

## Extra-articular deformities in arthritic knees-a grueling challenge for arthroplasty surgeons: An evidence-based update

Vishesh Khanna,<sup>1</sup>  
Senthil N. Sambandam,<sup>2</sup> Munis Ashraf,<sup>3</sup>  
Varatharaj Mounasamy<sup>4</sup>

<sup>1</sup>Sunshine Hospitals, Secunderabad, Telangana, India; <sup>2</sup>Louis A Johnson VA Medical Center, Clarksburg, WV, USA; <sup>3</sup>K.G. Hospital and Post Graduate Medical Institute, Arts College Road, Coimbatore, Tamil Nadu, India; <sup>4</sup>VCU Medical Center Ambulatory Care Center, Richmond, VA, USA

### Abstract

Critical to the success of a total knee arthroplasty (TKA) is the anatomical alignment. This may appear as a challenge in an extra-articular deformity (EAD) that may be inherent in certain people or result from fracture malunion, congenital disorders, nutritional, metabolic and infective causes. This appraisal aimed at providing the reader with an up-to-date overview of the research carried out on, and existent evidence of EAD correction while planning a TKA. We reviewed the current English literature on TKA in extra-articular knee deformities. Among the published data, a common initial approach of mandatory clinical and radiological assessment emerges as an obligatory step while handling cases with EAD. While several methods of managing the deformity and arthritis have been described, a broad division into intra-articular and extra-articular means can be deciphered. The relatively *old-school*, yet reliable thought process of extra-articular correction allows an all-inclusive restoration of alignment with the inherent complications related to the necessary osteotomy. A cohort of younger and more venturesome surgeons seem inclined towards performing navigated, intra-articular correction for mild to moderate and sometimes, severe deformities. The crux of the matter lies in obtaining a well-balanced knee without violating the all-important cruciates. Restoring the patient's ambulatory status seems sooner with the intra-articular methods which are also more precise in determining the axes and while removing minimum bone. Greatest satisfaction is accomplished in those with less grotesque, rotationally-aligned knees while meticulously balancing

soft-tissues and encouraging earlier weight-bearing.

### General background

Total knee arthroplasty (TKA) offers a gratifying solution to osteoarthritis (OA) of knee. A recent meta-analysis has identified significant improvements in intermediate and long-term quality of life (pain, function and knee scores) in patients after a TKA.<sup>1</sup> Up to 43% of patients even forget that they have metallic implants inside.<sup>2</sup> Appropriate patient and implant selection, presence of comorbidities, technique and duration of surgery, alignment and postoperative care are fundamental determinants of outcomes. More so, anatomical alignment in all 3 planes (coronal, sagittal and axial) is crucial for preventing instability, excessive stress across the polyethylene insert, and patient satisfaction.<sup>3-7</sup>

The achievable alignment depends on correctability of the deformity. In this context, certain situations can make surgery a grueling experience and also predispose to complications. These include severe deformities associated with soft-tissue contractures, laxity on the convex side and contractures on the concave side, bone loss and extra-articular deformities (EAD).<sup>8,9</sup> An EAD is associated with high rates of under-correction in upto 78.6% and substandard implant positioning in over 21% cases.<sup>10</sup> The deformity may exist in one, two or all three planes, in the femur and/or the tibia, and is most commonly a consequence of malunited fractures.<sup>11,12</sup> Fractures leading to extra-articular malunion occur beyond the knee's capsuloligamentous envelope and can heal in mechanically poor positions producing an EAD.<sup>13</sup>

Recognizing an EAD preoperatively allows a surgeon to choose between various management strategies to restore alignment in these knees. An indirect approach involves a corrective osteotomy at the deformity site and fixation using hardware, establishing the anatomic axis followed by mechanical axis restoration. The other, direct approach is to leave the deformity uncorrected and compensate for axial balance by performing an intra-articular correction. Although case series and reports on varying operative options for TKA in a knee with EAD have been published in the past, a concise review clarifying the approach to this unique challenge is lacking.<sup>11,14-27</sup>

This article looks at the available literature on dealing with a TKA for an EAD with emphasis on correction of deformity, attainment of desirable alignment and complications associated with various

Correspondence: Vishesh, Khanna, Sunshine Hospitals, Secunderabad, Telangana, 11/397 Sunder Vihar, Outer Ring Road, Near Paschim Vihar, New Delhi 110087, India.  
Tel.: +91.9811844647.  
E-mail: visheshkhanna85@gmail.com

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methods. We have reviewed relevant texts in our attempt to shed some light on this topic and help the reader gear up for this distinctive surgical scenario. We have performed an exhaustive search for pertinent texts on Medline (pubmed), google scholar, clinicalkey and knowledge genie.

### Axes, alignment and malalignment- their importance and implications

Before we delve into the complexities of this convoluted malady, it is prudent to revise certain principles, elementary, yet essential, to the fruition of a balanced knee after TKA. The three cardinal lines guiding clinicians in establishing *normal* alignment include the vertical, mechanical and anatomic axes, which are respectively described as passing along the center of the pubic symphysis, between the centers of the femoral head and the ankle; and through the centers of the intramedullary canals of the femur and tibia. Standard inclinations of the mechanical and anatomical axes, defined with respect to the vertical axis, for the femur are 3 and 6° respectively. Anatomical and mechanical tibial axes are, in most cases, overlapping and at 3° to the vertical axis.<sup>7</sup>

In the landmark paper by Dror Paley

and Kevin Tetsworth, joint orientation, in addition to alignment, has been described as vital part of the frontal plane evaluation of the knee joint. This orientation is of 5-7° valgus at the distal femur and around 3° of varus at the proximal tibia. The authors had introduced the *malalignment test* on the basis of which the origin of a deformity around the knee could be localized to either bone (or both). A step-wise evaluation begins with a standing, full-length radiograph (*scannogram*) of both lower limbs taken with the patellae facing forwards. The centers of the hip and ankle on each side are then joined with a line on the radiograph film and any deviation from the mechanical axis (MAD) is noted. This line should ideally pass through the medial spine (or between the medial and lateral tibial spines) and a consequent medial or lateral displacement is labelled as a varus or valgus deformity of the knee respectively<sup>28</sup> (Figure 1). The intersection of this weight-bearing line on the tibia has been also described, by Fujisawa *et al.* in 1979, to be passing through 62% of its plateau when measured from the medial end. This *Fujisawa point* correlates with the mechanical axis and is situated slightly lateral to the lateral tibial spine.<sup>29</sup>

Next, in case a deformity is present, its origin from the femur or tibia need to be defined. This may be performed by joining respective lines from the centers of the femoral head and ankle to the center of the knee. The lateral distal femoral (L DFA) and medial proximal tibial angles (MPTA) thus formed (using the above two lines and the femoral and tibial joint lines) should lie within the normal ranges of 86-89°. Any aberrations of these would suggest the likely etiology of the deformity. Needless to say, both femoral and tibial joint lines are parallel in normal knees and joint space anomalies would be the probable cause of an irregular association between the two<sup>28</sup> (Figure 1A).

While the concept of alignment itself has two sides to it, (that of the entire limb, and of the prosthesis), with respect to a TKA, alignment can be achieved in terms of and relative to the anatomical and mechanical axes, and soft-tissue balance. Two schools of thought, which have been described with regard to these, include mechanical and the 3-dimensional kinematic alignment. The former, popularized by Insall, involves cutting the femur and tibia tangential to their mechanical axes and a 3° external rotation of the femur to balance the soft-tissues.<sup>30</sup>

The kinematic concept of knee alignment stems from a cadaveric research done in 1993 by Hollister *et al.* where they used

a mechanical device on six specimens to describe knee motion. A variable flexion-extension axis (anterosuperior medially to posteroinferior laterally) perpendicular to the sagittal plane was identified passing through the origins of the collateral ligaments, superior to the intersections of the cruciates. The other axis, (longitudinal rotation axis) lay anterior and not perpendicular to the former axis producing an offset that leads to the valgus-external rotation observed with extension.<sup>31</sup>

A perfectly mechanically aligned knee after TKA, one of the anatomical aims of the operating surgeon, has long been held as the key to obtaining success.<sup>32,33</sup> Among a large cohort of 6070 TKAs, Fang *et al.* observed that a near-normal alignment (between 2.4 and 7.2° of valgus) was more likely to result in better overall survivorship.<sup>34</sup> Notwithstanding this, studies report-

ing over 20% of outliers have illustrated an insignificant impact of these aberrations over the functional outcomes.<sup>35</sup> Recent data advocates comparable to superior outcomes with kinematic alignment after TKA.<sup>36</sup>

In a randomized trial, Dossett *et al.* observed similar hip-knee-ankle (HKA) and anatomic angles in kinematically and mechanically aligned groups. With greater mean femoral valgus (by 2.4°) and tibial varus (by 2.3°) angles in the former group, significantly higher functional scores and flexion was reported in these patients.<sup>37</sup> Following up their patients after 2 years, the authors reasserted better function and range of movement (ROM) with anatomic knees.<sup>38</sup> Others have associated more neutral mechanical axis and better aligned joint lines in addition to superior function and ROM with kinematically aligned knees.<sup>39</sup> With these emerging trends, it is more likely

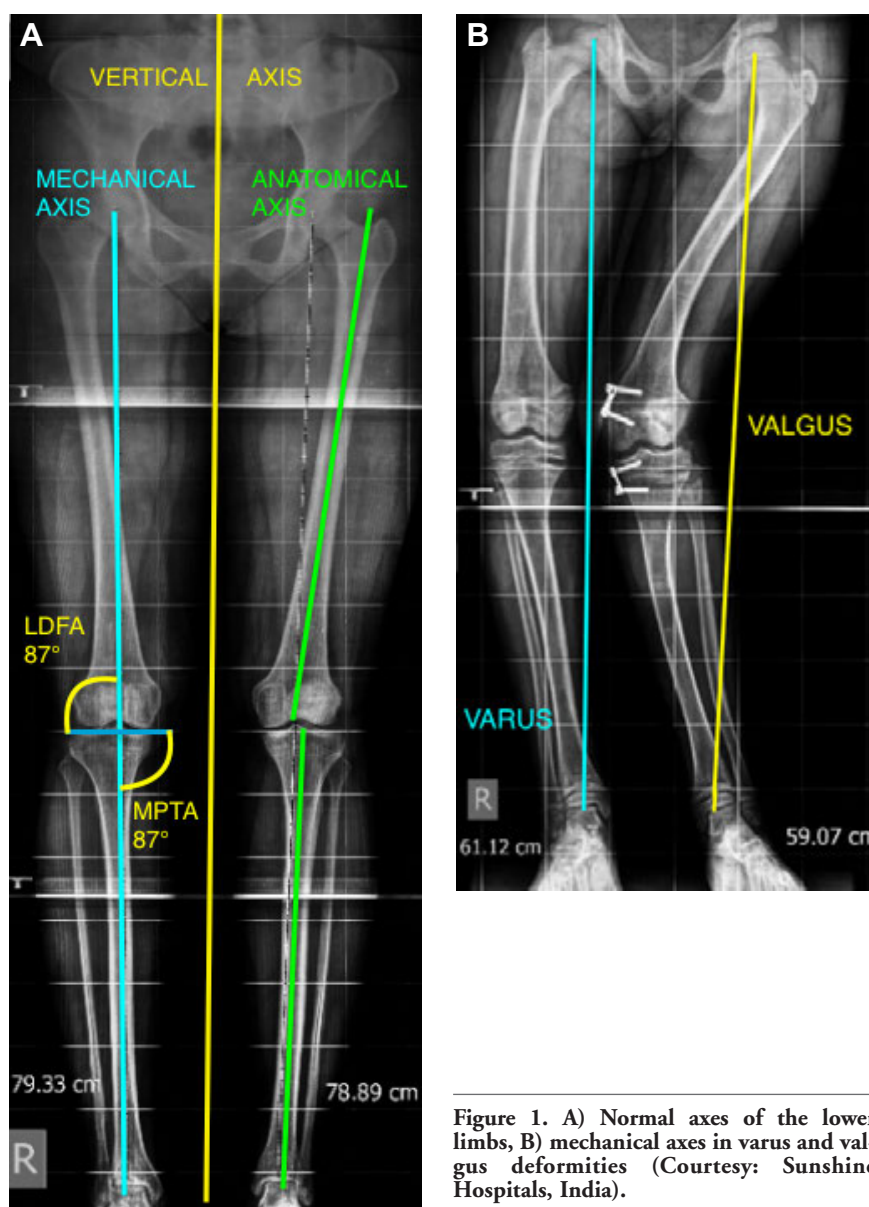


Figure 1. A) Normal axes of the lower limbs, B) mechanical axes in varus and valgus deformities (Courtesy: Sunshine Hospitals, India).

in the future for surgeons to be laying greater emphasis on kinematics when considering knee deformities with arthritis.

## Recognizing extra-articular deformities

Deformities of tibial and femoral shafts and metaphysis not involving the articular surfaces are defined as being extra-articular.<sup>22</sup> These may be uniplanar or multiplanar in their extent and occur proximal to femoral epicondyles and distal to tip of fibula (Figure 2). In the long run, an EAD can result in gross alteration of limb axis and secondary OA of the knee.<sup>40</sup> A broader definition by Rhee and colleagues classifies all angular deformities of the middle-distal thirds of femur and proximal-middle thirds of the tibia as EADs.<sup>27</sup> Problems are exacerbated when these deformities reach out to the rotational and sagittal planes. The closer it is to the joint, the greater impact it leaves on the alignment.<sup>40</sup> It is therefore a primary goal, in knees with EAD, to obtain a mechanically balanced knee without pain and with good ROM.

## History and examination

Fracture malunion is one of the commonest causes for an EAD.<sup>12</sup> In one series, the incidence of varus and recurvatum after distal femoral fractures is reported in almost 50% cases. This is commonly accompanied by pain (due to stretching of the posterior capsule) and functional impairment (pain, weakness and impairment of knee extension).<sup>41</sup> Post-traumatic, extra-articular malunions involving the femur and tibia may occur with equal frequency. Combined femoral and tibial malunions, though rare, may also occur in around 5% cases. The results of a French Hip and Knee Society study on 78 post-traumatic EADs revealed that varus HKA malalignment was the most common deformity (48 of 78 cases), followed by valgus (22 of 78). The femoro-tibial rotational profile was affected by malunion in up to 13% cases. Sagittal plane deformities including procurvatum and recurvatum can also occur in over 23% extra-articular malunions about the knee.<sup>13</sup> Stress fractures can malunite as well leading to EADs.<sup>42</sup> The EAD can also be a manifestation of a surgical procedure, commonly a high tibial osteotomy (HTO).<sup>11,42,43</sup>

One should also introspect for evidence of metabolic or congenital disorders that may reveal an underlying etiology. Blounts disease, hypophosphatemic rickets and

osteogenesis imperfecta have all been reported to be associated with EADs around the knee.<sup>14,15,26</sup> Excessive coronal bowing may also result from vitamin D and calcium deficiency leading to a combination of osteoporosis and osteoarthritis.<sup>42</sup> Recent research has demonstrated a particularly high incidence of femoral shaft bowing as a cause of EAD more so, in Asians. In a Chinese study, Yau *et al.* observed marked shaft bowing ( $>2^\circ$ ) in over 60% patients undergoing a TKA. It was the lateral bowing which was more common (71%) greatest being  $20^\circ$ .<sup>44,45</sup>

Besides trauma, congenital, metabolic and post-infective causes have been described for EAD. A recent study has revealed an inherent extra-articular metaphyseal-diaphyseal angulation of  $4^\circ$  or more in over 58% of a cohort of Indian population undergoing TKA for primary knee OA.<sup>10</sup>

## Radiological evaluation

Due recognition of EAD must be ensured by obtaining full-length standing AP radiographs of both lower limbs. This also helps in assessing the true severity of the deformity. Malunion may necessitate a computed tomography (CT) for assessing rotational deformities.<sup>46</sup> The *kneeling view* as popularized by Takai and colleagues, is a PA projection of the knee in  $80^\circ$  flexion that evaluates rotational deformities of the distal femur with accuracies at par with CT.<sup>47</sup>

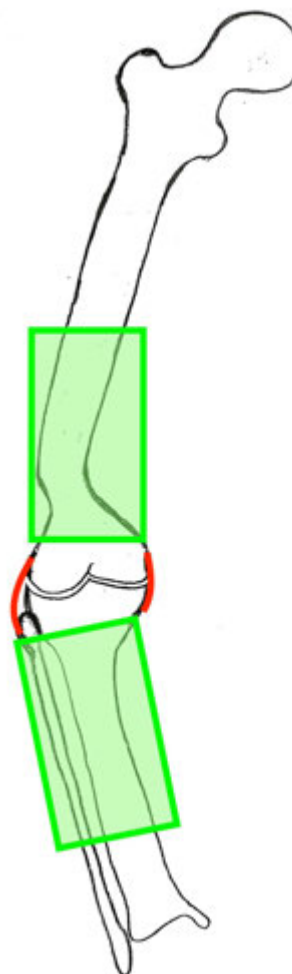
In most cases however, long-leg AP radiographs can be relied upon to evaluate deformities with strong reliability across different levels of surgical experience.<sup>48</sup> The radiographs must be made in neutral rotation with the patellae facing forwards to avoid errors in assessing deformities with femoral bowing.<sup>49</sup> These films are also handy in estimating coronal laxity, planning of bone resection levels and orientation of implants in relation to the mechanical axes. With both knees fully extended and approximately 18 inches apart, the x-ray beam focuses directly and perpendicularly over the knee and patella. Lateral projections must be obtained in a *truly lateral* sense with both, medial and lateral condyles superimposed over each other. Controlling magnification is pivotal before any estimation of component size is done. This has been conventionally performed using a ball or a coin of known dimensions.

A step-wise identification of important parameters helps in evaluating the overall coronal plane alignment and its magnitude (hip-knee-ankle axis, tibiofemoral or the hip-knee-ankle angles).<sup>50</sup>

## Preoperative planning

Baldini *et al.* in a concise review, have enlisted 6 pre-operative management considerations for a knee with EAD. These include; the location and magnitude of deformity, possibility of an intra-articular correction occasionally combined with an osteotomy, soft-tissue imbalance associated with intra-articular correction, fixation options (plates vs nails) for extra-articularly corrected knees and defining the roles of computer-assisted navigation surgery (CAS) and patient specific instrumentation (PSI). Each of these will be elaborately addressed in the subsequent sections.<sup>9</sup>

The closer the deformity is to the joint, the more challenging it becomes to obtain a balanced knee.<sup>40</sup> Deformities greater than  $15^\circ$  have been shown, in simulated tibial models, to significantly affect knee alignment.<sup>51</sup>



**Figure 2.** Defining an extra-articular deformity: a deformity originating beyond the collateral ligaments.

## Other factors affecting choice of treatment in EADs

A younger age may require meticulous restoration of anatomy. Underlying disorders like rheumatoid arthritis can make an osteotomy statutory for obtaining correction. Involvement of neighboring joints like the hip, for which a long proximal stem is inserted, may impede with insertion of a distal femoral stem.<sup>52</sup> Status of fracture union: staged procedures may be required in uniting fractures or osteotomy sites. Limb alignment must be evaluated with a 3 dimensional perspective. Skin, muscle and neurovascular status are important determinants of healing. Previous surgeries like an HTO and others, which might necessitate hardware removal and arranging accompanying logistics, should be kept in mind.

## Templating

A vast number of software options are available to surgeons allowing preoperative digital templating. This begins with obtaining images from the Picture Archiving and Communication Systems (PACS). After controlling magnification, the images are re-sized, alignment assessed and femoral and tibial shapes and sizes measured. Finally, the femur and tibia are overlapped in orthogonal planes to gauge the component size and plan augmentation by grafts, wedges, cement or stem extensions.<sup>27</sup>

## Tackling the EAD

Based on published literature, there are 3 principle surgical approaches to address the issue of an EAD when planning a TKA.<sup>19</sup>

*Extra-articular correction (EAC) with an osteotomy followed by TKA several months later as a two-stage procedure*

*Simultaneous, EAC and TKA as a single-stage procedure*

*Intra-articular correction (IAC) leaving the deformity as such and aligning the mechanical axis thereby nullifying the abnormal forces across the joint. Achieving this goal can be aided by navigation and by utilizing patient specific instrumentation (PSI)*

## Two-stage procedure (EAC plus TKA)

Hinged or constrained prosthesis can be

handy in dealing with instability arising from intra-articular deformity correction. These are however, not always practical especially in cases with severe deformities. It is here that EAC employing an HTO or supracondylar femoral osteotomy (SCFO) is indicated.<sup>14</sup> Rhee *et al.* observed persistent postoperative valgus position after navigated-IAC in a patient with history of multiple surgeries, severe valgus deformity, muscle weakness and ligament laxity. The authors regarded such procedures (with deformities  $> 15^\circ$ ) as challenging.<sup>27</sup>

In the present era, a 2-stage procedure for EAD correction followed by TKA is uncommonly practised. This option in varus knees involves creating a valgising osteotomy (open wedge type described for the tibia) followed by TKA at a later date. Although the pain-free period may last for a considerable amount of time, in knees with severe OA, this prerogative may be short-

lived and difficult to achieve in knees with grade 3 or 4 arthritis. Madelaine *et al.* have recommended this recourse mainly in younger people, lest a malunion of the osteotomy may complicate a future TKA (16). In the largest series on TKA with EADs published so far by the French Hip and Knee Society, EAC was carried out for individuals younger than their average population (56 vs 65). In 2 of 18 patients undergoing an osteotomy (proximal tibial and supramalleolar), a staged TKA was performed 8 and 12 months later.<sup>13</sup>

## Simultaneous, single-stage EAC and TKA

The current trend is towards performing an intra-articular correction. In a recent article, Ranawat and colleagues have achieved

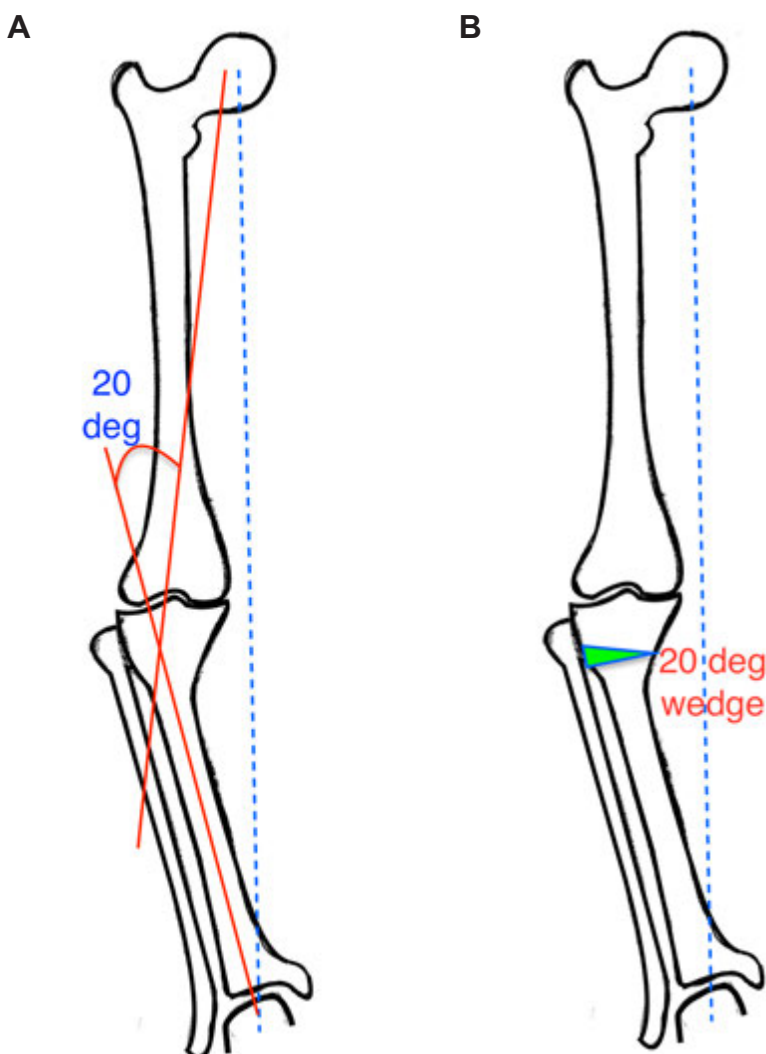


Figure 3. A,B) Tibial extra-articular deformity planned for extra-articular correction.

intra-articular correction successfully in femoral deformities as large as 32°.19 Notwithstanding this feat, deformities greater than 20° and 30° in the femur and tibia respectively would mandate large releases leading to ligamentous laxity and eventual malrotation of the femoral component.53 These have, therefore, conventionally been managed by extra-articular osteotomies to address correction.11 In addition to magnitude, a greater distance of an EAD from the knee also favors an EAC54 (Figures 3 and 4, Table 1).

Although the medial parapatellar arthrotomy is the most favored approach, an anterolateral subvastus exposure with tibial tubercle osteotomy maybe necessitated with severe deformities. Hundred percent healing rates of the tubercle have been reported.15

Opening wedge and closing wedge tibial osteotomies (OWO and CWO), performed extra-articularly, can be employed in correcting the frontal plane deformity without interfering with intra-articular resection or, the delicate balance among soft-tissues. These are however, rare surgeries that accompany a TKA (<0.5%). In a

recent French paper, the OWO was proffered as having the advantages of circumventing the need for releases along the convexity and allowing for more precise correction. While the osteotomy could be preceded or succeeded by a TKA, the authors suggest beginning by preparation of the osteotomy site first by elevating the pes anserinus and superficial MCL (leaving its proximal fibers intact). The osteotomy can then be made, as far possible from the plateau (so as to accommodate the tibial base plate). The medial plateau is elevated through the cut to reach up to the leg of the tibial cutting guide. Subsequently, preparation of the femur and tibia is done, implants cemented and the osteotomy was bridged by the stem and fixed internally with staples, wedges, metallic or cement wedges. Thirteen of 15 patients operated following these principles were either satisfied or very satisfied and substantial improvements were reported in Knee Society Scores (KSS) and functional scores.16

On the femoral side, an SCFO can be made and reliably fixed with angle-stable plates. In their large series, Veltman and colleagues from Netherlands on 10 knees,



Figure 4. Tibial extra-articular deformity corrected by extra-articular correction.

Table 1. Extra-articular correction for extra-articular deformity of the knee.

Author, year	Lonner <i>et al.</i> , 2000	Radke and Radke, 2002	Madelaine, 1997-2001	Veltman <i>et al.</i> , 2006-12
N.	11	10	15	16/21
Age (mean)			68.2	62
Site			T	F-10, T-11
Cause	MU-10, hR-1		Constitutional (8), trauma (3), Paget (1), HTO (3)	MU (10), Sx (7), OA (3), OI (1)
Planar deformity (°)	UP-5, BP-5, TP-1			
Approach	4-MPP 7-AL		MPP	
Tech			HTO (OW)	SCFO (10), HTO (11)
Correction (mean°)			10	
Mean Sx time (min)			116	
Preop MA (mean°)			18 var	F-12° var to 15° val; T-17° var to 11° val
Postop MA (mean°)	< 2 var	5-10 in 8 0-4 in 2	4 var*	
Preop Flx contr (mean°)	19		2.3	
Postop Flx contr (mean°)	2*		0	F-2, T-1
Preop KSS (mean)	10	28	47	
Postop KSS (mean)	87*	81*	61*	
Preop FS (mean)	22	47	45	
Postop FS (mean)	81*	76*	72*	
Preop ROM (mean°)	56		120	
Postop ROM (mean°)	89*		115.3	F-96, T-108
Implant			PS + tibial stem	PS + femoral stem (1)
F/U (mean months)	46		78	64
Cx	NFPE	None	# (4), NU (2), DI (1), stiff (1)	Inf (2), NU (2), # (1), stiff (2)

N, number of patients; Tech, technique utilized; Sx, surgery; MA, mechanical axis; Flx contr, flexion contracture; KSS, Knee Society Score; FS, functional score; ROM, range of movement; F/U, follow-up; Cx, complications; MU, malunion; hR, hypophosphatemic rickets; UP, BP, TP, uniplanar, biplanar, triplanar; MPP, medial parapatellar approach; AL, anterolateral approach; var, varus; \*, statistically significant; NFPE, non-fatal pulmonary embolism; HTO, high tibial osteotomy; OW, opening-wedge osteotomy; PS, posterior-stabilized; #, fracture; NU, nonunion; DI, deep infection; Stiff., stiffness; F, femur; T, tibia; OA, osteoarthritis; OI, osteogenesis imperfecta; SCFO, supracondylar femoral osteotomy; val, valgus; Inf, infection.

achieved a mean postoperative flexion and ROM of 98° and 96° respectively after an SCFO. In the same study, the tibial EAD was corrected by an HTO in 11 knees with even greater improvement in flexion and ROM to 109° and 108° respectively.<sup>14</sup> Following an osteotomy and proximal and distal medullary reaming, temporary stabilization using an external fixator, intramedullary femoral referencing and cuts is done along with osteotomy fixation (retrograde nailing and bone grafting) finally followed by prosthesis fixation. The authors have reported correction from 13.4° varus to 2.1° valgus. Although the osteotomy was on the verge of nonunion initially, it was salvaged by iliac crest grafting and plating. Overall improvement in functional score was almost 3-fold (35 to 90). Similar strategies have also been reported for tibial nonunion.<sup>55</sup> Good outcomes were also reported by Radke and Radke in 10 knees with EADs  $\geq 15^\circ$  where mean preoperative KSS and functional scores improved from 28 and 46.5 to 80.6 and 76 respectively. Devoid of any nonunions, their study cited advantages of EAC such as preservation of collaterals, precise restoration of axes and avoidance of managing bone defects.<sup>17</sup>

### Problems with osteotomies

Nonunion of osteotomy sites is a potential concern for EAC.<sup>55</sup> As a preventive measure, the osteotomy should be carried out through the metaphysis (which has the best healing potential), perfectly reduced with no interposing cement, fixed with rigid, rotationally stable osteosynthesis and reinforced with a rod through the osteotomy site.<sup>13,14</sup> Hazratwala *et al.* suggested a controlled osteotomy (anteriorly opened using laminar spreaders) at the apex of the deformity and leaving the posterior cortex intact to serve as a hinge and improve stability. Using fluoroscopy and direct vision, the deformity was corrected first, fixed with a locked nail and bone grafted along with packing of OP-1 bone morphogenic protein.<sup>56</sup> Among 16 EACs for EAD in a TKA, 2 patients each developed nonunion, deep infection and postoperative stiffness. The infections resulted in an arthrodesis in one while the other needed a gastrocnemius transfer for wound closure. One patient sustained a medial femoral condyle fracture during the osteotomy, which healed uneventfully after rigid internal fixation.<sup>14</sup>

A tibial plateau fracture can be an unfortunate setback (while tibial preparation) that may necessitate prolonged immobilization (up to 2 months). The authors submitted to using successive drills (instead

of impactors for the tibial tray) to avoid fractures and bone grafting and locked plating of the osteotomy site to allow early weight-bearing.<sup>16</sup> Other potential complications of an EAC include the development of pseudoarthrosis.<sup>13,14</sup>

Staged or simultaneous extra-articular correction of EAD has stood the test of time and is still relied upon for grossly deformed knees. It allows 3 dimensional correction and is more forgiving on ligament balancing than IAC. While balancing these delicate structures, the pes anserinus and superficial MCL should be spared until all other options are exhausted. In trained hands, outstanding results can satisfy patients and surgeons alike. Nonunion at the osteotomy can be avoided by proper planning and execution of the cut combined with anatomical reduction, rigid fixation, augmentation and early mobilization.

### Intra-articular correction

The decision to perform an IAC has to be made based on the preservation of the collateral ligament attachments at the femur (Figures 5 and 6). As long as their insertions are not violated, the *more straightforward* IAC can be attempted. Advantages are man-

ifold including a single-incision, two-in-one surgery and faster postoperative mobilization besides avoidance of infection, problems with union and failure of fixation.<sup>11,15</sup>

For the tibia, the passage of a line, originating distally and running through it into the proximal end of the knee is the guiding element. As long as this line passes within the tibial condyles, an IAC remains the procedure of choice.<sup>11</sup> With the landmark study of Wang and Wang, the earliest reports of IAC with concurrent TKA surfaced. The authors went on to theorize that femoral and tibial deformities measuring less than 20° or 30° respectively could be managed by intra-articular resection. Their technique on 15 patients with uniplanar, biplanar and triplanar deformities yielded satisfactory outcomes in over 85% cases.<sup>11</sup>

### IAC without navigation

Before the inception of navigated TKA (Table 2), unguided intra-articular resection was being performed using conventional instrumentation.<sup>11</sup> Over the last decade, while the majority of published literature comes from centers using Computer Assisted Surgery (CAS), a few surgeons report effective correction without em-

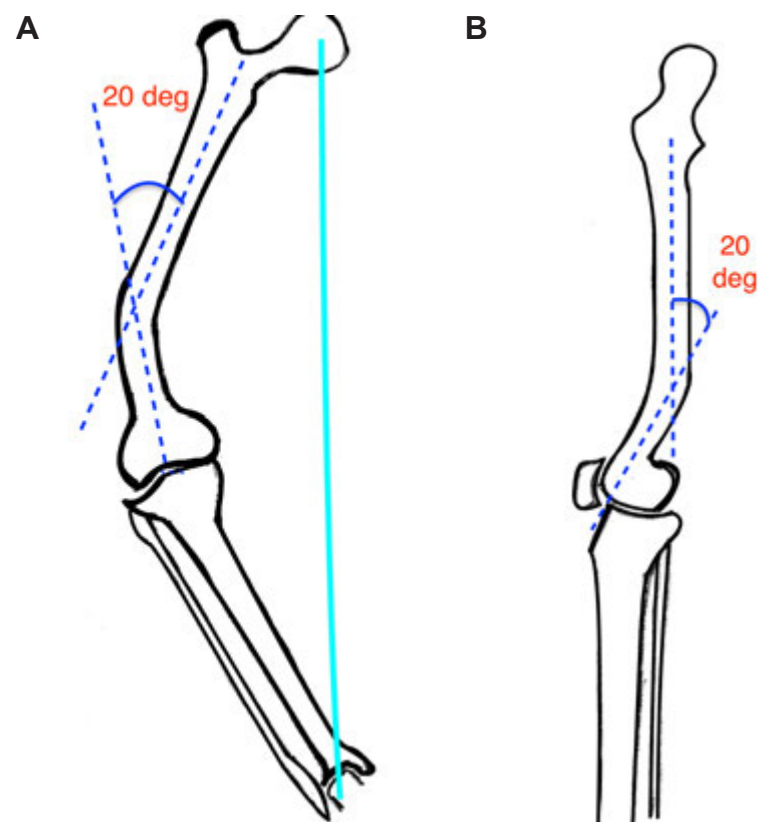


Figure 5. A, B) Femoral extra-articular deformity planned for intra-articular correction.

ing CAS. The authors cite surgeon experience and standard approaches as crucial factors that can help in achieving results comparable to CAS with manual non-navigated knees in shorter operative times using intramedullary and extramedullary guides.<sup>18,19</sup>

While inserting intramedullary rods can be challenging in a femur with EAD, it can be accomplished by lateralizing the entry point on femoral condylar surface in varus knees and vice versa in valgus knees. In over half of the patients, (including those with deformities of the middle third of femoral shaft and those which do not permit intramedullary rod insertion), extramedullary guides are necessary. When the tibia requires intramedullary guides, a similar lateralization/medialization can be done for the insertion point for varus and valgus deformities respectively. In around 25% cases, extramedullary referencing may be needed (deformities in the middle third of tibia). The defects arising from bone resection need to be grafted. For small (<5 mm) voids morselized bone from resected pieces may suffice while larger gaps need corticocancellous autografts.<sup>11</sup> Following bone resection, meticulous soft-tissue balancing is done. Over 90% knees are seen with varus deformities where greater resection of the lateral femoral and tibial condyles results in a relative elongation of the lateral structures.<sup>11</sup> Releasing the deep MCL, semimembranosus and posteromedial capsule help restore the balance initially.<sup>44</sup> With persisting imbalance, medial subperiosteal releases of the superficial MCL and pes anserinus may be needed.<sup>11</sup>

Laxity of lateral structures may necessitate popliteofibular ligament release. These cuts can result in asymmetric flexion (larger) and extension gaps that are dealt with by upsizing and posteriorly translating the femoral prosthesis. In severe varus cases, the medial epicondyle (with its attached deep MCL) can be osteotomized and distalized. Similarly, for severe valgus knees, routine cuts and releases may additionally warrant periosteal excision of the fibular head and lateral epicondylar distalization.<sup>46</sup> Larger releases can be tried with less untoward effects towards gap balancing in tibial deformities when compared to similar magnitudes of femoral deformities. This may be true as the tibia acts in both, flexion and extension.<sup>15,57</sup>

One of the largest series on IAC for post-fracture deformities was done on 36 knees at the Medical University of Lodz, Poland. Over a mean follow-up period of 4.8 years, Marczak *et al.* observed remarkable improvements in mean functional and clinical KSS from 45 and 39 to 80.5 and 78

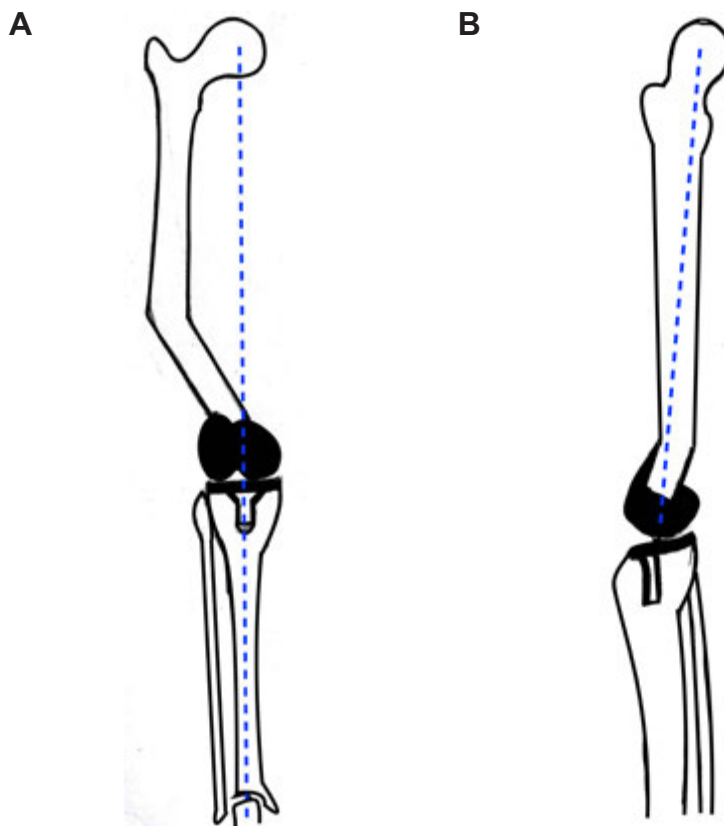


Figure 6. A, B) Femoral extra-articular deformity corrected by intra-articular correction.

Table 2. Non-navigated, intra-articular correction.

Authors	Wang and Wang	Koenig <i>et al.</i>
Year	1995-1998	2009
N.	15	2
Age (mean)	65	80
Site	F-7, T-8	F-1, T-1
Cause	MU	MU
Planar deformity n, (°)	UP-10, BP-3, TP-2; RD (3)	Var (33) + Rec(20), Val (32)
#-Sx interval (mean yrs)	18	
Preop MA (mean°)	23 var	
Postop MA (mean°)	0.3 var	
Preop Flx contr (mean°)		
Postop Flx contr (mean°)		
Preop KSS (mean)	22	40
Postop KSS (mean)	92*	95*
Preop FS (mean)	28	
Postop FS (mean)	87*	
Preop ROM (mean°)	78	
Postop ROM (mean°)	104*	
Implant	PS (12), CR (3)	
F/U (mean months)	38	
Cx	None	None

N, number of patients; #, fracture; Sx, surgery; MA, mechanical axis; Flx contr, flexion contracture; KSS, Knee Society Score; FS, functional score; ROM, range of movement; F/U, follow-up; Cx, complications; F, femur; T, tibia; MU, malunion; UP, BP, TP, uniplanar, biplanar, triplanar; RD, rotational deformity; var, varus; \*, statistically significant; PS, posterior-stabilized; CR, cruciate retaining; Rec, recurvatum; val, valgus.

respectively. Their study however, involved a heterogeneous population comprising of intra-articular (3 out of 11 femora and 13 of 27 tibiae) and extra-articular fractures. Though the authors have not mentioned results of intra-articular versus extra-articular fractures categorically, marked overall improvement in extension, knee scores and ROM were observed. Mean preoperative varus and valgus of 21.4 and 18.6 respectively were corrected to within 0-5° of valgus in all but 4 knees after surgery.<sup>18</sup> Even greater correction with intra-articular non-navigated knees was obtained by Wang *et al.* in 15 patients from a mean 22.3° varus preoperatively to 0.3° varus at mean 38 months of follow-up. This series also illustrated significant improvements in the mean ROM from 78.4 to 103.6 after surgery.<sup>11</sup>

A plethora of implant types with varying degrees of constraint and stem extension can be utilized ranging from primary condylar knees (ACS, Stryker), rotating hinge (Stryker) to constrained condylar implants (Triathlon, Legion, Biomet).<sup>18</sup>

The potential complications arising from non-navigated instrumentation include malalignment of the knee in both coronal and sagittal planes. An anterior tibial slope has also been reported to occur inadvertently. One has the option of converting to or adding a concomitant extra-articular osteotomy, if the need arises. Re-cutting

and re-suturing maybe required for healing problems (6% cases).<sup>18</sup> Stiffness and decreased ROM (<90°) can ensue especially when severe conditions prevail preoperatively. Poor outcomes may also be encountered in patients with rheumatoid arthritis and failed back surgery. Another major problem is the asymmetrical flexion and extension gaps that require ligamentous releases, which in turn leads to laxity ultimately demanding more constraint at the implant level.<sup>11</sup>

### IAC with navigation

Preoperative templating is useful for evaluating whether the deformity will impede implant positioning and if the cut would violate the collateral ligament attachments.<sup>26,27</sup> Navigation (Table 3) can help in determining the centers of rotation of the hip and the ankle and thereby, the mechanical axes of the femur and tibia with excellent results.<sup>26</sup> By obviating the need for an intramedullary entry into the canals, CAS theoretically reduces the risk of fat embolism.<sup>21,27</sup> It also provides the surgeon a real-time picture of planned and performed bone cuts. The popularity of CAS can be made out from the fact that almost 24% of primary TKAs in Australia every year are navigated.<sup>56</sup> Over the last decade, several studies and case reports have surfaced

unanimously favouring navigated intra-articular correction of EAD while performing TKA.<sup>13,21-27,42,56,58</sup>

In one of the oldest and largest series by Arun Mullaji and colleagues on 40 EADs, CAS was employed to achieve correction in 90% cases. The main advantage of using this technology lies in its calculation of mechanical axis using the centers of the 3 major joints of the lower limb; the hip, knee and ankle. The distorted anatomy does not prove a hindrance and neither does one have to rely on the intramedullary and extramedullary guides. Graduated resection also ensures that minimal bone resection takes place, which in turn, allows easier soft-tissue balancing. Also, in significant bowing, the distal femoral valgus correction angle (VCA) increases and is determined by the computer. In their series, Mullaji and colleagues observed a mean VCA of 10.23°. Placing conventional 5° or 7° cutting jigs in these deformities can lead to malalignment.<sup>42</sup> Patient selection is primarily based, like in non-navigated knees, on the original criteria established by Wang and Wang.<sup>11</sup> While templating it is crucial to determine the hip-knee-ankle axes along with the magnitude of EAD in both planes preoperatively.<sup>42</sup>

Navigation starts with the registration of the centers of femoral head, knee and ankle which is followed by insertion of a

**Table 3. Intra-articular correction + CAS.**

Authors	Catani <i>et al.</i>	Bottros <i>et al.</i>	Tigani <i>et al.</i>	Lin <i>et al.</i>	Liu <i>et al.</i>	Rhee <i>et al.</i>	Chou <i>et al.</i>	Shao <i>et al.</i>
Year	2003-2008	2004-2006	2004-2009	2006-2008	2006-2009	2007-2012	2008	2008-2010
n	20	9	9	3	8	13	1	12
Age (mean)	52		61		69		43	65.6
Site	F-11, T-9	F-9	F-6, T-3	F-2, T-1	F-7, F+T-1	F-9, T-4		F-11, T-1
Cause	MU		MU(8), VDDR (1)		MU(7), Cong (1)			MU(11), Blount's (1)
Planar deformity (°)	UP-15, BP-5					UP-3, BP-10		
#-Sx interval (mean yrs)	18					26	25	
Approach	MPP-19, LPPA-1							
T/F first	F			F	F	F	T	T
Preop MA (mean°)	10.4 var	5.1 var	26 val – 19 var		11 var	7 var	8 var	10 var
Postop MA (mean°)	0.8 var	1.3 var	0±3	0.5	1 var	0	1 var	1 var
Preop KSS (mean)	48	62	33	44	25	29	38	41
Postop KSS (mean)	91*	92*	80*	91*	84*	90*	82	95*
Preop FS (mean)	42	52	33	40	49			
Postop FS (mean)	85*	83*	74*	90*	86*			
Preop ROM (mean°)	67	70		100	85	84	90	84
Postop ROM (mean°)	94*	97*		117	106*	119*	95	115*
Implant	PS-16, Cons-4	PS-4, CR-5		MIS-TKA	PS	LPS Flex(10), PFC (3)	LPS Flex NRG (10), RPF (2)	
F/U (mean months)	37	19	30		24	37		12
Cx	None	Stiff-#	None	None	None			None

N, number of patients; #, fracture; Sx, surgery; F, femur; T, tibia; MA, mechanical axis; KSS, Knee Society Score; FS, functional score; ROM, range of movement; F/U, follow-up; Cx, complications; MU, malunion; UP, BP, uniplanar, biplanar; MPP, medial parapatellar approach; LPPA, lateral parapatellar approach; var, varus; \*, statistically significant; PS, posterior-stabilized; cons, constrained; CR, cruciate retaining; Stiff, stiffness; VDDR, vitamin D resistant rickets; val, valgus; MIS, minimally invasive surgery; Cong, congenital.



rigid pin each in the tibia and femur. To each of these, reflector spheres are attached that help in bringing about a spatial orientation of the lower limb axes. The deformities are then recorded and bone cuts made.<sup>42</sup> The surgeon has the option of performing the distal femur 1<sup>st</sup> or the tibia. Femoral orientation in the coronal plane is at 0° to the mechanical axis, in 2° flexion in sagittal plane, and in mid-orientation between the epicondylar axis and Whiteside line. Tibial cuts may precede the femoral resection and are taken at 0° to the mechanical axis in the coronal plane while the native slope is restored sagittally (if not already accounted for in the implant system). In some knees, the anatomical landmarks may be misleading making the transepicondylar axis, anteroposterior axis or their mid-orientation unreliable. A recommended strategy here is to have a balanced extension gap prior to achieving an appropriate femoral rotation and a flexion gap.<sup>26,57</sup>

For optimal rotational alignment of the tibia, it can be cycled a few times with the trials in place and its final position in extension can be chosen.<sup>21,27</sup> After removing osteophytes from both articular surfaces, gap balancing maybe performed using tensioning devices. Computer-verified and rectangular, balanced flexion and extension gaps are obtained by performing medial and lateral releases akin to those performed for non-navigated IAC. In case a severe deformity warrants an EAC (as was observed by Mullaji *et al.* in 7.5% cases), the rigid navigation pins are inserted farther away from the knee joint line to help accommodate extension rods.<sup>42</sup> Releases of adhesions in the infrapatellar fat pad, between the trochlea and quadriceps, scars impeding patellar eversion and the deep MCL helps in improving access to the knee. This can be followed by a tibiofemoral release. Although this can increase the intraoperative flexion to 120°, it is important to be wary of a patellar ligament rupture from the tibial tuberosity.<sup>26</sup> The choice of implant, is in most instances a cruciate-substituting knee.<sup>42</sup>

The use of CAS in patients with EAD operated by minimally invasive TKA (MIS-TKA) has also been described in a recent case series. The authors used a 12 cm medially curved skin incision and employed a minimedial parapatellar exposure. After laterally displacing the patella, reference pins and reflector spheres were set up and the procedure was mostly identical to the routine navigated TKA. The femur was done first, followed by the tibia and soft-tissue balancing and patellar resurfacing. All patients had implants from a previous fracture-surgery *in-situ* which were not

removed. Good outcomes were achieved with over a 2-fold increase in postoperative knee and functional scores along with improvement in the ROM as well. The authors advocated MIS-TKA with CAS for extra-articular problems around the knee with the advantage of lesser dissection (especially for pin placement in the anterior femoral shaft, quicker quadriceps rehabilitation and shorter stay at the hospital). Sharp learning curves and increased duration of surgery are some of the areas of concern with MIS.<sup>23</sup>

Careful patient selection can have a tremendous impact on the results of surgery. This is reflected in a previous series where mean femoral and tibial preoperative deformities of 9.3° and 6.3° were corrected intra-articularly restoring the mean preoperative HKA angle of 166.7° to 179.1° postoperatively. At mean 26.4 months postoperatively, mean KSS had improved to 90.4 points (from 49.7 preoperatively) and mean values for knee function scores rose from 47.3 points to 84.9 points after surgery. The authors did not encounter any complications for any of their patients.<sup>42</sup> Having said that, some authors have stretched their selection criteria quite beyond this limit. In a recent study on 9 EADs by Tigani *et al.*, femoral EADs comprising 7 cases had a higher magnitude of deformities (24° varus to 10° valgus and 14° to 15° of recurvatum). In all of their cases, the authors were able to restore the mechanical axis within 3° of neutral alignment.<sup>22</sup> In one of the earliest studies, Bottros *et al.* from the Cleveland Clinic, Ohio, USA, in 9 knees with mean preoperative varus of 5.1° observed substantial improvement in mean ROM, KSS and function scores. Postoperatively, mean varus alignment was 1.3°.<sup>24</sup> Similar success was reported from other parts of the world as well. In their study on 12 knees with EADs, Shao *et al.* reported significant improvements in Knee Society scores and ROM (from a mean preoperative 40.8 and 83.7° to 94.9 and 115° respectively) along with restoration of mechanical axis (from 10° varus to 0.9 varus) after TKAs using CAS technique.<sup>26</sup> Liu in a Chinese study on 8 EAD (mean 10.7° varus) correction by CAS TKA reported appreciable improvement in the mean mechanical axis (1.2° varus), KSS (from 24.63 to 84), functional scores (49.38 to 87.5) and flexion (85° to 106.25°) while achieving the normal posterior tibial slope of around 3° over a follow-up of 2 years without confronting any major complications.<sup>25</sup> From Korea, Rhee and colleagues retrospectively reviewed the results of 13 knees with EAD operated between 2007 and 2012 with mean follow-ups of 3.1 years. Over 90% of patients in their series

had good and excellent results. Though pre-existing implants have shown to remain silent, the option of removing them while performing a CAS TKA seems attractive in light of reducing infection rates and patient discomfort.<sup>27</sup>

Navigation has its own handicaps. It cannot determine the cases which demand extra-articular correction. In a biomedical study on 30 knee models, Tantavisut from Thailand observed greater postoperative malalignment in knees with ≥15° of deformity.<sup>50</sup> Additionally, the steep learning curve in correcting complex deformities may test the skills of even the most seasoned surgeons.<sup>42</sup> Rhee and colleagues from the Pusan National University Hospital, Korea reported an important shortcoming with CAS. Despite ensuring an on-table neutralization of HKA axis to 0° in all their 13 cases, the postoperative weight-bearing orthoscannograms-recorded axis was 0° in only 5 patients. In 4 patients, the axis measured <2°, while there was a deviation >2° in the remaining 4 cases. It was thought that minor deviations could have occurred due to errors in tracker placement and fixation, while larger ones had resulted from poor soft-tissue condition and ligamentous imbalance. The authors further went on to report rotational malalignment of 10° and 30° in 2 cases intra-articular correction of which would have brought about serious ligamentous imbalance. The latter had an anteversion of 46° which was accepted as it is by the authors.<sup>27</sup> Rotational malalignment has also been reported by others.<sup>11,13</sup> Correcting sagittal plane deformities (especially recurvatum) is yet another challenge in front of IAC-preferring surgeons as it can result in posteriorly-notched femur component and overstuffed patellofemoral joint.<sup>56</sup>

Although the mean surgical time and tourniquet time with IAC for EAD and TKA with navigation is greater than that for navigated TKA and non-navigated standard TKA, it is lower than that for any other surgical modality for such complicated scenarios.<sup>21</sup> The reference pin of the navigation system may sometimes break inside the bone if too much of a torque is applied. Leaving the broken part *in-situ* does not have any untoward complication though.<sup>22</sup> A fracture can also result from manipulation under anesthesia required for postoperative stiffness.<sup>24</sup>

The patellar tendon deserves a special mention. Tendon ruptures, partial and complete can occur with excessive retraction.<sup>21,27</sup> Although uncomplicated healing and functional recovery usually follow with primary repair by Ethibond sutures, it entails a 6-week immobilization on the patient.<sup>27</sup>

### Combined intra-articular and extra-articular correction

In a recent case report, a 34-year-old malunited supracondylar fracture in a 53-year-old with significant knee pain occurring daily was operated by combined intra-articular and extra-articular approach. Following an extra-articular correction by a supracondylar osteotomy and retrograde nail insertion, the preoperative varus had been reduced from 13° to 8° while the ROM had achieved an increment from 82° to 90°. This was followed by CAS where the tibia were first resected in 0.5° valgus while preserving the PCL and popliteus. Femoral cut were made generously (4 mm extra) distally to prevent a fixed flexion deformity and obtain mediolaterally equal extension gaps. Taking cuts from the posterior aspect, the medial and lateral flexion gaps were balanced and measured equal to the extension gap. The trial and fair prostheses were implanted. Bone from cuts was placed over the osteotomy site with BMP. Post CAS TKA, the varus was reduced to 3° and recurvatum to 5.5° from 38° preoperatively. Postoperative scores and ROM were significantly better. The authors thereby, described a novel, single-stage, opening-wedge osteotomy and navigated intrarticular correction in a challenging, severely deformed and arthritic knee with a good functional result.<sup>56</sup>

### Patient-specific instrumentation (PSI)

A largely unexplored territory at soaring costs and limited availability, PSI has had success in limited published work in EAD (Table 4). In a series of 10 knees, improvement of varus and ROM was reported after with PSI.<sup>12</sup> With future studies, the cost-effectiveness will be evaluated and compared against the existing standard of care.

As long as the collateral ligaments are not violated, IAC offers a superior modality of EAD correction with lower morbidity and quicker ambulatory status in almost 90% patients. Using a wide variety of techniques and prosthesis, orthopedicians from all over have successfully conquered severe EAD with non-navigated and non-navigated TKA. The challenge in these cases lies in achieving a rectangular flexion and extension gaps. In dire straits, the superficial MCL may have to be sacrificed. Based on the HKA axis, navigation allows more accurate determination of the centers of rotation of the respective joints. This hugely popular, precise technology allows calculated minimal bone cuts and easier soft-tissue balancing and avoids intrusion of the medullary canal. Since the anatomy is more distorted in knees with EAD, opting for the

tibia-first mode can minimize rotational malalignment. MIS-TKA has also been described recently. The best results are invariably achieved in patients with mild to moderate deformities with minimum rotational malalignment. Rough handling of soft-tissues and patellar tendon is at best, avoided. Combined IAC and EAC have both been described together in severe cases with recurvatum.

### Rehabilitation

Strategies to facilitate a smooth, pain-free postoperative course include the administration of femoral nerve blocks, periarticular injections and local ice application. Exercises may be initiated after drain removal (usually 24 hours). An added advantage of IAC is the immediate initiation of weight-bearing. This can be supplemented with continuous passive motion (CPM).<sup>25</sup> What follows is a period of ROM and muscle strengthening exercises<sup>(58)</sup>. The reported overall improvement in ROM after IAC with early weight-bearing varies

in literature from 67° to 119 (mean 13°) while functional scores have displayed a two-fold increase from a mean 41 preoperatively, to 84 after IAC (Tables 2 and 3).

After an EAC, a delay ranging from 6 to 55 days in weight-bearing may be required in up to 40% patients depending on the strength of fixation. This maybe responsible for a drop in postoperative ROM (from 120° to 115°). A note of the excellent preoperative ROM must be made in this study.<sup>16</sup> In contrast, Lonner *et al.* reported a 59% improvement in ROM in knees with severe preoperative flexion contractures (mean 19°) after EAC (from 56° to 89°).<sup>15</sup> As with IAC, functional scores with EAC have also improved remarkably (form a mean 38 to 76) (Table 1). From the analysed studies, it appears that early weight-bearing is more consistently associated with a consistent improvement in ROM. Functional outcomes are usually excellent after both, EAC and IAC. Most surgeons have, and still continue to allow full weight bearing with good, predictable outcomes.<sup>12</sup>

**Table 4. Patient-specific instrumentation.**

Authors	Thienpont <i>et al.</i>
Year	2008-2010
n	10
Age (mean)	59
Site	F-9, T-1
Cause	MU-9, implant-1
Planar deformity (°)	UP-4, MP-6
Approach	10-MIS-MPP
Tech	PSI
Correction (mean°)	F(9), T(11)
Mean Sx time (min)	
Preop MA (mean°)	7.4
Postop MA (mean°)	0.7*
Preop Flx contr (mean°)	
Postop Flx contr (mean°)	
Preop KSS (mean)	38
Postop KSS (mean)	91*
Preop FS (mean)	44
Postop FS (mean)	92*
Preop ROM (mean°)	87
Postop ROM (mean°)	112*
Implant	PSI
F/U (mean months)	41
Cx	Radiolucent lines

N, number of patients; Tech, technique utilized; Sx, surgery; MA, mechanical axis; Flxcontr, flexion contracture; KSS, Knee Society Score; FS, functional score; ROM, range of movement; F/U, follow-up; Cx, complications; F, femur; T, tibia; MU, malunion; UP, MP uniplanar, multiplanar; MIS, minimally invasive surgery; MPP, medial parapatellar approach; PSI, patient-specific instrumentation; \*, statistically significant.

## Conclusions

To summarize, extra-articular deformities can pose a unique challenge to orthopedicians by making a routine simple primary TKA complex. Careful assessment and planning are needed to ease the intraoperative course by describing an efficient surgical plan. Outcomes from various timelines and across diverse lands are equally divergent. The verdict, which can be derived from this appraisal, is that one-stage, intra-articular correction is the preferred trade-off of most present-day surgeons striving for operative, mechanically-aligned knees. Extreme circumstances warranting multi-planar correction may be efficiently handled with extra-articular methods. It is vital to preserve the collateral ligaments with either technique. Trends suggest that navigation is likely to outstrip non-navigated correction in the years to come.

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