Value of the Tibial Tuberosity–Trochlear Groove Distance in Patellar Instability in the Young Athlete

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Value of the Tibial Tuberosity–Trochlear Groove Distance in Patellar Instability in the Young Athlete

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Background: A lateralized tibial tubercle may be a relevant anatomic factor in patients with patellar instability and can be used as an indication for a distal realignment procedure. However, parameter values for the tibial tuberosity–trochlear groove (TT-TG) distance in the young patient have not been defined. It also remains to be determined how this parameter contributes to patellar instability in the growing knee joint.

Purpose: The purpose of this study was to evaluate the value of the TT-TG distance in patellar instability in the young athlete.

Study Design: Case control study; Level of evidence, 3.

Methods: Knee magnetic resonance images were collected from 109 patients with lateral patellar instability and from 136 control subjects. Student *t* test and multiple logistic regression analysis were used to compare the absolute and relative values of the TT-TG distance between patients and controls. The relative value was defined as the ratio between the TT-TG distance and the total width of the distal femur.

Results: The TT-TG distance (absolute and relative to femur width) differed significantly between patients with patellar dislocation and the control group (both $P < .01$). The TT-TG distances were on average 4 mm larger in patients with patellar dislocation; TT-TG distance divided by femur width was on average 5% larger in patients with patellar dislocation. Multiple logistic regression analysis confirmed the TT-TG distance as a significant risk factor for patellar dislocation ($P = .04$), but showed no significant interaction with patient age or femur width ($P = .95$ and $P = .15$, respectively).

Conclusion: A lateralized tibial tubercle is a relevant anatomic factor in the young athlete and in the adult patient with lateral patellar instability. Its parameter values and its influence on patellar dislocation are independent of patient age and should therefore be evaluated as in adults.

Keywords: tibial tuberosity–trochlear groove distance; immature; patella; instability

Stability of the patellofemoral joint is maintained by a complex interplay among active, passive, and static stabilizers that act in harmony during knee motion.[1] Changes in this complex interplay, either due to trauma or as part of an individual's anatomy, may result in primary and recurrent lateral patellar dislocations (LPDs). The main anatomic factors that contribute to an unstable patella include trochlear dysplasia, patella alta, increased tibial tuberosity–trochlear groove (TT-TG) distance, and patellar tilt.[5] In addition, injury to the medial patellofemoral ligament (MPFL) has been described in the majority of LPDs and may predict instability after nonoperative treatment.[3,7,14,19]

Although there is no clear consensus about the management of primary LPD, there are certain implications for operative treatment, including the presence of an osteochondral fragment, substantial disruption of the medial soft tissue stabilizers, and a laterally subluxated patella with normal alignment of the contralateral knee.[20] In addition, surgery may be required in patients where nonoperative treatment has failed and instability episodes limit sports activity or even an active lifestyle. In those patients, preoperative planning requires a detailed analysis of an individual's anatomy, including the identification and evaluation of predisposing factors that contribute to LPD.

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The TT-TG distance represents the radiographic measurement of the quadriceps vector, which represents a lateral force displacement on the patella during knee motion. It has been measured to be greater than 20 mm in patients with recurrent patellar dislocations, as compared with 13 mm in control subjects.[5] Thus, a lateralized tibial tubercle may be a relevant anatomic factor and can be used as an indication for a distal realignment procedure. However, parameter values of the TT-TG distance at different developmental stages have not been defined in the current literature; it remains to be determined how this measurement relates to patellar instability in the growing knee joint.[18] Therefore, the purpose of this study was to evaluate the TT-TG distance in the young athlete. We hypothesized that the TT-TG distance changes with increasing age, so that its effect on lateral patellar instability needs to be evaluated differently in the young athlete when compared with the adult patient.

MATERIALS AND METHODS

Study Group

Patient selection was performed according to methods in a related study (Balcarek et al[2]). The study group was composed of 109 patients (male/female, 56/53; age range, 10-47 years) with 109 knee MRI investigations who had been treated for lateral patellar instability between February 2006 and June 2010. We used a picture archiving and communications system workstation (Centricity, GE Healthcare, St Giles, United Kingdom) to screen knee MRI investigations that were performed at the Department of Radiology at our clinic between February 2006 and July 2010. The MRIs were evaluated by 2 orthopaedic surgeons (P.B., K.-H.F.) with 8 and 12 years of experience, respectively, with agreement by consensus. We looked for evidence of acute or recurrent LPD. The criteria for LPD included joint effusion; contusion on the lateral femoral condyle or the medial patellar facet; osteochondral fragments; injury to the medial ligamentous stabilizers, the medial retinaculum and the MPFL; and a lateralized patella.[10] The MRI-based diagnosis of lateral patellar dislocation was made in patients who met 3 or more of the criteria.

Additionally, to be included, the medical records of those patients with MRI evidence of LPD were examined for evidence of lateral patellar instability. Patients had to have a history of a primary or recurrent LPD, including a documented dislocated patella that required reduction by an emergency doctor or a convincing history of giving way and clinical findings of joint effusion and tenderness along the medial patella facet, along the medial retinaculum, or at the medial femoral condyle.

The criteria for exclusion were any history of a prior realignment procedure, trochleaplasty, accompanying fracture, or a multiple-ligament injury to the knee joint. Standard knee arthroscopy and medial reefing were not exclusion criteria. These criteria were used to identify 109 patients, who formed the study group for this investigation.

TABLE 1
Comparison of Age, Femur Width, and TT-TG Distances (Absolute and Relative to Femur Width) Between Patients With Dislocation and the Control Group[a]

Factor	Dislocation (n = 109)	Control (n = 136)	*P* Value
Age, y	21.6 ± 7.9	18.0 ± 9.0	<.01
Male sex	56 (51%)	64 (47%)	.52
Femur width, mm	78.5 ± 6.3	76.8 ± 8.3	.06
TT-TG, mm	14.6 ± 4.6	10.6 ± 4.0	<.01
TT-TG/femur width (%)	18.8 ± 6.2	13.8 ± 5.2	<.01

[a]Descriptive values are the mean ± standard deviation. TT-TG, tibial tuberosity–trochlear groove.

TABLE 2
Distribution of Gender and Age of the Study Group and the Control Group

	Years			
	<10	>10 to <13	>13 to <16	>16
Males				
Patient	0 (0%)	2 (13%)	14 (58%)	40 (56%)
Control	10 (100%)	13 (87%)	10 (42%)	31 (44%)
Females				
Patient	0 (0%)	8 (25%)	15 (52%)	30 (54%)
Control	8 (100%)	24 (75%)	14 (48%)	26 (46%)

Control Group

We evaluated MRI knee examinations of 136 patients (male/female: 64/72; age range, 5-42 years) who served as controls. The examinations were performed during the same period and were matched for age and gender. Reasons for MRI investigations were internal derangements of the knee such as meniscal tears, anterior cruciate ligament rupture, or cartilage lesion of the medial or lateral femorotibial joint space. None of these participants had symptoms or objective pathologic findings related to the patellofemoral joint.

The demographics of the study group and the control group are summarized in Table 1 and Table 2. For a better overview and with regard to skeletal maturation, the distribution of gender of the study group and the control group was divided in 4 groups aged <10 years, 10 to 13 years, 14 to 15 years, and ≥16 years.

MRI Technique

The MRI examinations were performed on a 1.5-T or 3.0-T imager (Magnetom TrioTim Syngo MR B15 and Magnetom Symphony Syngo MR A30, Siemens, Erlangen, Germany). The patients underwent imaging with the knee positioned in full extension. The following sequences were routinely performed and used for this study. The Magnetom TrioTim Syngo MR B15 utilized a transverse

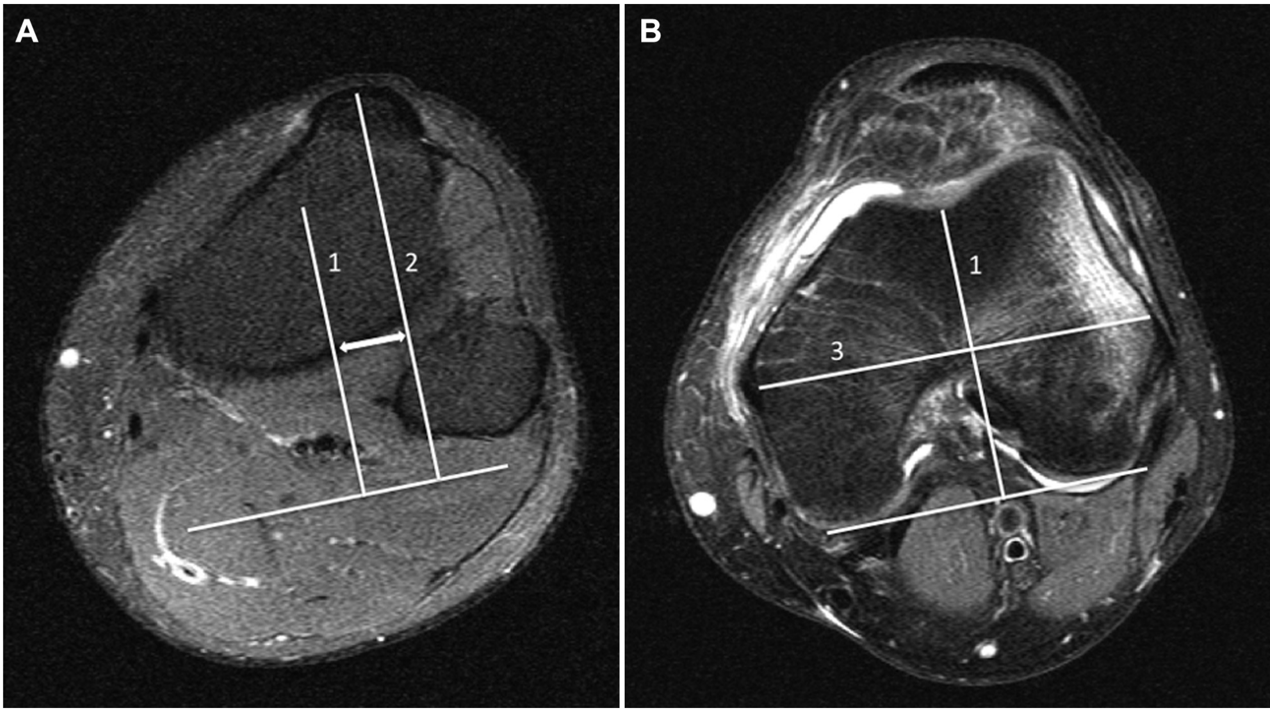

Figure 1. Measurement of tibial tuberosity–trochlear groove (TT-TG) distance. A, The first line (1) was drawn through the deepest point of the trochlear groove, perpendicular to the posterior condyle tangent. The second line (2) was drawn in parallel to the trochlear line through the most anterior portion of the tibial tubercle. The distance between these 2 lines represented the TT-TG distance. B, The third line (3) measured the total width of the distal femur from the medial to the lateral epicondyle, parallel to the posterior condyle tangent.

fat-saturated proton-density weighted fast spin-echo imaging sequence (repetition time/echo time, 4000/53 milliseconds; flip angle, 150°; field of view, 200 × 200 mm; section thickness, 4.0 mm). The Magnetom Symphony Syngo MR A30 utilized a transverse fat-saturated proton-density weighted fast spin-echo imaging sequence (repetition time/echo time, 4500/33 milliseconds; flip angle, 150°; field of view, 160 × 160 mm; section thickness, 4.0 mm).

TT-TG Measurement

The TT-TG distance was assessed according to Schoettle et al.[17] The first transverse cranio-caudal image that depicted a complete cartilaginous trochlea was used to determine the deepest point within the trochlear groove. A line was drawn through the deepest point of the trochlear groove, perpendicular to the posterior condyle tangent. A second line was drawn in parallel to the trochlear line through the most anterior portion of the tibial tubercle. The distance between the 2 lines represented the TT-TG distance (Figure 1). To provide a parameter that was independent of growth, we measured the total width of the distal femur from the medial to the lateral epicondyle, in parallel to the posterior condyle tangent. The relative TT-TG distance was then calculated as the ratio of the TT-TG distance to the total width of the femur.

Statistical Analysis

Age, femur width, and absolute and relative TT-TG distances were compared between patients with patellar dislocation and the control group by *t* tests. Normality of these factors was checked by quantile-quantile plots. Gender distribution was compared between the 2 groups by Fisher's exact test. Except for gender, all factors were additionally studied by multiple logistic regression analysis. The difference of mean TT-TG distances between patients and controls was additionally characterized by 95% confidence intervals, separately for the different age groups and for gender. Effects were assumed to be significant if P values were smaller than 5%. All analyses were performed with free R software (version 2.8, http://www.r-project.org).

RESULTS

The TT-TG distance (absolute and relative to femur width) was significantly different between controls and patients with patellar dislocation (both $P < .01$, Table 1). The TT-TG distances were on average 4 mm larger in patients with patellar dislocation; TT-TG distance divided by femur width was on average 5% larger in patients with patellar dislocation. Femur width was also larger in the study group, but this trend was not significant ($P = .06$). In detail, mean TT-TG differences and 95% confidence

TABLE 3
Mean TT-TG Differences (in Millimeters) and 95% Confidence Intervals (Values in Square Brackets) Between Patients and Controls Listed Separately for Gender and Age Groups[a]

	Years		
	≥10 to <13	≥13 to ≤16	>16
Males	4.8 [2.4, 7.2]	7.0 [2.4, 11.7]	1.9 [−0.2, 4.1]
Females	3.2 [−0.4, 6.8]	7.3 [3.8, 10.8]	4.0 [2.2, 5.9]

[a]TT-TG, tibial tuberosity–trochlear groove.

TABLE 4
Multiple Logistic Regression Analysis With TT-TG Distance, Age, and Femur Width as Risk Factors for Patellar Dislocation[a]

Factor	P
Age	.39
Femur width	.25
TT-TG	.04
TT-TG—age[b]	.95
TT-TG—femur width[b]	.15

[a]TT-TG: tibial tuberosity–trochlear groove.
[b]Interaction.

intervals between patients and controls listed separately for gender and age groups are shown in Table 3.

To prove the independence of the absolute TT-TG distance, multiple logistic regression analysis was performed with age, femur width, and the TT-TG distance as independent factors. In this analysis, the TT-TG distance remained as the only significant risk factor for dislocation (P = .04, Table 4). In addition, there was no significant interaction of TT-TG distances with age or femur width (P = .95 and P = .15, respectively) (Table 4). This means that the influence of the TT-TG distance on dislocation was independent of patient age. The 95% confidence intervals as shown in Table 3 and illustrated in Figure 2 did not overlap and therefore confirmed this independence.

Please note that grouping of age was only performed to illustrate the nonsignificant interaction between the TT-TG distance and age (logistic regression) by 95% confidence intervals. Our conclusions are not primarily drawn from the analysis of the age groups, but from logistic regression.

DISCUSSION

This study was designed to evaluate the TT-TG distance in the young athlete and to assess how this measurement contributes to patellar instability at different ages. We found that the TT-TG distance (absolute and relative to femur width) was significantly different between patients with patellar dislocation and the control group but its influence on patellar instability was independent of patient age. Thus, we had to refute our initial hypothesis that the TT-TG distance changes with increasing age and conclude that, in the young patient, the effect of the TT-TG distance on LPD should be evaluated with the same approach used in adult patients.

The complexity and broad variety of factors associated with LPD and the risk of persistent patellofemoral complaints after first-time dislocation renders treatment challenging and controversial. It is necessary to understand the relevant contributions and injury patterns of the different patellar-stabilizing mechanisms that are represented particularly by the quadriceps muscles, the joint geometry, and the retinaculae. In addition, the MPFL represents the major soft tissue restraint against LPD.[6] This ligament is injured in over 90% of patients after LPD and may predict instability after nonoperative treatment.[3,7,14,19] Thus, the purpose of the clinical and radiologic assessment should be the identification of each factor causing instability so that appropriate treatment may be selected.[4] This, in turn, is based on the knowledge of the parameter values of the TT-TG distance and the related impact on lateral patellar instability.

It has been shown recently that, in pediatrics, MPFL injury patterns and the magnitude of trochlear dysplasia seen on MRI were similar to those seen in adults.[3,21] The authors concluded that physicians are confronted with similar anatomic risk factors and similar injuries to the soft tissue restraints in children and adults with patellar instability. In addition to trochlear dysplasia, an increased TT-TG distance has been defined as a major factor of LPD and can be used as an indication for a distal realignment procedure.[5] The goal of this procedure is the correction of the relationship between the trochlear groove and the tibial tubercle to diminish the lateral force vector elicited by quadriceps muscle activation. To date, controversy remains as to what value should be considered to be an indication for surgery.[5,12] This essentiality is especially true for children and adolescents with open epiphyses that often limit surgical procedures to soft tissue approaches. Koëter et al[12] considered a distance of >15 mm to be pathologic and, as such, an indication for surgery in symptomatic patients, whereas Dejour et al[5] recommended medialization of the tibial tubercle if a threshold of 20 mm was exceeded. In all cases, however, the postoperative position of the tibial tubercle should be 10 to 12 mm lateral to the trochlear groove to avoid excessive medial transposition. Our study group had 12 patients (11%) with a TT-TG distance of ≥20 mm, whereas 38 patients (35%) showed a distance of more than 15 mm. The control group had 3 patients (2.2%) with a TT-TG distance of 20 mm and 14 patients (10.3%) with a TT-TG distance of more than 15 mm. Thus, according to Koëter et al,[12] we would consider a distance of more than 15 mm as an indication for distal realignment surgery in symptomatic patients.

Preoperative CT or MRI investigation is required to demonstrate the need for a distal realignment surgery and to plan for corrective surgical measures. Goutallier et al[8] introduced TT-TG measurements between the most anterior point of the tibial tuberosity and the deepest point of the trochlear groove, perpendicular to the posterior condyle tangent. With the use of superimposed CT images, Muneta

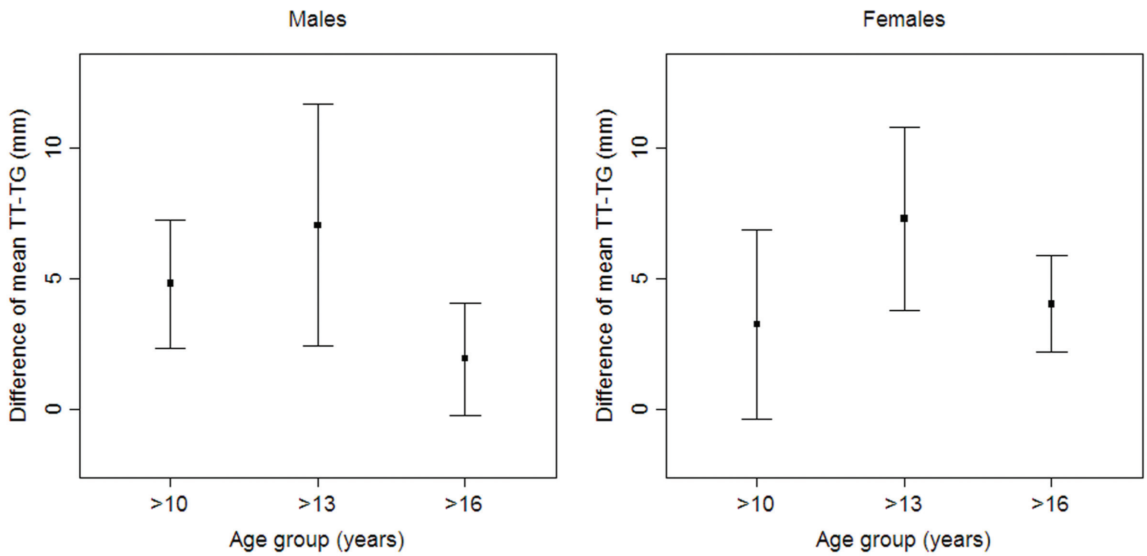

Figure 2. The 95% confidence intervals for the differences of mean tibial tuberosity–trochlear groove (TT-TG) distances between patients and controls listed separately for gender and age groups. The intervals do not overlap; the TT-TG distance is assessed as independent from age as a risk factor for patellar dislocation. Values are shown in Table 4.

et al[13] used a technique to measure TT-TG distance that has become accepted as the gold standard. Schoettle et al[17] demonstrated that the TT-TG distance could also be measured reliably on transverse magnetic resonance images. Using references on bony landmarks, the authors found a mean TT-TG distance of 13.9 ± 4.5 mm on magnetic resonance images as compared with 14.4 ± 5.4 mm on CT scans, in a study population composed of patients who underwent imaging because of patellofemoral instability. The mean TT-TG distance of our study group averaged 14.6 ± 4.6 mm, whereas the mean distance in the control subjects was 10.6 ± 4.0 mm. In addition, we used relative TT-TG distance to diminish the effect of size in the relatively smaller-boned knees of children and adolescents. Again, the relative TT-TG distance differed significantly between the study group and the control group (both $P < .01$) but we found no significant interaction of TT-TG distances with age or femur width ($P = .95$ and $P = .15$, respectively). Thus, we concluded that the influence of the TT-TG distance on dislocation was independent of patient age.

It remains controversial how increased TT-TG distance in children with open epiphyses can be corrected. The risk of proximal tibial deformity is a significant concern and the development of genu recurvatum after proximal tibial surgery has been defined in the literature.[11] The most frequently performed operation is the Roux-Goldthwait procedure, which comprises a detachment of the lateral half of the patellar tendon, followed by reattachment at a more medial position. This operation can be combined with a vastus medialis muscle advancement, a semitendinosus tenodesis, and a lateral release described as the "3-in-1" or the "4-in-1" procedure. This approach has yielded good results after midterm follow-ups.[9,15] However, other authors found it difficult to balance the 2 arms so that they carried equal forces. In addition, the procedure can lead to attenuation and hypotrophy of the transferred limb, resulting in a smaller and weaker patellar tendon.[18] On the other hand, it has been reported that a "safe" but isolated repair of the medial structures combined with lateral release in children <16 years of age did not improve the long-term outcome.[16] Thus, despite numerous published articles on patellar instability, the literature lacks evidence-based studies that evaluated which operative procedure is successful and safe in both children and adolescents, in whom open epiphyses limit surgical procedures.

To the best of our knowledge, this is the first study that aims to provide a more distinct view on the TT-TG distance and its effect on lateral patellar instability in the young patient. However, several limitations were noticed and deserve mention. First, the control group did not have completely asymptomatic knees. The MRI investigations were performed because of internal derangements of the knee such as meniscal tears, anterior cruciate ligament rupture, or cartilage lesion of the medial or lateral femorotibial joint space. However, none of these patients had symptoms or objective pathologic findings related to the patellofemoral joint. Second, with regard to imaging evaluations, observers could not be blinded as to whether images had been obtained in controls or in patients with LPD. As multiple findings of LPD were generally apparent on each image, it was not possible to perform blinded evaluation of each sign. Third, our study group did not comprise patients of <10 years of age and included few patients aged 10 to 13 years. We cannot exclude the possibility that studying more patients might yield a significant difference when evaluating the TT-TG distance at different developmental stages. Finally, this is a cross-sectional, not a longitudinal, study. Thus, commenting on possible changes in the TT-TG distance over maturation is limited. However, multiple logistic regression analysis found no significant interaction between age and TT-TG distances as risk factors for patellar dislocation.

CONCLUSION

A lateralized tibial tubercle is a relevant anatomic factor in the young athlete and in the adult patient with lateral patellar instability. Its parameter values and its influence on patellar dislocation are independent of patient age and should therefore be evaluated as in adults.

REFERENCES

1. Amis AA, Senavongse W, Bull AM. Patellofemoral kinematics during knee flexion-extension: an in vitro study. *J Orthop Res*. 2006;24:2201-2211.
2. Balcarek P, Jung K, Ammon J, et al. Anatomy of lateral patellar instability: trochlear dysplasia and tibial tubercle–trochlear groove distance is more pronounced in women who dislocate the patella. *Am J Sports Med*. 2010;38(11):2320-2327.
3. Balcarek P, Walde TA, Frosch S, et al. Patellar dislocations in children, adolescents and adults: a comparative MRI study of medial patellofemoral ligament injury patterns and trochlear groove anatomy [published online ahead of print July 15, 2010]. *Eur J Radiol*. doi:10.1016/j.ejrad.2010.06.042.
4. Dandy DJ. Chronic patellofemoral instability. *J Bone Joint Surg Br*. 1996;78(2):328-335.
5. Dejour H, Walch G, Nove-Josserand L, Guier C. Factors of patellar instability: an anatomic radiographic study. *Knee Surg Sports Traumatol Arthrosc*. 1994;2(1):19-26.
6. Desio SM, Burks RT, Bachus KN. Soft tissue restraints to lateral patellar translation in the human knee. *Am J Sports Med*. 1998;26(1):59-65.
7. Elias DA, White LM, Fithian DC. Acute lateral patellar dislocation at MR imaging: injury patterns of medial patellar soft-tissue restraints and osteochondral injuries of the inferomedial patella. *Radiology*. 2002;225(3):736-743.
8. Goutallier D, Bernageau J, Lecudonnec B. The measurement of the tibial tuberosity: patella groove distanced technique and results. *Rev Chir Orthop Reparatrice Appar Mot*. 1978;64:423-428.
9. Joo SY, Park KB, Kim BR, Park HW, Kim HW. The 'four-in-one' procedure for habitual dislocation of the patella in children: early results in patients with severe generalised ligamentous laxity and aplasis of the trochlear groove. *J Bone Joint Surg Br*. 2007;89(12):1645-1649.
10. Kirsch MD, Fitzgerald SW, Friedman H, Rogers LF. Transient lateral patellar dislocation: diagnosis with MR imaging. *AJR Am J Roentgenol*. 1993;161(1):109-113.
11. Kocher MS, Saxon HS, Hovis WD, Hawkins RJ. Management and complications of anterior cruciate ligament injuries in skeletally immature patients: survey of the Herodicus Society and the ACL Study Group. *J Pediatr Orthop*. 2002;22:452-457
12. Koëter S, Diks MJ, Anderson PG, Wymenga AB. A modified tibial tubercle osteotomy for patellar maltracking: results at two years. *J Bone Joint Surg Br*. 2007;89(2):180-185.
13. Muneta T, Yamamoto H, Ishibashi T, Asahina S, Furuyu K. Computerized tomographic analysis of tibial tubercle position in the painful female patellofemoral joint. *Am J Sports Med*. 1994;22:67-71
14. Nomura E. Classification of lesions of the medial patello-femoral ligament in patellar dislocation. *Int Orthop*. 1999;23(5):260-263.
15. Oliva F, Ronga M, Longo UG, Testa V, Capasso G, Maffulli N. The 3-in-1 procedure for recurrent dislocation of the patella in skeletally immature children and adolescents. *Am J Sports Med*. 2009;37(9):1814-1820.
16. Palmu S, Kallio PE, Donell ST, Helenius I, Nietosvaara Y. Acute patellar dislocation in children and adolescents: a randomized clinical trial. *J Bone Joint Surg Am*. 2008;90(3):463-470.
17. Schoettle PB, Zanetti M, Seifert B, Pfirrmann CW, Fucentese SF, Romero J. The tibial tuberosity-trochlear groove distance: a comparative study between CT and MRI scanning. *Knee*. 2006;13(1):26-31.
18. Sillanpää PJ, Mäenpää HM, Arendt EA. Patellar instability: treatment of lateral patella dislocation in the skeletally immature athlete. *Oper Tech Sports Med*. 2010;18(2):83-92.
19. Sillanpää PJ, Peltola E, Mattila VM, Kiuru M, Visuri T, Pihlajamäki H. Femoral avulsion of the medial patellofemoral ligament after primary traumatic patellar dislocation predicts subsequent instability in men: a mean 7-year nonoperative follow-up study. *Am J Sports Med*. 2009;37(8):1513-1521.
20. Stefancin JJ, Parker RD. First-time traumatic patellar dislocation: a systematic review. *Clin Orthop Relat Res*. 2007;455:93-101.
21. Zaidi A, Babyn P, Astori I, White L, Doria A, Cole W. MRI of traumatic patellar dislocation in children. *Pediatr Radiol*. 2006;36(11):1163-1170.