Anterior cruciate ligament deterioration correlates with patella osteoarthritis

Takanori Iriuchishima · Keinosuke Ryu · Shin Aizawa · Hiroshi Yorifuji · Tetsuji Ohyama · Freddie H. Fu

Received: 20 August 2013 / Accepted: 22 September 2013 / Published online: 17 October 2013
© Springer-Verlag Berlin Heidelberg 2013

Abstract

Purpose The correlation between anterior cruciate ligament (ACL) condition and patella osteoarthritic (OA) changes has not been well reported. The aim of this study was to reveal the correlation between ACL deterioration and the morphology of OA changes in the patella. The hypothesis was that significant correlation between ACL deterioration and patella OA morphology would be revealed in this study.

Methods Two hundred ninety-one cadaveric knees from 151 cadavers were included in this study with a median age of 83 years (54–98). Knees were opened with a sub-vastus approach and the ACL condition was classified as intact or deteriorated. Patella OA lesions were classified using Han's method: type 1, no or minimal lesion; type 2, medial facet lesion without involvement of the ridge; type 3, lateral facet

lesion without involvement of the ridge; type 4, lesion involving the ridge only; type 5, medial facet lesion with involvement of the ridge; type 6, lateral facet lesion with involvement of the ridge; and type 7, global lesion. OA depth evaluation was performed following Outerbridge's classification. Statistical analysis of the collected data was performed using generalized estimating equations (GEE).

Results The ACL was intact in 277 knees and deteriorated in 14 knees. Patella OA lesions were observed as follows: type 1, 29 %; type 2, 15 %; type 3, 2 %; type 4, 12 %; type 5, 18 %; type 6, 2 %; and type 7, 22 %. Outerbridge's classification of over grade 2 OA depth was observed in 73.5 % of subjects. When patella OA was divided into types 1–4 and types 5–7, ACL deterioration was correlated with the occurrence of type 5–7 patella OA [OR 6.44, 95%CI 2.27–18.25, $p=0.000$]. When patella OA was divided into types 1–6 and type 7, ACL deterioration was correlated with the occurrence of type 7 patella OA [OR 6.02, 95%CI 2.57–14.09, $p=0.000$]. When patella OA depth was divided into grades 1–3 and grade 4, ACL deterioration was highly correlated with the occurrence of grade 4 patella OA [OR 9.31, 95%CI 2.96–29.33, $p=0.025$].

Conclusion ACL deterioration is a strong risk factor of wider and deeper OA changes in the patella. For clinical relevance, subjects with ACL tear should be aware of the progression of patella OA.

T. Iriuchishima (✉)
Department of Orthopaedic Surgery, Kamimoku Hotsprings
Hospital, Ishikura, 198-2, Minakami-city, Gunma, Japan
e-mail: sekaiwoseisu@yahoo.co.jp

K. Ryu
Department of Orthopaedic Surgery, Surugadai Nihon University
Hospital, Tokyo, Japan

S. Aizawa
Department of Functional Morphology, Nihon University School of
Medicine, Tokyo, Japan

H. Yorifuji
Department of Anatomy, Gunma University Graduate School of
Medicine, Maebashi, Gunma, Japan

T. Ohyama
Department of Biostatistics, Faculty of Medicine, Oita University,
Yufu, Oita, Japan

F. H. Fu
Department of Orthopaedic Surgery, University of Pittsburgh,
Pittsburgh, PA, USA

Keywords Osteoarthritis · Patella · Anterior cruciate ligament · Knee

Abbreviation

ACL Anterior cruciate ligament
OA Osteoarthritis
PF Patello-femoral

Introduction

It is believed that anterior cruciate ligament (ACL) dysfunction can be a cause of patello-femoral (PF) osteoarthritic (OA) changes [1–4]. PF-OA is one of the most severe causes of knee pain in the elderly population [5–7]. Once PF-OA occurs, patients develop anterior knee pain and sometimes have difficulty using stairs or bending the knees at deep flexion angles [5, 6, 8]. Several reports have revealed that PF-OA progresses after an ACL tear. The reported prevalence of PF-OA progression after ACL tear is 13–28 % [9–12]. Even after ACL reconstruction, PF-OA progression has been reported in short to mid-term follow-up periods [10, 11]. However, many reports of PF-OA after ACL tear or reconstruction include follow-up data of less than 20 years [10–18], and the evaluation of PF-OA in elderly subjects without ACL function has not been well investigated. Moreover, although tibio-femoral OA changes have been well described in previous reports [19–22], reports on the morphology of PF-OA are rare [5, 6, 23]. In particular, structural changes in the patella have not been well reported [5].

The objective of this study was to reveal the correlation between ACL condition and the morphology of OA changes in the patella. The hypothesis was that significant correlation between ACL deterioration and patella OA morphology would be revealed in this study.

Materials and methods

Two hundred ninety-one knees from 151 cadavers of the Japanese population were evaluated in this study (formalin fixed, anatomical specimens). The median age was 83 years (range, 54–98). Of the 291 knees, 148 were female, and 143 were male. Knees were opened with a subvastus approach.

Evaluation of ACL condition

With careful dissection, synovial tissue around the ACL was resected. To evaluate the ACL condition macroscopically, knees were deeply flexed and the tension was evaluated with a steel probe. The antero-medial (AM) and postero-lateral (PL) bundles were divided according to their difference in tension patterns during knee range of motion, and their insertion sites were identified. With the knee at 90° of flexion, the taut ACL fibers were regarded as the AM bundle, and the relaxed fibers were regarded as the PL bundle. ACL condition was classified as (1) intact, (2) partial tear or deterioration of the AM bundle, (3) partial tear or deterioration of the PL bundle, and (4) complete tear or deterioration.

Evaluation of patella OA lesions and depth

The patellar cartilage was assessed by the location and depth of OA lesions. The location of the OA lesion was classified according to the involvement of the medial facet, lateral facet, and the central ridge, previously reported by Han et al. [5, 6, 24]. This classification contains seven types of lesions:

- Type 1, no or minimal lesion
- Type 2, medial facet lesion without involvement of the ridge
- Type 3, lateral facet lesion without involvement of the ridge
- Type 4, lesion involving the ridge only
- Type 5, medial facet lesion with involvement of the ridge
- Type 6, lateral facet lesion with involvement of the ridge
- Type 7, global lesion

In this classification, Types 1–4 can be considered as isolated OA lesions of the medial, ridge, or the lateral facet in the patella. Types 5 and 6 can be considered as combined OA lesions of two facets in the patella, and type 7 is global OA lesion.

Depth was determined using Outerbridge's classification [25]. Grading was as follows:

- Grade 1, normal cartilage or softening and swelling of the cartilage
- Grade 2, partial-thickness defect which did not reach the subchondral bone and was less than 1.3 cm in diameter
- Grade 3, partial-thickness defect which did not reach the subchondral bone and was more than 1.3 cm in diameter
- Grade 4, exposed subchondral bone and visible reactive tissue formation

When there were multiple lesions of different Outerbridge's classification grades, the sizes of the lesions were added up. Lesions with degenerative changes more severe than Outerbridge's classification grade 2 were regarded as OA lesions.

Statistical analysis

Generalized estimating equations (GEE) were performed to reveal the correlation between ACL condition and patella OA type, and ACL condition and patella OA depth. Collected data were analysed using SPSS for Windows, version 19.0 (SPSS Inc., Chicago, IL, USA) software. Values were considered significantly different at $p < 0.05$.

Results

ACL condition

The ACL was intact in 277 knees and completely deteriorated in 14 knees. No partial tears of the ACL were observed in this study.

Patella OA lesion and depth

OA lesions (Table 1) were observed as follows: type 1, 83 knees (29 %); type 2, 45 knees (15 %); type 3, 7 knees (2 %); type 4, 34 knees (12 %); type 5, 51 knees (18 %); type 6, 7 knees (2 %); type 7, 64 knees (22 %).

The depth of OA was observed as follows: grade 1, 77 knees (26 %); grade 2, 28 knees (10 %); grade 3, 58 knees (20 %); grade 4, 128 knees (44 %). Outerbridge's classification of over grade 2 was observed in 74 % of all subjects. When categorizing lesions found at the medial or lateral side of the patella, OA lesions, except for Type 1 OA, were found predominantly at the medial side.

Correlation of ACL condition and patella OA

When patella OA was divided into types 1–4 (isolated OA lesions) and types 5–7 (two facet OA and global lesions), ACL deterioration was significantly correlated with the occurrence of type 5–7 patella OA [odds ratio (OR) 6.55, 95 % confidence interval (CI) 2.27–18.25, $p=0.000$] (Table 2). When patella OA was divided into types 1–6 (two OA lesions of two facets or less) and type 7 (global lesions), ACL deterioration was significantly correlated with the occurrence of type 7 patella OA [OR 6.02, 95%CI 2.57–14.09, $p=0.000$] (Table 3).

When patella OA depth was divided into grades 1–2 and grades 3–4, ACL deterioration was correlated with the occurrence of grade 3–4 patella OA depth [OR 2.49, 95%CI 1.08–5.74, $p=0.033$] (Table 4). When patella OA depth was divided into grades 1–3 and grade 4, ACL deterioration was highly correlated with the occurrence of grade 4 patella OA depth [OR 9.31, 95%CI 2.96–29.33, $p=0.025$] (Table 5).

Table 1 Correlation between OA lesions in the patella and ACL condition

Side	ACL	OA type						
		1	2	3	4	5	6	7
Left knee	Rupture	0	0	0	1	0	1	5
	Intact	40	20	4	4	15	25	3
Right knee	Rupture	0	0	0	0	0	0	7
	Intact	43	25	3	18	26	3	23

ACL anterior cruciate ligament, OA osteoarthritis

OA lesions in the patella were evaluated using Han's method: type 1, no or minimal lesion; type 2, medial facet lesion without involvement of the ridge; type 3, lateral facet lesion without involvement of the ridge; type 4, lesion involving the ridge only; type 5, medial facet lesion with involvement of the ridge; type 6, lateral facet lesion with involvement of the ridge; type 7, global lesion

Table 2 Correlation between ACL condition and the occurrence of patella OA lesions of two or more facets

ACL condition	Left knee		Right knee	
	1–4	5–7	1–4	5–7
OA type	1–4	5–7	1–4	5–7
Rupture ^a	1	6	0	7
Intact	79	57	89	52

ACL anterior cruciate ligament, OA osteoarthritis, OR odds ratio, CI confidential interval

When patella OA were divided into types 1–4 (isolated OA lesions) and types 5–7 (two facet OA and global lesions), ACL deterioration was significantly correlated with the occurrence of type 5–7 patella OA

^aOR 6.44, 95%CI 2.27–18.25, $p=0.000$

Discussion

The most important finding of this study was that ACL deterioration was significantly correlated with the occurrence of wider and deeper OA lesions of the patella. In this study, the risk of global patella OA was more than six times greater in knees with ACL deterioration when compared to knees with intact ACL, and the risk of Outerbridge's grade 4 OA in the patella was more than nine times greater in knees with ACL deterioration.

In this study, femoral side OA evaluation was not included. This is because femoral side OA in the PF joint is strongly influenced by tibio-femoral OA [26, 27]. To eliminate the bias of other factors, only patella OA lesions were evaluated in this study. Although the data was not included, all knees with ACL deterioration had global and Outerbridge grade 4 OA on the femoral side in the PF joint. Although significant correlation between patella side and femoral side OA lesions and depth has been reported previously in studies using the same OA evaluation method [6, 22, 28], further research including femoral side OA evaluation with statistical analysis is needed in future studies.

ACL dysfunction is considered to be one of the major risk factors of knee OA [1, 9, 14, 15, 17, 18, 29, 30]. When the

Table 3 Correlation of ACL condition and the occurrence of global patella OA lesions

ACL condition	Left knee		Right knee	
	1–6	7	1–6	7
OA type	1–6	7	1–6	7
Rupture ^a	2	5	0	7
Intact	107	29	118	23

ACL anterior cruciate ligament, OA osteoarthritis, OR odds ratio, CI confidential interval

When patella OA was divided into types 1–6 (OA lesions of two facets or less) and type 7 (global lesions), ACL deterioration was significantly correlated with the occurrence of type 7 patella OA

^aOR 6.02, 95%CL 2.57–14.09, $p=0.000$

Table 4 Correlation of ACL condition and the occurrence of patella OA more severe than grade 3

ACL condition	Left knee		Right knee	
	1–2	3–4	1–2	3–4
OA grade	1–2	3–4	1–2	3–4
Rupture ^a	1	6	0	7
Intact	52	84	52	89

ACL anterior cruciate ligament, OA osteoarthritis, OR odds ratio, CI confidential interval

When patella OA depth was divided into grades 1–2 and grades 3–4, ACL deterioration was significantly correlated with the occurrence of grade 3–4 patella OA

^aOR 2.49, 95%CI 1.08–5.74, $p=0.033$

ACL is injured, not only tibio-femoral OA, but also PF-OA progression is seen in long-term follow up [11, 23, 30]. In a recent systematic review, OA progression was reported in more than 50 % of subjects with ACL tears in a ten to 20 year follow up [9]. One possible cause of knee OA progression after ACL injury is the change in knee kinematics [3, 31–34]. Neuman et al. [10] reported on the prevalence of PF-OA 15 years after ACL injury. In their report, 16 % of subjects with ACL tears exhibited PF-OA progression. Although injury and deterioration of the ACL are different, the pathophysiology of PF-OA in knees without ACL function, especially in the terminal phase of life, has not been well documented. In this study, 13 of the 14 knees with ACL deterioration had severe patella OA. A significantly higher prevalence of deep and wide PF-OA was observed in knees without ACL function than in knees with intact ACL.

Several studies have tried to reveal the correlation between ACL condition and PF kinematics [3, 31–34]. Hsieh et al. [3] reported that excision of the ACL resulted in a significant increase in lateral patella tilt and lateral patella shift. They mentioned that abnormal patella kinematics after removal of the ACL resulted from changes in the kinematics of the tibio-femoral joint. Hsieh et al. [31] also evaluated the PF contact area and pressure before and after ACL excision. After ACL

excision, the PF contact area significantly decreased, and medial PF contact pressure also decreased at 30° of knee flexion. Shin et al. [32] reported on the in vivo kinematics of PF, and the contact area in ACL intact, ACL deficient, and reconstructed knees using magnetic resonance image based 3-dimensional PF knee models. They revealed that the patella tilt was altered, and that the patella shifted laterally due to ACL injury. In their study, ACL injuries reduced the PF contact area at both extended and flexed knee positions. Van de Velde et al. [34] suggested that the elongation of the patella tendon after ACL injury could be a cause of abnormal PF kinematics. Recently, Tajima et al. [33] reported the pressure difference in the PF joint before and after ACL reconstruction. In their study, ACL deficiency resulted in a significant decrease in the total and medial PF contact areas and in an increase in lateral PF contact pressure. Regarding the increase or decrease in contact pressure associated with ACL dysfunction, it is still unknown which of the two has a more negative impact on the progression of PF-OA. However, it is certain that the change of contact pressure and contact area induces abnormal pressure distribution in the PF joint, which is likely to result in PF-OA progression. Moreover, the change in PF kinematics after ACL injury might be influenced by the antero-posterior and rotational stability in the tibio-femoral joint [9]. Instability of the tibio-femoral joint after ACL injury might alter PF kinematics and could be a cause of PF-OA [33]. The above biomechanical studies are challenging and useful in revealing the pathophysiology of PF-OA and ACL dysfunction. However, most of these studies are time zero studies, which cannot reveal the long-term effects of abnormal PF kinematics and the occurrence of PF-OA. To evaluate the long-term effects of ACL dysfunction and the progression of PF-OA, a relatively large sample size of cadaveric knees was used in this study. Most of the knees with ACL deterioration in our study had global OA lesions with severe OA depth in the patella. Consistent knee instability due to ACL deterioration and resultant abnormal PF kinematics might be a cause of this condition.

The were limitations to this study. First, ACL condition, location and depth of OA were determined by macroscopic evaluation only. Although, the evaluation was performed by the well trained orthopaedic surgeons, and the same OA evaluation method has been previously reported [5, 6, 22, 26], histological or radiographic evaluation should be performed in future studies. Second, only Japanese subjects were included in this study. Knee morphology and the incidence of OA might be influenced by differences in ethnicity [2, 20], and therefore, knees of other ethnic groups should be evaluated in future studies. Third, only patella side OA was evaluated in this study. Because femoral side OA is strongly influenced by tibio-femoral OA [1, 21], only patella OA was evaluated in this study in order to eliminate potential bias.

Table 5 Correlation of ACL condition and the occurrence of grade 4 patella OA

ACL condition	Left knee		Right knee	
	1–3	4	1–3	4
OA grade	1–3	4	1–3	4
Rupture ^a	2	5	1	6
Intact	81	55	79	62

ACL anterior cruciate ligament, OA osteoarthritis, OR odds ratio, CI confidential interval

When patella OA depth was divided into grades 1–3 and grade 4, ACL deterioration was highly correlated with the occurrence of grade 4 patella OA

^aOR 9.31, 95%CL 2.96–29.33, $p=0.025$

For clinical relevance, ACL deterioration is strongly correlated with the prevalence of wider and deeper patella OA. This data is useful for the prevention of knee OA progression after ACL injury, and for the selection of knee surgery.

Conclusion

ACL deterioration is a strong risk factor of wider and deeper OA changes in the patella. Physicians should be aware of this when they treat subjects with ACL dysfunction in order to prevent the progression of patella OA and PF-OA.

References

- Delince P, Ghafil D (2012) Anterior cruciate ligament tears: conservative or surgical treatment? A critical review of the literature. *Knee Surg Sports Traumatol Arthrosc* 20:48–61
- Hashikawa T, Osaki M, Ye Z et al (2011) Factors associated with radiographic osteoarthritis of the knee among community-dwelling Japanese women: the Hizen-Oshima study. *J Orthop Sci* 16:51–55
- Hsieh YF, Draganich LF, Ho SH, Reider B (1998) The effects of removal and reconstruction of the anterior cruciate ligament on patellofemoral kinematics. *Am J Sports Med* 26:201–209
- Louboutin H, Debarge R, Richou J, Selmi TA, Donell ST, Neyret P, Dubrana F (2009) Osteoarthritis in patients with anterior cruciate ligament rupture: a review of risk factors. *Knee* 16:239–244
- Iriuchishima T, Ryu K, Aizawa S, Yorifuji H, Shirakura K (2012) Evaluation of the prevalence, lesion, and depth of osteoarthritic changes in the patella. *Knee Surg Sports Traumatol Arthrosc* 20:2460–2464
- Iriuchishima T, Ryu K, Aizawa S, Yorifuji H (2012) Cadaveric assessment of osteoarthritic changes in the patello-femoral joint: evaluation of 203 knees. *Knee Surg Sports Traumatol Arthrosc* 21:2172–2176
- van Jonbergen HP, Poolman RW, van Kampen A (2010) Isolated patellofemoral osteoarthritis. *Acta Orthop* 81:199–205
- Kalichman L, Zhang Y, Niu J et al (2007) The association between patellar alignment and patellofemoral joint osteoarthritis features-an MRI study. *Rheumatology (Oxford)* 46:1303–1308
- Lohmander LS, Englund PM, Dahl LL, Roos EM (2007) The long-term consequence of anterior cruciate ligament and meniscus injuries. *Am J Sports Med* 35:1756–1769
- Neuman P, Kostogiannis I, Friden T, Roos H, Dahlberg LE, Englund M (2009) Patellofemoral osteoarthritis 15 years after anterior cruciate ligament injury-a prospective cohort study. *Osteoarthr Cartil* 17:284–290
- Øiestad BE, Holm I, Engebretsen L, Aune AK, Gunderson R, Risberg MA (2012) The prevalence of patellofemoral osteoarthritis 12 years after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc* 21:942–949
- Øiestad BE, Holm I, Engebretsen L, Risberg MA (2011) The association between radiographic knee osteoarthritis and knee symptoms, function and quality of life 10–15 years after anterior cruciate ligament reconstruction. *Br J Sports Med* 45:583–588
- Andersson D, Samuelsson K, Karlsson J (2009) Treatment of anterior cruciate ligament injuries with special reference to surgical technique and rehabilitation: an assessment of randomized controlled trials. *Arthroscopy* 25:653–685
- Frobell RB, Roos EM, Roos HP, Ranstam JR, Lohmander LS (2010) A randomized trial of treatment for acute anterior cruciate ligament tears. *N Engl J Med* 363:331–342
- Mihelic R, Jurdana H, Jotanovic Z, Madjarevic T, Tudor A (2011) Long-term results of anterior cruciate ligament reconstruction: a comparison with non-operative treatment with a follow-up of 17–20 years. *Int Orthop* 35:1093–1097
- Murrell GC, Maddali S, Horovitz L, Oakley SP, Warren RF (2009) The effects of time course after anterior cruciate ligament injury in correlation with meniscal and cartilage loss. *Am J Sports Med* 29:9–14
- Øiestad BE, Engebretsen L, Storheim K, Risberg MA (2009) Knee osteoarthritis after anterior cruciate ligament injury: a systematic review. *Am J Sports Med* 37:1434–1443
- Streich NA, Zimmermann D, Bode G, Schmitt H (2011) Reconstructive versus non-reconstructive treatment of anterior cruciate ligament insufficiency. A retrospective matched-pair long-term follow-up. *Int Orthop* 35:607–613
- Muraki S, Oka H, Akune T et al (2009) Prevalence of radiographic knee osteoarthritis and its association with knee pain in the elderly of Japanese population-based cohorts: the ROAD study. *Osteoarthr Cartil* 17:1137–1143
- Nagamine R, Miyanishi K, Miura H, Urabe K, Matsuda S, Iwamoto Y (2003) Medial torsion of the tibia in Japanese patients with osteoarthritis of the knee. *Clin Orthop Relat Res* 408:218–224
- Tanamas S, Hanna FS, Cicuttini FM, Wluka AE, Berry P, Urquhart DM (2009) Does knee malalignment increase the risk of development and progression of knee osteoarthritis? A systematic review. *Arthritis Rheum* 61:459–467
- Yamada K, Healey R, Amiel D, Lotz M, Coutts R (2002) Subchondral bone of human knee joint in aging and osteoarthritis. *Osteoarthr Cartil* 10:360–369
- Li RT, Lorentz S, Xu Y, Harner CD, Fu FH, Irrgang JJ (2011) Predictors of radiographic knee osteoarthritis after anterior cruciate ligament reconstruction. *Am J Sports Med* 39:2595–2603
- Han I, Chang CB, Lee S, Lee MC, Seong SC, Kim TK (2005) Correlation of the condition of the patellar articular cartilage and patellofemoral symptoms and function in osteoarthritic patients undergoing total knee arthroplasty. *J Bone Joint Surg [Br]* 87B:1081–1084
- Outerbridge RE (1961) The etiology of chondromalacia patellae. *J Bone Joint Surg [Br]* 43-B:752–757
- Elahi S, Cahue S, Felson DT, Enghman L, Sharma L (2000) The association between varus-valgus alignment and patellofemoral osteoarthritis. *Arthritis Rheum* 43:1874–1880
- Tecklenburg K, Dejour D, Hoser C, Fink C (2006) Bony and cartilaginous anatomy of the patellofemoral joint. *Knee Surg Sports Traumatol Arthrosc* 14:235–240
- Chang CB, Seong SC, Kim TK (2008) Evaluations of radiographic joint space-do they adequately predict cartilage conditions in the patellofemoral joint of the patients undergoing total knee arthroplasty for advanced knee osteoarthritis? *Osteoarthr Cartil* 16:1160–1166
- Keays SL, Newcombe PA, Bullock-Saxton JE, Bullock MI, Keays AC (2010) Factors involved in the development of osteoarthritis after anterior cruciate ligament surgery. *Am J Sports Med* 38:455–463
- Lohmander LS, Ostberg A, Englund M, Roos H (2004) High prevalence of knee osteoarthritis, pain, and functional limitations in female soccer players twelve years after anterior cruciate ligament injury. *Arthritis Rheum* 50:3145–3152
- Hsieh YF, Draganich LF, Ho SH, Reider B (2002) The effects of removal and reconstruction of the anterior cruciate ligament on the contact characteristics of the patellofemoral joint. *Am J Sports Med* 30:121–127
- Shin CS, Carpenter RD, Majumder S, Ma CB (2009) Three-dimensional in vivo patellofemoral kinematics and contact area

- of anterior cruciate ligament-deficient and -reconstructed subjects using magnetic resonance imaging. *Arthroscopy* 25: 1214–1223
33. Tajima G, Iriuchishima T, Ingham SJ et al (2010) Anatomic double-bundle anterior cruciate ligament reconstruction restores patellofemoral contact areas and pressures more closely than nonanatomic single-bundle reconstruction. *Arthroscopy* 26:1302–1310
34. Van de Velde SK, Gill TJ, DeFrate LE, Papannagari R, Li G (2008) The effect of anterior cruciate ligament deficiency and reconstruction on the patellofemoral joint. *Am J Sports Med* 36:1150–1159