Preoperative Factors Correlating With Prolonged Range of Motion Deficit After Anterior Cruciate Ligament Reconstruction

Bénédicte Quelard, Bertrand Sonnery-Cottet, Rachad Zayni, Roger Ogassawara, Thierry Prost and Pierre Chambat

Am J Sports Med 2010 38: 2034 originally published online August 11, 2010
DOI: 10.1177/0363546510370198

Preoperative Factors Correlating With Prolonged Range of Motion Deficit After Anterior Cruciate Ligament Reconstruction

Bénédicte Quelard,* MD, Bertrand Sonnery-Cottet,†‡ MD, Rachad Zayni,‡ MD, Roger Ogassawara,‡ MD, Thierry Prost,§ MD, and Pierre Chambat,‡ MD
*From the *Centre Hospitalier Public d'Hauteville, Unité Inter, France, ‡Centre Orthopédique Santy, Lyon, France, and §DDASS d'Haute-Savoie, Annecy, France*

Background: Impaired postoperative range of motion remains one of the most frequent complications after anterior cruciate ligament reconstruction.

Purpose: This study was undertaken to determine the preoperative factors associated with prolonged range of motion deficit after anterior cruciate ligament reconstruction.

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

Methods: Between January 2007 and March 2008, a consecutive series of 217 patients underwent anterior cruciate ligament reconstruction and were reviewed at 6 weeks and 3 months after surgery. In this series, all data of patients who required a further surgery for arthrolysis until December 2009 were studied. Goniometric range of motion measurement was performed the day before surgery and at 6 weeks and 3 months postoperatively. Bone contusions were analyzed on preoperative magnetic resonance imaging (MRI). All MRI scans were performed in the 6 months before surgery. Seven potential risk factors—age, sex, limited preoperative range of motion, meniscal lesions, bone contusion(s), operative delay less than 45 days, and rehabilitation—were assessed using univariate analysis. The correlations between the significant factors previously identified were analyzed further using multivariate logistic regression analysis.

Results: Limited preoperative range of motion ($P < .001$), typical bone contusions of the lateral compartment ($P < .001$), operative delay less than 45 days ($P = .003$), and female sex ($P = .049$) were found to be significantly correlated with delayed recovery. The limited preoperative mobility and the presence of typical contusions were strongly correlated ($P < .001$). In the group of patients who underwent surgery within 45 days, delayed recovery was strongly correlated with limited preoperative mobility ($P = .0008$) and to the presence of typical contusions ($P < .001$). Arthrolysis was correlated with delayed range of motion (odds ratio [OR], 8.2; 95% confidence interval [CI], 1.9-50; $P = .001$) and bone bruise (OR, 7.6; 95% CI, 1.7-46.1; $P = .002$).

Conclusion: Preoperative limited range of motion and typical bone bruises of the lateral femoral condyle and tibial plateau are major risk factors for a difficult rehabilitation after anterior cruciate ligament reconstruction.

Keywords: bone bruise; ACL reconstruction; rehabilitation; limited range of motion.

According to many authors, impaired postoperative range of motion (ROM) remains one of the most frequent complications after anterior cruciate ligament (ACL) reconstruction, found in 7% to 26% of cases.[2,3,11,20,23,24] This complication is often related to limited preoperative ROM and early surgery after the injury.[6,16,17,30] Other factors, including bone contusions, can also lead to such complication. This lesion, often referred to as a bone bruise, is associated with ACL tears in up to 70% to 80% of cases.[26] These contusions are the result of high articular compressive impact during a traumatic event. They typically occur on the lateral femoral condyle close to the trochleocondylar recess and on the posterior aspect of the lateral tibial plateau (Figure 1). The pathophysiologic consequences of these lesions after ACL reconstruction are still poorly understood. Histologically, these lesions are a combination of trabecular microfractures, hemorrhagic effusion, and medullary edema.[19,22] According to the literature, these lesions can take from 6 weeks to 2 years to resorb.[4,5,7,10,14,18,25-27] Their diagnosis is based on MRI. Comparative studies have reported slower effusion resorption, slower articular pain relief, and slower mobility and muscle function recovery when ACL rupture is

†Address correspondence to Bertrand Sonnery-Cottet, MD, Centre Orthopédique Santy, 24 Avenue Paul Santy, 69008 Lyon, France (e-mail: sonnerycottet@aol.com).

The authors declared that they had no conflicts of interests in their authorship and publication of this contribution.

The American Journal of Sports Medicine, Vol. 38, No. 10
DOI: 10.1177/0363546510370198

Figure 1. Bone contusions of the tibial plateau and lateral condyle on MRI examination: isosignal T1, hypersignal T2, and short tau inversion recovery (STIR) sequences

associated with bone contusions.[13,29] However, the influence of bone contusions on recovery after ACL reconstruction has never been studied. The objective of this study was to determine the preoperative factors, including bone bruises, correlating with prolonged ROM deficit after ACL reconstruction.

MATERIALS AND METHODS

Demographic Data

This study evaluated a longitudinal, prospective series of patients with an isolated ACL rupture, operated on by the same surgeon between January 2007 and March 2008, using the same surgical technique.[9] All patients underwent MRI before surgery. Exclusion criteria were MRI done more than 6 months before surgery, ACL revision, and osteochondral or capsuloligamentous lesions that required additional procedures during the ACL reconstruction. All patients were reviewed by the same independent observer at 6 weeks and 3 months postoperatively to evaluate ROM. All data of patients who required an arthrolysis until December 2009 were studied. The MRI requested before the surgery was analyzed by the observer at 3 months postoperatively to determine the localization of bone contusions.

The series consisted of 217 patients, including 139 male (64%) and 78 female (36%) patients. The mean age was 29 years (range, 14-62 years). Most (90.8%) ruptured ligaments were due to a sports injury, with a majority of ski accidents (Table 1). The mean delay between the ACL rupture and surgery was 416 days (range, 7 days-30 years), with a median of 103 days. Only 10 patients had a delay longer than 2 years. They did not have bone bruise on MRI; however, they were kept in the series because of the longitudinal consecutive nature of this study. The mean delay between MRI and surgery was 74 days, with a 63-day median delay.

TABLE 1
Causes of Anterior Cruciate Ligament (ACL) Injury

Accidents Causing ACL Rupture	No. of Cases	Percentage
Skiing, snowboarding	92	Sports accidents 90.8%
Football, rugby	47	
Basketball, volleyball, handball	31	
Tennis, squash, badminton	9	
Judo, karate, boxing, wrestling	9	
Other sports (horseback riding, rollerblading, mountain biking, etc)	9	
Daily life and road traffic accidents	20	9.2%

Operative Technique

All surgeries were performed with the patient under general anesthesia and femoral nerve block. The ACL reconstructions were performed under arthroscopic control, with an autograft taken from the medial third of the patellar tendon with a trapezoidal tibial bone plug and a patellar bone plug. Graft fixation at the femoral level was done by press-fit of the tibial bone plug in the lateral condyle tunnel. At the tibial level, primary fixation of the patellar bone plug was achieved with a resorbable interference screw.[9] Appropriate positioning of the transplant was checked on postoperative radiographs, according to the technique described by Aglietti et al.[1]

Rehabilitation

Restoration of full terminal knee extension was the primary objective.[8] Extension deficit was determined with the patient in the supine position with the legs hanging off the end of the bed. Passive ROM exercises, thigh muscle contractions, and forearm crutch-assisted ambulation were initiated 1 day after the surgery. After the fourth postoperative day, all patients followed the same rehabilitation protocol. A total of 99 patients (45.6%) did their rehabilitation in a specialized center and 118 patients (54.4%) were rehabilitated by an independent physical therapist (see online Appendix for this article at http://ajs.sagepub.com/supplemental/).

ROM Evaluation

Knee ROM was measured the day before surgery, at 6 weeks, and at 3 months after surgery. Patients with at least 1 of the following 2 criteria, as compared with the

TABLE 2
Factors Related to Delayed Recovery (Univariate Analysis)[a]

Factor		Delayed Recovery	χ^2	P^b
Limited preoperative mobility	Yes	75.1%	41.3	**<.0001**
	No	19.1%		
Presence of a contusion, irrespective of the localization	Yes	34%	14.9	**.0001**
	No	8.2%		
Presence of a contusion on LTP only	Yes	9.6%	0.07	0.97
	No	8.2%		
Presence of a typical bone contusion on LC + LTP	Yes	46.2%	38.5	**<.0001**
	No	8.8%		
Operative delay <45 days	Yes	38.5%	11.0	**.003**
	No	18.3%		
Meniscal lesions	No	41.5%	0.397	.53
Postoperative management type	Center	29.3%	0.6	.43
	Independent	24.6%		
Sex	Female	34.6%	3.9	**.049**
	Male	22.3%		
Age	Mean age of patients with delayed recovery	28.5 y	*t* test 0.24	.67
	Mean age of patients with no delayed recovery	29.2 y		

[a]LTP, lateral tibial plateau; LC, lateral condyle.
[b]**Bold face** indicates statistical significance ($P < .05$).

contralateral knee, were considered as having prolonged ROM deficit: lack of full extension ≥5° and/or deficit of flexion >30° at 3 weeks; lack of full extension and/or flexion limitation >15° at 3 months.

Bone Contusion Evaluation

All MRI scans were analyzed by the same observer 3 months after surgery. The observer's results were compared with the radiologist's conclusions. In the absence of agreement, a third opinion was obtained.

For each MRI, following items were noted: presence of bone contusions on the lateral femorotibial compartment and localization of the bone contusion(s)—lateral condyle (LC), lateral tibial plateau (LTP), or typical bone bruise contusion (ie, lateral condyle and lateral tibial plateau [LC + LTP]).

Statistical Analysis

Statistical analysis was performed using the Epi Info software, version 3 (Centers for Disease Control and Prevention, Atlanta, Georgia). Seven factors believed to have an effect on postoperative recovery were evaluated: age, sex, limited preoperative ROM, bone contusion(s), time from trauma to surgery less than 45 days, meniscal tears, and postoperative management (rehabilitation center or independent physical therapist). Such presumed risk factors were first analyzed using a univariate analysis; qualitative variables were compared using the Pearson χ^2 test or the Fisher exact test when sample size was insufficient. Quantitative variables were compared using the Student *t* test. Correlation between the various significant factors previously identified was examined using multivariate logistic regression analysis. The influence of time from injury to surgery was then analyzed. The significance threshold for tests was set at a $P < .05$.

RESULTS

At the time of surgery, 29 patients (13.4%) had incomplete ROM. Delayed ROM recovery was observed in 58 patients (26.7%) at 6 weeks and 26 (12%) at the 3-month follow-up. Limitation of extension was observed in 18 patients, flexion deficit in 6, and both limitations in 34 patients. The incidence of meniscal lesions found during surgery was 34%, with a majority being lateral meniscal tears (54%). Only 16% of these lesions were repaired. Patients with delayed ROM recovery had an incidence of meniscal lesions not statistically different compared with the group without delayed ROM ($P = .53$). At the last follow-up, in December 2009, 5% of patients underwent further surgery for arthrolysis. The incidence of arthrolysis in the group without delayed ROM was 2%, compared with 13.8% in the group with delayed ROM (odds ratio [OR], 8.2; 95% confidence interval [CI], 1.9-50; $P = .001$).

On MRI examination, 156 patients (72%) had a contusion on the lateral femorotibial compartment: 104 (48%) had typical bone contusions on the LC and LTP, and 52 (24%) were only localized to the LTP. No isolated contusion of the lateral femoral condyle was observed.

Analysis of Potential Risk Factors

Out of the 7 studied factors, 4 were significantly related to delayed recovery: limited preoperative ROM ($P < .001$), presence of typical contusion of the lateral compartment ($P < .001$), time from injury to surgery <45 days ($P = .003$), and female sex ($P = .049$).

Neither age, rehabilitation, meniscal lesions, nor the presence of an isolated contusion of the lateral tibial plateau had any significant influence on postoperative recovery (Table 2). No significant difference was observed between patients with an isolated contusion of the LTP and those without any

TABLE 3
Initial Logistic Regression Table Including All Significant Factors Identified in Univariate Analysis[a]

Factor	Coefficient	P^b	Odds Ratio (OR)	95% Confidence Interval for OR
Limited preoperative mobility	–2.11	**.0001**	0.12	0.04-0.36
Presence of a typical bone image contusion on LC + LTP	2.05	**<.0001**	7.77	3.4-17.5
Operative delay <45 days	.42	.41	1.52	0.6-4.1
Sex	–.88	**.025**	0.42	0.19-0.90

[a]LTP, lateral tibial plateau; LC, lateral condyle.
[b]**Bold face** indicates statistical significance ($P < .05$).

TABLE 4
Final Logistic Regression Table After Exclusion of Non-significant Risk Factors[a]

Factors	Coefficient	P^b	Odds Ratio (OR)	95% Confidence Interval for OR
Limited preoperative mobility	–2.27	**<.0001**	0.10	0.04-0.29
Presence of a typical bone image contusion on LC + LTP	2.02	**<.0001**	7.57	3.36-17.05
Sex	–.94	**.015**	0.39	0.18-0.83

[a]LTP, lateral tibial plateau; LC, lateral condyle.
[b]**Bold face** indicates statistical significance ($P < .05$).

contusion (9.6% and 8.2%, respectively, of delayed recovery, with a P value of .72 for the Fisher exact test).

Analysis of Confirmed Risk Factors

The 4 previously identified factors related to delayed recovery were introduced in a logistic regression model. Results from the univariate analysis, provided in Tables 3 and 4, show that 3 factors remained significant, each of them potentially able to induce delayed recovery independently from the 2 others. These 3 factors were limited preoperative mobility ($P < .001$), presence of typical bone contusions of the lateral compartment ($P < .001$), and female sex ($P = .015$).

Limited preoperative ROM and the presence of typical bone contusions were strongly correlated; 24 of the 29 patients (82.7%) with limited ROM before surgery had a contusion of the LC and LTP, compared with 80 of the 188 patients (42.6%) with full preoperative ROM ($\chi^2 = 16.27$; $P < .001$). However, these 2 factors remained significant in the logistic regression model, which suggests that the presence of a typical bone contusion of the lateral compartment is a risk factor for delayed recovery, even in the absence of limited preoperative ROM.

TABLE 5
Influence of Operative Delay on the Risk of Delayed Recovery as a Function of the Factors Considered[a]

Factor	OD, days	N	Delayed Recovery, %	χ^2	P^b
Limited preoperative mobility	<45	15	80	Fisher test	.46
	≥45	14	71.4		
Presence of a contusion on LC + LTP	<45	21	85.7	16.5	**.00005**
	≥45	83	36.1		
Female sex	<45	20	50	.24	.62
	≥45	58	29.3		
Absence of contusion	<45	5	0	Fisher test	.64
	≥45	56	8.9		
Isolated LTP contusion	<45	13	0	Fisher test	.22
	≥45	39	12.8		

[a]OD, operative delay; LTP, lateral tibial plateau; LC, lateral condyle.
[b]**Bold face** indicates statistical significance ($P < .05$).

TABLE 6
Influence of Limited Preoperative Mobility, Presence of a Typical Bone Contusion, and Sex in Patients With an Operative Delay <45 Days[a]

Factor		N	Delayed Recovery, %	χ^2	P^b
Limited preoperative mobility	Yes	15	80	11.2	**.0008**
	No	24	25		
Presence of a contusion on LC + LTP	Yes	21	85.7	28.6	**<.0001**
	No	18	0		
Sex	Females	20	50	0.24	.62
	Males	19	42.1		

[a]OD, operative delay; LTP, lateral tibial plateau; LC, lateral condyle.
[b]**Bold face** indicates statistical significance ($P < .05$).

If female sex was considered, neither limited preoperative ROM nor the presence of a contusion of the LC were significantly related to this factor (respectively, $\chi^2 = .46$; $P = .50$ and $\chi^2 = .06$; $P = .81$).

Influence of Operative Delay

Operative delay shorter than 45 days had an influence on postoperative recovery only in the group of patients with typical bone contusions ($P = .00005$). There was no significant influence on delayed recovery of the following factors: female sex, patients with isolated contusion of the LTP, and patients with limited preoperative ROM (Table 5). In the group of patients who underwent surgery within 45 days, delayed recovery was strongly correlated with limited preoperative ROM ($P = .0008$) and with the presence of typical bone contusions ($P < .001$) (Table 6).

It should be noted that in the group of patients with typical bone contusions and full preoperative ROM, delayed recovery was observed in 75% of those who had undergone surgery within 45 days, versus 31% of those who had undergone surgery beyond 45 days (Fisher exact test, $P = .02$)

Analysis of Patients Who Underwent Arthrolysis

Bone bruises were statistically correlated with arthrolysis (OR, 7.6; 95% CI, 1.7-46.1; $P = .002$).

DISCUSSION

Prevention of recovery difficulties and impaired mobility after ACL reconstruction is one of the daily preoccupations of surgeons and physical therapists. Many studies have attempted to identify factors correlated with stiffness, but results have not been clear concerning the role of certain factors, such as operative delay.[11,12,15,21,28] Cosgarea et al[6] observed a correlation between limited preoperative extension and stiffness after ACL reconstruction; their results were corroborated by Mayr et al,[17] who concluded that limited postoperative ROM is more related to inflammation and to preoperative limited ROM than to the operative delay itself. The results of our study are in agreement with those obtained by the latter authors,[17] and also provide an insight into why different conclusions were found by authors who reported the effect of operative delay on postoperative outcomes. In this study, typical bone contusions of the lateral compartment were found to be a risk factor, while isolated contusion of the LTP had no influence on postoperative recovery. In our series, 72% of patients had bone bruises, but only 48% of them had typical bone contusions on the lateral femoral condyle and tibial plateau. Short operative delay and typical bone contusions were found to be closely related with delayed postoperative recovery. Given the required time for bone contusions to resorb (6 weeks to 2 years),[4] the shorter the delay between trauma and surgery, the greater the probability of bone contusions at the time of surgery. Conversely, the longer the operative delay, the greater the chance of total resolution of contusions, as confirmed by the study of Atkinson et al,[4] who found a reduced frequency of such lesions by one-third between 4 to 10 weeks after the trauma and by 50% between 10 and 26 weeks. Resorption time is likely related to the magnitude of the hemorrhage and medullary edema.

Limited preoperative ROM was another major risk factor. It was significantly related to typical bone contusions of the lateral compartment, in accordance with the observations made by Johnson et al,[13] who demonstrated that ROM recovery is slower when the ruptured ACL is associated with bone contusions. A high risk of difficult rehabilitation was observed for patients undergoing surgery within 45 days without having achieved full knee ROM (80% delayed recovery). However, full knee ROM did not exclude a difficult postoperative recovery in the event of typical contusions of the lateral compartment (75% of delayed recovery in the event of a surgery performed within 45 days after the trauma).

In our series, female sex was an unexplained risk factor. This factor has never been reported to be associated with delayed recovery in previous publications. Only 1 study reported a significant link between impaired postoperative ROM and male sex.[12] Compared with the group of male patients, neither typical contusions of the lateral compartment nor impaired ROM were more frequent in female patients. However, 34.3% of female patients with typical contusions of the lateral compartment underwent surgery within 45 days, versus 14.5% of male patients ($P = .01$).

To our knowledge, this is the first report that demonstrates a correlation between bone bruises, delayed ROM recovery, and the incidence of arthrolysis after ACL reconstruction. This observation has resulted in a modification of the way we manage patients with ACL tears and led us to postpone surgery for those with typical bone bruises on MRI.

The main weakness of our study is the time between MRI and surgery, knowing that half of the contusions observed disappear within 6 months after trauma. Such bias could have been avoided by systematically performing MRI within 4 weeks before surgery. Such a procedure remains difficult to implement, as patients often bring MRI scans along for their first consultation with the surgeon. Our choice of a dichotomized 45-day operative delay suggests that most of the contusions that are visible on preoperative MRI should still be observed at the time of surgery in patients having undergone surgery within 45 days after ACL rupture. The resorption time variability of these lesions may explain the absence of delayed recovery in some patients with typical contusions of the lateral compartment who underwent surgery within 45 days (14.3%) and, conversely, the existence of delayed recovery in patients with typical contusions of the lateral compartment who had undergone surgery beyond 45 days (36.1%).

CONCLUSION

Our study has demonstrated that preoperative limited ROM and typical bone bruises of the lateral femoral condyle and tibial plateau are major risk factors for a difficult rehabilitation after ACL reconstruction. These 2 factors were strongly correlated. Full preoperative ROM does not guarantee a smooth postoperative recovery when typical contusions of the lateral compartment are present, especially if surgery is performed rapidly after ACL rupture. A correlation between bone bruises, delayed ROM recovery, and incidence of arthrolysis was demonstrated.

ACKNOWLEDGMENT

The authors acknowledge Olivier Rachet and Frédéric Lavoie for their kind contribution in preparing the manuscript.

REFERENCES

1. Aglietti P, Buzzi R, D'Andria S, Zaccherotti G. Long-term study of anterior cruciate ligament reconstruction for chronic instability using the central one-third patellar tendon and a lateral extraarticular tenodesis. *Am J Sports Med*. 1992;20(1):38-45.

2. Allum R. Complications of arthroscopic reconstruction of the anterior cruciate ligament. *J Bone Joint Surg Br*. 2003;85(1):12-16.
3. Almekinders LC, Moore T, Freedman D, Taft TN. Post-operative problems following anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 1995;3(2):78-82.
4. Atkinson PJ, Cooper TG, Anseth S, Walter NE, Kargus R, Haut RC. Association of knee bone bruise frequency with time post injury and type of soft tissue injury. *Orthopedics*. 2008;31(5):440.
5. Bretlau T, Tuxoe J, Larsen L, Jorgensen U, Thomsen HS, Lausten GS. Bone bruise in the acutely injured knee. *Knee Surg Sports Traumatol Arthrosc*. 2002;10(2):96-101.
6. Cosgarea AJ, Sebastianelli WJ, DeHaven KE. Prevention of arthrofibrosis after anterior cruciate ligament reconstruction using the central third patellar tendon autograft. *Am J Sports Med*. 1995;23(1):87-92.
7. Davies NH, Niall D, King LJ, Lavelle J, Healy JC. Magnetic resonance imaging of bone bruising in the acutely injured knee: short-term outcome. *Clin Radiol*. 2004;59(5):439-445.
8. DeCarlo MS, Sell KE. Normative data for range of motion and single-leg hop in high school athletes. *J Sport Rehabil*. 1997;6(3):246-255.
9. Garofalo R, Mouhsine E, Chambat P, Siegrist O. Anatomic anterior cruciate ligament reconstruction: The two incision technique. *Knee Surg Sports Traumatol Arthrosc*. 2006;14:510-516.
10. Graf BK, Cook DA, De Smet AA, Keene JS: ''Bone bruise'' on magnetic resonance imaging evaluation of anterior cruciate ligament injuries. *Am J Sports Med*. 1993;21(2):220-223.
11. Graf BK, Ott JW, Lange RH, Keene JS. Risk factors for restricted motion after anterior cruciate reconstruction. *Orthopedics*. 1994;17(10):909-912.
12. Harner CD, Irrgang JJ, Paul J, Dearwater S, Fu FH. Loss of motion after anterior cruciate ligament reconstruction. *Am J Sports Med*. 1992;20(5):499-506.
13. Johnson DL, Bealle DP, Brand JC Jr, Nyland J, Caborn DN. The effect of a geographic lateral bone bruise on knee inflammation after acute anterior cruciate ligament rupture. *Am J Sports Med*. 2000;28(2):152-155.
14. Lahm A, Erggelet C, Steinwachs M, Reichelt A. Articular and osseous lesions in recent ligament tears: arthroscopic changes compared with magnetic resonance imaging findings. *Arthroscopy*. 1998;14(6):597-604.
15. Marcacci M, Zaffagnini S, Iacono F, Neri MP, Petitto A. Early versus late reconstruction for anterior cruciate ligament rupture. *Am J Sports Med*. 1995;23(6):690-693.
16. Mauro SC, Irrgang JJ, Williams BA, Harner CD. Loss of extension following anterior cruciate ligament reconstruction: analysis of incidence and etiology using IKDC Criteria. *Arthroscopy*. 2008;24(2):146-153.
17. Mayr HO, Weig TG, Plitz W. Arthrofibrosis following ACL reconstruction: reasons and outcome. *Arch Orthop Trauma Surg*. 2004;124(8):518-522.
18. Miller MD, Osborne JR, Gordon WT, Hinkin DT, Brinker MR. The natural history of bone bruises: a prospective study of magnetic resonance imaging-detected trabecular microfractures in patients with isolated medial collateral ligament injuries. *Am J Sports Med*. 1998;26(1):15-19.
19. Mink JH, Deutsch AL. Occult cartilage and bone injuries of the knee: detection, classification and assesssment with MR imaging. *Radiology*. 1989;170:823-829.
20. Mohtadi NG, Webster-Bogaert S, Fowler PJ. Limitation of motion following anterior cruciate ligament reconstruction: a case-control study. *Am J Sports Med*. 1991;19(6):620-625.
21. Noyes FR, Berrios-Torres S, Barber-Westin SD, Heckmann TP. Prevention of permanent arthrofibrosis after anterior cruciate ligament reconstruction alone or combined with associated procedures: a prospective study in 443 knees. *Knee Surg Sports Traumatol Arthrosc*. 2000;8(4):196-206.
22. Rangger C, Kathrein A, Freund MC, Klestil T, Kreczy A. Bone bruise of the knee: histology and cryosections in 5 cases. *Acta Orthop Scand*. 1998;69(3):291-294.
23. Shelbourne KD, Gray T. Anterior cruciate ligament reconstruction with autogenous patellar tendon graft followed by accelerated rehabilitation: a two- to nine-years followup. *Am J Sports Med*. 1997;25(6):786-795.
24. Shelbourne KD, Wilckens JH, Mollabashy A, DeCarlo M. Arthrofibrosis in acute anterior cruciate ligament reconstruction and rehabilitation. *Am J Sports Med*. 1991;19(4):332-336.
25. Speer KP, Spritzer CE, Bassett FH 3rd, Feagin JA Jr, Garrett WE Jr. Osseous injury associated with acute tears of the anterior cruciate ligament. *Am J Sports Med*. 1992;20(4):382-389.
26. Speer KP, Warren RF, Wickiewicz TL, Horowitz TL, Henderson L. Observations on the injury mechanism of anterior cruciate ligament tears in skiers. *Am J Sports Med*. 1995;23(1):77-81.
27. Spindler KP, Schils JP, Bergfeld JA, et al. Prospective study of osseous, articular and meniscal lesions in recent anterior cruciate ligament tears by magnetic resonance imaging and arthroscopy. *Am J Sports Med*. 1993;21(4):551-557.
28. Sterett WI, Hutton KS, Briggs KK, Steadman JR. Decreased range of motion following acute versus chronic ACL reconstruction. *Orthopedics*. 2003;26(2):151-154.
29. Vincken PW, Ter Braak BP, Van Erkel AR, Coerkamp EG, Mallens WM, Bloem JL. Clinical consequences of bone bruise around the knee. *Eur Radiol*. 2006;16(1):97-107.
30. Wasilewski SA, Covall DJ, Cohen S. Effect of surgical timing on recovery and associated injuries after cruciate ligament reconstruction. *Am J Sports Med*. 1993;21(3):338-342.