Does the Surgical Correction of Tibial Torsion with Genu Varum Produce Outcomes Similar to Those in Varus Correction Alone?

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Abstract

The aim of this article is to study the relationship between tibia vara and external tibial torsion in adults. The following questions were asked: (1) what is the incidence of rotational deformity in patients with genu varum and (2) do patients who undergo correction of tibial torsion with genu varum have similar outcomes to those who undergo simple tibia vara correction? In this study, 69 patients (138 limbs) underwent bilateral proximal tibial osteotomy for the correction of genu varum. Patients with simple coronal plane deformity (varus alone) were treated with either a monolateral external fixator or a hexapod frame. Those with concomitant external tibial torsion were treated with circular external fixation. The primary outcome was the ability to achieve the desired correction of alignment in the coronal, sagittal, and axial planes. Secondary outcomes included a postoperative Knee Injury and Osteoarthritis Outcome Score (KOOS) and a routine patient satisfaction questionnaire. The incidence of tibial torsion among the entire group of patients with bilateral tibia vara was 46% and overwhelmingly external in direction. The two groups had some significant differences in demographics with torsion patients tending to be younger and thinner. The final mechanical axis deviation and medial proximal tibial angle values for both groups did not differ significantly ($p = 0.956$). The postcorrection thigh–foot axis was not significantly different between the two groups ($p = 0.666$). Time to union was not significant ($p > 0.999$). KOOS was not different between the two groups in symptoms, pain, activities of daily living, and return to sport. There was a difference in the quality of life score between the two groups ($p = 0.044$). There was no difference between the two groups regarding the patient questionnaire. Based on the finding of this analysis, the incidence of rotational malalignment with genu varum is close to 50%. The recognition of this close association with external tibial torsion deformity may allow for further insights into the role of rotation in varus deformity-related knee pathology and treatment. Patients can expect nearly identical outcomes from this surgery.

Keywords
- ► external tibial torsion
- ► miserable malalignment
- ► genu varum
- ► varus

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Genu varum is a common malalignment that causes excessive loading of the medial compartment of the knee[1] and increases the incidence of arthritis.[2] Patients with medial compartment osteoarthritis and a medial mechanical axis deviation (MAD) have been suitable candidates for high (proximal) tibial osteotomy where both decreased knee pain and impedance of arthritic progression have been observed.[3,4] Recently, osteotomy has been used to correct tibial deformity with great accuracy prior to the onset of knee osteoarthritis.[5] Proximal tibial osteotomy (PTO) improved knee pain and was thought to prevent the development of arthritis.[5] We have noticed in our practice that many patients who present with congenital genu varum have an associated tibial malrotation. Despite a copious amount of literature about the varus knee and successful treatments ranging from tibial osteotomy to knee replacement, little attention has been directed toward concomitant tibial torsion. In general, treatments for tibia vara are successful at restoring coronal alignment[5–7] but ignore axial malrotation. Fouilleron et al reported on a technique to correct both varus and rotation but did not compare this to varus correction alone.[8] Some of the effects of external tibial torsion have been elucidated[9,10] but more likely exist. It is plausible that the correction of genu varum without addressing tibial torsion will lead to an inferior outcome. The aim of this article is to study the relationship between tibia vara and tibial torsion in adults and to look at treatment outcomes for both conditions. The following questions were asked: (1) what is the incidence of rotational deformity in patients who present for surgery with congenital genu varum, and what are the predictors of these deformities and (2) do patients who undergo correction of tibial torsion with genu varum have similar outcomes to those who undergo uniplanar tibia vara correction as measured through alignment, time to union, and functional outcome?

Materials and Methods

Between the years 2003 and 2014, 69 patients (138 limbs) underwent bilateral PTO for the correction of genu varum. Demographics were recorded (►**Table 1**). Patients who were found to have a simple coronal plane deformity (varus alone) were treated with a monolateral external fixator and a hemicallotasis technique or with a circular hexapod frame for larger varus deformities. Those patients who were seen to have concomitant tibial torsion were treated with a hexapod external fixator utilizing computer-assisted deformity correction web-based software.[11] Both systems relied on distraction osteogenesis for deformity correction and union at the osteotomy site. All the patients were part of an Institutional Review Board (IRB) approved prospective registry. In addition, a separate IRB approval was obtained specifically for this project, and patients who were enrolled in the study were consented for a follow-up phone interview. Inclusion criteria included bilateral PTO for genu varum with or without coexisting rotational deformity, age older than 18 years, no femoral rotational deformity (anteversion/retroversion), and no history of previous tibial surgery. Patients who underwent concomitant foot and ankle surgery and unilateral surgery were excluded. Patients with advanced arthritis were excluded (only Kellgren–Lawrence grades 0–1 were included).[12] Patients with Blount's disease were excluded.

Table 1 Patient demographics

	Varus ($n = 37$)	Varus–torsion ($n = 32$)	p-Value
Age, mean (SD)	36.9 (10.3)	29.9 (9.1)	0.004
BMI, mean (SD)	25.3 (4.0)	21.8 (3.9)	0.001
Female	12 (32%)	18 (56%)	0.047
Smokers	4 (11%)	1 (3%)	0.363
OA knee	4 (11%)	2 (6%)	0.679

Abbreviations: BMI, body mass index; OA, osteoarthritis; SD, standard deviation.

Outcomes were measured in several ways: the primary outcome was the ability to achieve the desired correction of alignment in the coronal and axial planes. Alignment was documented with radiographs measuring MAD as well as joint orientation angles, mechanical lateral distal femoral angle (mLDFA), medial proximal tibial angle (MPTA), and posterior proximal tibial angle (PPTA).[13] Axial alignment was documented using thigh–foot axis (TFA) measurement in the prone physical exam. Secondary outcomes included a postoperative Knee Injury and Osteoarthritis Outcome Score (KOOS)[14] and a routine patient satisfaction questionnaire used in our practice. Complications were recorded. This was a level III study.

Surgical Protocol

Patients were evaluated preoperatively through physical exam and radiographs. The examination included a prone assessment of the TFA and femoral version. TFA was measured using a goniometer and recorded for every patient (►**Fig. 1A, B**). A TFA of 10 to 20 was considered normal. A TFA of more than 22 or less than 0 degrees was considered abnormal and merited correction. These norms may be controversial, but these are the criteria we have used for indicating surgery and have been supported in other series.[8] Femoral version was measured clinically with the patient in the prone position. Patients with clinically relevant abnormal femoral version, including miserable malalignment (concomitant external tibial torsion and femoral anteversion), were excluded from this study. (If femoral version was considered relevant, then a derotational osteotomy of the femur was performed.) Radiographs included a 51-inch standing, bipedal, hip-to-ankle X-ray (►**Fig. 2**). MAD was measured as well as joint orientation angles mLDFA, MPTA, and PPTA (►**Fig. 3**). Abnormal MPTA was corrected through a tibia osteotomy. If the varus deformity lay in the femur, then the mLDFA was corrected through a femoral osteotomy and the patient was excluded from the study. The primary surgeons selected the operative treatment based on the presence or absence of an abnormal TFA. Computed

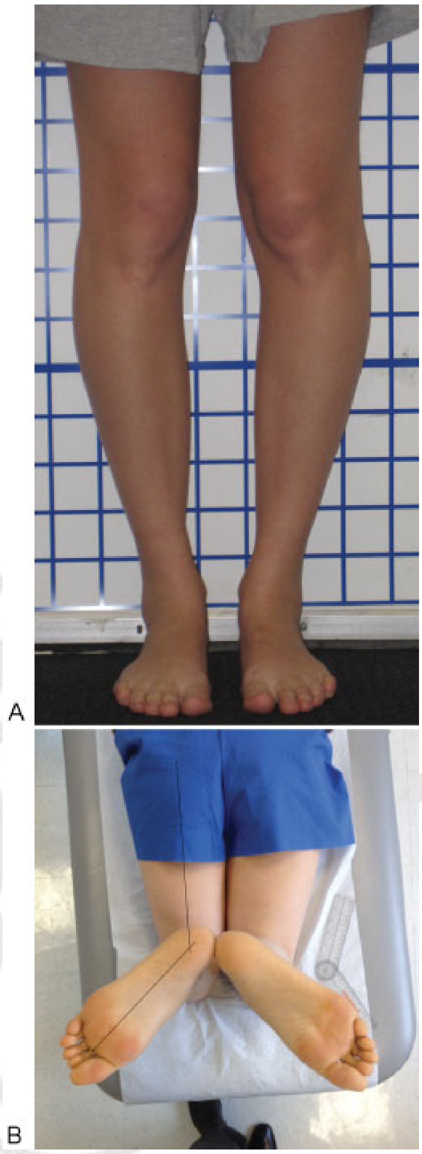

Fig. 1 (**A**) The typical squinting patella sign of external tibial torsion and genu varum is noted. (**B**) The TFA is measured by placing the patient prone, knees and ankles positioned 90 degrees, and then drawing a line down the thigh axis and down the axis of the foot (using the first web space) and measuring the angle created by their intersection. TFA, thigh–foot axis.

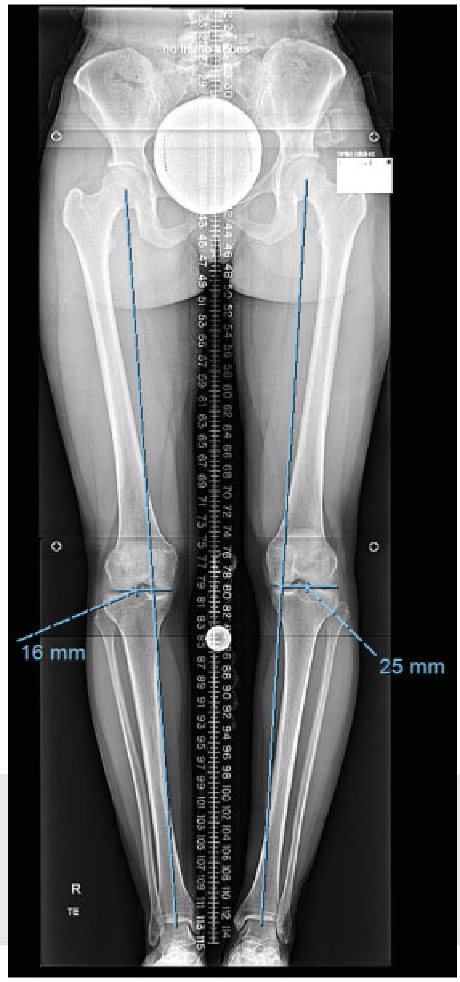

Fig. 2 In this patient with simple genu varum, the mechanical axis lines are seen and the deviation quantities were measured.

tomography (CT) version studies were obtained on some patients, but too few patients had these scans to make them useful to this study. If the patient had a normal TFA and the varus deformity was less than 12 degrees, then the surgery consisted of a partial tibial osteotomy without fibular osteotomy. The lateral cortex was left intact (►**Fig. 4**). A monolateral, hinged, external fixator was applied to the medial side of the tibia, and the medial cortex was gradually distracted, creating an open wedge, until the desired correction was achieved (►**Fig. 5A, B**). If a patient had a varus deformity of more than 12 degrees, the tibial osteotomy was completed, a fibular osteotomy was made, and a circular, hexapod, external fixator was used. This algorithm has provided reliable results.[5] The circular frame had the ability to translate the bone and had excellent control of the osteotomy for larger deformities. For patients who were seen to have both varus and tibial torsion, a complete tibial osteotomy was created also using a multiple drill hole and osteotome technique (►**Fig. 6A–C**). A fibular osteotomy was used to allow for rotational movement of the fibula without stressing the distal or proximal syndesmosis. An oblique fibular osteotomy was made using an oscillating saw (►**Fig. 6D**). For large rotational deformities (> 30 degrees), a syndesmotic screw was used to protect the ankle even though the fibula was osteotomized. Half pins were 6 mm and hydroxyapatite coated. No acute correction was performed in the operating room. The true apex of the axial deformity is not known. Instead, the apex of the varus deformity was used for both corrections. All osteotomies were made just distal to the insertion of the patellar tendon on the tibial tubercle (►**Fig. 6C**).

Patients received thromboprophylaxis and pin care starting postoperative day (POD) 2. Patients were taught to adjust the external fixator while in the hospital. Frame adjustments were started on POD 7. Patients followed up in the office at 2-week intervals for X-rays to measure alignment (►**Fig. 7**).

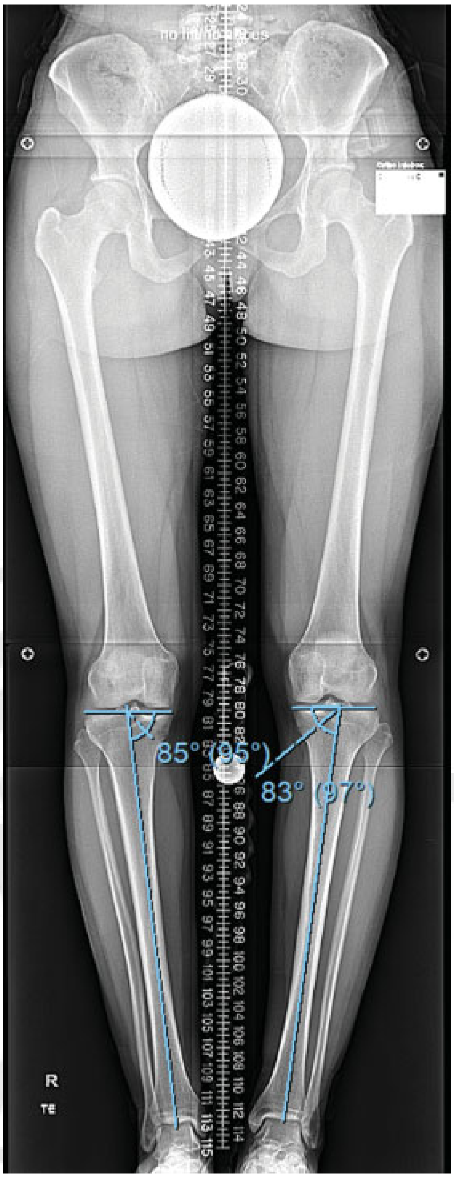

Fig. 3 The medial proximal tibial angles are shown here in the same patient seen in ►**Fig. 2**.

As these patients had no intra-articular deformity, the desired correction was a mechanical axis of zero. The MPTA was corrected until the MAD was 0 mm on a long, standing radiograph; there was no ideal target value for the MPTA. Once the desired alignment was obtained, the frame adjustments were stopped and consolidation progress was followed up at monthly intervals (►**Fig. 8A–C**). The external fixators were removed in the operating room under intravenous sedation.

Statistical Analysis

Statistical analysis comprised reporting of means and standard deviations for continuous variables and frequencies and percentages for discrete variables of the study population. Shapiro–Wilks' tests were used to confirm the continuous variables did not meet the assumption of normality. Therefore, nonparametric Mann–Whitney's *U* tests were used to evaluate differences in the continuous variables. Chi-square and Fisher's exact tests were used to evaluate associations between categorical variables between the study groups. Full-factorial generalized linear models were used to evaluate the differences in various radiographic measures between the genu varum patients and those with genu varum and tibial torsion. One-sample *t*-tests were used to compare the postoperative MAD and TFA values against a desired postoperative target of 0 mm and 15 degrees in MAD and TFA, respectively. Statistical significance was set to $p \leq 0.05$, and all analyses were performed using SPSS version 22.0 (IBM Corp.).

Fig. 4 This intraoperative fluoroshot shows the partial tibial osteotomy with an intact lateral cortex.

Results

In this study, 69 patients (138 limbs) were studied with an average follow-up of 78 months (range: 24–168). The mean age was 33.6 years, and body mass index (BMI) was 23.7. There were 30 females and 39 males. The mean MAD went from 26.3 mm medial (range: 6–88 mm medial) preoperative to 2.4 mm medial (range: 17 lateral–13 medial) postoperative ($p = 0.0001$). These outcome measurements were then analyzed for each group (►**Table 2**). Of the 69 patients (138 limbs) who presented with varus deformity, 32 were found to have a concomitant tibial torsional deformity (varus–torsion). The incidence of tibial torsion among the entire group of patients with bilateral congenital tibia vara was 46%. Patients with simple varus deformity ($n = 37$) were corrected with a monolateral frame or a hexapod frame, and those with varus and torsion ($n = 32$) were corrected with a hexapod circular external fixator as per surgical protocol. The two groups had some significant differences in demographics with torsion patients tending to be younger, female, and with a lower BMI (►**Table 1**). A multivariable logistic

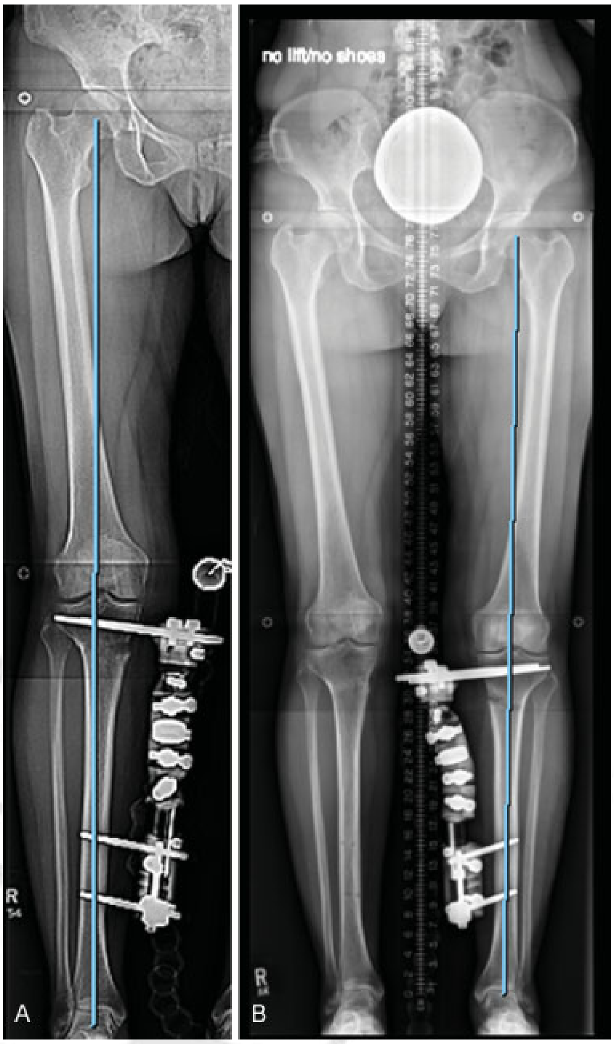

Fig. 5 (A) In the same patient seen in ►**Fig. 2**, the gradual correction has been completed, and the mechanical axis is ideal. Note that in this patient, a slight valgus overcorrection of the tibia was performed to compensate for a mild femoral varus deformity. The resulting mildly varus joint line is thought to be cartilage safe although there is no data to confirm this. (B) The contralateral side was treated in a similar fashion with the final alignment film shown.

regression analysis was performed using all variables. Being female did not predict presentation with varus–torsion after adjusting for all other factors. Lower BMI was found to be a significant risk factor for presenting with a varus–torsion deformity. BMI of more than 30 was input as a discrete variable, and the effect was no longer significant; however, increasing age did become a significant factor against presenting with varus–torsion with each additional year in age associated with a 7% decreased risk of presenting with an associated torsional deformity.

Pre- and postoperative MAD, MPTA, PPTA, and TFA were analyzed in both groups (►**Tables 2–4**). Each group had a significant change in MAD and MPTA ($p < 0.001$). The final MAD and MPTA values for both groups were within normal and did not differ significantly ($p = 0.890$ and 0.554, respectively). The pre- and post-PPTA values were similar (►**Table 2**) in both groups. The average preoperative TFA was quite different between the two groups. The varus–torsion group consisted of two patients with internal torsion (average: 7.5 degrees; range: 5–10 degrees internal) and 30 with external torsion (average: 30.6 degrees; range: 22–45 degrees external). Although the change in TFA before and after surgery in the torsion group was significant ($p < 0.001$), the postcorrection TFA was not significantly different between the two groups ($p = 0.666$). The ideal target values for MAD and TFA were compared with final values obtained in both groups (►**Table 3**). Although the two groups showed no significant difference in final values for MAD and TFA, the difference between the target value for MAD and the MAD achieved was significant in both groups. The ability to achieve the target rotational correction was also significant in the torsion group. These statistical findings suggest precision without accuracy in these techniques but ignore the clinical implications.

Time to union, as measured by the time in the frame, for the entire cohort was 105 days. Union was achieved in the varus group in 105 days and in the torsion group in 103 days. This was not significant ($p > 0.999$). Patients in the varus group were treated with either a monolateral or hexapod frame. To further understand this relationship between the effect of the hexapod frame and the monolateral frame, the varus-alone group was broken into two groups based on the type of external fixator used (and therefore magnitude of deformity) (►**Table 4**). The groups differed significantly in age and preoperative MAD with patients who had larger varus deformities presenting at younger ages. The final MAD and PPTA were similar. The time in frame was significantly longer for the hexapod group despite a younger mean age.

The KOOS was not different between the varus–torsion and the varus-alone groups in symptoms, pain, activities of daily living (ADLs), and return to sport (►**Table 5**). There was a difference in the quality of life score between the two groups ($p = 0.021$). There was no difference between the two groups regarding the routine follow-up, limb deformity, and patient satisfaction questionnaire (►**Table 5**).

Complications were recorded (►**Table 6**). One patient in the varus–torsion group had a compartment syndrome which occurred on POD 2 and was treated emergently with anterior–lateral fasciotomy and peroneal nerve decompression. She healed without further complication. Her contralateral tibia surgery was performed with a prophylactic percutaneous fasciotomy, and her postoperative course was uncomplicated. One patient in the varus–torsion group had a venous thrombus in the popliteal vein discovered 10 days after surgery despite prophylaxis with aspirin 325 mg twice daily. She received a 3-month treatment with low-molecular-weight heparin and the clot resolved. For her contralateral side surgery, she received prophylactic enoxaparin 40 mg once daily for 6 weeks postsurgery. One patient in the varus group experienced a mild knee twisting injury several months after frame removal and required an arthroscopic partial medial meniscectomy. There was one case of peroneal nerve entrapment at the fibular neck in the varus–torsion group in one limb only. It was discovered 1 year after surgery

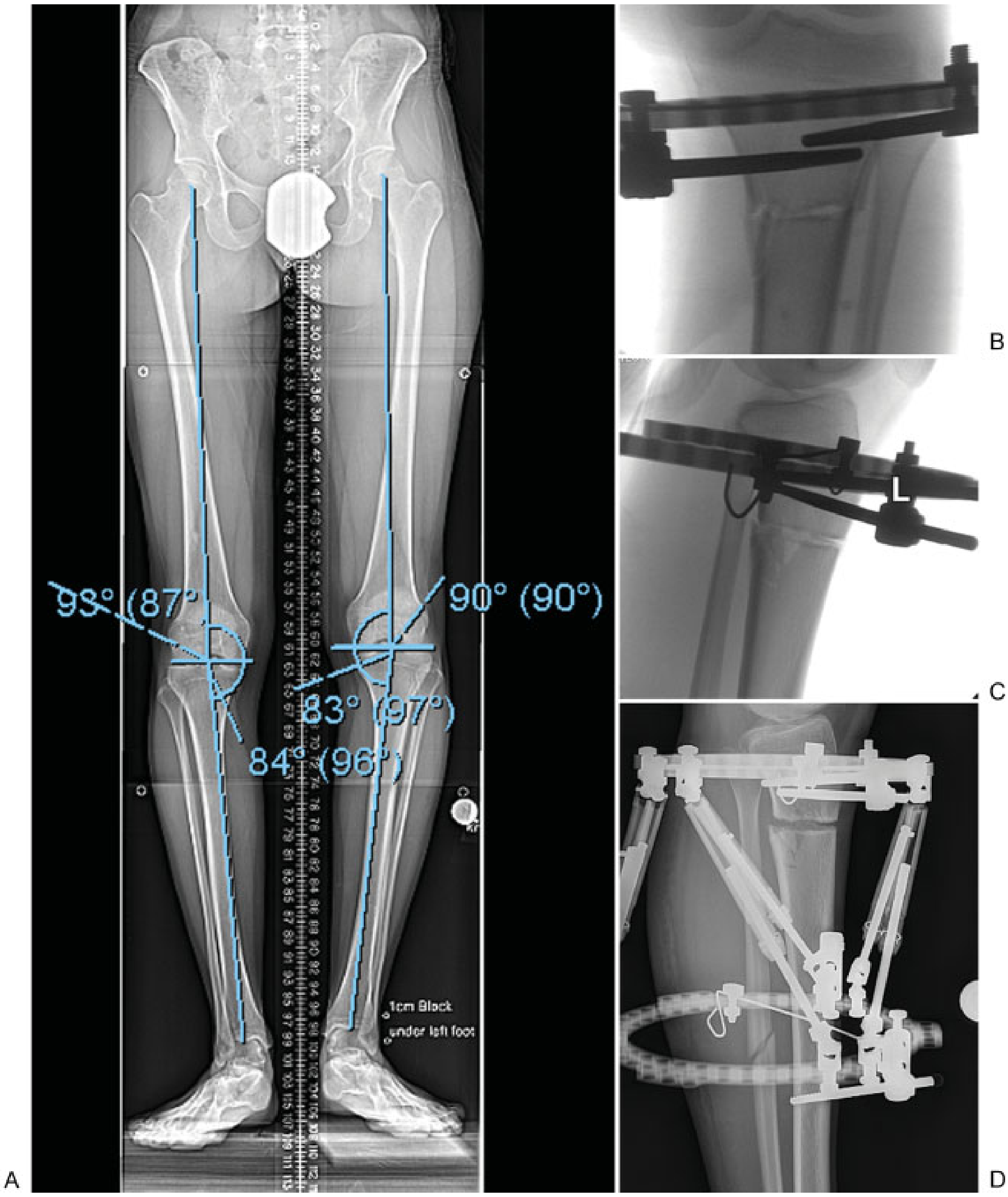

Fig. 6 (**A**) Continuing with the patient shown in ►**Fig. 1**, the joint orientation angles are measured demonstrating abnormal MPTA and normal mLDFA. Note the external rotation of the ankles with the patellas pointing forward. (**B**) The intraoperative fluoroshot shows an AP of the completed osteotomy. (**C**) The lateral of the same surgery shows the osteotomy with some comminution which had no impact on the outcome. Her PPTA was 75 degrees and her knee came to full extension; therefore, the tibial slope was not altered. (**D**) This radiograph of the same patient demonstrates the oblique fibular osteotomy made in the mid-diaphysis where the surgery is technically simplified due to less soft tissue. AP, anteroposterior; mLDFA, mechanical lateral distal femoral angle; MPTA, medial proximal tibial angle; PPTA, posterior proximal tibial angle.

and was without sensory or motor changes clinically. The patient felt the leg was clumsy and nerve conduction study showed mild conduction velocity slowing across the fibular neck without motor changes on electromyography. A common peroneal nerve decompression relieved the symptoms completely. Pin infections are ubiquitous in limb deformity surgery with external fixation and are not considered true complications. This retrospective series did not provide adequate documentation of pin infections, and no statement can be made comparing the two groups.

Discussion

The surgical correction of tibia vara is successful at establishing normal limb alignment and can be accomplished with various techniques.[15,16] Excellent results have been obtained for tibia deformity correction using circular fixation.[11,17–19] It has been suggested that the optimal technique for varus correction could be determined by considering total angular deformity: varus deformities of 12 degrees or less could be addressed with a simple hinged monolateral external fixator

Fig. 7 The same patient as in ►**Fig. 1** is seen after completing treatment with ideal alignment. A TFA is measured after completion of the adjustment period to ensure that the desired rotational alignment has been achieved. TFA, thigh–foot axis.

(or internal plate), and a varus of more than 12 degrees required circular fixation for accurate and stable correction.[5] In these previous studies, the coincidence of tibial torsion was not illustrated. The current article aims to draw attention to the association between tibial torsion and non-Blount's tibia vara in adults and further seeks to assess postsurgical outcomes of these patients with more complex deformity when compared with varus malalignment alone.

The incidence of tibial torsion in conjunction with tibial varus in our patient cohort was 46%. We suspect that this strong association between varus and rotation is pervasive through all patient populations. Although there is a large body of literature dedicated to varus knee deformity,[3,4,7,15,16] very few studies have focused on rotational deformity with varus.[20,21] Berard et al studied eight patients with a combination of congenital tibia vara and external tibial torsion both corrected with a PTO. Seven of the eight patients were female with ages between 20 and 38 years. The average amount of rotational correction was ~17 degrees through an infratubercle osteotomy. All of these osteotomies healed well without complications.[20] Potentially, half of the patients who undergo surgical correction of genu varum today have a coexisting rotational deformity that was ignored. Our findings suggest that the vast majority of these rotational deformities are external in nature. Internal tibial torsion is often associated with varus, but external torsion is a less commonly known comorbidity. There was a large female contingency in the varus–torsion cohort which raises the question of whether this external torsion deformity is more prevalent in women. After an exhaustive literature search, we were unable to find any article commenting on tibial torsion and gender. The current study documents a trend toward a higher incidence of external tibial torsion in women. It also shows a need for further study to establish "normal" tibial alignment in men and women. Lower BMI was found to be a risk factor for varus with torsion. When BMI of more than 30 was input into the multivariable regression analysis, age became a significant risk factor for varus with torsion with younger patients presenting with this combined deformity and older patients presenting with varus-alone deformity. Neither analysis showed sex to be a significant predictor of deformity type. The clinical utility of these findings is not readily identifiable other than to imply that orthopaedic surgeons need to measure TFA in all patients with bilateral genu varum and particularly in those who present with lower BMIs and at younger ages. We cannot make the statement that varus–torsion deformity is more painful than varus-alone deformity as we have no preoperative KOOSs, but this may be why the varus–torsion patients present at a younger age.

What is not known is how the long-term outcomes compare for patients who undergo correction of the rotational deformity at the time of genu varum correction versus those operated cases with the same deformity in whom the rotation was not addressed. Theoretically, the persistence of rotational deformity will continue to exert abnormal torque through the knee predisposing the patient to an increased risk for patella femoral pain, ligament injury, meniscal tears, and cartilage shear stresses.[8,9,22,23] We observed that before surgery, some of these varus external rotation patients walk with a normal foot progression angle (FPA) and internal rotation of the knee, while others walk with an external FPA and normal axial rotation of the knee. The presence of uncorrected rotational deformity after total knee replacement may also exert abnormal stresses on the implant shortening its lifespan. This review brings to light the need for different treatment algorithms based on the presence or absence of tibial rotational deformity. In our experience, circular fixation is ideal in correcting both rotation and varus of the tibia. In this series, simple varus deformity less than 12 degrees was corrected with a monolateral external fixator. All of these fixators may help prevent the introduction of rotational deformity that can occur during open osteotomy with internal fixation.

Patients who undergo treatment of tibial torsion with genu varum have similar outcomes to those who undergo correction of simple tibia vara alone. There was no significant difference in final MAD, MPTA, PPTA, and TFA between the two groups. Both groups had excellent corrections of varus deformity. There was no significant difference in time to union between the groups. Despite a longer adjustment period, twisting of the periosteum, and adding mild additional length to run the programs, the hexapod treated varus–torsion group healed in the same time period as the opening wedge varus correction cohort. Perhaps, the

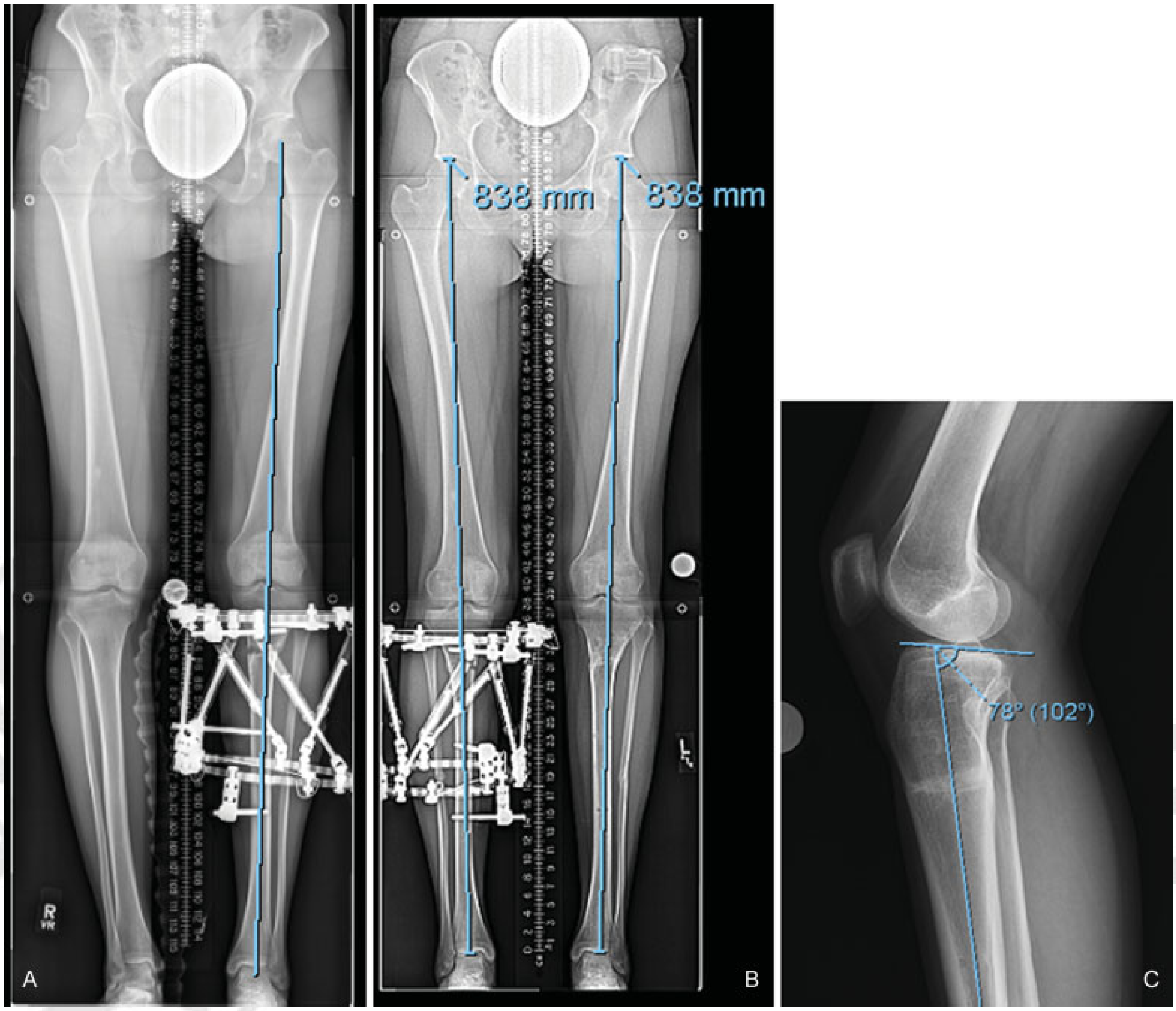

Fig. 8 (**A**) Final coronal alignment is checked with a standing radiograph. The MAD is shown. (**B**) In the same patient seen in ►**Fig. 1**, the final alignment is checked and compared with the contralateral side to ensure symmetry. (**C**) The sagittal alignment cannot be ignored when performing a complete osteotomy and rotational correction. The adjustments could cause flexion of the proximal tibia, for example. Close attention must be paid to the lateral X-ray at the end of the adjustment period to ensure that no sagittal deformity has been introduced. In this case, the patient had full knee extension and her posterior tibial angle of 78 degrees was maintained. MAD, mechanical axis deviation.

Table 2 Primary outcomes

	Preoperative, mean (SD)		*p*-Value	Postoperative, mean (SD)		*p*-Value
	Var	Var-Tor		Var	Var-Tor	
MPTA (deg)	80.9 (7.9)	80.3 (8.9)	0.472	87.8 (2.0)	87.2 (1.8)	0.554
MAD medial (mm)	26.7 (9.9)	25.8 (14.0)	0.551	2.3 (3.6)	2.4 (3.3)	0.890
PPTA (deg)	79.2 (3.4)	78.6 (2.6)	0.293	79.2 (3.4)	79.5 (2.5)	0.604
TFA (deg)	17.7 (5.0)	30.6 (10.1) (22–45 external torsion range) 7.5 (5–10 internal torsion range)	< 0.001	15.0 (5.0)	13.5 (3.0) (both external and internal patients)	0.666
Time in frame (d)				104.6 (23.2)	103.2 (22.1)	> 0.999

Abbreviations: MAD, mechanical axis deviation; MPTA, medial proximal tibial angle; PPTA, posterior proximal tibial angle; SD, standard deviation; TFA, thigh–foot axis; Var, varus-alone; Var Tor, varus–torsion.

Table 3 Target alignment accuracy

	Varus	Varus–torsion
Target MAD	0	0
Difference between postoperative MAD and target MAD (mm) (absolute value) (SD)	2.4 (3.7) $p < 0.001$	2.2 (3.2) $p < 0.001$
Target TFA (deg)	15	15
Difference between postoperative TFA and target TFA (deg) (absolute value)	0 $p > 0.999$	1.5 $p = 0.023$

Abbreviations: MAD, mechanical axis deviation; SD, standard deviation; TFA, thigh–foot axis.

Table 5 Functional outcomes

KOOS (0–100 scale)	Var (mean) (SD)	Var-Tor (mean) (SD)	*p*-Value
Symptoms	92.7 (9.9)	91.7 (9.5)	0.756
Pain	95.2 (7.6)	93.3 (7.8)	0.440
ADL	98.2 (5.1)	97.2 (3.9)	0.505
Sport	91.0 (13.6)	84.3 (20.8)	0.211
QoL	88.0 (14.5)	75.8 (25.3)	0.044
LLCRS questionnaire			
Question	**Var**	**Var-Tor**	***p*-Value**
Confidence (*n*) (%)	21 (84%)	15 (94%)	0.682
knee pain (*n*) (%)	25 (100%)	15 (94%)	0.781
Knee function (*n*) (%)	24 (96%)	16 (100%)	> 0.999
Fixator (*n*) (%)	23 (92%)	13 (81%)	0.581
Worthwhile (*n*) (%)	25 (100%)	15 (94%)	0.781

Abbreviations: ADL, activities of daily living; KOOS, Knee injury and Osteoarthritis Outcome Score; LLCRS, Limb Lengthening Complex Reconstruction Service; QoL, quality of life; SD, standard deviation; Var, varus-alone; Var Tor, varus–torsion.
Note: Number of patients who "somewhat" or "definitely" agreed, and percentage of people who "somewhat" or "definitely" agreed.

younger age of the varus–torsion patients offsets the increased osseous trauma resulting in no increase in healing time. In both groups, the PTO site healed predictably and quickly. The accuracy of the deformity correction regardless of technique was clinically excellent: the MAD was an average of 2.4 or 2.2 mm away from the target of 0 mm in the varus and varus–torsion cohorts, respectively. The TFA was an average of 1.5 degrees off from the target of 15 degrees after rotational correction. Although these results were found to be significant deviations from the target alignment, they are clinically very accurate and support the power of postoperative adjustability that external fixation provides.

When subanalyzing the varus-alone group and comparing patients who had hexapod fixation for larger deformity and monolateral fixation for smaller deformity, both frames were able to correct the coronal plane deformity with high clinical accuracy (within < 3 mm of the MAD goal) without adversely affecting the sagittal plane alignment. The time required for union was significantly different between the subgroups with more time needed for healing the hexapod patients (116 vs. 98 days). This makes sense given the larger deformities corrected, need for complete tibial osteotomy, and need for fibular osteotomy. The varus–torsion cohort had healing times intermediate between the two varus-alone groups (103 days). The patients with torsion were slightly younger and would be expected to heal faster than the varus-alone hexapod patients. The intact lateral cortex and intact fibula of varus-alone monolateral patients may have allowed for a more rapid osteotomy healing despite their more advanced age. The varus-alone patients with deformities of larger magnitude presented at a significantly younger age. This may, too, be due to pain.

A comparison of final functional outcomes showed no significant difference between the groups with both scoring very highly on KOOS with the exception of the quality of life questions. These questions focus on the patient's perception of how much they need to protect the operated leg in a minimum of 2 years postsurgery. The varus–torsion patients were able to perform ADLs and sports equally well to the varus group, but the former's perception of their leg strength and recovery was less robust. Possible reasons for this may be the perception that they underwent a more difficult and life altering surgery. There may be a relative delay in proprioception recovery

Table 4 Varus-alone breakout by frame type

	Varus—hexapod frame (SD)	Varus—monolateral frame (SD)	*p*-Value
Age (y)	32.2 (8.0)	39.4 (10.9)	0.036
Preoperative MAD (medial)	31.7 (13.1)	24.6 (6.7)	0.000
Postoperative MAD (absolute value)	3.2 (3.5)	2.0 (3.7)	0.504
Pre-PPTA	78.6 (4.7)	79.2 (2.6)	0.499
Post-PPTA	78.7 (4.5)	79.4 (2.7)	0.450
TIF (d)	116.0 (31.5)	97.7 (12.8)	0.001

Abbreviations: MAD, mechanical axis deviation; PPTA, posterior proximal tibial angle; SD, standard deviation; TIF, time in frame.

Table 6 Complications

	Varus	Varus–torsion
Nonunion	0	0
Unplanned surgery	1	2
Compartment syndrome	0	1
DVT	0	1
Total complications	1	3

Abbreviation: DVT, deep vein thrombosis.

(specifically, the ability to reorient the brain to the new position of the foot in two planes) due to a large rotational change. In the multivariable regression analysis, gender was not found to be significant variable. The data suggest that advanced age and increased BMI comport higher functional scores, but we believe that the effect sizes were not meaningful enough to draw these conclusions, and age and BMI have no effect on our algorithm for surgical treatment further minimizing the importance of these variables.

Complications from these two surgeries are not common but can be profound. To diagnose compartment syndrome early, patients must be observed for 2 days postsurgery for this potentially devastating condition. Our incidence was 1 out of 138 limbs (0.7%) in this series. One can also perform prophylactic fasciotomies to prevent compartment syndrome, but the benefit of this procedure must be weighed against the risk of symptomatic muscle herniation, superficial peroneal nerve injury, and change in the contour of the leg. The need for peroneal nerve decompression at the time of fasciotomy once a compartment syndrome has been identified is controversial. Gradual stretching of the peroneal nerve from rotational correction of the tibia seems to be very well tolerated. The one case of clumsiness of the foot and leg in our series may have been due to peroneal nerve entrapment at the fibular neck. There may be more cases of subclinical peroneal nerve entrapment that go unrecognized; however, this study shows how most patients return to the same high level of function after surgery without nerve decompression. No one in this series suffered from preoperative patellar instability, and it should be noted that the technique presented, an infratubercle osteotomy, will not deliberately impact patellar malalignment. In patients with patella instability, a tibial tubercle osteotomy with medialization may be needed in a staged setting.[24]

There are many limitations to this retrospective study. The patients are self-selected and may not represent the general population. The majority of the patients studied did not suffer from osteoarthritis. Therefore, the conclusions of this article may not be directly applicable to patients with moderate medial knee osteoarthritis and varus deformity. Treatment was not randomized but was selected based on the deformity recognized preoperatively. The algorithm to treat varus of more than 12 degrees with circular fixation is based on expert opinion not rigorous data analysis. Rotational deformity was measured through physical exam. CT version or X-ray imaging system data may be more accurate.

Conclusion

Based on the findings of this analysis, the incidence of rotational malalignment with congenital genu varum is close to 50% in patients undergoing surgical realignment. The recognition of this common association with tibial torsion deformity, particularly external torsion, may allow for further insights into the role of rotation in varus deformity-related knee pathology and treatment. The correction of both tibial torsional deformity and varus simultaneously with external fixation and gradual adjustments can yield excellent results. Patients can expect nearly identical outcomes from this surgery when compared with varus-alone deformity correction.

Conflict of Interest
None.

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