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Original Research

Staged Extra-Articular Deformity Correction in the Setting of Total Knee Arthroplasty

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ABSTRACT

Background: Extra-articular lower-leg deformities mandate unique considerations when planning total knee arthroplasty (TKA). Poor limb alignment may increase perioperative complications and cause early implant failure. This study reports on the safety and efficacy of staged, extra-articular deformity correction about the knee in the setting of osteoarthritis and TKA.
Methods: A retrospective review was conducted from December 2007 to December 2019 identifying 30 deformities in 27 patients (average age: 52.7 years; range 31-74) who underwent staged surgical correction of extra-articular deformity in preparation for TKA. Patient demographics, surgical details, clinical and radiographic measurements, severity of knee arthritis, and complications were collected.
Results: There were 17 femur and 12 tibia deformities. There was an average improvement of 14.7° of deformity measured in the coronal plane and 12.7° of deformity in the sagittal plane in the femur and 13.5° in the coronal plane and 10.3° in the sagittal plane in the tibia. Leg length discrepancies improved by 26 mm on average (1-100 mm). After an average 3.1-year follow-up, 12 out of 27 patients proceeded with primary or revision TKA. There were no cases of blood transfusion, nerve palsy, or compartment syndrome, and all patients achieved bony union.
Conclusions: Staged, extra-articular deformity correction is a safe and effective approach to improve limb alignment in the setting of knee osteoarthritis and TKA.

Introduction

Extra-articular lower-leg deformities pose a unique challenge when planning for total knee arthroplasty (TKA) [1]. A deformity is considered extra-articular about the knee if it is proximal to the femoral epicondyle or distal to the fibular neck [2,3]. Optimal mechanical alignment with a balanced weight distribution across the knee joint is critical for the success and longevity of a TKA implant [4–8]. In general, extra-articular deformities may cause alignment deviations and create an unbalanced force distribution through the knee [1,9]. The magnitude, direction, and location of an extra-articular deformity relative to the knee joint all affect mechanical alignment [9]. Larger deformities have a greater impact on the global axes, and moreover, the closer the deformity apex to the knee joint, the larger the direct effect it will have on aberrant mechanical forces across the knee [10,11]. To address extra-articular deformities in the setting of knee osteoarthritis, mechanical alignment is often corrected through 2 approaches: extra-articular deformity correction with an osteotomy followed by a knee replacement or a 1-stage intra-articular correction at the time of knee replacement through planned bony resection.

Current literature suggests that intra-articular resections with proper soft-tissue tensioning may be used to correct extra-articular angular deformities less than 20° in the femur and 30° in the tibia [3,12,13]. A major consideration of intra-articular correction is the preservation of the knee collateral ligaments: Over-zealous intra-articular corrections may lead to instability and flexion arc imbalances that affect TKA implant functionality [1].

For complex deformities in multiple planes, deformities close to the knee joint line, and deformities with large leg length

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discrepancies (LLDs), a staged osteotomy to correct mechanical malalignment prior to TKA may be preferable [12,14–16]. In our practice, multiplanar and complex extra-articular deformity correction is performed in a staged fashion, which allows for compartmentalization of deformity correction, unrestricted by impending arthroplasty implants. It provides greater flexibility in surgical planning, shorter operative times, and subsequent usage of standardized implants [1,17]. There is currently a paucity of data on investigating and describing the staged-corrective approach to complex extra-articular deformities in the setting of knee osteoarthritis.

The primary purpose of this study is to report the safety and efficacy of staged-deformity correction of extra-articular lower-extremity deformities in patients indicated for TKA. Second, this study presents a large variety of correction techniques along with outcomes related to TKA timing and componentry.

Material and methods

Study design

After institutional review board approval, a retrospective database review was conducted for all skeletally mature patients maintained in our medical records from December 2007 to December 2019 who underwent surgical correction for a femoral and/or tibial extra-articular deformity in the setting of knee osteoarthritis. Patients with bifocal deformities and those indicated for revision TKA were included. Patients were excluded from the study if there was less than a 1-year follow-up or incomplete medical records. Descriptive preoperative measures included patient demographics, deformity etiology and classification, TKA history, and the severity of knee osteoarthritis according to the Kellgren and Lawrence classification system.

Deformity correction surgery

All deformity surgeries were planned and performed by 1 of 2 senior surgeons. Surgery included either an acute or gradual correction with a variety of surgical techniques such as plate/screw constructs, static intramedullary nails, internal lengthening nails, ringed external fixation systems, or monorail frames. Osteotomy technique and fixation methods were selected by each surgeon based on surgeon preference, but determining factors included the initial and planned deformity correction magnitude, bone segment and location of the center of rotation of angulation (diaphyseal or metaphyseal), and other patient-specific factors. Surgical techniques have been previously published based on the principles of deformity correction [1,18–27].

The goal of surgery was to correct bony deformity in order to optimize a total knee arthroplasty. The goal was not necessarily to fully correct the mechanical axis alignment to neutral. In the setting of knee osteoarthritis, there is an inherent intra-articular deformity or joint-line incongruence due to uneven cartilage wear between the medial and lateral knee compartments. Furthermore, extra-articular deformities contribute to abnormal forces across the knee that can preferentially exacerbate joint degeneration. Deformity correction prior to TKA can improve anatomic bone segment alignment and, in turn, lead to more standard joint resections during a subsequent arthroplasty to reduce collateral ligament compromise. After TKA, an improved mechanical axis deviation normalizes forces across the joint that prolongs implant longevity. Consequently, more conventional, elementary arthroplasty implants can be used without the need for more constrained or long-stemmed components.

Table 1
Patient demographics.

Sample characteristics	n	%	M	SD
Sex				
Men	15	55.6		
Women	12	44.4		
Deformity Laterality				
Right	15	55.6		
Left	12	44.4		
Bone				
Femur	17[a]	58.6		
Tibia	12	41.4		
Referral Status				
Arthroplasty surgeon	18	66.7		
Self	6	22.2		
Other physician	3	11.1		
Deformity Etiology				
Trauma	20	74.1		
Congenital	3	11.1		
Neonatal osteomyelitis	2	7.4		
Rickets	1	5.0		
Undocumented	1	5.0		
Age, y			52.7	10.9
Body Mass Index, kg/m^2			29.6	6.2

[a] One patient had a multi-apical femur deformity.

Study outcomes

The primary outcomes of this study are global and segmental radiographic deformity measurements before and after extra-articular deformity correction, as well as postoperative complications. Secondary outcomes include timing of TKA and implant componentry used after deformity correction (unconstrained, constrained, hinged, mega-prosthesis, stemmed) [28].

Data analysis

Descriptive statistics were used to summarize demographic and deformity data. Means and standard deviations were reported for continuous demographic variables in Table 1. The average deviation from the standardized normal reference value and the range were reported for continuous radiographic variables in Table 2. Analysis

Table 2
Radiographic deformity measurements.

Deformity measurements	Reference	Preoperative	Postoperative	Delta
Global Deformity ($n = 27$)				
MAD (mm)	0	50 (5-100)	20 (0-84)	35 (0-98)
mTFA (°)	2	13.4 (2-32)	5.7 (0-25)	10.3 (0-28)
LLD (mm)	0	32 (8-170)	10 (0-70)	26 (1-100)
JLCA (°)	0	5.1 (0-34)	2.9 (0-10)	3.3 (0-24)
Segment Deformity ($n = 29$)				
Femur ($n = 17$)				
mLDFA (°)	87	12 (2-31)	5.1 (0-16)	7.5 (2-15)
PDFA (°)	83	8.5 (0-29)	5.6 (0-12)	9.3 (0-35)
Coronal plane (°)	0	16 (0-39)	2.2 (0-8)	14.7 (0-34)
Sagittal plane (°)	0	16.6 (1-39)	4.6 (0-12)	12.7 (1-32)
Tibia ($n = 12$)				
mMPTA (°)	87	11.9 (4-31)	3 (0-7)	11.9 (1-32)
PPTA (°)	81	8.3 (0-22)	3.8 (0-23)	6.8 (0-16)
Coronal plane (°)	0	14.6 (4-32)	2.8 (0-5)	13.5 (3-32)
Sagittal plane (°)	0	10.7 (0-20)	0.8 (0-2)	10.3 (0-20)

MAD, mechanical axis deviation; mTFA, mechanical tibio-femoral angle; mLDFA, mechanical lateral distal femoral angle; LLD, leg length discrepancy; JLCA, joint line congruence angle; mMPTA, mechanical medial proximal tibial angle; PDFA, posterior distal femur angle; PPTA, posterior proximal tibial angle.
All values are listed as the average deviation from the standardized normal reference (range).

was performed using Microsoft Excel 2019 Statistical Analysis Toolpak (Redmond, WA).

Results

Patient demographics, referral data, and deformity etiology are summarized in Table 1. Three patients had a pre-existing TKA that was evaluated for revision arthroplasty as exemplified in Figure 1. One patient had a medial unicondylar knee arthroplasty done prior to deformity correction. The remainder of patients had pre-existing symptomatic knee osteoarthritis classified by the Kellgren and Lawrence system (2 with grade 2; 10 with grade 3; and 11 with grade 4) [28].

Radiographic deformity measurements are presented in Table 2. Twenty-four patients had a single-segment deformity with 1 dominant apex (14 femurs and 10 tibias). One patient had a multi-apical deformity of the femur. Two patients had both femoral and tibial deformities that were corrected. The most common deformity was a combined femoral varus and procurvatum deformity (12 out of 30 deformities), followed by femoral varus (3 patients), tibial varus and recurvatum (3 patients), and tibial valgus (3 patients). The average distance from the joint line to the deformity center was 183 mm in the femur (58-295 mm) and 111 mm in the tibia (24-288 mm). Rotational assessment was not objectively documented post-operatively and was excluded from the analysis. The range of extra-articular deformities included in this study are exemplified

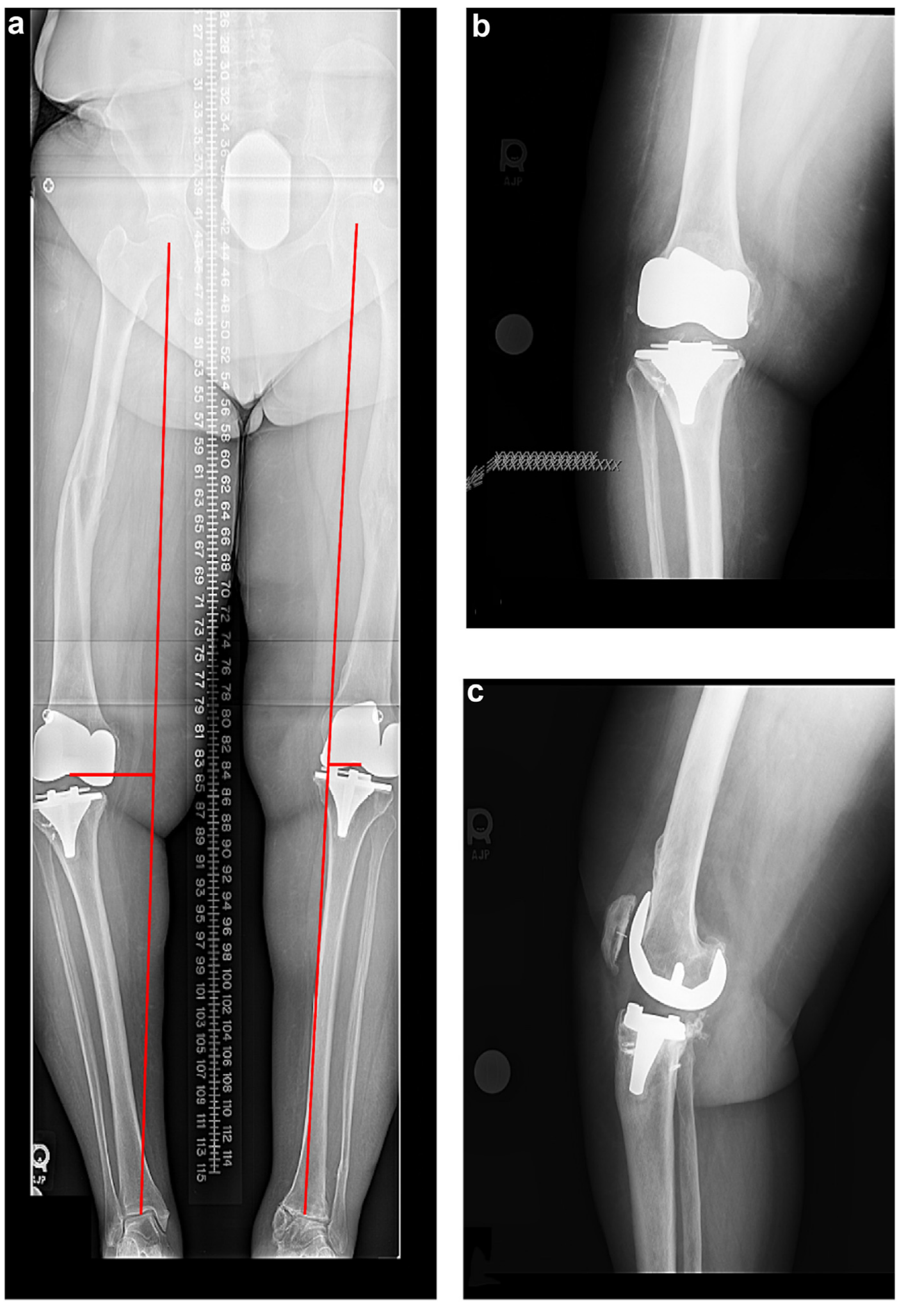

Figure 1. Radiographs of a failing, symptomatic right total knee arthroplasty in the setting of uncorrected extra-articular deformity. Standing hip-to-ankle radiographs demonstrate genu varum with a mid-diaphyseal femur deformity (a). Note the incongruent joint line and knee subluxation on the anteroposterior (AP) (b) and lateral (c) views.

Figure 2. Standing hip-to-ankle radiographs of 5 patients with extra-articular deformity. (a) Post-traumatic bifocal extra-articular deformity in the femur and tibia with resultant leg length discrepancy after a motor vehicle accident. (b) Genu valgum with extra-articular tibial deformity and shortening in the setting of severe knee osteoarthritis. (c) Congenital deformity of the distal femur and tibia in a patient with fibular hemimelia. (d) Persistent femur-based genu varum after femoral lengthening in the setting of a previous right-sided medial unicompartmental knee arthroplasty and high tibial osteotomy. (e) Genu varum and procurvatum of the distal left femur after a motor vehicle crash.

radiographically in Figure 2 and clinically in Figure 3. Presurgical deformity planning for a select case is demonstrated in Figure 4.

On segment analysis, 17 of 29 bone segments were corrected with an intramedullary nail (static or lengthening) including the multi-apical femoral deformity that was treated with a double-level osteotomy and a single retrograde nail. Five segments were corrected with a hexapod frame and 5 segments with mono-lateral external fixation. Two patients had acute correction performed with a distal femoral wedge osteotomy with plate fixation. Figure 5 demonstrates a range of the surgical techniques and devices used for extra-articular correction corresponding to the deformities shown in Figures 2 and 3.

The average patient follow-up was 3.1 years after their deformity surgery date (range 1-12.2 years). Ten out of 24 (41.7%) patients without a pre-existing TKA went on to get a TKA at an average of 2.9 years after their deformity correction (range 1-12 years). Two out of the 3 patients that had a failed or symptomatic TKA went on to revision TKA. An example of the correction course is presented in Figure 6.

Of the 12 patients that underwent primary or revision TKA after deformity correction, only 4 patients (33.3%) had stemmed implants (2 primary and 2 revision TKA). Ten of those 12 used constrained polyethylene liners; however, there were no hinged or mega-prosthesis used. An example of the staged correction of an extra-articular deformity prior to TKA is demonstrated in Figure 7.

There were no cases of blood transfusion, nerve palsy, or compartment syndrome perioperatively. There were 4 cases of superficial pin tract infections that were treated successfully with oral antibiotics. These were not considered a complication due to the common occurrence and minor treatment required [29]. There was 1 case of a nonfatal postoperative pulmonary embolism treated with therapeutic anticoagulation. One patient underwent gastrocnemius release for an equinus deformity. There was 1 mechanical failure of a lengthening nail that underwent exchange nailing. There were 2 cases of delayed union successfully treated with bone marrow aspirate concentrate, with all patients achieving bony union.

Two patients experienced complications with a subsequent arthroplasty procedure. There was 1 case of wound dehiscence that was treated with intraoperative wound closure and 1 patient that had a TKA dislocation after a fall that required operative reduction and polyethylene liner exchange. There were no postoperative prosthetic joint infections.

Discussion

This study reports on the advantages of staged extra-articular deformity correction in the setting of TKA. Staged deformity correction is a safe and reliable tool that compartmentalizes the surgical correction of extra-articular deformity in preparation for

Figure 3. Preoperative clinical photos corresponding to radiographic deformities illustrated in Figure 2a-e.

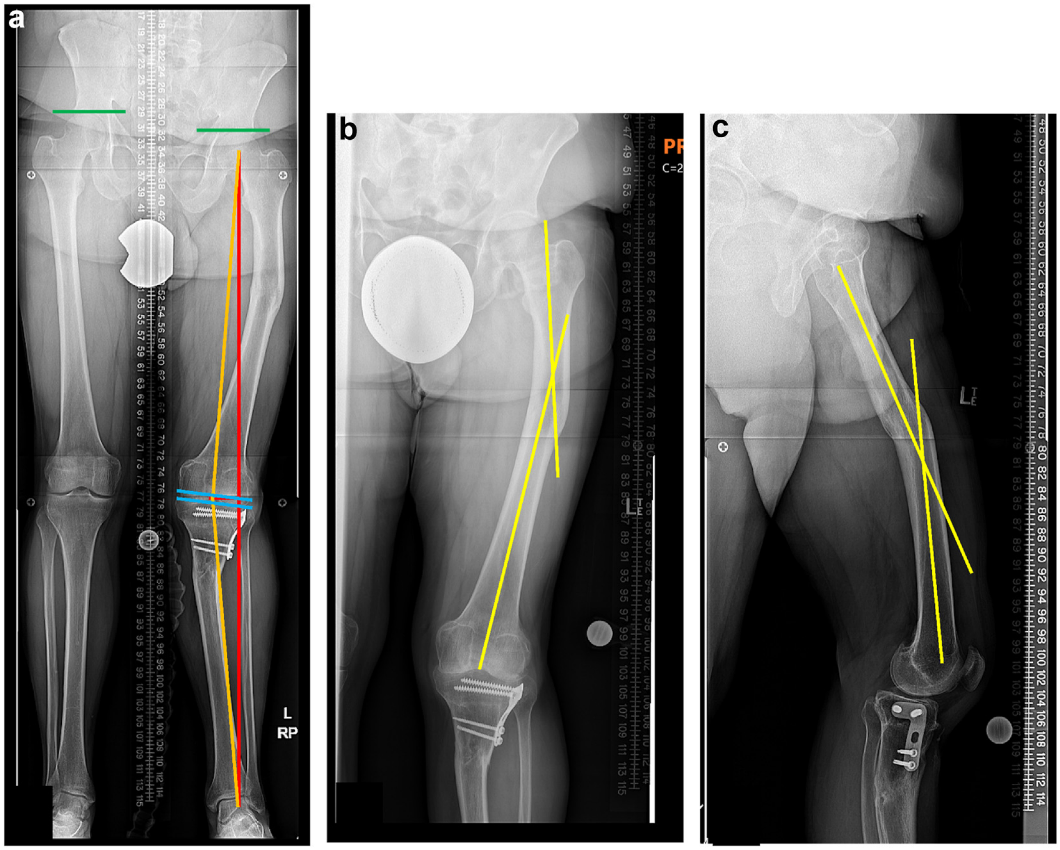

Figure 4. (a) Global deformity analysis with mechanical axis deviation (MAD) (red), mechanical tibiofemoral angle (orange), joint line convergence angle (blue), and leg length discrepancy (green). AP (b) and lateral (c) femur radiographs used to calculate segmental deformity angulation and translation.

TKA, effectively optimizing surgical approaches and rehabilitation for both procedures.

There have been few studies exploring the staged correction of extra-articular deformities prior to TKA. Takahashi et al. [30] reported on a case in which a severe, complex tibial deformity originating from a previous fracture was corrected both acutely with a percutaneous osteotomy and gradually with the application of a hexapod external fixator prior to knee arthroplasty. The correction of the tibial varus and recurvatum helped normalize the previously seen tibial-femoral malalignment, allowing for knee arthroplasty to subsequently follow. Tawari et al. [17] described similar findings in their case analysis: Three patients had multiplanar, extra-articular tibial deformities corrected using a hexapod external fixator prior to TKA. The use of the fixator normalized limb alignment prior to knee arthroplasty in all 3 patients and consequently allowed for the usage of standardized primary TKA implants. As reported, the advantage of using primary implants is that it allows for standardized expectations and easily navigable postoperative care [30]. Conversely, the use of hinged or overconstrained prosthetics can be challenging when obtaining proper alignment in the setting of severe extra-articular deformities [10,31].

There are multiple case series describing osteoarthritis with extra-articular deformity managed with a single-staged TKA with compensatory intra-articular correction [3,12,15,16,32–36]. Xiao-Gang et al. [15] reported improved Hospital for Special Surgery knee scores, range of motion, and mechanical axis deviation in 9 patients with an extra-articular deformity—7 of which underwent intra-articular correction of the extra-articular deformity with TKA and 2 that underwent simultaneous but separate extra-articular osteotomy and TKA. They note that 4 patients had knee instability requiring increased implant constraint. Rajgopal et al. [37] similarly reported statistically significant improvements in radiographic measurements, functional range of motion, and Hospital for Special Surgery knee scores in their cohort of 36 arthritic knees with an extra-articular deformity that underwent TKA with compensatory intra-article bony resections and soft-tissue balancing. Of note, the authors recommended that extra-articular deformities more severe than reported in their cohort (18° in the femoral coronal plane, 15° in the femoral sagittal plane, and 24° in the tibial coronal plane) should be managed with extra-articular correction [37]. Vedoya and Sel proposed that a corrective osteotomy should be performed for extra-articular deformities if a bony resection would affect the collateral ligaments of the knee [3].

In general, intra-articular correction of extra-articular deformities with a TKA should be reserved for minor deformities that do not compromise knee stability. Larger and asymmetric bony resection can lead to soft-tissue imbalance and an unstable TKA, often with residual deformity. These circumstances have been shown to decrease implants' lifespan and patients' satisfaction and quality of life [38,39].

The correction of extra-articular deformity, therefore, should improve implant longevity and patient outcomes. Chalmers et al. [40] reported an improvement of Knee Society scores from 59 points preoperatively to 93 points postoperatively in a series of 207 patients with extra-articular deformity and osteoarthritis treated with high tibial osteotomies followed by staged TKA. Their series had a 97% 10-year survivorship free from aseptic loosening.

Extra-articular deformities pose a challenge when planning for TKA, and there are no widely followed guidelines for when extra-articular deformities may or may not require a separate corrective

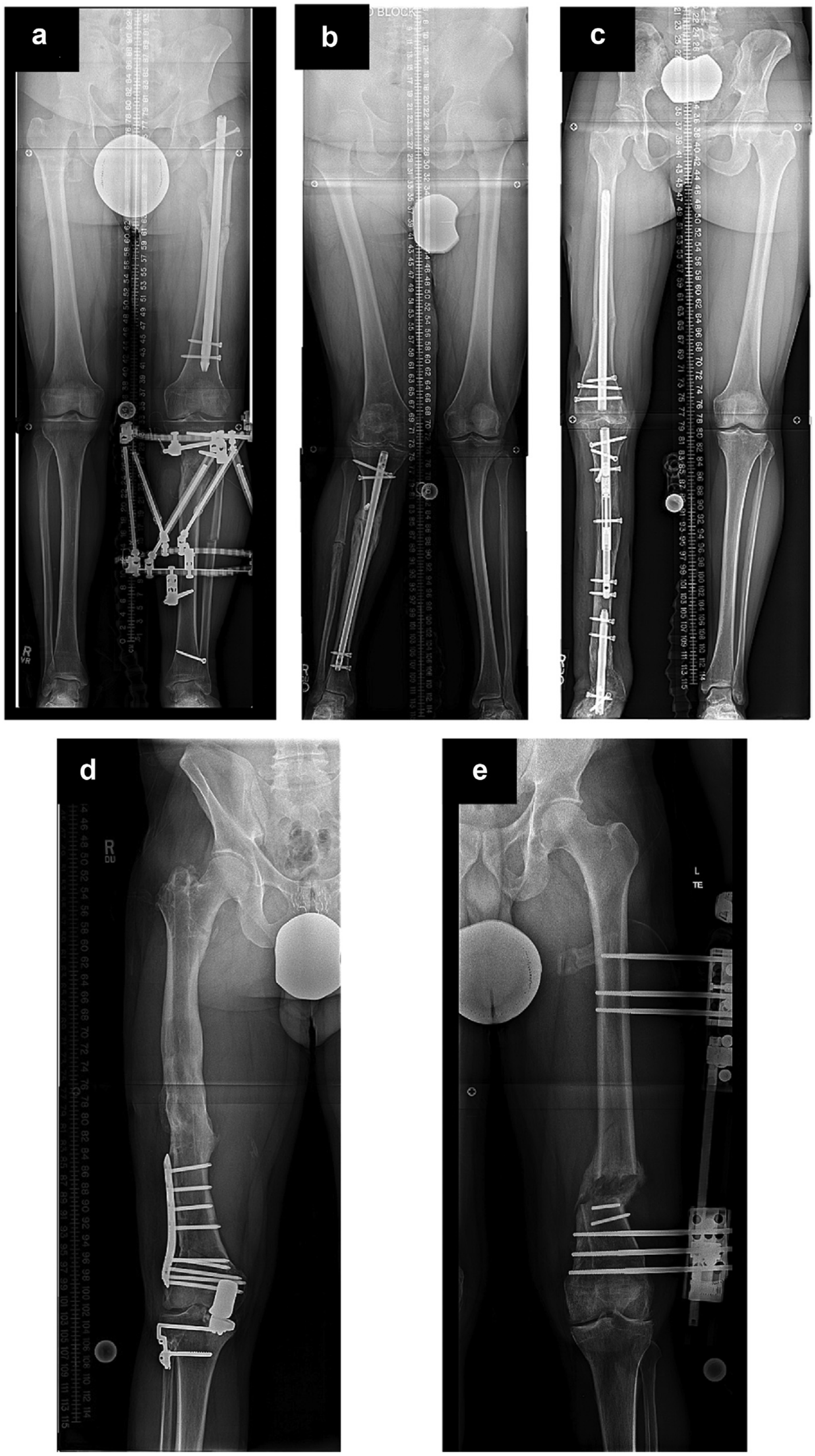

Figure 5. Examples of the various acute and gradual correction techniques used in deformity correction. A static intramedullary nail with an external hexapod system (a), a static intramedullary tibial nail (b), a combination of a tibial lengthening nail and static intramedullary lengthening nail (c), lateral femoral plate fixation (d), and an external femoral monolateral frame (e).

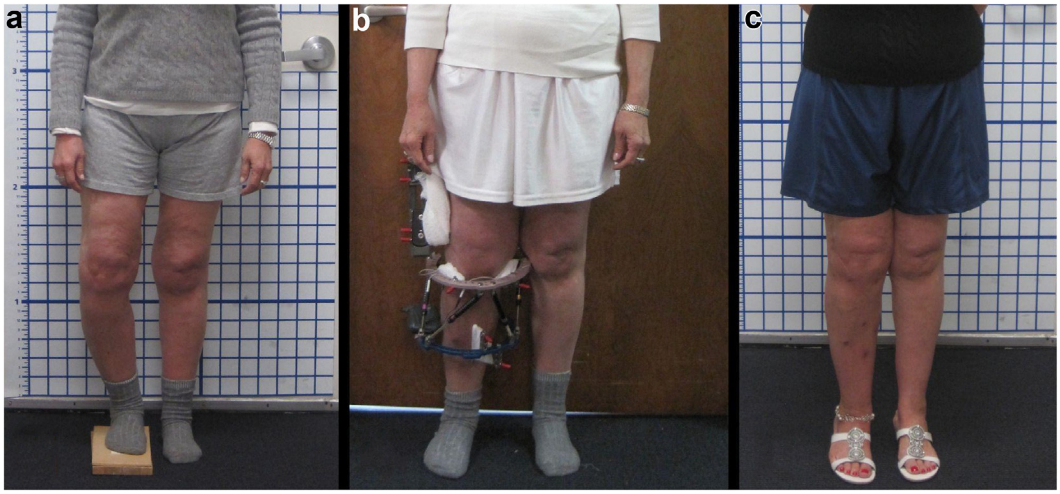

Figure 6. Demonstration of the corrective course in a 57-year-old female with a 31-mm limb length discrepancy and femoral varus with an 84-mm medial MAD. Preoperative photo with a block under the short limb (a), mid-correction with a monolateral frame for leg length discrepancy and a tibial hexapod frame for varus correction (b), and postoperative photo at 5 months (c).

in the setting of knee osteoarthritis [33,41]. Moreover, there are no standard recommendations for performing staged vs simultaneous deformity correction with a TKA [42,43].

Sun et al. [35] report improved radiographic and functional outcomes in 7 knees that underwent single-stage corrective supracondylar osteotomies with TKA. Notably, all 7 patients were fixed with long cemented femoral stems. Similarly, Lonner et al. [42] reported significant improvements in Knee Society scores in 11 knees with an extra-articular deformity that underwent simultaneous extra-articular correction with TKA. While the

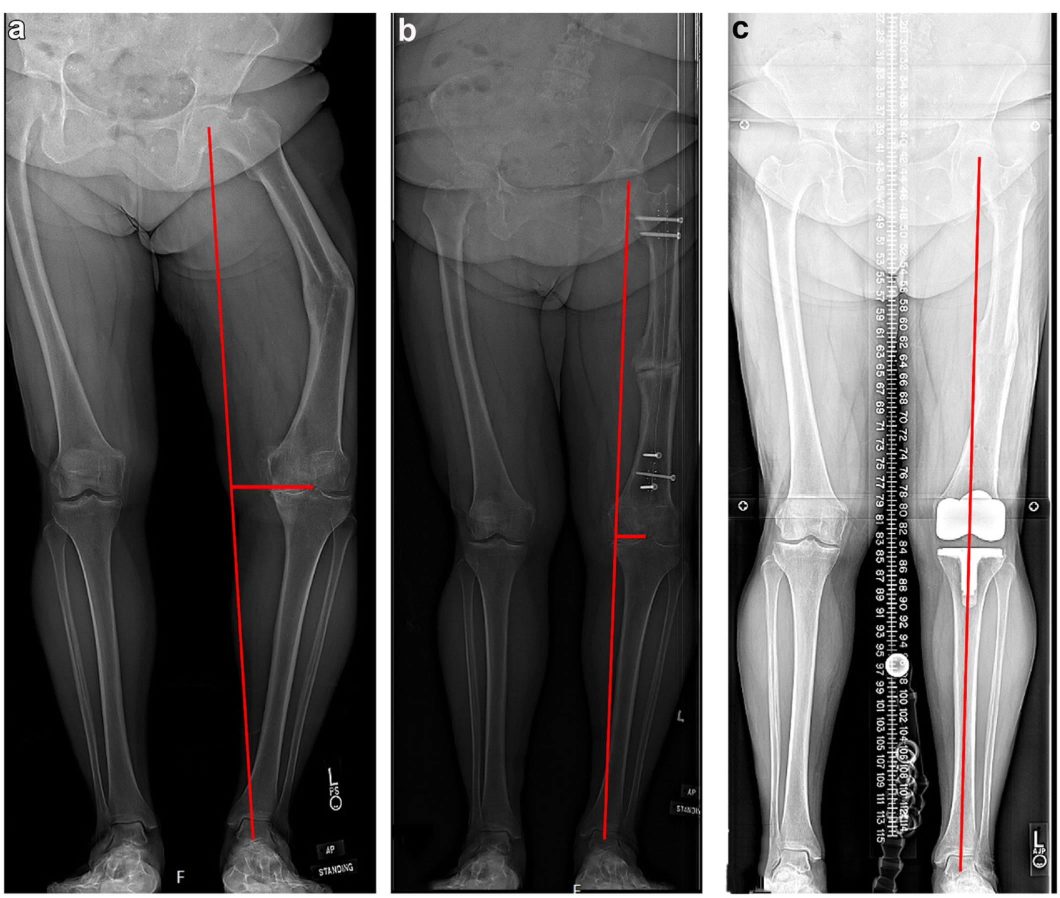

Figure 7. Demonstration of the staged extra-articular deformity correction prior to total knee arthroplasty in a 61-year-old female with a femoral malunion varus deformity following a motor vehicle accident (a). The malunion was corrected with a static antegrade intramedullary nail (b) prior to total knee arthroplasty (c). Notably, anatomical bone segment alignment was optimized in the deformity correction, not global mechanical alignment to help simplify the future arthroplasty procedure.

extra-articular correction successfully corrected the limb malalignment from a radiographic perspective as reported by the authors, the simultaneous approach likely encumbered functional recovery affecting the postoperative range of motion [1,42,44]. The restricted weight-bearing status following extra-articular deformity correction contradicts postoperative full weight-bearing following TKA. In addition, several studies show that longer operative times are a risk factor for TKA infection [45–49]. A staged approach to deformity correction prior to TKA likely reduces the operative time compared to arthroplasty with concurrent deformity correction.

The presence of a LLD is another consideration for a staged-deformity correction prior to TKA. Uncorrected LLDs have been shown to negatively affect the outcomes of TKA procedures [50,51]. Kim et al. [51] reported worse functional outcomes in patients with greater than 15 mm of LLD compared to those with less. Similarly, in a literature review of randomized and controlled trial and observational studies of LLD and TKA, an LLD of greater than or equal to 10 mm is associated with worse functional outcomes [50]. A staged approach allows for adequate lengthening and healing of the regenerate prior to undergoing a TKA procedure.

While not the intent of this study, it was shown that correction of extra-articular deformities may delay the immediate need for total joint replacement. At a minimum of 1 year after deformity correction, only 55.6% of patients, all of whom were previously indicated for TKA, underwent arthroplasty surgery. In these cases, it is thought that the correction of the extra-articular deformity improved joint mechanics by offloading the pathologic knee compartment. As in joint-preservation surgeries, deformity correction could prolong the native joint and postpone the need for TKA. Further investigation with longer clinical follow-up is required to substantiate this theory.

There are multiple limitations inherent to this single-center, nonrandomized study. There is a diverse range of deformities with a variety of correction techniques and implants that were primarily driven by surgeon experience. Larger case volumes would allow for deformity stratification and possibly improved treatment algorithms. In addition, patient-reported outcome measures could be included to assess the perceived intervention impact. Future studies may focus on a specific extra-articular deformity and corrective technique in the setting of TKA and could include patient-reported outcomes.

Despite these limitations, this article importantly demonstrates the power and efficacy of a staged approach to extra-articular deformity management in the setting of TKA.

Conclusions

Staged correction of lower-extremity extra-articular deformities prior to TKA is safe and effective. An initial deformity correction not only improves limb alignment but may prevent perioperative complications during TKA due to normalized anatomy and soft-tissue tension. Moreover, a staged approach may allow for simpler TKA componentry and may even delay TKA as a joint-preservation approach.

Conflicts of interest

S. J. Wallace is a paid consultant for Johnson & Johnson. A. T. Fragomen is a paid consultant for NuVasive and Smith and Nephew. T. J. Reif is a paid consultant for Johnson & Johnson, Paragon28, and WishBone and is a speaker bureau for NuVasive. S. R. Rozbruch receives royalties from NuVasive, is a paid consultant for NuVasive, Johnson & Johnson, and Osteosys, and has stock options from Osteosys; the other author has no relationship to disclose.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2023.101247.

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