Current Reviews in Musculoskeletal Medicine (2021) 14:67–75
https://doi.org/10.1007/s12178-020-09688-y

HOT TOPICS

Tibial Torsion and Patellofemoral Pain and Instability in the Adult Population: Current Concept Review

Martyn Snow [1]

Accepted: 17 December 2020 / Published online: 8 January 2021

Abstract

Purpose of review Tibial torsion is a recognized cause of patellofemoral pain and instability in the paediatric population; however, it is commonly overlooked in the adult population. The aim of this review article is to summarize the current best evidence on tibial torsion for the adult orthopaedic surgeon.

Recent Findings The true incidence of tibial torsion in the adult population is unknown, with significant geographical variations making assessment very difficult. CT currently remains the gold standard for quantitatively assessing the level of tibial torsion and allows assessment of any associated femoral and knee joint rotational anomalies. Surgical correction should only be considered after completion of a course of physiotherapy aimed at addressing the associated proximal and gluteal weakness. Tibial torsion greater than 30° is used as the main indicator for tibial de-rotation osteotomy by the majority of authors. In patients with associated abnormal femoral rotation, current evidence would suggest that a single-level correction of the tibia (if considered to be a dominant deformity) is sufficient in the majority of cases. Proximal de-rotational osteotomy has been more commonly reported in the adult population and confers the advantage of allowing simultaneous correction of patella alta or excessive tubercle lateralization. Previous surgery prior to de-rotational osteotomy is common; however, in patients with persistent symptoms surgical correction still provides significant benefit.

Summary Tibial torsion persists into adulthood and can play a significant role in patellofemoral pathology. A high index of suspicion is required in order to identify torsion clinically. Surgical correction is effective for both pain and instability, but results are inferior in patients with very high pain levels pre-surgery and multiple previous surgeries.

Keywords Tibial torsion · Patellofemoral pain · Patella instability · Rotational osteotomy

Introduction

Tibial torsion is defined as any twisting of the tibia on its longitudinal axis which produces a change in the alignment of the planes of motion of the proximal and distal articulations (1). It undergoes structural remodelling, which begins in utero and progresses throughout childhood and adolescence to skeletal maturity (2).

The prevalence of rotational pathology of the femur and tibia has been reported to be as high as 50% within the paediatric population (3) and are consequently routinely assessed as part of lower limb examination. Most torsional problems resolve with age, leaving only a small percentage of older children and adults with a cosmetic and functional problem. It is estimated that tibial torsion affects 1% of the adult population (1), although the true incidence is unclear. In adulthood, tibial torsion is often overlooked as a cause of knee pathology; it is poorly assessed and consequently largely undertreated.

Tibial torsion can have a significant effect on gait and muscle function, which is proportionate to its direction and magnitude (4). This can result in joint overload and disturbed patellofemoral mechanics (5,6). The aim of this review article is to summarize the current best evidence on tibial torsion for the adult orthopaedic surgeon. This review will focus on the identification of tibial torsion, its measurement and surgical treatment in the adult population with patellofemoral pain and/or instability.

✉ Martyn Snow
snowmartyn@gmail.com

[1] The Royal Orthopaedic Hospital, Bristol Road South, Northfield, Birmingham, UK

Cause of Normal and Abnormal

Staheli (7) reported that most torsional abnormalities are a result of intrauterine moulding and are extreme manifestations of normal development. Genetically predetermined differences may make one individual appear initially, or persist with, more rotation than others.

Mechanical loading is a known key determinant for bone adaptions and remodelling. LeDamany (8) was one of the first to document torsion in infants and hypothesized that muscle tensions and local forces gave rotary stress to the distal tibial epiphysis that resulted in the development of torsion. Subsequently, Schneider undertook experimental rotational osteotomies on young dogs and observed an average of 55% de-rotation because of local muscle and mechanical forces that untwisted the femur (9). Gait analysis would also suggest that muscle forces could be a key driver of rotational remodelling and mechano-adaption in man. Yang et al. (10) determined that during walking, running and stair climbing, bending and torsion are the predominant tibial loading regimes.

Thus, the origins of tibial torsion are multifactorial and complex. It would appear that adult tibial torsion is not just a hangover from developmental abnormality and is likely influenced by local biomechanical factors, genetics and a range of pathologies. Tibial torsion likely changes throughout life as we age, responding to environmental stimulus and potentially contributing/protecting against disease.

Normal Values of Tibial Torsion

LeDamany (8) in 1909 was the first to report on the normal values of tibial torsion. Using anthropometry, he found the mean value in 100 specimens to be 23.7°. Subsequently, numerous authors have published values for the healthy adult individual and these are summarized in Table 1.

The methods of measurements can be broken down into 3 broad categories. Clinical measurements are the easiest to obtain of the 3 methods and the population can be chosen carefully, so as to ensure they are representative of the normal population; i.e., there is no history of knee pain or patellofemoral problems. However, as will be discussed, the examination is the least accurate method of quantifying torsion. Cadaver measurements are the gold standard in terms of measurement accuracy; however, their weakness is that commonly no history is known or reported about the individual and whether they are representative of a normal sample

Table 1 A summary of reported values for tibial torsion in healthy adults

Paper	Measure	Total no. of measurements	Age	M:F	Mean torsion° right:left	Standard deviation R:L
Elftman [61]	Cadaver	35		All male	27.4	1.25
Gandhi [62]	Cadaver	100		50:50	29.38:28.06	4.95:4.58
Hutter [1]	Cadaver	40			22.1:19.8	
Yoshioka [15]	Cadaver	31	61–89	14:1	24	9.3
Butler-Manuel[63]	Cadaver	21			36.3	6.3
LeDamany [8]	Cadaver	100		50:50	23.7	
Turner [5]	Tropometre				19	4.8
Malekafzali [64]	Physical exam	100			14.5:14	
Tamari [17]	Clinical	404		1:1.5	43.1	9.7
Hutchins [16]	Torsiometre	112	17–25	1:1	17.4	2.5
Clementz [65]	Fluoroscopy	100			30.77:28.6	7.8:7.6
Hudson [24]	Ultrasound	102	29.1	43:59	21.6	8
Schneider [9]	MRI	98			41.	8.8
Larson [66]	CT	100			23.5:23.1	
Eckhoff [11]	CT	448			38:33	11:9
Strecker [12]	CT	504			36.4:33.0	15.9
Jakob [67]	CT	45			30	
Waidelich [68]	CT	19			33.1	8
Liodakis [41]	CT	8			28.5	7.6
Vanhove [14]	CT	98	64	2:1	25.5:27.8	7.7:7.6
Mullaji [13]	CT	50	31.3	42:8	21.6	7.6
Yagi [6]	CT	24	59.9	1:2	23.5	5.1
Jend [69]	CT	70			40	9
Reikeras [70]	CT	100	37	48:52	33	
Erkocak [71]	CT	40			26	4.2

population. Furthermore, the age of the individual is also much higher in cadaver specimens than those measured by examination or imaging. Imaging studies probably provide the best compromise, in that they have acceptable accuracy, are readily available and the population can be selected.

Higher levels of tibial torsion in the right leg compared to the left (1,8), (11), (12–14) have been reported but there appear to be no gender differences (15) (16). Authors have suggested that torsion does change with age (13). With mechano-adaption, rotational remodelling may continue throughout life and potentially adapt to localized pathologies, e.g. osteoarthritis. Tamari et al. (17) demonstrated tibiofibular torsion was significantly larger in a younger and middle age group compared to an older age group of females, whereas there were no significant age-related differences in the male subjects. It was proposed that postmenopausal osteoporosis may cause a deformity in the proximal part of the tibia contributing to the age-related difference.

Based on the anthropometric and cadaver data, clinical and imaging studies, a range of 24° to 30° seems to correspond to normal values for external tibial torsion for patients of European origin.

Cultural Differences

Geographical and cultural variations appear to exist in the normal levels of tibial torsion; therefore, European values cannot be applied universally. Weinberg et al. (18) studied 577 cadavers (1158 tibia), with a mean age of 56; there were 398 Whites and 179 African Americans. African Americans were found to have significantly increased tibial torsion compared with Whites.

Kristen et al. (19) found a significant difference between 22 Japanese and 41 Caucasian subjects using axial MRI. Tibial torsion was 39.88° (SD ± 8.88) for the Caucasian population and 33.48° (SD ± 10.08) for the Japanese subjects. Tibial torsion has also been found to be significantly lower in a Japanese population with knee OA compared with their counterparts in Australia (20) and Saudi Arabia respectively (21),(22). It has been proposed that this consistently lower torsion is potentially linked to the Japanese culture of Seiza sitting. Similar and as yet unknown variations may exist among many other cultures throughout the world, as a consequence of environmental factors.

Biomechanical Effects of Torsion

Isolated tibial torsion can lead to a variety of secondary compensatory or induced kinematic abnormalities during gait (23),(24). These may be subtle and multilevel in nature may be variable across subjects and may include coupled pelvic rotation and hip abduction/adduction; hip, knee and ankle transverse rotations and contralateral limb compensation. Maximum compensation occurs at the hip and then becomes less effective, proceeding distal to the foot, wherein the foot minimally compensates through midfoot pronation (25•).

The foot progression angle (FPA) represents the angular difference between the axis of the foot with the direction in which an individual is walking and in healthy adults, it has been shown to be 4.5 (± 5.8) degrees (24). Isolated tibial torsion leads to an increased FPA; however, this is reduced with compensatory internal rotation of the hip (26••). The result is the inward-pointing knee and the typical “knee in” gait (Fig. 1). This compensatory mechanism creates a dynamic valgus and a resultant valgus vector on the patella (25•). As long as there is adequate internal and external hip rotation (normally equal), minor to moderate degrees of abnormal lower limb alignment can be tolerated. Gait analysis has shown that walking in a toe-out manner leads to reduced ankle power (27), lower ankle inversion and a lower knee adduction moment than when walking with feet pointed forward, supporting the presence of dynamic valgus. An external rotation deformity of 10° and 25° is needed to increase the abduction moments by 1 and 2 SD relative to the norm (27).

On axial loading in a cadaver model, medial compartment contact pressure increased by 17.7% and 4.9% at 15° and 30° tibial internal rotation, respectively. Conversely, medial compartment contact pressure at 15° external rotation decreased by 10.8% and increased in the lateral compartment by 22.8% (29). This is consistent with the work of Hudson (30), who found a higher medial bone mineral density of the proximal tibia, and was related to internal tibial torsion, limited hip rotation and high medial knee joint loads of healthy knees. These increased forces in the medial compartment with increasing internal tibial torsion likely explain the numerous observational studies that have shown a consistent increased incidence of medial OA in patients with reduced external tibial rotation (5),(21),(31),(20). Yagi et al. (21) actually found a correlation between tibial torsion and the severity of OA; external torsion was 14.1° for mild, 11.9° for moderate and 7.5° for severe stages of osteoarthritis. These torsional changes are thought to occur as a consequence of gait mechanics, rather than as a consequence of developmental predisposition. The location of the compensatory reduced external rotation has been reported in the proximal (6) and distal tibia (32). These findings have potential implications for patients who are overcorrected following surgery.

Excess tibial torsion can alter the capacity of muscles to accelerate joints in the sagittal plane at the knee and hip. Hicks (4) demonstrated using computer modelling that excessive tibial torsion diminished the capacity of the gluteals and soleus to extend the hip and knee by altering the skeletal platform on which the muscles act, thus reducing their capacity to support an upright posture during gait. De-rotational osteotomy has been shown to normalize the FPA and knee adduction moment (26••),(27) resulting in a more “symmetrical,” gait with

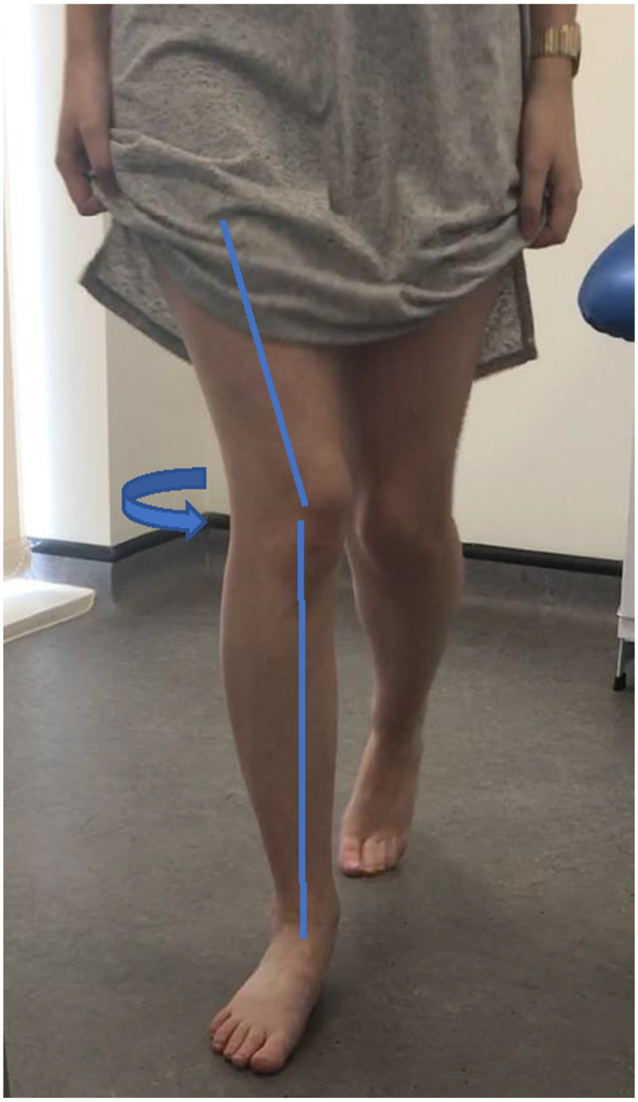

Fig. 1 Clinical picture demonstrating the inward-pointing knee and the typical "knee in" gait of a patient with tibial torsion. Compensatory internal rotation of the hip results in a dynamic valgus and a resulting lateral vector on the patella. Typical gait pattern of increased FPA and the knee pointing inwards (as a result of compensatory hip internal rotation) during stance phase resulting in a dynamic valgus

less variation. This requires less joint compensation to keep the foot pointed straight ahead and the patella tracking central. The valgus vector on the patella is significantly reduced and patellar instability is minimized. Alexander (26••) noted that in patients who demonstrated significant compensatory hip internal rotation pre-operatively, this continued at a mean of 15 months post-correction. The combination of hip internal rotation and resultant slight knee varus increased hip and knee adduction moments. It is unclear when or if the compensatory hip rotation improves post-surgery and this needs to be targeted with rehabilitation. If only the tubercle is moved and the tibia is not de-rotated, then the potential for more joint incongruity and increased joint reaction force is created (25•).

Clinical Examination

A history of patellofemoral instability, pain and activity-related symptoms should be documented. External tibial torsion can be screened firstly by noting the appearance of squinting patella or an inwardly pointing knee while the patient is standing. This condition has been ascribed mainly to femoral anteversion, but it can also be caused by primary external tibial torsion (33),(21). The foot position and coronal alignment of the knee should be noted. Gait should be observed to determine foot and knee position during the stance phase, in order to assess the dynamic component of a malrotated foot. With compensatory internal rotation at the hip, the knee will move inwards during stance; conversely, with little compensation or in severe cases, there will be an increased FPA. Using CT, FPA showed a strong correlation with tibial torsion but very weak correlation with femoral torsion (23).

An initial screening test for tibial torsion can be performed with the patient supine. Hip internal and external rotation is first examined in 90° of hip flexion and then in neutral flexion (0 degrees) with the foot perpendicular to the ground. In 90° of flexion, the internal and external rotations should be symmetrical, while in neutral, the internal rotation will be grossly restricted, while the external rotation will be excessive. The mismatch in internal and external rotation between hip flexion and neutral should alert the clinician to the likelihood of external tibial torsion. This test distinguishes tibial torsion from femoral anteversion, where the mismatch between internal and external rotation persists both in hip flexion and extension (34).

The 3 most commonly described techniques to specifically measure tibial torsion are the thigh-foot angle (TFA), the transmalleolar axis (TMA) (35) and the second toe test (36) (Figs. 2 and 3). Because of anatomic variations, surface landmarks may not consistently represent the tibial rotational alignment. Milner and Soames (37) showed poor repeatability of the TFA and 3 variations of the TMA in 10 cadaveric tibiae and 3 living subjects. Lee (38) determined that the interobserver reliability and concurrent validity with CT were highest for TMA, followed by TFA, and then the second toe test.

Imaging Assessment of Tibial Torsion

Specific imaging studies are required to quantify a rotational deformity. Plain X-rays cannot quantify torsion, but when tibial torsion is marked, radiographs may show the femur in the antero-posterior projection and the tibia in the oblique projection or vice versa.

A CT rotational profile involving slices through the hip, knee and ankle enables quantification of both femoral and tibial rotational deformities. Proximally, the tibia can either be measured using the posterior axis or the transcondylar axis

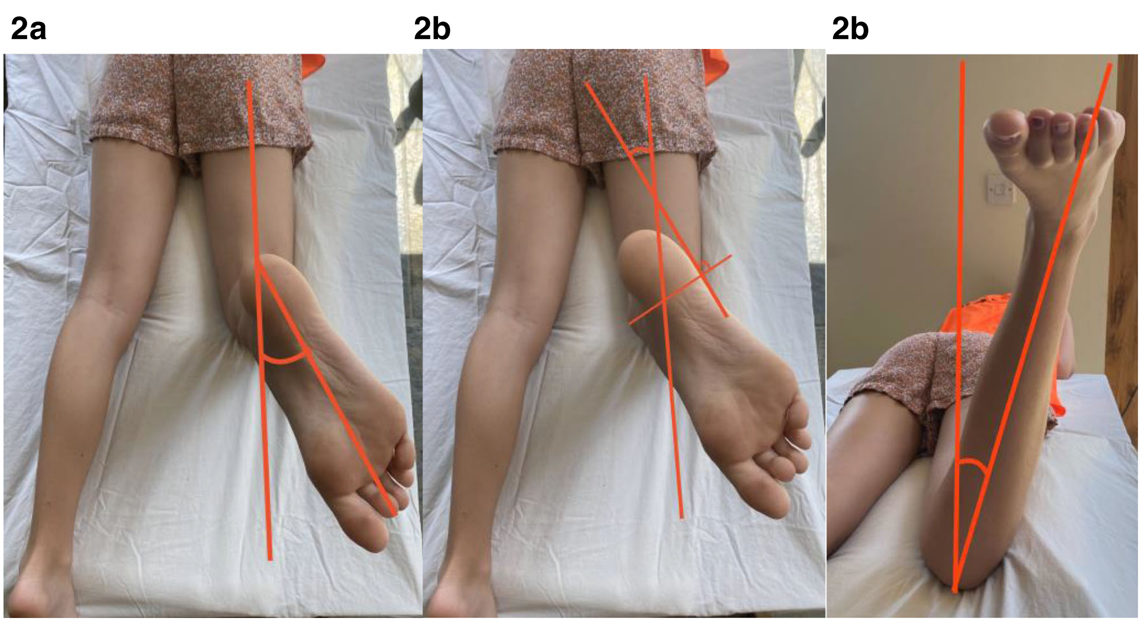

Fig. 2 Measurement of the **a** TFA; the angle between the longitudinal axis of the thigh and the longitudinal axis through the 2nd metatarsal with the foot held in subtalar neutral **b** TMA; the angle between the longitudinal axis of the thigh and a line perpendicular to the axis connecting the most prominent portions of the medial and lateral malleolus. **c** Second toe test: the patient is prone with the knee extended; the hip is rotated until the 2nd toe points directly towards the floor; the knee is then flexed to 90° while preventing a change in thigh rotation; the angle between the vertical and the tibial longitudinal axes is the degree of tibial torsion

(11). The posterior axis is defined as the line joining the two most posterior points of the plateau and the transcondylar axis is the line between the widest points of the tibial condyles. Distally either a trans-tibial (11) or bimalleolar axis (39) is used. The trans-tibial axis is defined by drawing a line on the distal articular surface of the tibia connecting the tip of the medial malleolus to the mid-point of the lateral border (fibular sulcus) (Fig. 3).

Reader error is the main source of error; Panou (40) demonstrated that CT measurements were dependent on reader experience. Proximally, there is no significant difference in torsion measured by the posterior condylar axis versus the trans-tibial axis (11). In the distal end of the tibia, the bimalleolar axis provides higher interobserver and intraobserver reliability than the trans-tibial (41) methods.

EOS is a low-dose biplanar radiographic imaging system manufactured by EOS imaging (formerly Biospace Med, Paris, France) and was first clinically applied in 1998 for paediatric hip and spine diseases. Yan (42) showed no statistical differences between tibial torsion measured using the EOS system and 3D CT in 18 healthy individuals. These findings have also been confirmed with 2D CT (43),(44). The potential advantages of EOS are its ability to also measure the mechanical axis weight-bearing and its low radiation doses (3 to 43 times less than a X-ray and 4 to 87 less than CT) (45•). Limitations include post-processing user errors, high capital costs and difficulty modelling patients who have severe deformities.

MRI has been used to measure rotational profiles in children with good reproducibility (46,47); however, little work has been done comparing tibial torsion to other modalities in adults. MRI has been compared to EOS for tibial torsion assessment in 2 studies, with MRI measuring on average 5° lower in one (48) and 3° in another (43). More work is needed to determine if measurements of tibial torsion on MRI are comparative to CT and if the same levels of torsion can be used as indicators of correction. CT for now should be considered to be the gold standard; however, EOS offers significant promise for the future.

Indications for Surgical Correction

The detection of a torsional deformity is not an indication for a rotational osteotomy. Primarily, patients must have significant physical symptoms despite targeted physical therapy and non-surgical strategies. Commonly, patients have a number of anatomical predisposing factors and it needs to be determined if the tibial torsion is the dominant cause of symptoms.

As previously discussed, the normal values for tibial torsion are variable among the population and therefore, it is difficult to set an absolute value at which tibial torsion should be corrected. Not all studies define their indication for surgery or quantify the level of torsion with pre-operative CT. The majority of studies reporting post-osteotomy outcomes state that osteotomy was indicated with a foot thigh angle of greater than 30° on examination

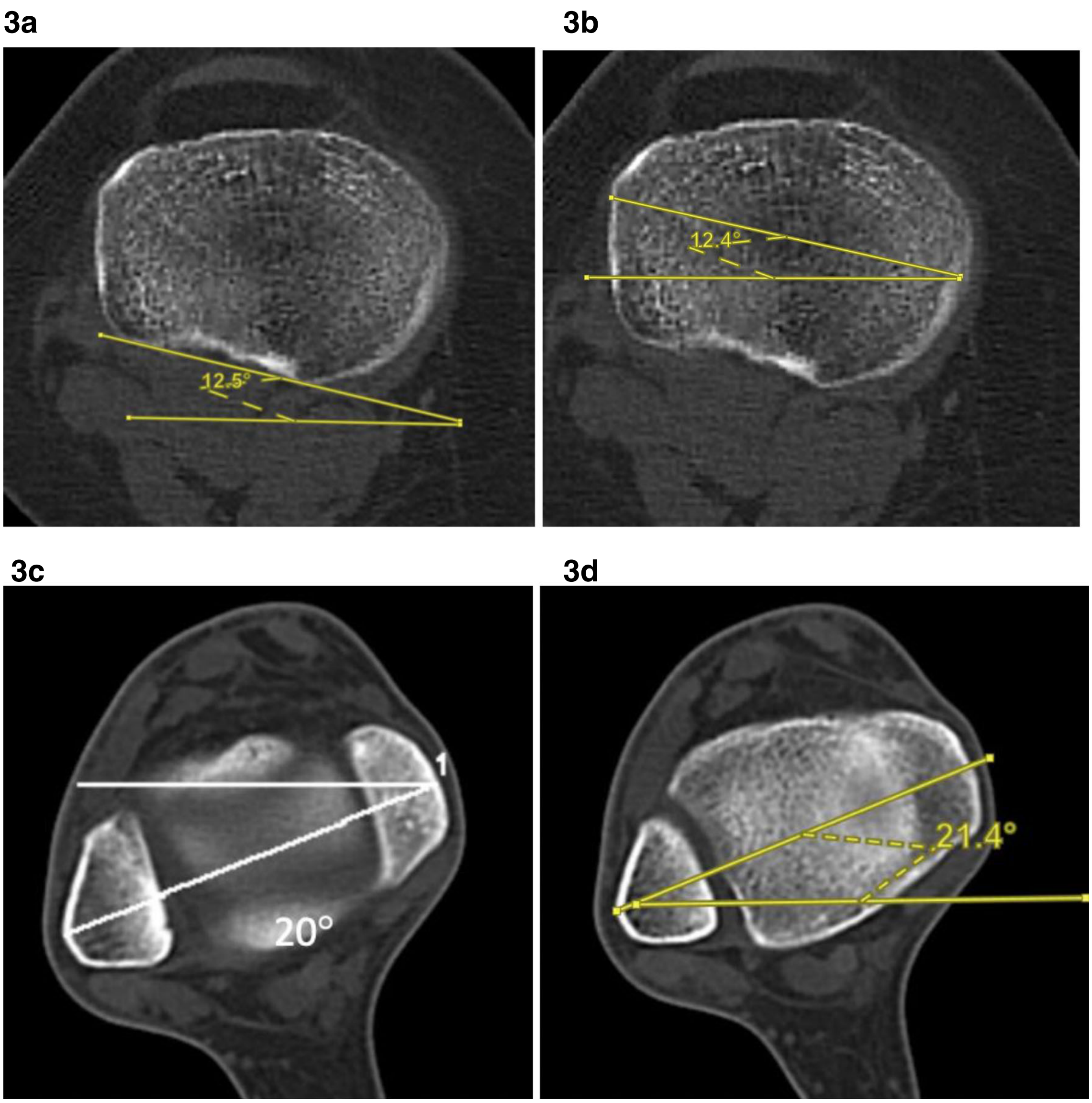

Fig. 3 **a** Proximal posterior axis—line the contour of the posterior condyles. **b** Transcondylar axis across the widest diameter of the tibial condyles. **c** Distal bimalleolar axis—drawn in a cut just below the tibial pilon's articular surface, with the medial and lateral malleoli and talar dome evident between the centres of the dense surfaces of the malleoli. **d** Distal trans-tibial axis, a line on the distal articular surface of tibia connecting the tip of the medial malleolus to the mid-point of the lateral border (fibular sulcus)

(25•,26–49,50),29]. From the studies that have quantified the deformity on CT, the level at which correction was carried out was variable and is difficult to interpret, as authors commonly fail to state what they consider to be normal values for torsion. Thresholds as low as 5° more than normal (52) have been used, with other studies recommending correction when torsion is 20° more than normal (53),(27). Fouilleron et al. (54) and Server (55) placed an absolute value of 30° torsion as an indication for corrective osteotomy. The authors' indication is if the bimalleolar axis of the distal tibia is greater than 50° relative to the distal femoral angle.

Surgical Technique: Proximal or Distal

The Tibia can be divided into two segments based on the two different sites for rotational osteotomy proposed: proximal metaphysis and distal metaphysis.

Proximal supra-tubercle osteotomy principally has the advantage of being able to simultaneously correct the tibial tubercle to trochlea groove (TTTG) distance and or patella height in patients with an associated abnormality. The TTTG distance can be corrected with or without removing the tibial tubercle. Computer modelling has shown that the TTTG distance reduces by 0.68 mm per degree of tibial correction (56).

This formula can help predict if the tibial correction alone is sufficient to correct the TTTG distance or conversely if it will overcorrect in patients with a normal TTTG pre-operatively.

Supra-tubercle osteotomy reduces the valgus forces on the patella even during non-weight-bearing activities, such as jumping and the swing-through phases of walking and running. Conversely, infra-tubercle osteotomy functions only during weight-bearing activities. By correcting the TTTG angle simultaneously with tibial torsion, the surgeon partially corrects femoral torsion as the need for functional hip compensation is diminished. Supra-tubercle osteotomy has the added advantage of compression from the extensor mechanism, through the large surface area of the proximal tibia, increasing stability and facilitating healing. Finally, there is the opportunity to simultaneously correct coronal mal-alignment of the knee if required (51).

The need for fibula osteotomy has been questioned by authors for both proximal and distal osteotomy (53,57,58). Undertaking a fibula osteotomy or a disruption of the proximal tibia-fibula joint appears to reduce the tension at the osteotomy site enabling easier correction. Paulos reported in a cadaver model that partial fibula head excision and posterior capsular release increased internal tibial rotation by 15°, while the torque to hold correction was reduced by approximately 50% (25•). Jud et al. used patient-specific instrumentation (PSI) to assist with rotational correction in 12 distal femur and seven tibia (59). In all tibial rotational osteotomies, an undercorrection was noted of 10.3 ± 4.4° compared to a difference of planned correction in the femur of 5.4 ± 2.7°. This consistent undercorrection was thought to be a consequence of not undertaking a fibula osteotomy.

Distal osteotomy is perceived to be technically easier and safer with regard to neurovascular injury. It is commonly performed in the skeletally immature and in post-traumatic cases of mal-rotation. The osteotomy is then stabilized with a variety of methods including plate fixation, external fixation and IM nail.

Results of Correction

Proximal Osteotomy

There are a number of studies that have reported good results with a proximal supra-tubercle osteotomy (25•,26–49,50,54,55,60), which is the most common osteotomy reported in adults. Fouilleron reported a retrospective series of 36 supra-tubercle osteotomies, performed in association with a fibular neck osteotomy (54). Seven patients (24.1%) had a history of previous surgery on the extensor apparatus, and the mean de-rotation was 25°. There were 3 complications: 1 deep vein thrombosis, 1 peroneal nerve palsy that resolved and 1 stiff knee that required manipulation. The Lille and IKS score significantly improved and no significant differences were found in cases with femoral anteversion of > 20°, suggesting that the need for simultaneous correction of any associated femoral anteversion is not required in the majority of patients. Of note is that only 58% of patients returned to sport at the same level post-surgery.

Paulos et al. (25•) compared 12 patients who underwent a supra-tubercle and de-rotational high tibial osteotomy (D-HTO) with a historical group of 13 patients who underwent an Elmslie-Trillat-Fulkerson realignment procedure. Rotational osteotomy resulted in significantly greater improvement in KOOS and Kajula score compared to isolated tubercle osteotomy. Gait analysis also revealed rotational osteotomy patients had more symmetrical gait patterns, with less variability and less compensatory gait changes.

Drexler and Cameron (49) reported the results of a combined supra-tubercle osteotomy and tibial tuberosity transfer in 15 knees presenting with patella subluxation, secondary to excessive external tibial torsion. The median follow-up period was 84 months and a median rotational correction of 36° was performed. Significant improvement was found in the knee severity score, Kujala score, the SF-12 outcome, WOMAC score and VAS score. Two patients had a non-union of the tibial osteotomy site with varus collapse; one patient required bone grafting, while another patient required revision to total knee arthroplasty. Overall, 91% were rated as good or excellent overall. Cameron et al. (50) have also reported similar results in a group of 17 patients with previous failed tibial tubercle osteotomy. However, knees that had undergone multiple unsuccessful surgical procedures had significantly poorer outcomes ($p < 0.01$), stressing the importance of making the diagnosis of tibial torsion early in the treatment pathway. Patients with less painful symptoms pre-operatively had significantly better outcomes ($p < 0.01$). Age, sex, degree of tibial torsion, presence of femoral trochlear dysplasia and patellar height did not affect results. It is the author's preferred technique to undertake a proximal osteotomy with a tibial tubercle osteotomy. The proximal tibia-fibula joint is dislocated and the osteotomy is stabilised with a low profile locking plate.

Distal Osteotomy

Stotts and stevens (58) reported the results of mid-diaphyseal osteotomy, using an intra-medullary nail in 59 patients at 22.6-month follow-up. The mean torsion was 40.2° and no fibula osteotomy was performed. The rotational correction averaged 28.8°, with 83.1% of patients having a contemporaneous lateral patellar release. Major complications were present in 5 patients (8.5%). They included peroneal nerve palsy, infection, non-union and refracture of the osteotomy. At the final follow-up, 76.3% of patients had no pain in the extremity, and 2 out of 8 patients had residual patellar instability; no outcome scores were performed. In total, 85.2% of patients required nail removal.

Stevens et al. (53) retrospectively reported 16 consecutive patients (22 knees), with a mean age of 17, who had all undergone knee surgery prior to distal osteotomy (and femur in 36%) using a IM nail. Knee pain was significantly improved after torsional treatment (8.6 pre-op vs. 3.3 post-op), 70% of patients had some continued knee pain and 43% had continued patellar instability after torsional treatment. Activity level was improved in 65% of cases, remained the same n 13% and was decreased after 20%. No validated outcome scores were reported but the authors concluded that compared to their previously reported outcomes, (10 years prior) where rotational correction was the primary surgery, inferior outcomes occur when performed for revision surgery.

Few studies report performing associated procedures with rotational osteotomy, even when treating instability. Paulos (25•) et al. routinely performed a medial retinacula reinforcement with suture but no study undertook a formal MPFL reconstruction or trochleoplasty. The lateral release was performed in select cases (58) (53) or routinely (55)(50) by a number of authors, with universally good results. No study reported a correlation between associated procedures and outcomes.

Conclusions

Tibial torsion should be considered as a potential cause of patellofemoral dysfunction in the adult population. Surgical correction in patients in whom torsion is diagnosed as the dominant cause of patella pain and instability produces good results. However, results deteriorate in patients who have undergone multiple prior surgeries, highlighting the importance of early recognition.

Compliance with Ethical Standards

Conflict of Interest Martyn Snow declares that he has no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:
- • Of importance
- •• Of major importance

1. Hutter C, Scott W. Tibial torsion. J Bone Joint Surg. 1949;31A: 511–8.
2. Staheli L. Torsional deformity. Pediatr Clin N Am. 1977;24:799–811.
3. Fabry G, Cheng LX, Molenaers G. Normal and abnormal torsional development in children: Clin Orthop. 1994 May;NA;(302):22–26.
4. Hicks J, Arnold A, Anderson F, Schwartz M, Delp S. The effect of excessive tibial torsion on the capacity of muscles to extend the hip and knee during single-limb stance. Gait Posture. 2007 Oct;26(4):546–52.
5. Turner MS. The association between tibial torsion and knee joint pathology. Clin Orthop. 1994 May;302:47–51.
6. Yagi T, Sasaki T. Tibial torsion in patients with medial-type osteoarthritic knee. Clin Orthop. 1986 Dec;213:177–82.
7. Staheli L. Lower extremity rotational problems in children. J Bone Joint Surg. 1985;67A:39.
8. LeDamany P. La torsion de tibia, normale. Da- thologique, experimentale. J Anat et Physiol. 1909;45:598.
9. Schneider M. The effect of growth on femoral torsion. An experimental study in dogs. J Bone Joint Surg. 1963;45A:1439.
10. Yang P-F, Kriechbaumer A, Albracht K, Sanno M, Ganse B, Koy T, et al. On the relationship between tibia torsional deformation and regional muscle contractions in habitual human exercises in vivo. J Biomech. 2015 Feb;48(3):456–64.
11. Eckhoff DG, Kramer RC, Watkins JJ, Burke BJ, Alongi CA, Stamm ER, et al. Variation in tibial torsion. Clin Anat. 1994;7(2):76–9.
12. Strecker W, Keppler P, Gebhard F, Kinzl L. Length and torsion of the lower limb. J BONE Jt Surg. 1997;79(6):5.
13. Mullaji A, Sharma A, Marawar S, Kohli A. Tibial torsion in non-arthritic Indian adults: a computer tomography study of 100 limbs. Indian J Orthop. 2008;42(3):309–13.
14. Vanhove F, Noppe N, Fragomen AT, Hoekstra H, Vanderschueren G, Metsemakers W-J. Standardization of torsional CT measurements of the lower limbs with threshold values for corrective osteotomy. Arch Orthop Trauma Surg. 2019 Jun;139(6):795–805.
15. Yoshioka Y, Siu DW, Scudamore RA, Cooke TDV. Tibial anatomy and functional axes. J Orthop Res. 1989 Jan;7(1):132–7.
16. Hutchins PM, Rambicki D, Comacchio L, Paterson DC. Tibiofibular torsion in normal and treated clubfoot populations. J Pediatr Orthop. 1986 Aug;6(4):452–5.
17. Tamari K, Tinley P, Briffa K, Aoyagi K. Ethnic-, gender-, and age-related differences in femorotibial angle, femoral antetorsion, and tibiofibular torsion: cross-sectional study among healthy Japanese and Australian Caucasians. Clin Anat. 2005;19(1):59–67.
18. Weinberg DS, Park PJ, Morris WZ, Liu RW. Femoral version and tibial torsion are not associated with hip or knee arthritis in a large osteological collection. J Pediatr Orthop. 2017;37(2):e120–8.
19. Hovinga KR, Lerner AL. Anatomic variations between Japanese and Caucasian populations in the healthy young adult knee joint. J Orthop Res Off Publ Orthop Res Soc. 2009;27(9):1191–6.
20. Tamari K, Briffa NK, Tinley P, Aoyagi K. Variations in torsion of the lower limb in Japanese and Caucasians with and without knee osteoarthritis. J Rheumatol. 2007 Jan;34(1):145–50.
21. Yagi T. Tibial torsion in patients with medial-type osteoarthrotic knees. Clin Orthop. 1994;302:52–6.
22. Moussa M. Rotational malalignment and femoral torsion in osteoarthritic knees with patellofemoral joint involvement. Clin Orthop. 1994;304:176–83.
23. Radler C, Kranzl A, Manner HM, Höglinger M, Ganger R, Grill F. Torsional profile versus gait analysis: consistency between the anatomic torsion and the resulting gait pattern in patients with rotational malalignment of the lower extremity. Gait Posture. 2010 Jul;32(3):405–10.
24. Hudson D. The rotational profile: a study of lower limb axial torsion, hip rotation, and the foot progression angle in healthy adults. Gait Posture. 2016;49:426–30.
25.• Paulos L, Swanson SC, Stoddard GJ, Barber-Westin S. Surgical correction of limb malalignment for instability of the patella: a comparison of 2 techniques. Am J Sports Med. 2009;37(7): 1288–300 **Whilst published 11years ago, it is the only trial to**

compare outcomes of tibial de-rotational osteotomy and isolated tibial tubercle osteotomy.

26.•• Alexander N, Wegener R, Lengnick H, Payne E, Klima H, Cip J, et al. Compensatory gait deviations in patients with increased outward tibial torsion pre and post tibial derotation osteotomy. Gait Posture. 2020;77:43–51 **Summarises the biomechanical consequences of tibial torsion and the compensatory mechanisms associated with it. Also provides some inside as to the biomechanical benefit of corrective ostetomy**.
27. MacWilliams BA, McMulkin ML, Baird GO, Stevens PM. Distal tibial rotation osteotomies normalize frontal plane knee moments. J Bone Jt Surg-Am Vol. 2010;92(17):2835–42.
28. Andrews M, Noyes FR, Hewett TE, Andriacchi TP. Lower limb alignment and foot angle are related to stance phase knee adduction in normal subjects: a critical analysis of the reliability of gait analysis data. J Orthop Res. 1996;14(2):289–95.
29. Yazdi H, Mallakzadeh M, Sadat Farshidfar S, Givehchian B, Daneshparvar H, Behensky H. The effect of tibial rotation on knee medial and lateral compartment contact pressure. Knee Surg Sports Traumatol Arthrosc. 2016 Jan;24(1):79–83.
30. Hudson D, Royer T, Richards J. Bone mineral density of the proximal tibia relates to axial torsion in the lower limb. Gait Posture. 2007;26(3):446–51.
31. Bombaci H. Tibial torsion: cause or consequence of osteoarthritis? Acta Orthop Traumatol Turc. 2012;46(3):181–5.
32. Mochizuki T, Tanifuji O, Koga Y, Hata R, Mori T, Nishino K, et al. External torsion in a proximal tibia and internal torsion in a distal tibia occur independently in varus osteoarthritic knees compared to healthy knees. J Orthop Sci. 2017;22(3):501–5.
33. Cooke TD, Price N, Fisher B, Hedden D. The inwardly pointing knee. An unrecognized problem of external rotational malalignment. Clin Orthop. 1990;260:56–60.
34. Ramaswamy R, Kosashvili Y, Murnaghan JJ, Yau CK-M, Cameron JC. Bilateral rotational osteotomies of the proximal tibiae and tibial tuberosity distal transfers for the treatment of congenital lateral dislocations of patellae: a case report and literature review. Knee. 2009;16(6):507–11.
35. Staheli LT, Corbett M, Wyss C, King H. Lower-extremity rotational problems in children. Normal values to guide management. J Bone Joint Surg Am. 1985;67(1):39–47.
36. Gage J, Schwartz M, Koop S. The identification and treat- ment of gait problems in cerebral palsy. 2nd ed. Mac Keith Press; 2009.
37. MILNER CE, SOAMES RW. A comparison of four in vivo methods of measuring tibial torsion. J Anat. 1998;193(Pt 1):139–44.
38. Lee S, Chung C, Park M, Choi T. Tibial torsion in cerebral palsy: validity and reliability of measurement. Clin Orthop Relat Res. 2009;467(8):2098–104.
39. Goutallier D, Van Driessche S, Manicom O, Sariali E, Ali ES, Bernageau J, et al. Influence of lower-limb torsion on long-term outcomes of tibial valgus osteotomy for medial compartment knee osteoarthritis. J Bone Joint Surg Am. 2006;88(11):2439–47.
40. Panou A, Stanitski DF, Stanitski C, Peccati A, Portinaro NM. Intraobserver and inter-observer errors in CT measurement of torsional profiles of lower limbs: a retrospective comparative study. J Orthop Surg. 2015;10(1):67.
41. Liodakis E, Doxastaki I, Chu K, Krettek C, Gaulke R, Citak M, et al. Reliability of the assessment of lower limb torsion using computed tomography: analysis of five different techniques. Skelet Radiol. 2012;41(3):305–11.
42. Yan W, Xu X, Xu Q, Yan W, Sun Z, Jiang Q, et al. Femoral and tibial torsion measurements based on EOS imaging compared to 3D CT reconstruction measurements. Ann Transl Med. 2019;7(18):460–0.
43. Buck FM, Guggenberger R, Koch P. Femoral and tibial torsion measurements with 3D models based on low- dose biplanar radiographs in comparison with standard CT measurements. AJR Am J Roentgenol. 2012;199:607–12.
44. folinais D, Theklen P, Delin C, Radier C, Catonne Y, Lazennec J. Measuring femoral and rotational alignment: EOS system versus computed tomography. Orthop Traumatol Surg Res. 2013;99(5):509–16.
45.• Shih YC, Chau MM, Arendt EA, Novacheck TF. Measuring lower extremity rotational alignment: a review of methods and case studies of clinical applications. J Bone Jt Surg. 2020;102(4):343–56 **Review article which summarises the different radiological measurement techniques for both tibial and femoral rotation**.
46. Guenther KP, Tomczak R, Kessler S, Pfeiffer T, Puhl W. Measurement of femoral anteversion by magnetic resonance imaging–evaluation of a new technique in children and adolescents. Eur J Radiol. 1995;21(1):47–52.
47. Muhamad AR, Freitas JM, Bomar JD, Dwek J, Hosalkar HS. CT and MRI lower extremity torsional profile studies: measurement reproducibility. J Child Orthop. 2012;6(5):391–6.
48. Rosskopf AB, Buck FM, Pfirrmann CWA, Ramseier LE. Femoral and tibial torsion measurements in children and adolescents: comparison of MRI and 3D models based on low-dose biplanar radiographs. Skelet Radiol. 2017;46(4):469–76.
49. Drexler M, Dwyer T, Dolkart O, Goldstein Y, Steinberg EL, Chakravertty R, et al. Tibial rotational osteotomy and distal tuberosity transfer for patella subluxation secondary to excessive external tibial torsion: surgical technique and clinical outcome. Knee Surg Sports Traumatol Arthrosc. 2014;22(11):2682–9.
50. Cameron JC, Saha S. External tibial torsion: an underrecognized cause of recurrent patellar dislocation. Clin Orthop. 1996;328:177–84.
51. Krengel WF, Staheli LT. Tibial rotational osteotomy for idiopathic torsion. A comparison of the proximal and distal osteotomy levels Clin Orthop 1992;(283):285–289.
52. Schröter S, Elson DW, Ateschrang A, Ihle C, Stöckle U, Dickschas J, et al. Lower limb deformity analysis and the planning of an osteotomy. J Knee Surg. 2017;30(5):393–408.
53. Stevens PM, Gililland JM, Anderson LA, Mickelson JB, Nielson J, Klatt JW. Success of torsional correction surgery after failed surgeries for patellofemoral pain and instability. Strateg Trauma Limb Reconstr. 2014;9(1):5–12.
54. Fouilleron N, Marchetti E, Autissier G, Gougeon F, Migaud H, Girard J. Proximal tibial derotation osteotomy for torsional tibial deformities generating patello-femoral disorders. Orthop Traumatol Surg Res. 2010;96(7):785–92.
55. Server F, Miralles RC, Garcia E, Soler JM. Medial rotational tibial osteotomy for patellar instability secondary to lateral tibial torsion. Int Orthop. 1996;20(3):153–8.
56. Jud J, Singh S, Tondelli T, Fürnstahl P, Fucentese SF, Vlachopoulos L. Combined correction of tibial torsion and tibial tuberosity-trochlear groove distance by supratuberositary torsional osteotomy of the tibia. Am J Sports Med. 2020.
57. Erschbamer M, Gerhard P, Klima H, Ellenrieder B, Zdenek-Lehnen K, Giesinger K. Distal tibial derotational osteotomy with external fixation to treat torsional deformities: a review of 71 cases. J Pediatr Orthop B. 2017;26(2):179–83.
58. Stotts AK, Stevens PM. Tibial rotational osteotomy with intramedullary nail fixation. Strateg Trauma Limb Reconstr. 2009;4(3):129–33.
59. Jud L, Vlachopoulos L, Beeler S, Tondelli T, Fürnstahl P, Fucentese SF. Accuracy of three dimensional-planned patient-specific instrumentation in femoral and tibial rotational osteotomy for patellofemoral instability. Int Orthop [Internet]. 2020 13 [cited 2020 Mar 28]; Available from: https://doi.org/10.1007/s00264-020-04496-y
60. Strecker W, Dickschas J. Torsional osteotomy: operative treatment of patellofemoral maltracking. Oper Orthop Traumatol. 2015;27: 505–24.