluate the presence and severity of bone contusions on the lateral femoral condyle (LFC) and lateral tibial plateau (LTP). The severity of bone contusions was defined as none, minimal, moderate and severe, using the International Cartilage Repair Society (ICRS) grading system [4] (Fig. 2).

The previously utilized method [16, 17] was conducted to measure the lateral meniscal slope (LMS) and lateral posterior tibial slope (LPTS) preoperatively in MRI scans: The first step was to define the central sagittal slice, which consisted of attachment of the posterior cruciate ligament (PCL) and the intercondylar eminence. The second step was to draw two circles, the first circle was tangent to the anterior, posterior and proximal borders of the tibia and the second circle was centered on the perimeter of the first circle. Thus, the longitudinal axis is defined as the line connecting the two centers of the circles (Fig. 3a). The last step was to measure the angle between the line

**Fig. 1** Flowchart of patient selection. *ACL* anterior cruciate ligament, *MRI* magnetic resonance imaging



**Fig. 2** Sagittal MRI illustrating the bone contusions in the ACL ruptured patients

perpendicular to the tibial longitudinal axis and the tangent to the lateral bony tibial plateau and lateral meniscal borders (Fig. 3b, c). The tangent to the lateral meniscal borders was defined as the line connecting the superior anterior and posterior meniscal borders on the middle

slice between the most medial slice and the central sagittal slice.

An examination of ALL status was conducted on T2 weighted coronal plane, normally, the ALL could be seen starting from the lateral epicondyle of the distal femur, going obliquely to the proximal tibia between Gerdy's tubercle and fibula head [30].

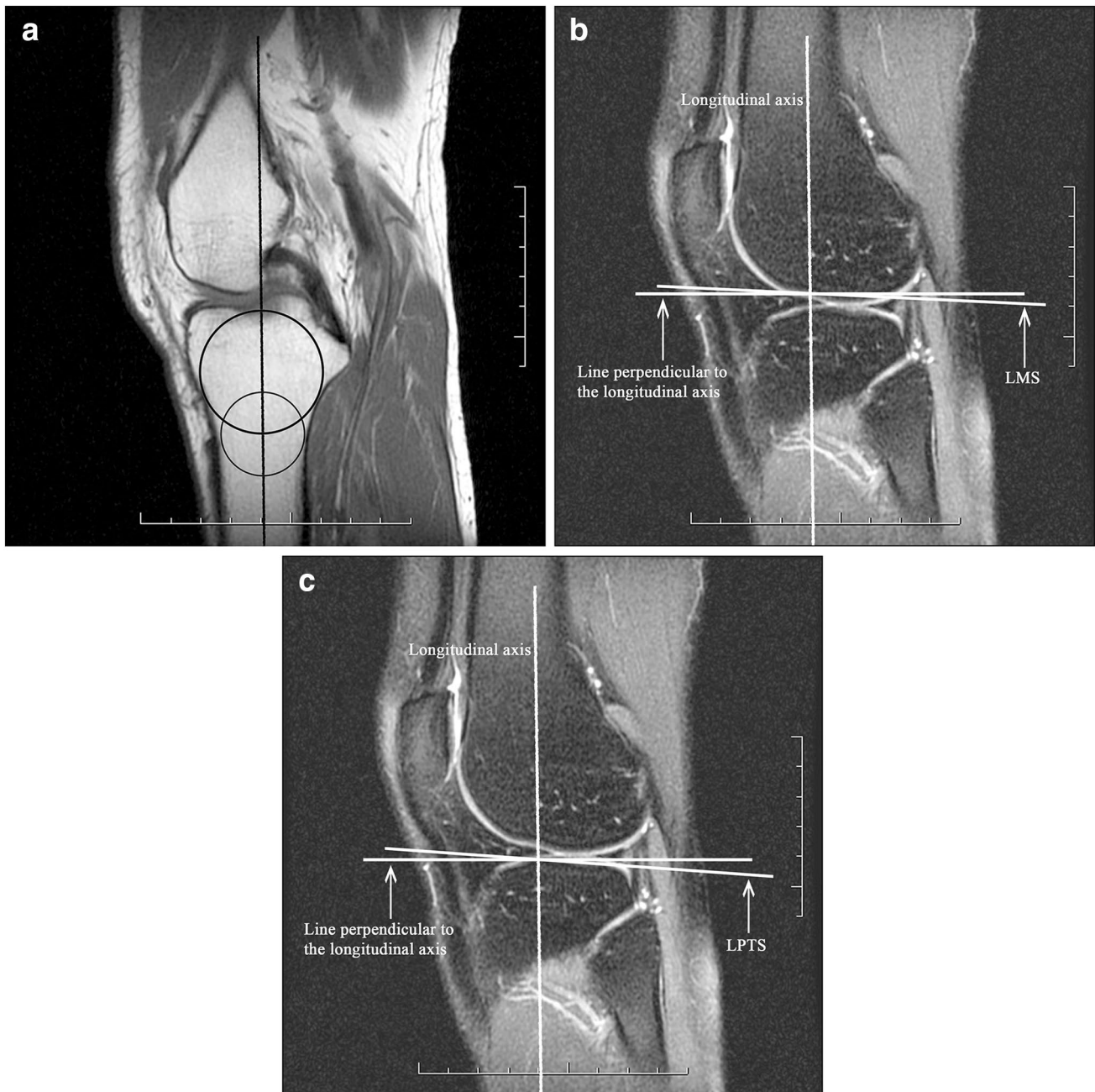
### Intraoperative assessment

All the meniscal tears, intra-articular cartilage damage and other abnormalities were documented using the images and videos recorded during surgery. Meniscal tears were evaluated according to ISAKOS classification [38]. Cartilage degradation was evaluated according to Outerbridge classification [24].

This study was approved by the institutional review board of the First Affiliated Hospital of Chongqing Medical University (IRB approval number: 2017-108).

### Statistical analysis

Outliers were checked, then corrected or excluded before statistical analysis. A sample size calculation was performed using the formula for difference in means in case–control study. Standard deviation ( $\sigma$ ) of LMS in samples was set as 4, difference between case and control group was 2.5, 80% power, 0.05 significance level and equal number of case



**Fig. 3** **a** The central sagittal slice consisted of attachment of the posterior cruciate ligament (PCL) and the intercondylar eminence, the longitudinal axis is defined as the line connecting the two centers of the circles. **b** Measurement of the angle between the line perpendicular

to the tibial longitudinal axis and the tangent to the lateral meniscal borders. **c** Measurement of the angle between the line perpendicular to the tibial longitudinal axis and the tangent to the lateral bony tibial plateau

and control group, the sample size should be 41 in each group. So, the sample size in our study with 63 cases and 56 controls was ample to discover the difference between two groups.

In this study, descriptive data were calculated for LMS, LPTS, bone contusions and demographic data. The population was divided into two groups according to the

presence of bone contusions. An intraclass correlation coefficient (ICC) was used to evaluate the reliability of measurement performance. ICC value  $> 0.9$  were considered excellent, values of  $0.8–0.9$  indicated good reliability. The inter-observer ICCs were 0.92 for the severity of bone contusions at LFC and LTP and 0.82 for ALL status. The

inter-observer ICCs were 0.9 and 0.87 for LPTS and LMS, suggesting a good reliability.

Pearson Chi square test or Fisher exact test were used to compare categorical variables and Student *t* test was utilized to compare continuous variables. The predictors of lateral bone contusions (LFC, LTP or both) including age, gender, BMI LMS, LPTS and associated findings including meniscal lesion and cartilage damage were examined by multivariable logistic regression.

Currently there is not an established criterion for the abnormal value of LMS and LPTS, thus, the mean and SD of the control group were calculated and  $\geq 1$  SD from the mean was considered abnormal ( $\geq 6.52$  for LMS;  $\geq 10.36$  for LPTS). Odds ratio (OR) or adjusted OR (AOR) and 95% confidence interval (CI) were computed.  $P < 0.05$  was considered statistically significant. Analyses were conducted using SAS 9.4 (Cary, NC, USA).

## Results

### Descriptive statistics

The mean LMS in the study group was  $6.5 \pm 3.5$  and mean LMS in the control group was  $3.8 \pm 2.7$  ( $P < 0.01$ ). The incidence of cartilage damage, ALL abnormality and concomitant meniscal tears were also significantly higher in the study group than in the control group (Table 1). In addition, there were more males in the study group. Whereas, age, LPTS, and BMI were similar between groups.

### Relationship between LMS/LPTS and bone contusions

The multivariable logistic regression analysis for predictors of the presence of bone contusions was presented in Table 2. The LMS was found to be significantly correlated with bone contusions (AOR 7.0; 95% CI 2.42–20.0). In addition, further analysis showed that the LMS (LFC: AOR 16.5; 95% CI 5.40–50.20;  $P < 0.01$ ; LTP: AOR 31.8; 95% CI 8.68–116.7;  $P < 0.01$ ) was an independent risk factor of lateral bone contusions (LFC and LTP). However, LPTS was not found to be associated with bone contusions.

The severity of bone contusions was further analyzed by multivariable logistic regression. Only LMS was found to be significantly associated with the moderate/severe lateral bone contusions (LFC: AOR 12.2; 95% CI 2.59–57.5;  $P < 0.01$ ; LTP: AOR 23.4; 95% CI 5.88–93.4;  $P < 0.01$ ), whereas LPTS, BMI, age and gender were not.

### Associate findings with the presence of bone contusions

Multivariable logistic regression was used for the presence of bone contusions of the knee. The multivariable logistic regression analysis (Table 3) reveals that lateral bone contusions was significantly associated with concomitant lateral meniscal lesions (OR 2.0; 95% CI 3.30–46.3) and antero-lateral complex injury (OR 53.5; 95% CI 12.47–229.50). Both lateral and medial bone contusions (OR 2.9; 95% CI 1.04–8.18; OR 3.1; 95% CI 1.11–8.80) were found to be significantly associated with cartilage injury.

**Table 1** Descriptive data

	No contusion ( <i>n</i> = 56)	With contusion ( <i>n</i> = 63)	<i>P</i> value
Age	34.2 ± 11.4	31.1 ± 10.3	ns
Gender ( <i>n</i> , %)			< 0.01
Male	31 (55.4)	50 (79.4)	
Female	25 (44.6)	13 (20.6)	
BMI	24.2 ± 2.1	24.7 ± 2.0	ns
LPTS	8.2 ± 2.1	8.9 ± 3.3	ns
LMS	3.8 ± 2.7	6.5 ± 3.5	< 0.01
Concomitant meniscal tear ( <i>n</i> , %)	11 (19.6)	29 (46.0)	< 0.01
Cartilage damage ( <i>n</i> , %)	0	20 (31.8)	< 0.01
ALL status ( <i>n</i> , %)			
Normal	48 (96)	34 (55.7)	< 0.01
Injury	2 (4)	27 (44.3)	

Comparisons between study and control groups



**Table 2** Multivariate logistic regression for predictors of bone contusions

	Contusion (n = 63)		LFC (n = 33)		MFC (n = 23)		LTP (n = 35)		MTP (n = 23)	
	Odds ratio (95% CI)	P value	Odds ratio (95% CI)	P value	Odds ratio (95% CI)	P value	Odds ratio (95% CI)	P value	Odds ratio (95% CI)	P value
Age	1.0 (0.95, 1.00)	ns	1.0 (0.92, 1.01)	ns	1.0 (0.98, 1.07)	ns	1.0 (0.896, 1.01)	ns	1.0 (0.95, 1.03)	ns
Gender	3.7 (1.43, 9.56)	<0.05	1.5 (0.47, 4.48)	ns	4.0 (1.19, 13.10)	0.03	4.5 (1.10, 18.0)	0.04	3.1 (0.95, 10.00)	ns
BMI	1.2 (0.93, 1.44)	ns	1.2 (0.91, 1.50)	ns	1.1 (0.892, 1.40)	ns	1.4 (1.03, 1.91)	0.03	0.9 (0.75, 1.18)	ns
LPTS	1.8 (0.51, 6.03)	ns	1.0 (0.29, 3.59)	ns	0.5 (0.12, 2.20)	ns	3.7 (0.834, 16.4)	ns	0.3 (0.07, 1.30)	ns
LMS	7.0 (2.42, 20.00)	<0.01	16.5 (5.40, 50.20)	<0.01	0.6 (0.20, 1.84)	ns	31.8 (8.68, 116.7)	<0.01	2.2 (0.79, 5.98)	ns

## Discussion

The main findings in the current work were: First, patients in the study group (ACL injuries + bone contusions) showed significantly increased LMS, more cartilage damage and concomitant meniscal tears especially lateral meniscal tears than in the control group (Isolated ACL injuries). Second, increased LMS was further demonstrated by multivariable logistic regression to be an independent risk factor for both the presence and severity of lateral bone contusions, whereas, LPTS, BMI and age were not. Third, bone contusions were significantly correlated with cartilage damage.

Bone contusions detected by MRI have gained increasing interest since their first description [40]. ACL rupture has long been suggested to be correlated with early occurrence of degenerative osteoarthritis, which was originally explained by abnormal knee kinematics and ligament insufficiency. However, recent studies have indicated that even after ACL reconstruction, many of these patients will develop degenerative changes in less than 10 years [6, 11, 22]. These results showed that the occurrence of early degenerative arthritis have some other predisposing factors such as intra-articular cartilage damage and bone contusions. In addition, the location of bone contusions was always specific to the injured ligament, thus investigating bone bruise location could be essential to help orthopaedic surgeons better understand the mechanism of ligament injury [14, 20, 33]. On the basis of these findings, Speer et al. [32] suggested a pivot-shift like injury of the femoral condyle and posterolateral tibial rim. However, to our knowledge, the exact mechanism and risk factors for lateral bone contusions still remain unknown. When a pivot-shift like movement occurs, the tibia translates anteriorly and internally rotates, the lateral femoral condyle moves posteriorly and subluxation occurs. In addition to bone contusions, this movement could result in damages on several structures like ALL and lateral meniscus, which are rotational stabilizers of the knee. Thus, bone contusions may serve as a bridge between LMS/LPTS and rotational instability. Previously, studies have shown that the ALL could be observed on MRI and ultrasound, making ALL evaluation possible [15, 27]. Song et al. [30] has indicated several associated findings of bone contusions in patients with ACL injury including high grade pivot-shift, concomitant lateral meniscal tear and ALL abnormality. These findings are yet to be verified but they could help us better understand that pivot-shift like mechanism of ACL injury could imply a series of injuries occurred not only on ACL but also the lateral meniscus, ALL, cartilage damage and bone contusions.

Previously, an increased LPTS as measured on MRI has been regarded as a risk factor for ACL injury in the native

**Table 3** Associated findings for the presence of bone contusions

	Cartilage injury		Medial meniscal lesions		Lateral meniscal lesions	
	AOR (95% CI)	<i>P</i> value	AOR (95% CI)	<i>P</i> value	AOR (95% CI)	<i>P</i> value
Age	1.0 (0.96, 1.06)	ns	1.0 (0.95, 1.04)	ns	1.0 (0.96, 1.07)	ns
Gender	2.2 (0.56, 8.74)	ns	1.5 (0.47, 4.91)	ns	4.2 (0.82, 21.90)	ns
BMI	1.0 (0.75, 1.26)	ns	0.9 (0.71, 1.20)	ns	0.8 (0.62, 1.08)	ns
Lateral bone contusions	<b>3.1 (1.06, 8.83)</b>	<b>&lt; 0.05</b>	<b>0.3 (0.07, 0.88)</b>	<b>&lt; 0.05</b>	<b>12.4 (3.30, 46.30)</b>	<b>&lt; 0.05</b>
Medial bone contusions	<b>3.1 (1.08, 8.68)</b>	<b>&lt; 0.05</b>	<b>3.8 (1.35, 10.08)</b>	<b>&lt; 0.05</b>	0.5 (0.15, 1.74)	ns

Bold values indicate statistical significance ( $P < .05$ )

knee [1]. It has been suggested that with increased LPTS, the ACL will suffer from greater loading and thus, injury could more easily happen [13]. However, recent studies have suggested that tibial slope measurement should not be conducted using the bony tissue [8, 21, 34]. The soft tissue such as meniscus and cartilage on the tibial plateau may more accurately reflect the true surface of tibia and thus play a crucial role in controlling the anterior translation of the tibia in the ACL ruptured knee [35]. Currently, it is still too early to indicate that the decision to perform HTO in patients with ACL injury should be made based on LPTS or LMS, but due to the discrepancy of different results, considering both as a reference may be a better choice. When lateral bone contusions occur, the lateral femoral condyle often moves posteriorly to impact on the posterolateral part of the tibia including the posterior horn of the lateral meniscus. A previous study has suggested the association between increased medial meniscal slope and medial meniscal ramp lesions in noncontact ACL injury patients [29]. When the menisci are unable to serve as a secondary stabilizer, the pivot-shift like movement easily happens and thus lateral bone contusions occur [30]. However, whether the LPTS or LMS is an independent risk factor of lateral bone contusions still remains unclear. This study showed that LMS, rather than LPTS was significantly increased in the study group (ACL injuries + bone contusions) than in the control group (isolated ACL injuries), moreover, only increased LMS was demonstrated by multivariable logistic regression to be strongly correlated with both the presence and severity of lateral bone contusions, which indicated that only LMS, rather than LPTS, was an independent risk factor.

Understanding of the anatomic predictors and associated injuries of bone contusions might help us better evaluate the ACL injury. Patients who have increased LMS might be of greater risk of concomitant bone contusions, especially lateral bone contusions, and early occurrence of degenerative arthritis. Increased LMS was indicated in this study to correlate with higher prevalence of lateral bone contusions, which could be associated with concomitant meniscal tear and intra-articular cartilage damage.

MRI was used to visualize the true surface geometry of the tibio-femoral articulation in this study. In addition, high inter-observer ICCs in MRI measurement of LMS and LPTS indicated good reliability. However, limitations still exist. First, this is a retrospective case-control study. Second, a larger sample size would strengthen this study and provide insights into other associated findings although a sample size calculation was performed and it showed that our study with 63 cases and 56 controls was ample to discover the difference between two groups. Third, patients in the study group were not matched by age and sex to control group participants and there were more males in the study group. This could be explained by the fact that males are more involved in physically demanding sports and thus, severe injury could more easily happen in males.

To our knowledge, this is the first study focusing on correlation between increased LMS and lateral bone contusions in patients with noncontact ACL injuries. The lateral bone contusions associated with ACL injury were multifactorial and several factors should be taken into account. This could help orthopaedic surgeons in identifying susceptible individuals who may experience greater benefit from targeted ACL injury-prevention counseling and intervention. In addition, since higher LMS, ALL injury, bone contusions are risk factors for rotational instability after ACL injury, this study would help to identify patients undergoing ACL reconstruction who may benefit from additional surgical procedures such as extra-articular tenodesis.

## Conclusion

An increased LMS was associated with and could be an independent risk factor for lateral bone contusions in non-contact ACL injury. In addition, the presence of lateral bone contusions is associated with intra-articular cartilage damage, ALL injury and concomitant meniscal tears. These factors above should be considered by orthopedic surgeons as part of the preoperative evaluation of patients with ACL injury.

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## Compliance with ethical standards

**Conflict of interest** The authors have declared that no competing interests exist.

**Ethical approval** This study was approved by the institutional review board of the First Ailiated Hospital of Chongqing Medical University (IRB approval number: 2017-108).

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