RBO REVISTA BRASILEIRA DE ORTOPEDIA
www.rbo.org.br

Original article

Femoropatellar radiographic alterations in cases of anterior cruciate ligament failure☆

Diego Protásio de Vasconcelos[a,*], *Alan de Paula Mozella*[b], *Pedro Guilme Teixeira de Sousa Filho*[b], *Gustavo Cardilo Oliveira*[b], *Hugo Alexandre de Araújo Barros Cobra*[b]

[a] *Orthopedics and Traumatology Service, University Hospital, Federal University of Sergipe, Aracaju, SE, Brazil*
[b] *Knee Surgery Center, National Institute of Traumatology and Orthopedics (INTO), Rio de Janeiro, RJ, Brazil*

ARTICLE INFO

Article history:
Received 8 September 2013
Accepted 17 October 2013
Available online 31 January 2015

Keywords:
Joint instability
Anterior cruciate ligament
Patellofemoral joint

ABSTRACT

Objective: To make a comparative analysis on three femoropatellar radiographic parameters, between knees with chronic failure of the anterior cruciate ligament (ACL) and normal knees.
Methods: Thirty volunteer patients with a diagnosis of unilateral isolated chronic ACL injury for more than one year and a normal contralateral knee were selected. Digital radiographs were produced for all the patients, on both knees in absolute lateral view at 30° of flexion, with and without load-bearing on one leg, and in axial view of the patella at 30°. The Caton–Deschamps patellar height index, Merchant patellar congruence angle and Laurin lateral patellar tilt angle were measured on the radiographs obtained from the normal knees and knees with ACL injuries, and comparative analysis was performed between these two groups.
Results: The patellar height was statistically significantly lower ($p < 0.001$) in the knees with ACL failure than in the normal knees, both on radiographs without loading and on those with single-foot loading. The Merchant patellar congruence angle was significantly smaller ($p < 0.001$) in the normal knees and the lateral patellar tilt angle was smaller ($p < 0.001$) in the knees with ACL failure.
Conclusion: Chronic ACL failure gave rise to a statistically significant change in the femoropatellar radiographic values studied ($p < 0.001$). Knees with injuries to this ligament presented lower patellar height values, greater tilt and lateral displacement of the patella, in relation to the femoral trochlea, in comparison with the normal contralateral knees.

© 2015 Sociedade Brasileira de Ortopedia e Traumatologia. Published by Elsevier Editora Ltda. All rights reserved.

☆ Work developed at the Knee Surgery Center of the National Institute of Traumatology and Orthopedics (INTO), Rio de Janeiro, RJ, Brazil.

* *Corresponding author.*
E-mail: diegoprotasio@yahoo.com.br (D.P. de Vasconcelos).

http://dx.doi.org/10.1016/j.rboe.2015.01.005

2255-4971/© 2015 Sociedade Brasileira de Ortopedia e Traumatologia. Published by Elsevier Editora Ltda. All rights reserved.

Alterações radiográficas femoropatelares na insuficiência do ligamento cruzado anterior

Palavras-chave:
Instabilidade articular
Ligamento cruzado anterior
Articulação patelofemoral

RESUMO

Objetivo: Análise comparativa de três parâmetros radiográficos femoropatelares entre joelhos com insuficiência crônica do ligamento cruzado anterior (LCA) e joelhos normais.
Métodos: Foram selecionados 30 pacientes voluntários com diagnóstico de lesão crônica isolada unilateral do LCA havia mais de um ano e joelho contralateral normal. Todos os pacientes foram submetidos a radiografias digitais de ambos os joelhos nas incidências em perfil absoluto a 30° de flexão, com e sem carga monopodal, e axial de patela a 30°. Foram mensurados, nas radiografias obtidas, o índice de altura patelar de Caton-Deschamps, o ângulo de congruência patelar de Merchant e o ângulo de inclinação lateral da patela, descrito por Laurin, nos joelhos normais e nos joelhos com lesão do LCA e foi feita análise comparativa entre esses dois grupos.
Resultados: A altura patelar foi inferior, de forma estatisticamente significante ($p < 0{,}001$), nos joelhos com insuficiência do LCA em comparação com os joelhos normais, tanto nas radiografias sem carga quanto nas com carga monopodal. O ângulo de congruência patelar de Merchant foi significativamente menor ($p < 0{,}001$) nos joelhos normais e o ângulo de inclinação lateral da patela foi inferior ($p < 0{,}001$) nos joelhos com insuficiência do LCA.
Conclusão: A insuficiência crônica do LCA alterou de forma estatisticamente significante ($p < 0{,}001$) os valores dos parâmetros radiográficos femoropatelares estudados. Joelhos com lesão desse ligamento apresentaram menores valores de altura patelar, maior inclinação e deslocamento laterais da patela em relação à tróclea femoral comparados com os joelhos contralaterais normais.
© 2015 Sociedade Brasileira de Ortopedia e Traumatologia. Publicado por Elsevier Editora Ltda. Todos os direitos reservados.

Introduction

Anterior cruciate ligament (ACL) injuries are among the commonest knee injuries, with growing incidence due to the increasingly large number of individuals involved in sports activities.[1] Failure of this ligament causes anterior and rotational instability of the knee, characterized by recurrent episodes of anterior and rotational (*i.e.* internal rotational) subluxation of the tibia over the femur.[2] These episodes may cause functional losses and limit sports practices and certain activities of daily living.[3]

Significant biomechanical and kinematic alterations have been recognized over recent decades, in knees with ACL failure. Laboratory studies on gait analysis have shown that knees with ACL injuries present greater internal rotation,[4] less external rotation[5] and increased medial translation of the tibia over the femur,[6] in comparison with normal knees, during the stance and swing phases of gait. Several authors[7–10] have stated that ACL failure gives rise to loss of tibiofemoral kinematic balance and causes abnormal biomechanical behavior, which puts the knee at risk of secondary injuries.

Despite the large number of studies that have examined the effects of ACL injuries on tibiofemoral kinematics, few have analyzed femoropatellar alterations in patients with failure of this ligament.[9] Baugher et al.[11] demonstrated that patients with ACL failure presented irreversible atrophy of the quadriceps muscle and warned of the possible consequences of this for the patellofemoral joint.

According to Hsieh et al.,[12,13] alterations to tibiofemoral kinematics that result from ACL injuries affect the kinematics of the patellofemoral joint and cause imbalance of the extensor mechanism and abnormal distribution of forces between the patella and the femoral trochlea. These authors[12,13] showed that there were increases in lateral translation and lateral inclination of the patella in relation to the femur, after resection of the ACL in the knees of cadavers. *In vivo*, Van de Velde et al.[14] demonstrated that ACL failure alters the contact area and femoropatellar tracking.

Femoropatellar radiographic parameters may aid in diagnosing alterations of the patellofemoral joint. In the present study, we made a comparative analysis on three femoropatellar radiographic parameters that are commonly used in clinical practice, with the aim of detecting differences in these parameters between knees with chronic ACL failure and normal knees.

Methods

After approval for this study had been obtained from our institution's Research Ethics Committee, 30 volunteer patients (17 males and 13 females) who were attended at the Knee Surgery Center of this institution were selected. All of them presented a diagnosis of ACL injury alone, which had occurred in one knee (while the contralateral knee remained normal) more than 12 months earlier, and they fulfilled the inclusion and exclusion criteria of the sample (Table 1). The subjects' mean age was 28 years, with a range from 17 to 46, and the mean

Table 1 – Inclusion and exclusion criteria of the sample.

Inclusion criteria

1. Skeletally mature individuals under the age of 60 years
2. Diagnosis of single unilateral ACL injury that had occurred more than 12 months earlier
   2.1. Anterior translation of the tibia over the femur greater than 5 mm, without an endpoint in relation to the contralateral knee, using KT-1000.
   2.2. Lachman, Anterior Drawer and Pivot-Shift tests positive
   2.3. Other ligament and meniscus tests negative
   2.4. Magnetic resonance imaging (MRI) showing single ACL injury
3. Contralateral lower limb and knee without alterations on physical examination
4. Individuals who agreed to participate and signed the free and informed consent statement of the study

Exclusion criteria

1. Presence of alterations of any origin (congenital, traumatic, metabolic, inflammatory or degenerative) that were genetically inherited or acquired, in either of the lower limbs, other than a single ACL injury in one of the knees
2. Presence of a deformity of varus, valgus, antecurvatum, recurvatum or torsional nature in either of the lower limbs
3. Previous surgery in either of the lower limbs
4. Pregnant women

length of time with the ACL injury was 32 months, ranging from 14 to 70.

All the patients underwent digital radiography on both knees: the knee with ACL failure and the normal contralateral knee. Five radiographs were produced on each patient: two (one on each knee) in absolute lateral view with flexion of 30°, without loading on the lower limb, performed with the patient in lateral decubitus on the radiographic table; two (one on each knee) in absolute lateral view with flexion of 30°, performed in an upright standing position with the body weight borne on one foot on the side radiographed; and one axial radiograph of the patella, covering both knees in accordance with the technique of Merchant et al.,[15] but with the knees flexed at 30°, instead of 45°.

All the 150 digital radiographs obtained were analyzed by the same examiner, using tools for measuring distances in millimeters and angles, within the DicomViewer® software (Microdata, Rio de Janeiro, Brazil).

The values of three femoropatellar radiographic parameters were recorded: the patellar height, which was measured on the lateral-view radiographs of the knee by means of the method described by Caton–Deschamps[16] (Fig. 1); Merchant's angle of patellar congruence, measured on axial radiographs of the patella as described by Merchant et al.[15] (Fig. 2); and the angle of lateral inclination of the patella, measured in accordance with the technique of Laurin et al.[17] (Fig. 3), on axial radiographs of the patella.

The values of the femoropatellar radiographic parameters obtained from the knees with ACL failure (case group) and from the normal contralateral knees (control group) were subjected to the Kolmogorov–Smirnov and Shapiro–Wilk normal distribution tests, and were compared using the paired Student's *t* test to evaluate the statistical significance ($p < 0.05$). Pearson's correlation test was used to assess the correlations

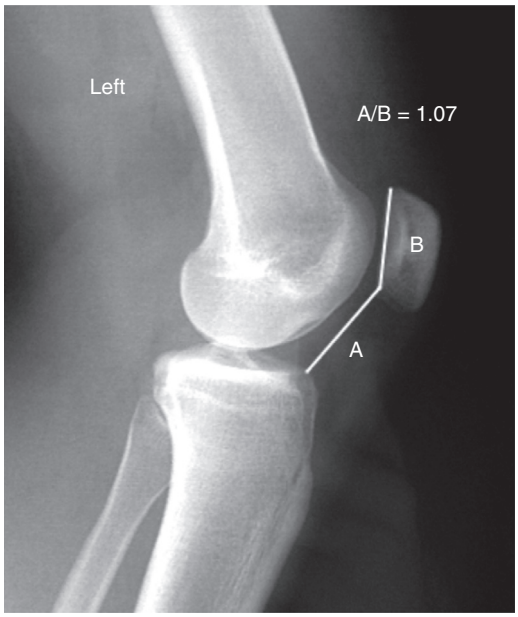

Fig. 1 – Caton–Deschamps patellar height index (A/B) from radiographs of the knee in absolute lateral view: (A) distance between the anterior margin of the joint surface of the tibia and the lower limit of the joint surface of the patella; (B) distance between the upper and lower limits of the joint surface of the patella.

between the time elapsed since ACL injury and the values for the patellar height, Merchant's congruence angle and the lateral inclination angle of the patella.

Results

Among the 30 volunteers, 57% ($n = 17$) were men and 43% ($n = 13$) were women. The mean time that had elapsed since the ligament injury was 32 ± 14 months, with a range from 14 to 70. The subjects' mean age was 28 ± 7.6 years, ranging from 17 to 46. The ACL injuries were distributed equally on the two sides: 50% ($n = 15$) in the right knee and 50% ($n = 15$) in the left knee. The trauma mechanism that caused the ligament tear was indirect in 83% ($n = 25$) and direct in 17% ($n = 5$). The commonest causes were soccer practice (57%, $n = 17$), falls from a height (16.5%, $n = 5$), traffic accidents (16.5%, $n = 5$) and martial arts practice (10%, $n = 3$).

The mean values for the patellar height in the two groups, without weight-bearing on the lower limb and with weight-bearing on a single foot, are shown in Figs. 4 and 5. The patellar height values were statistically significantly smaller ($p < 0.001$) in the knees with ACL failure (case group) than in the normal knees (control group), both on the radiographs without weight-bearing and in those with weight-bearing on a single foot. Single-foot weight-bearing gave rise to a statistically significance increase ($p < 0.001$) in the patellar height values in the two groups in a similar manner (Fig. 5).

Table 2 shows the mean, standard deviation and maximum and minimum values of Merchant's patellar congruence angle in each group. The mean value of this angle in the normal

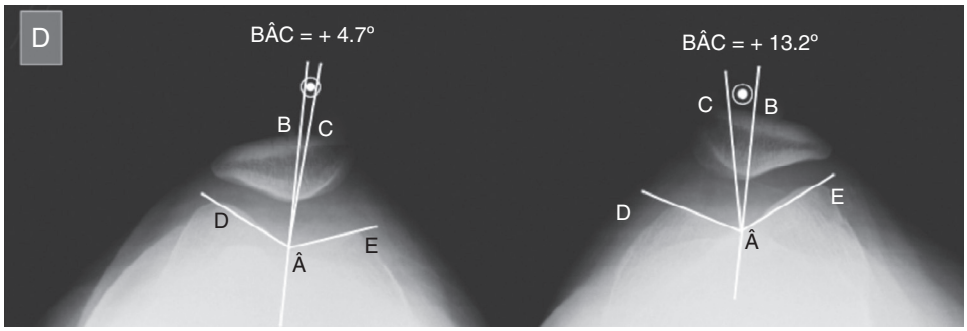

Fig. 2 – Merchant's patellar congruence angle (BÂC). Line C bisects the angle DÂE, which is the angle of the trochlear sulcus. Line B joins the vertex of the angle DÂE to the lowest point of the patellar crest. BÂC = +4.7° in the normal knee and BÂC = +13.2° in the left knee with an anterior cruciate ligament injury.

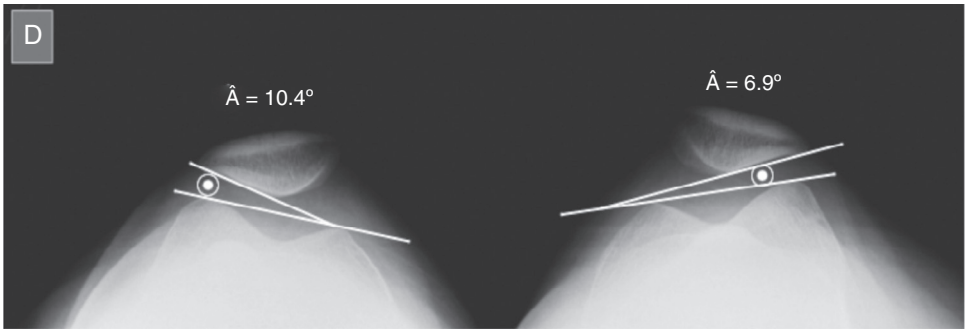

Fig. 3 – Lateral inclination angle (Â) of the patella as described by Laurin et al.,[17] formed by a line that joins the anterior limits of the medial and lateral femoral condyles and another line tangential to the lateral facet of the patella. Â = 10.4° in the normal right knee and Â = 6.9° in the left knee with an anterior cruciate ligament injury.

knees was −2.57° ± 5.86°. This value was statistically significantly lower ($p < 0.001$) than that of the knees with ACL failure (+2.08° ± 6.16°), as shown in Fig. 6.

The mean value of the lateral inclination angle of the patella in the group of knees with ACL injuries was 6.70° ± 4.86°, and this value was significantly lower ($p < 0.001$) than that of the normal knees (11.25° ± 4.54°), as shown in Fig. 7. Table 3 presents the mean, standard deviation and maximum and minimum values of the lateral inclination angle of the patella in each group.

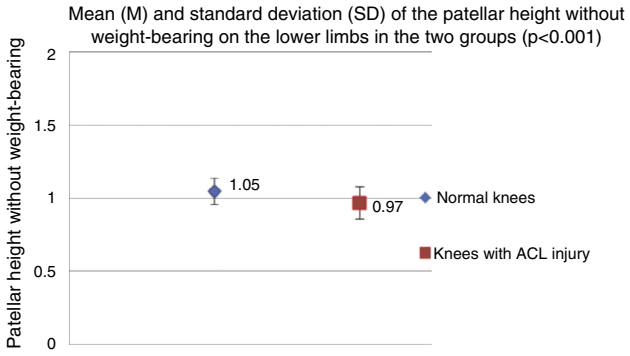

Fig. 4 – Mean and standard deviation of the patellar height without weight-bearing on the lower limbs in the two groups.

Pearson's correlation test did not show any significant correlation ($r = 0.14$) between the time that had elapsed since the ligament injury and the values for the patellar height, Merchant's patellar congruence angle and the lateral inclination angle of the patella in the knees with ACL failure.

Discussion

The effects of ACL failure on tibiofemoral kinematics are well documented in the literature. Rotational alterations[4,5] and translational alterations[6] to the tibiofemoral joint during the

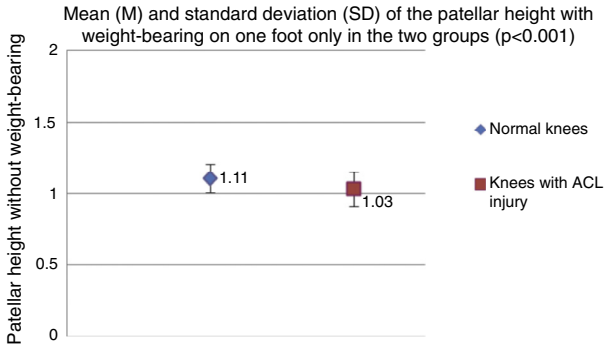

Fig. 5 – Mean and standard deviation of the patellar height with weight-bearing on one foot only in the two groups.

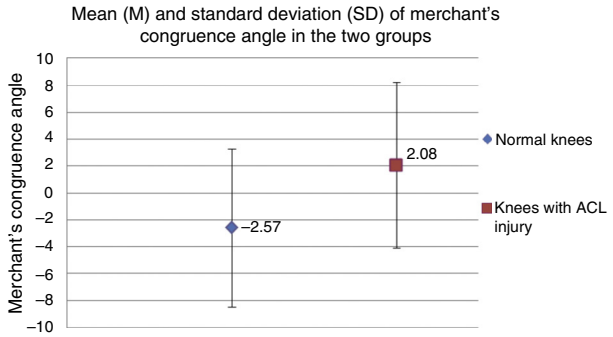

Fig. 6 – Mean and standard deviation of Merchant's congruence angle in the two groups.

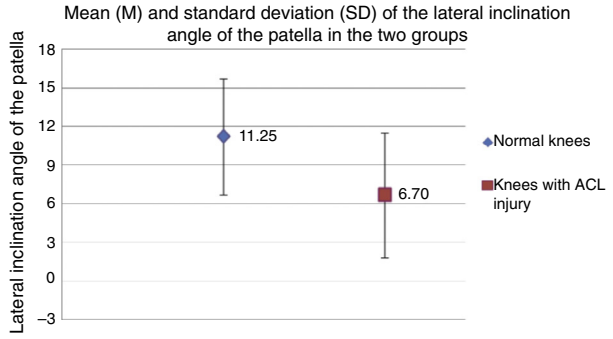

Fig. 7 – Mean and standard deviation of the lateral inclination angle of the patella in the two groups.

stance and swing phases of gait have been demonstrated. According to Hsieh et al.,[13] alterations to tibiofemoral kinematics inevitably cause changes to the femoropatellar joint and modify its normal functioning.

Using radiographic parameters that are commonly applied in clinical practice, we sought to detect these possible femoropatellar alterations in knees with chronic ACL injuries alone that had occurred more than 12 months earlier. For this, we used the normal contralateral knee of the came patient as the control.

Table 2 – Mean, standard deviation (SD) and minimum and maximum values for Merchant's patellar congruence angle in the two groups.

	Merchant's patellar congruence angle			
	Mean	SD	Min	Max
Normal knees	−2.57	5.86	−13.90	7.80
Knees with ACL injuries	2.08	6.16	−13.20	13.20

Table 3 – Mean, standard deviation (SD) and minimum and maximum values for the lateral inclination of the patella in the two groups.

	Lateral inclination angle of the patella			
	Mean	SD	Min	Max
Normal knees	11.25	4.54	0.00	21.00
Knees with ACL injuries	6.70	4.86	−4.80	14.80

In analyzing the patellar height, we found a significantly lower value ($p < 0.001$) in the group of knees with ACL injuries than in the group of normal knees. On the radiographs without weight-bearing, the Caton–Deschamps patellar height index for the knees with ACL injuries was 0.97 ± 0.11, while it was 1.05 ± 0.09 for the normal knees (Fig. 4). These values were very similar to those recorded by Lin et al.,[18] who compared the patellar height without weight-bearing on the lower limbs using the Insall-Salvati patellar height index, in knees with ACL injury (0.99 ± 0.11) and without ACL injury (1.05 ± 0.12). Furthermore, these authors, and also Aglietti et al.,[19] found significantly lower patellar height values in male patients with ACL injuries and concluded that a low patella is a risk factor for ligament injury. In our sample, we did not observe any statistically significant difference ($p > 0.05$) in patellar height values between men and women. Moreover, since we used the contralateral normal knee of the same patient as the control, we cannot say whether the lower values for patellar height that we found in the knees with ACL injury are a risk factor for ligament injury, or whether they are a consequence of chronic injury.

Weight-bearing on a single foot statistically significantly increased the patellar height values in both groups ($p < 0.01$) (Fig. 5). Yiannakopoulos et al.[20] observed that there was a mean increase in the Caton–Deschamps patellar height index of 0.11 when body weight was borne by normal knees. These authors suggested that the increase in patellar height due to proximal translation of the patella through contraction of the quadriceps when weight is borne by the lower limbs might be greater in knees with ligament failure. Van de Velde et al.[14] detected relative stretching of the patellar tendon in knees with ACL injury, which could theoretically cause an even greater increase in patellar height in these knees during quadriceps contraction. However, in our study, the mean increase in patellar height was the same (0.06) in the two groups.

Merchant's patellar congruence angle reflects the position of the patella in relation to the trochlear sulcus. Its values can be negative, which indicates that the crest of the patella is located medially to the trochlear sulcus; or positive, when the crest of the patella is located laterally to the trochlear sulcus.[15] Thus, the more positive the value of the angle is, the greater the lateral displacement of the patella in relation to the femoral trochlea will be; and the more negative it is, the greater the medial displacement will be. In our study, the mean value of this angle in the normal knees was $-2.57^\circ \pm 5.86^\circ$, *versus* $+2.08^\circ \pm 6.16^\circ$ ($p < 0.001$) in the knees with ACL failure, which indicates that the positioning of the patella was more lateral in relation to the trochlear sulcus in the group of knees with ligament lesions. This finding is concordant with what was found by Van de Velde et al.,[14] who recorded greater lateral displacement of the patella in millimeters, in relation to the trochlear sulcus, in knees with ACL injuries at flexions between 0° and 30°. On average, the lateral displacement of the patella found by these authors[14] was 1.7 mm greater ($p < 0.001$) in knees with ACL failure than in normal knees. Hsieh et al.[13] also recorded lateral displacement of the area of femoropatellar contact and greater contact pressure between the patella and trochlea at

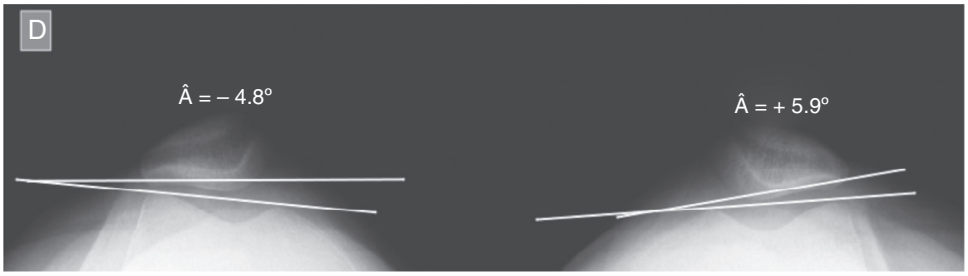

Fig. 8 – Negative lateral inclination angle (Â) of the patella (Â = –4.8°) in the right knee with ACL injury and positive angle (Â = +5.9°) in the normal left knee.

flexions between 0° and 90°, in the knees of cadavers with ligament injuries.

As the patella tilts laterally, there is a decrease in the lateral inclination angle of the patella, as described by Laurin et al.[17] This occurs because the line that is tangential to the lateral facet of the patella becomes more parallel to the line that joins the anterior limits of the medial and lateral femoral condyles. In cases of severe lateral tilting, inversion of this angle may occur, thus becoming negative through medial opening, instead of through lateral opening (Fig. 8). In our sample, this inversion of the angle only occurred in two knees with ACL injuries (−2.2° and −4.8°) and it was not recorded in any of the normal knees. The mean value of the lateral inclination angle of the patella in the knees with ACL injuries was 6.70° ± 4.86°, which was significantly smaller ($p < 0.001$) than what was measured in the normal knees (11.25° ± 4.54°). These results reveal that there was greater lateral tilting of the patella in the knees with ACL injuries, which was on average 4.55° greater than in the normal knees. Similar values were also reported by Van de Velde et al.,[14] who recorded a mean increase in lateral tilting of 5.2°, for the patellae of knees with ACL injuries over the first 30° of flexion.

There is no consensus in the literature regarding whether femoropatellar alterations might be reversible through ACL reconstruction. In the knees of cadavers, Hsieh et al.[12,13] found that after ACL reconstruction, the patellar tilt, contact area and femoropatellar contact pressure returned to values close to those of normal knees. On the other hand, in an *in vivo* study, Van de Velde et al.[14] documented that these alterations persisted even after ligament reconstruction, which suggested that this procedure alone would not be capable of correcting them. Further research will be needed in order to confirm these hypotheses.

Small changes to patella orientation in relation to the femoral trochlea may cause significant changes to femoropatellar biomechanics.[14] According to some authors,[14,21,22] the greater displacement and greater lateral inclination of the patella found in knees with ACL failure might be related to the appearance of anterior pain in the knee and femoropatellar arthrosis.

We believe that femoropatellar alterations in knees with ACL injuries or in those that undergo reconstruction of this ligament are often underdiagnosed in clinical practice. An appropriate radiological examination with detailed analysis on the femoropatellar radiographic parameters might aid in recognizing these alterations and enable rational therapeutic approaches.

Conclusion

In our sample, chronic ACL failure statistically significantly altered the values of the femoropatellar radiographic parameters evaluated ($p < 0.001$). Knees with chronic injuries to this ligament presented lower values for patellar height, greater tilting and greater lateral displacement of the patella in relation to the femoral trochlea, in comparison with the normal contralateral knees.

Conflicts of interest

The authors declare no conflicts of interest.

REFERENCES

1. Ristanis S, Giakas G, Papageorgiou CD, Moraiti T, Stergiou N, Georgoulis AD. The effects of anterior cruciate ligament reconstruction on tibial rotation during pivoting after descending stairs. Knee Surg Sports Traumatol Arthrosc. 2003;11(6):360–5.
2. Dennis DA, Mahfouz MR, Komistek RD, Hoff W. In vivo determination of normal and anterior cruciate ligament-deficient knee kinematics. J Biomech. 2005;38(2):241–53.
3. Buckwalter JA, Lane NE. Athletics and osteoarthritis. Am J Sports Med. 1997;25(6):873–81.
4. Georgoulis AD, Papadonikolakis A, Papageorgiou CD, Mitsou A, Stergiou N. Three-dimensional tibiofemoral kinematics of the anterior cruciate ligament-deficient and reconstructed knee during walking. Am J Sports Med. 2003;31(1):75–9.
5. Andriacchi TP, Dyrby CO. Interactions between kinematics and loading during walking for the normal and ACL deficient knee. J Biomech. 2005;38(2):293–8.
6. DeFrate LE, Papannagari R, Gill TJ, Moses JM, Pathare NP, Li G. The six degrees of freedom kinematics of the knee after ACL deficiency: an in-vivo imaging analysis. Am J Sports Med. 2006;34(8):1240–6.
7. Andriacchi TP, Mundermann A, Smith RL, Alexander EJ, Dyrby CO, Koo S. A framework for the in vivo pathomechanics of osteoarthritis at the knee. Ann Biomed Eng. 2004;32(3):447–57.
8. Li G, Park SE, DeFrate LE, Schutzer ME, Ji L, Gill TJ, et al. The cartilage thickness distribution in the tibiofemoral joint and

its correlation with cartilage-to-cartilage contact. Clin Biomech (Bristol, Avon). 2005;20(7):736–44.
9. Li G, DeFrate LE, Zayontz S, Park SE, Gill TJ. The effect of tibiofemoral joint kinematics on patellofemoral contact pressures under simulated muscle loads. J Orthop Res. 2004;22(4):801–6.
10. Van de Velde SK, DeFrate LE, Gill TJ, Moses JM, Papannagari R, Li G. The effect of anterior cruciate ligament deficiency on the in vivo elongation of the medial and lateral collateral ligaments. Am J Sports Med. 2007;35(2):294–300.
11. Baugher WH, Warren RF, Marshall JL, Joseph A. Quadriceps atrophy in the anterior cruciate insufficient knee. Am J Sports Med. 1984;12(3):192–5.
12. Hsieh YF, Draganich LF, Ho SH, Reider B. The effects of removal and reconstruction of the anterior cruciate ligament on patellofemoral kinematics. Am J Sports Med. 1998;26(2):201–9.
13. Hsieh YF, Draganich LF, Ho SH, Reider B. The effects of removal and reconstruction of the anterior cruciate ligament on the contact characteristics of the patellofemoral joint. Am J Sports Med. 2002;30(1):121–7.
14. Van de Velde SK, Gill TJ, DeFrate LE, Papannagari R, Li G. The effect of anterior cruciate ligament deficiency and reconstruction on the patellofemoral joint. Am J Sports Med. 2008;36(6):1150–9.
15. Merchant AC, Mercer RL, Jacobsen RH, Cool CR. Roentgenographic analysis of patellofemoral congruence. J Bone Joint Surg Am. 1974;56(7):1391–6.
16. Caton J, Deschamps G, Chambat P, Lerat JL, Dejour H. Patella infera: a propos of 128 cases. Rev Chir Orthop Reparatrice Appar Mot. 1982;68(5):317–25.
17. Laurin CA, Levesque HP, Dussault R, Labelle H, Peides JP. The abnormal lateral patellofemoral angle: a diagnostic Roentgenographic sign of recurrent patellar subluxation. J Bone Joint Surg Am. 1978;60(1):55–60.
18. Lin CF, Wu JJ, Chen TS, Huang TF. Comparison of the Insall-Salvati ratio of the patella in patients with and without an ACL tear. Knee Surg Sports Traumatol Arthrosc. 2005;13(1):8–11.
19. Aglietti P, Insall JN, Cerulli G. Patellar pain and incongruence. I: Measurements of incongruence. Clin Orthop Relat Res. 1983;(176):217–24.
20. Yiannakopoulos CK, Mataragas E, Antonogiannakis E. The effect of quadriceps contraction during weight-bearing on four patellar height indices. J Bone Joint Surg Br. 2008;90(7):870–3.
21. Øiestad BE, Holm I, Engebretsen L, Aune AK, Gunderson R, Risberg MA. The prevalence of patellofemoral osteoarthritis 12 years after anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc. 2013;21(4):942–9.
22. Tajima G, Iriuchishima T, Ingham SJ, Shen W, van Houten AH, Aerts MM, et al. Anatomic double-bundle anterior cruciate ligament reconstruction restores patellofemoral contact areas and pressures more closely than nonanatomic single-bundle reconstruction. Arthroscopy. 2010;26(10):1302–10.