



Distal femoral torsional osteotomy increases the contact pressure of the medial patellofemoral joint in biomechanical analysis

Franz Liska¹ · Constantin von Deimling² · Alexander Otto¹ · Lukas Willinger¹ · Ralf Kellner³ · Andreas B. Imhoff¹ · Rainer Burgkart² · Andreas Voss¹

Received: 23 February 2018 / Accepted: 25 September 2018 / Published online: 29 September 2018
© European Society of Sports Traumatology, Knee Surgery, Arthroscopy (ESSKA) 2018

Abstract

Purpose Torsional osteotomy of the distal femur allows anatomic treatment of patellofemoral instability and patellofemoral pain syndrome in cases of increased femoral antetorsion. The purpose of this study was to investigate the effects of distal femoral torsional osteotomy on pressure distribution of the medial and lateral patellar facet.

Methods Nine fresh frozen human knee specimens were embedded in custom-made 3D-printed casts and tested with a robotic arm. Torsional osteotomy could be simulated ranging from increased femoral antetorsion of 25° with a corresponding lateralization of the patella to an overcorrected value of 5° of femoral antetorsion. The peak and mean lateral and medial compartment pressure was measured in 0°, 15°, 30°, 45°, 60° and 90° flexion beginning with neutral anatomic muscle rotation.

Results The medial aspect of the patella showed a significant influence of femoral torsion with an increase of mean and peak pressure in all flexion angles with progressive derotation from 15° external rotation to 5° internal rotation ($p=0.004$). The overall pressure difference was highest in near extension and stayed on a constant level with further flexion. On the lateral facet, the derotation resulted in decrease of pressure in near extension; however, it had no significant influence on the mean and peak pressure through the different torsion angles (n.s.). Unlike on the medial facet, a significant consistent increase of peak pressure from 0° to 90° flexion could be shown ($p=0.022$) on the lateral patella aspect.

Conclusion Distal femoral torsional osteotomy to correct pathological femoral antetorsion leads to a redistribution of retropatellar pressure. External derotation leads to an increased peak pressure on the medial patellar facet and can impair simultaneous cartilage repair. However, as the lateral patellofemoral load decreases, it has a potential in preventing patellofemoral osteoarthritis.

Keywords Distal femoral osteotomy · Rotational osteotomy · Retropatellar pressure · Contact pressure

Franz Liska, Constantin von Deimling contributed equally to this work.

✉ Andreas B. Imhoff
imhoff@tum.de

Franz Liska
Franz.Liska@tum.de

Constantin von Deimling
constantin.deimling@tum.de

Alexander Otto
alexander.otto@tum.de

Lukas Willinger
l.willinger@tum.de

Ralf Kellner
Ralf.Kellner@wiwi.uni-regensburg.de

Rainer Burgkart
rainer.burgkart@tum.de

Andreas Voss
a.voss@tum.de

¹ Department of Orthopaedic Sports Medicine, Hospital Rechts der Isar, Technical University Munich, Ismaningerstr. 22, 81675 Munich, Germany

² Department of Orthopedics and Sports Orthopedics, Hospital Rechts der Isar, Technical University Munich, Ismaningerstr. 22, 81675 Munich, Germany

³ Chair for Statistics and Risk Management, University of Regensburg, 93053 Regensburg, Germany

Introduction

Patellofemoral instability includes patella tilt, maltracking, subluxation and dislocation [31]. The multifactorial cause of patellofemoral instability comprises medial patellofemoral ligament (MPFL) disruption, trochlear dysplasia, excessive tibial tubercle (TT) lateralization with elevated tibial tubercle–trochlear groove (TTTG) distance, or patella alta [1, 30]. Another important factor, though sometimes underestimated, includes variances of mechanical malalignment such as genu valgum or femoral anteversion [5, 9, 27]. It affects all corresponding static and dynamic factors of patellofemoral instability as it is essential for bony morphology and the resulting muscular strain [7, 16, 30]. Distal femoral osteotomy (DFO) procedures combined with additional external torsional osteotomies have been proved to be a reliable option for correction of torsional pathologies in patellofemoral instability [4, 16, 32]. High success rates with torsional osteotomies are reported in the literature [6, 17, 32].

Patellar dislocation and chronic patellofemoral instability are linked to the development of abnormal contact stress and joint degeneration [22, 24]. Frequently, concomitant osteochondral injuries, especially cartilage lesions of the patellar surface, are present [12, 23, 29]. As a major contributor to adverse clinical outcomes, these lesions demand a simultaneous treatment. In literature, due to the numerous complex variables influencing treatment of patellofemoral instability, there is still a lack of high-level evidence [21].

Torsional osteotomies are more frequently performed in patellofemoral dysbalance in the last few years, so biomechanical analyzation of the mechanical load gives an important indication for evaluating treatment options in the clinical setting. It is unknown if a torsional DFO leads to increased peak contact pressure to the opposing retropatellar articular cartilage and hence might influence the outcome of a cartilage treatment. The purpose of the current study was to evaluate the effects of torsional DFO on retropatellar contact pressure in human cadaveric knees, as there is an enormous lack of evidence in literature. It was hypothesized that torsion significantly increases the articular contact patterns of the medial patellar facet. On the other hand, a reduction of the lateral facet contact pressure would be preferable in cases of early osteoarthritis. According to the results found in this study, a guideline might be given to the clinician for concomitant patellar cartilage therapy.

Materials and methods

To investigate the hypothesis, nine fresh frozen human knee specimens (Med Cure, Orlando, USA) were used. No ethics approval was required for this cadaver study. The mean age was 66.1 ± 11.5 (range 43.2–77.4) years; there were five males and four females. The knees had no history of disease or prior surgery. All knee specimens were thawed overnight at room temperature.

Prior to testing, every knee underwent a radiological evaluation. The mean Caton–Deschamps index of 0.95 ± 0.09 (range 0.79–1.06) indicated a physiological patella height and the patellar morphology was mainly Wiberg type 2. No trochlear dysplasia, osteoarthritis or any patellar deformity was evident.

Each specimen initially consisted of all bone and soft tissue transected 20 cm proximal and distal to the joint line. The soft tissue was excised leaving capsule, fascia, ligaments and tendons intact. The quadriceps muscles were separated into five components: rectus femoris, vastus intermedius, vastus medialis longus, vastus medialis obliquus and vastus lateralis. Additionally, the tractus iliotibialis (ITB) has been prepared for testing. The vastus intermedius was elevated from the anterior femoral shaft and grouped with the rectus femoris. The muscular components and the ITB were each stitched to cloth material and additionally fixed with cable wires to apply muscle load with a total of 205N [11, 25, 34]. The specimens were embedded in 3D-printed castings using quick hardening polyurethane resin (RenCast® FC Isocyanate/FC 52 Polyol). To ensure correct loading, the tibia was potted perpendicular to the joint with the knee in full extension. The femur was aligned parallel to its anatomic axis. Axial rotation of both the tibia and the femur was minimized with respect to the epicondyle axis. To realize these orientation specifications, a cross line laser was utilized during the potting procedure. Specimens were kept moist throughout the preparation and the experiment by spraying physiological saline water occasionally.

A 4041 Tekscan sensor (Tekscan Inc., Boston, USA) was used to measure patellofemoral mean and peak contact pressure. The sensor was 0.1 mm thick with two separate sensors measuring 40.1×24.9 mm each, detecting a maximal pressure of 3.45 MPa. Calibration and equilibration were carried out based on manufacturer's guidelines [3, 8]. The sensor was inserted through the suprapatellar recess maintaining the medial and lateral capsule and ligaments. The two separate sensors covered both the medial and lateral patellar surfaces being pasted up to the cartilage (Superglue, Pattex©, Düsseldorf, Germany) to prevent it from moving during knee flexion.

A six-axis robot arm was used for biomechanical testing (Staubli, RX 90 B, Germany, Bayreuth). The tibia was

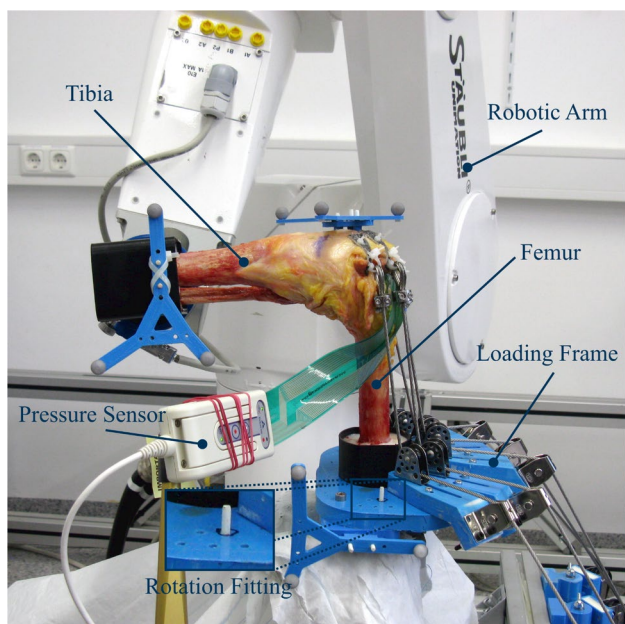


Fig. 1 Experimental arrangement of the robotic knee simulator. The femur (*F*) and tibia (*T*) were potted in custom-made 3D casts. The femur and the rotatable loading frame were attached to the robot's base frame. The tibia was connected to the robot's tipycylinders using a bone cement compound. A pressure-sensitive sensor foil was inserted through the suprapatellar recess and fixed with glue. The rotation angle was set by prefabricated fitting (an enlarged detail of the rotation frame)

connected to the tip of the robotic system which consisted of a multidimensional force torque sensor (90M40A3, JR3 Inc., Woodland, USA). The femur and the rotatable loading mechanism were attached to the robot's base frame (Fig. 1). Each of the six different muscle strings were positioned and loaded individually in accordance with directions and physiological cross-sectional areas regarding the anatomic characteristics [10, 34]. Hyperextension of the joint was determined by the system neutralizing the applied loads. The resulting pose was utilized to calculate the measurement flexion angles. To account for the femur mass, half of every specimen's weight and the connector's weight were compensated. All other acting forces and moments, except the torque around the fixed epicondyle axis, were minimized during all applied motions. The peak and mean lateral and medial compartment pressure was then measured in 0°, 15°, 30°, 45°, 60° and 90° flexion (with an error of less than 0.1°). Before the investigation, all specimens were preconditioned by three flexion–extension cycles from 0° to 90° of flexion.

The study concentrated on the investigation of the peak pressure on the medial and lateral patellofemoral compartment during torsional adjustment osteotomy of the femur. To mimic the torsional osteotomy, a special custom-made loading frame was designed to rotate the femur's muscle strings manually in

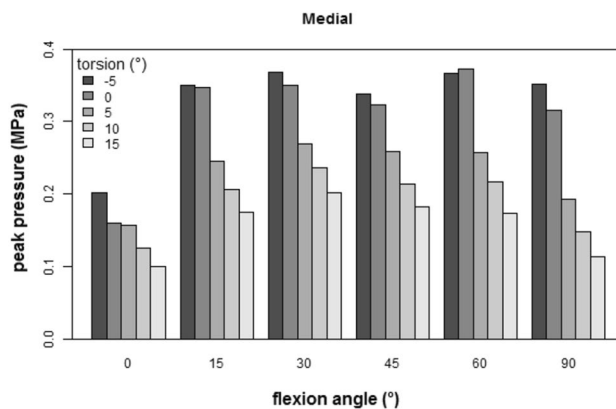


Fig. 2 Peak medial patellofemoral joint contact pressures (in MPa), $n=9$, from 0° to 90° flexion, for five different torsion angles with 15° simulating increased femoral antetorsion to -5° simulating overcorrected femoral antetorsion

5° steps from 5° external rotation to 15° internal rotation with the femur being fixed. Accordingly, a stepwise clinical relevant situation could be simulated ranging from increased femoral antetorsion of 25° with a corresponding lateralization of the patella to an overcorrected standard value of 5° of femoral antetorsion with a then medialized patella. The peak and mean lateral and medial patellofemoral compartment pressures were then measured in 0°, 15°, 30°, 45°, 60° and 90° flexion beginning with neutral anatomic muscle rotation.

Statistical analysis

The statistical analysis is based upon a two-factor analysis of variance (ANOVA) with repeated measures. Hereby, differences between various conditions of angle and rotation were tested. The data set is balanced and includes nine specimens for which observations are given under each condition. To control for possible violations against the sphericity assumption, a Huynh–Feldt and Greenhouse–Geisser correction was conducted. For all statistical decisions, a significance level of 0.05 was used. Violations against the sphericity assumption seemed to be of minor extent in the overall analysis and only have to be taken into account when analyzing differences under the medial pressure setup. The analysis is conducted with SPSS version 24.0 (IBM, Armonk, New York), while the results were additionally recalculated with R version 3.4.2 (Austria, Vienna). Given the exploratory nature of this study, a priori sample size analysis was not performed.

Results

The medial aspect of the patella (Fig. 2) showed a significant influence of external femoral derotation with an increase of peak pressure with progressive derotation from 15°

internal torsion to 5° external torsion ($p=0.004$) as well as a tendency to higher peak pressures in all flexion angles (n.s.). Similarly, the mean medial contact pressure increased ($p=0.008$). Accordingly, a decrease of mean and peak pressure was detected for the lateral facet and femoral external derotation from 15° internal torsion to 5° external torsion (Fig. 3). The strongest effect was measured between 0° and 30° of knee flexion. However, the derotation had no significant influence through the different flexion angles (n.s.). Still, a consistent increase of peak pressure from 0° to 90° flexion could be detected ($p=0.022$). Retropatellar mean pressure was lowest in near extension and increased gradually with flexion. The mean pressure remained <0.41 MPa for flexion up to 90°.

Discussion

The most important finding of this study was that the patellofemoral pressure at the medial facet increases significantly in distal femoral torsional osteotomies. Mean and peak pressure of the medial facet increases highest in 15°–30° flexion angles and remains on a constant level with further flexion. In simulated increased femoral antetorsion and corresponding lateralization of the patella, the mean and peak pressure is higher on the lateral facet compared to the medial facet and increases with continuous knee flexion.

Osteotomies around the knee have been utilized independently as well as in combination with cartilage repair techniques to improve symptoms of cartilage pathology and patellofemoral symptoms. In the tibiofemoral joint, both opening- and closing-wedge femoral or tibial osteotomies have been established as a technique to off-load damaged cartilage areas in an attempt to provide symptom relief [14, 20, 36]. In the setting of cartilage repair, a concomitant

osteotomy can be used to off-load the repair site and to support the healing process [2].

In pathologic femoral antetorsion, a distal femoral torsional osteotomy provides significant pain relief as well as patellofemoral stability. In a cadaver study of mature femora, Lee et al. quantified the impact of femoral antetorsion on quadriceps tension and patellofemoral contact pressure [19]. Increased femoral antetorsion caused greater lateral contact pressure of the patella. The highest pressure values were noted between 30° and 60° of knee flexion. Dickschas et al. reported significant pain relief and correction of patellar tracking with femoral torsional osteotomies in patients with additional torsional deformity of the femur causing anterior knee pain and patellar instability [6, 35].

Osteochondral fractures are frequent concomitant lesions after patellar dislocation [33]. Nomura et al. reported even a 95% incidence of cartilage damage with 72% of osteochondral lesions located on the medial patellar facet [28]. In chronic patellofemoral instability with lateralized patella, OA develops in the lateral patellofemoral joint, mainly due to consistent lateral hyperpression [15]. The results of this study confirm the influence of lateralized patella and corresponding hyperpression. This suggests a favorable situation of torsional osteotomies to reduce lateral facet pressure and therefore prevent early OA. In a previous in vitro assessment, equivalent findings of excessive lateral hypercompression in pathologic femoral antetorsion could be demonstrated [19]. Despite the advantages of torsional osteotomies for the lateral facet, this assessment revealed an increase of retropatellar pressure of the medial facet in external derotation osteotomy. Elevated intraarticular pressure impairs the outcome of cartilage repair techniques. Kuroda et al. demonstrated the potentially ill effects of overmedialization of the tuberosity [18]. In elevated TTTG, cartilage lesions on the medial facet of the patella pose a contraindication for medial tubercle transposition, as it increases the intraarticular pressure as well. For cartilage lesions of the lateral facet, antero-medialization of the tibial tubercle is meant to be successful in cartilage repair [13].

Analogous to surgical medialization of the tuberositas tibiae, the data presented in this study show that torsional osteotomies have a significant influence on patellar pressure. This suggests that the surgical combination of torsional osteotomy and cartilage repair has to take the localization of the cartilage defect into account. Located on the medial patellar facet, the simultaneous intervention might have negative effects on the outcome of cartilage repair. On the other hand, treating cartilage lesions of the lateral facet, the outcome might be favorable. Furthermore, the results indicate that external torsional osteotomy might delay the development of early OA, especially of the lateral facet by reducing the intraarticular pressure forces. In future cartilage studies involving the patellofemoral joint, lesions should be separated by location and evaluated

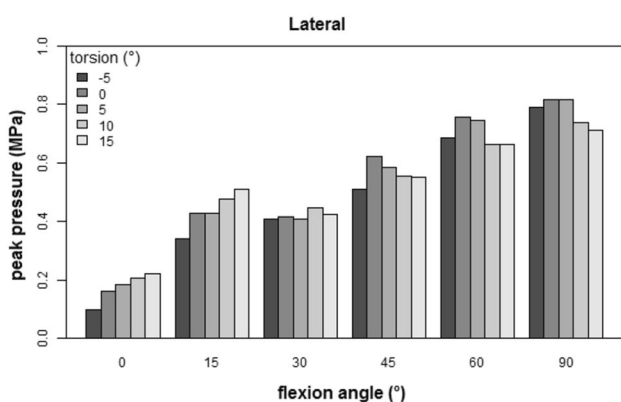


Fig. 3 Peak pressure of the lateral patellofemoral joint facet (in MPa), $n=9$, from 0° to 90° flexion, for five different torsion angles with 15° simulating increased femoral antetorsion to -5° simulating overcorrected femoral antetorsion

separately, to better target available and advancing treatment options in this region.

The clinical relevance of the present data is highlighted by the fact that torsional osteotomy influences the retropatellar pressure dissimilarly regarding the lateral and medial facet. As a result, the outcome of simultaneous cartilage repair can be impaired at the medial facet, but be favorable on the lateral facet. This poses important information for the orthopedic surgeon using simultaneous interventions. Furthermore, a torsional osteotomy can reduce a prearthrotic deformity of the patellofemoral joint.

Limitations of this study include those inherent to in vitro testing. The specimens' flexion angles were reached by the robot neutralizing all measured loads except the torque around the epicondyle axis. Care was taken to avoid misalignment of that axis, since it would have induced different motions and thereby in deviations regarding the pressure measurements and the flexion poses. Nonetheless, the flexion poses might differ from the ones, which would have been reached by real in vivo conditions. Like in other in vitro studies, the specimens were elderly and it is unknown if the mean age influences the studies' outcome.

Since, among others, Mueller et al. [26] demonstrated that the amount of muscle loads does not necessarily affect biomechanical experiments, the muscle loads were chosen to be static and lower than in vivo, to consider the test setup boundaries.

Conclusion

Distal femoral torsional osteotomy increases medial patellofemoral contact pressure and can impair simultaneous cartilage repair. However, as the lateral patellofemoral load decreases, it has a potential in preventing patellofemoral osteoarthritis.

Funding The Technical University of Munich has received direct funding from the German Arthritis Foundation and the German speaking Society for Arthroscopy and Joint Surgery (AGA).

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

References

1. Aglietti P, Buzzi R, Insall J (2001) Disorders of the patellofemoral joint. In: Insall JN, Scott WN (eds) *Surgery of the knee*, 3. edn. Churchill Livingstone, Philadelphia, pp 913–1043
2. Bauer S, Khan RJ, Ebert JR et al (2012) Knee joint preservation with combined neutralising high tibial osteotomy (HTO) and matrix-induced autologous chondrocyte implantation (MACI) in younger patients with medial knee osteoarthritis: a case series with prospective clinical and MRI follow-up over 5 years. *Knee* 19:431–443
3. Brimacombe JM, Wilson DR, Hodgson AJ, Ho KC, Anglin C (2009) Effect of calibration method on Tekscan sensor accuracy. *J Biomech Eng* 131:034503 1–4
4. Brinkman JM, Freiling D, Lobenhoffer P, Staubli AE, van Heerwaarden RJ (2014) Supracondylar femur osteotomies around the knee: patient selection, planning, operative techniques, stability of fixation, and bone healing. *Orthopade* 43(Suppl;1):1–10
5. Bruce WD, Stevens PM (2004) Surgical correction of miserable malalignment syndrome. *J Pediatr Orthop* 24:392–396
6. Dickschas J, Harrer J, Pfefferkorn R, Strecker W (2012) Operative treatment of patellofemoral maltracking with torsional osteotomy. *Arch Orthop Trauma Surg* 132:289–298
7. Dye SF (2005) The pathophysiology of patellofemoral pain: a tissue homeostasis perspective. *Clin Orthop Relat Res* 436:100–110
8. Drewniak EI, Crisco JJ, Spenciner DB, Fleming BC (2007) Accuracy of circular contact area measurements with thin-film pressure sensors. *J Biomech* 40:2569–2572
9. Eckhoff DG, Montgomery WK, Kilcoyne RF, Stamm ER (1994) Femoral morphometry and anterior knee pain. *Clin Orthop Relat Res* 302:64–68
10. Farahmand F, Senavongse W, Amis AA (1998) Quantitative study of the quadriceps muscles and trochlear groove geometry related to instability of the patellofemoral joint. *J Orthop Res* 16:136–143
11. Farahmand F, Tahmasbi MN, Amis AA (1998) Lateral force-displacement behaviour of the human patella and its variation with knee flexion: a biomechanical study in vitro. *J Biomech* 31:1147–1152
12. Farr J, Covell DJ, Lattermann C (2012) Cartilage lesions in patellofemoral dislocations: incidents/locations/when to treat. *Sports Med Arthrosc Rev* 20:181–186
13. Frosch S, Balcarek P, Walde TA et al (2011) The treatment of patellar dislocation: a systematic review. *Z Orthop Unfall* 149:630–645
14. Fu FH, Zurakowski D, Browne JE et al (2005) Autologous chondrocyte implantation versus debridement for treatment of full-thickness chondral defects of the knee: An observational cohort study with 3-year follow-up. *Am J Sport Med* 33:1658–1666
15. Guettler JH, Demetropoulos CK, Yang KH, Jurist KA (2004) Osteochondral defects in the human knee: influence of defect size on cartilage rim stress and load redistribution to surrounding cartilage. *Am J Sports Med* 32:1451–1458
16. Heegaard J, Leyvraz PF, Curnier A, Rakotomanan L, Huiskes R (1995) The biomechanics of the human patella during passive knee flexion. *J Biomech* 28:1265–1279
17. Hinterwimmer S, Minzlaff P, Saier T, Niemeyer P, Imhoff AB, Feucht MJ (2014) Biplanar supracondylar femoral derotation osteotomy for patellofemoral malalignment: the anterior closed-wedge technique. *Knee Surg Sports Traumatol Arthrosc* 22:2518–2521
18. Kuroda R, Kambic H, Valdevit A et al (2001) Articular cartilage contact pressure after tibial tuberosity transfer. A cadaveric study. *Am J Sports Med* 29:403–409
19. Lee TQ, Anzel SH, Bennett KA et al (1994) The influence of fixed rotational deformities of the femur on the patellofemoral contact pressures in human cadaver knees. *Clin Orthop Relat Res* 302:69–74
20. Liska F, Voss A, Imhoff FB, Willinger L, Imhoff AB (2018) Nonunion and delayed union in lateral open wedge distal femoral osteotomies—a legitimate concern? *Int Orthop* 42(1):9–15
21. Liu JN, Steinhaus ME, Kalbian IL, Post WR, Green DW, Strickland SM, Shubin Stein BE (2017) Patellar instability management:

- a survey of the international patellofemoral study group. *Am J Sports Med.* <https://doi.org/10.1177/0363546517732045>
22. Mäenpää H, Lehto MUK (1997) Patellofemoral osteoarthritis after patellar dislocation. *Clin Orthop Relat Res* 339:156–162
 23. Mashoof AA, Scholl MD, Lahav A, Greis PE, Burks RT (2005) Osteochondral injury to the mid-lateral weight-bearing portion of the lateral femoral condyle associated with patella dislocation. *Arthroscopy* 21:228–232
 24. Mehta VM, Inoue M, Nomura E, Fithian DC (2007) An algorithm guiding the evaluation and treatment of acute primary patellar dislocations. *Sports Med Arthrosc Rev* 15:78–81
 25. Merican AM, Amis AA (2009) Iliotibial band tension affects patellofemoral and tibiofemoral kinematics. *J Biomech* 42:1539–1546
 26. Mueller O, Lo JH, Wuenschel M, Obloh C, Wuelker N (2009) Simulation of force loaded knee movement in a newly developed in vitro knee simulator. *Biomed Eng* 54(3):142–149
 27. Nelitz M, Dreyhaupt J, Williams SR, Dornacher D (2015) Combined supracondylar femoral derotation osteotomy and patellofemoral ligament reconstruction for recurrent patellar dislocation and severe femoral anteversion syndrome: surgical technique and clinical outcome. *Int Orthop* 39:2355–2362
 28. Nomura E, Inoue M, Kurimura M (2003) Chondral and osteochondral injuries associated with acute patellar dislocation. *Arthroscopy* 19:717–721
 29. Nomura E, Inoue M (2005) Second-look arthroscopy of cartilage changes of the patellofemoral joint, especially the patella, following acute and recurrent patellar dislocation. *Osteoarthr Cartil* 13:1029–1036
 30. Panagiotopoulos E, Strzelczyk P, Herrmann M, Scuderi G (2006) Cadaveric study on static medial patellar stabilizers: the dynamizing role of the vastus medialis obliquus on medial patellofemoral ligament. *Knee Surg Sports Traumatol Arthrosc* 14(1):7–12
 31. Sheehan FT, Derasari A, Fine KM, Brindle TJ, Alter K (2010) Q-angle and J-sign: Indicative of Maltracking Subgroups in Patellofemoral Pain. *Clin Orthop Relat Res* 468(1):266–275
 32. Staheli LT (1989) Torsion—treatment indications. *Clin Orthop Relat Res* 247:61–66
 33. Stanitski CL, Paletta GA Jr (1998) Articular cartilage injury with acute patellar dislocation in adolescents. *Arthroscopic and radiographic correlation.* *Am J Sports Med* 26:52–55
 34. Stephen JM, Lumpaopong P, Dodds AL, Williams A, Amis AA (2015) The effect of tibial tuberosity medialization and lateralization on patellofemoral joint kinematics, contact mechanics, and stability. *Am J Sports Med* 43(1):186–194
 35. Strecker W, Dickschas J (2015) Torsional osteotomy: Operative treatment of patellofemoral maltracking. *Oper Orthop Traumatol* 27:505–524
 36. Tang WC, Henderson IJ (2005) High tibial osteotomy: long term survival analysis and patients' perspective. *Knee* 12:410–413