Tibiofemoral Malalignment

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Biomechanical Rationale

The normal knee joint is able to withstand a lifetime of repetitive stress, generally without the development of degenerative changes. Excessive forces that surpass the tolerance of articular cartilage can result from acute trauma or chronic overload [1–3], for example, due to malalignment.

Malalignment refers to deviation from normal alignment, which in the case of the tibiofemoral joint is a straight line, or 180° or 0° depending on the point of reference. By definition, if the line connecting the hip and ankle joints (mechanical axis) is off-center at the knee toward the medial compartment, it is varus malalignment, and if it is toward the lateral compartment, it is valgus malalignment. This deviation can be idiopathic (congenital or genetic), posttraumatic, or due to degenerative changes with loss of cartilage height in one compartment.

In a normally aligned knee, the load distribution (not the mechanical axis) during gait is shifted slightly medial, with the center being located approximately 4–8 mm medial to the center of the tibia [4]. This is secondary to the normal human gait: the hip abductors allow the pelvis to remain neutral. During the single-limb stance phase and a neutral pelvis, the center of gravity is medial to the limb. This results in the medial compartment bearing approximately 60–70% of the total load transferred across the knee joint, provided it is neutrally aligned [5]. Even load distribution between the compartments occurs between 0 and 4° of valgus alignment [6]. During normal ambulation, average peak forces reach close to three times body weight, which increases to six times body weight during higher-level activities [7, 8]. Any deviation of the mechanical axis negatively affects load distribution across the tibiofemoral compartments. Biomechanical studies have demonstrated that deviation of as little as 3° from neutral elevates peak stresses [9], and a 4–6° increase in varus alignment increases medial compartment loads by an additional 20% [10]. Not surprisingly, malalignment has accordingly been identified as an independent predictor not only for the development, but also for the progression of osteoarthritis (OA) using conventional radiographs [11–14] and magnetic resonance imaging (MRI) [15–17]. Over the course of only 18 months, a varus malaligned knee was four times as likely than a neutrally aligned knee to show progression of medial compartment OA, while the risk for the lateral compartment in valgus aligned knees was increased by a factor of five [14]. The resultant cartilage damage and loss of joint space accentuate the malalignment, in effect creating a self-reinforcing vicious positive feedback cycle [18, 19].

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By normalizing the mechanical axis, or more commonly, overcorrecting the axis into the contralateral compartment, the abnormal pressure in the affected compartment can be reduced, which aids in alleviating pain and potentially increasing the outcomes of associated cartilage repair procedures by optimizing the local stress environment [20]. Although no controlled studies investigating the incremental effects of realignment on cartilage repair exist, several investigators have noted a positive tissue response in the unloaded compartment after isolated osteotomy. Residual cartilage had an improved appearance upon visual inspection at second-look arthroscopy [21–23] and histologically in biopsy specimens [24], although the tissue was predominantly fibrocartilage [24, 25]. Another study demonstrated beneficial effects of high tibial osteotomy (HTO) on glycosaminoglycan content through the use of delayed gadolinium-enhanced magnetic resonance imaging of cartilage (dGEMRIC) [26]. Van Thiel et al. [27] investigated the effects of HTO on medial compartment loads, specifically in conjunction with a medial meniscal transplant, and found a significant drop of total and medial compartment pressures between neutral and 3° of valgus, raising the question of whether even neutrally aligned knees with medial compartment cartilage defects may benefit from a minimal "over"-correction.

Indications and Contraindications for Osteotomy

The indications for osteotomy are lower extremity malalignment associated with symptomatic unicompartmental OA, cartilage defects, meniscal deficiency, and/or ligament instability [28–31]. Specifically, for cartilage repair and meniscal transplantation, the addition of an osteotomy to the primary restorative procedure should be considered when the mechanical alignment deviates more than 3–5° from neutral. The decision can be modified by the type, size, and location of the defect: less aggressive correction is needed for defects that are traumatic, small, and/or closer to the midline, as well as for defects in otherwise normal compartments. Larger defects that span the entire width of the compartment, degenerative or bipolar defects and those associated with meniscal deficiency, should result in more aggressive overcorrection, both in terms of indication for osteotomy and amount of overcorrection. For example, a typical medial femoral condyle osteochondritis dissecans (OCD) lesion in a young patient with a normal meniscus and intact surrounding and opposing cartilage would require correction only for pronounced varus alignment greater than 5°. In this case, overcorrection should be avoided, with the final mechanical axis falling between the tibial spines. Conversely, a middle-aged patient with a large medial femoral condyle defect due to a previous medial meniscectomy should be considered for correction to the lateral tibial spine, if the meniscal and chondral pathologies are restored and overcorrected to 5° valgus, if they are treated with an HTO as an isolated procedure.

In general, preoperative MRI or arthroscopy should be considered to assess the condition of the articular cartilage in all three compartments and the status of the menisci. While acknowledging that one historical study showed no correlation of HTO outcome with the lateral compartment status, after reviewing other studies, it is recommended that meniscal deficiency or degenerative changes in the contralateral compartment are a contraindication for osteotomy and the patient should be considered for arthroplasty. Patellofemoral OA, however, appears to be more benign, with several groups reporting good outcomes of HTO, distal femoral osteotomy (DFO), and medial unicompartmental replacement even in the presence of patellofemoral OA [32–34]. Additional contraindications include inflammatory arthritis, limited motion (<90° flexion, >15° flexion contracture), tibial subluxation >1 cm, obesity, smoking, and osteoporosis [28, 35–39].

Informed Consent Process

Treatment alternatives should be discussed with the patient, including nonoperative management options such as nonsteroidal anti-inflammatory drugs (NSAIDs), injection therapy (steroid and viscosupplementation), unloader bracing, and activity modification. If conservative management has failed and a point has been reached where surgical intervention is considered, treatment alternatives such as prosthetic replacement with unicompartmental vs. total knee replacement should be discussed. There is no consensus or firm recommendation regarding treatment with osteotomy vs. arthroplasty. Generally, osteotomy is offered to patients that are younger (<60 years), more active (physical laborers or athletes), and unwilling or unable to accept activity restrictions associated with prosthetic replacement [28]. While a Cochrane meta-analysis has concluded that there is "silver level" evidence that HTO improves pain and function, no trials have compared HTO with conservative management [40].

Risks of the procedure include standard surgical risks such as infection, incomplete pain relief, damage to neurovascular structures, and thromboembolic disease. Risks specific to osteotomy include delayed or nonunion of the osteotomy site, hardware failure, and painful hardware requiring removal. Furthermore, the postoperative cosmetic appearance of a valgus knee should be discussed with patients, especially when overcorrection is planned.

Patient Evaluation

History

Patients present with localized medial or lateral knee pain, often with a history of remote knee injury or surgery, for example, anterior cruciate ligament (ACL) reconstruction or meniscal resection. Typically, symptoms of swelling and pain are activity-related and can wax and wane over the course of months. Smoking status and general health/medical comorbidities should be elucidated, as well as a complete surgical history taken.

Physical Examination

Patient height and weight are recorded, as they can affect the choice of fixation device and type of osteotomy. The hip joints are examined for any restricted motion suggestive of hip OA that may refer pain to the knee. The clinical alignment of both lower extremities is evaluated, both in double-leg and single-leg stance, and the patient is asked to ambulate to assess for dynamic instability, such as a double (varus alignment with lateral ligament deficiency) or triple varus thrust (additional hyperextension). The presence of swelling, muscle atrophy, and scars/incisions is noted, as well as the general condition of the soft tissues and skin. The patient is asked to fully range the knee, and this is repeated passively by the examiner, who then also tests stability for ACL, posterior cruciate ligament (PCL), the posterolateral corner, and the medial and lateral collateral ligaments. Tenderness of the medial and lateral joint lines is evaluated, as well as the presence of mechanical symptoms such as crepitation and catching. Lastly, the neurovascular status of the lower leg and foot is assessed.

Imaging

Standard weight-bearing anteroposterior in extension, flexed posteroanterior (PA) (Rosenberg), lateral, and patellar radiographs are obtained to confirm or rule out unicompartmental arthritis, depending on the specific indication for osteotomy (OA vs. cartilage repair). Attention is paid to any previous surgical procedure or posttraumatic deformity, as well as to patellar height and posterior slope of the tibial plateau. A bilateral full-length lower extremity alignment radiograph is

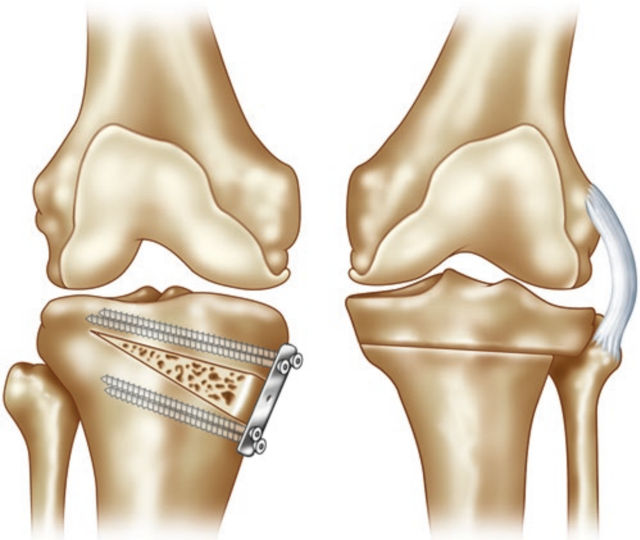

Fig. 6.1 (*Left*) Opening wedge HTO; (*right*) closing wedge HTO. Notice the relatively more preserved proximal tibial anatomy with opening wedge HTO in comparison with closing wedge HTO, where a lateral step-off between tibial plateau and shaft can complicate subsequent arthroplasty. Also, if the proximal tibiofibular joint is released (rather than a fibular shaft osteotomy being performed), the fibular head migrates proximally in relation to the tibial plateau, resulting in loosening of the posterolateral structures

obtained with double-leg standing and with single-leg standing in case of associated knee laxity with a varus thrust.

MRI is frequently obtained to more thoroughly assess the articular surfaces, ligaments, and menisci. More advanced degrees of cartilage or meniscal damage in the contralateral compartment present a contraindication for osteotomy, since accelerated breakdown can ensue, with early failure of the procedure.

Surgical Planning

Type of Osteotomy

Both opening and closing wedge osteotomies are available to address malalignment (Fig. 6.1). Historically, the most common procedure was a closing wedge osteotomy [41, 42]. Opening wedge osteotomies, however, have become the preferred procedures due to their comparatively easier techniques, perceived greater safety, and ability to “dial in” the degree of correction even after the cut has been made. Specifically for the tibia, medial opening wedge HTO also preserves the tibiofibular joint without loosening of the posterolateral structures, has a very low risk of injury to the peroneal nerve, and allows easier adjustment of the tibial slope. The disadvantages are the potential for delayed or nonunion with loss of correction, longer weight-bearing restrictions, and a greater incidence of patella baja and inadvertently increased posterior tibial slope (Fig. 6.2). Conversely, lateral closing wedge HTO does not require bone grafting, allows earlier weight-bearing, and has less risk of nonunion, loss of correction, patella baja, and increased tibial slope. However, closing wedge osteotomy alters the tibial shape more than opening wedge HTO, with the potential for compromised outcomes after subsequent arthroplasty. Furthermore, if a fibular osteotomy is performed, there are additional risks for nonunion and peroneal nerve palsy. Patients at risk for nonunion, such as heavy patients or smokers, should be strongly considered for closing wedge osteotomy, if they are surgical candidates at all.

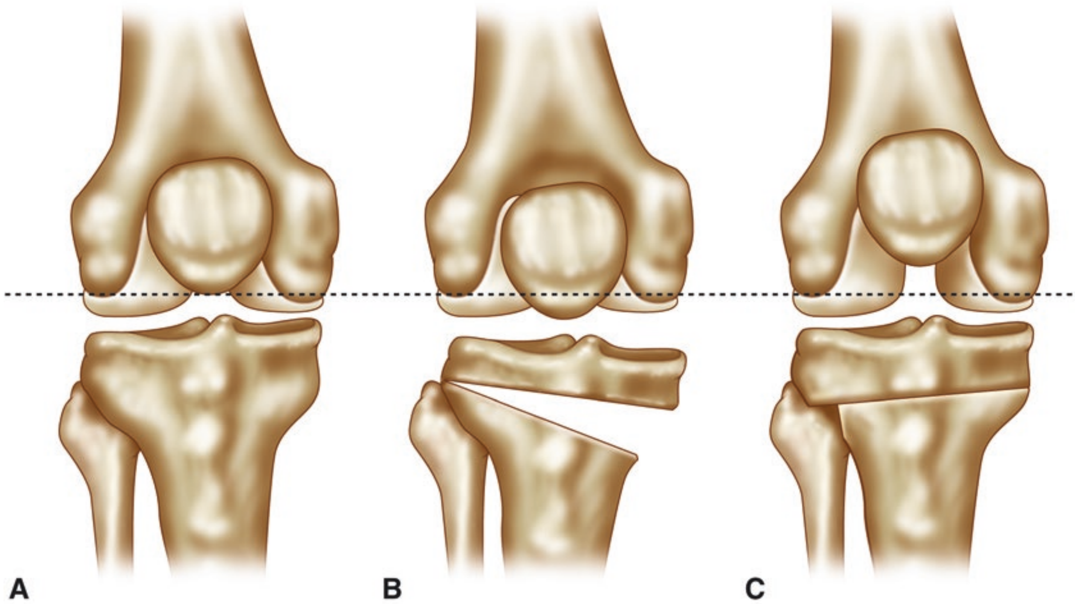

Fig. 6.2 (**a**) Normal knee. (**b**) Opening wedge high tibial osteotomy. (**c**) Closing wedge high tibial osteotomy. The dotted line demonstrates changes to patellar height with the two types of osteotomy: decreasing height (patella baja) with opening and increasing height (patella alta) with closing wedge HTO

Summarizing, opening wedge HTO is the current standard; closing wedge HTO should be considered for patients with preexisting patella baja and concerns for nonunion.

Isolated lateral compartment OA is much less common than medial; for example, only 5–10% of unicompartmental knee replacement is performed in the lateral compartment [43]. Most commonly, valgus alignment and lateral compartment OA are treated in the distal femur. Correction on the tibial side is possible, but it frequently leads to an oblique joint line except in very small corrections or when addressing post-traumatic tibial deformities, such as a depressed lateral tibial plateau fracture. A benefit of a varus-producing HTO, however, is that it unloads the lateral compartment in both flexion and extension, whereas a DFO is biomechanically effective only near full extension [44–46]. Correction in the tibia can therefore be considered in cases that have a predominantly posterior femoral condyle wear pattern with preserved joint line on extension views and collapse on flexion PA radiographs. Analogous to HTO, both opening and closing wedge techniques exist for DFO. Patellar height and tibial slope are unaffected by femoral procedures, and the decision between the two techniques is mostly influenced by surgeon's preference, although concerns for nonunion in a specific patient should lead to consideration of closing wedge osteotomy.

Planning of Correction

Lower extremity hip to ankle alignment radiographs are necessary to calculate the desired correction angle. The mechanical axis is defined as the line connecting the centers of the hip and ankle joints. Ideally, this line should fall through the center of the tibial plateau (neutral alignment). To calculate the required degree of correction, two separate lines are drawn from the centers of the hip and ankle joints, respectively, to the location on the tibial plateau that the mechanical axis is to be shifted to. The angle between the two lines is the required correction angle (Fig. 6.3). Depending on the specific indication

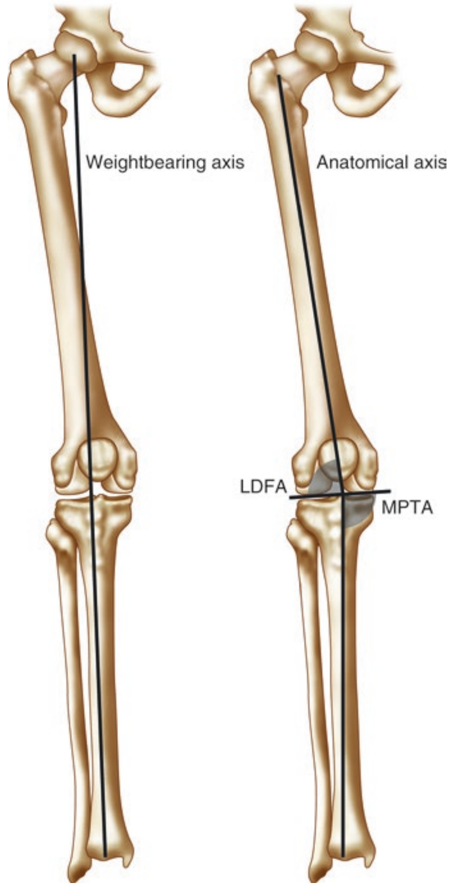

Fig. 6.3 Important angles for osteotomy planning. (*Left*) The mechanical axis formed by connecting the centers of the hip and ankle joints. (*Right*) The tibiofemoral, or alpha angle, formed by the long axes of the femur and tibia, the lateral distal femoral angle (LDFA) between the long axis of the femur and the joint line, and the medial proximal tibial angle (MPTA) between the joint line and the long axis of the tibia (smaller, darker quarter circles)

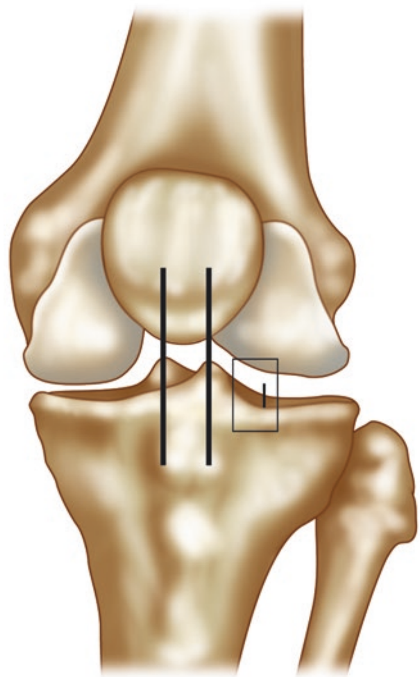

Fig. 6.4 Standing anteroposterior knee radiograph demonstrating the neutral zone bordered by the tibial spines (*thick black lines*) and two recommendations for overcorrection: Hernigou zone (3–6° of valgus) (*box*),and Fujisawa point (62% across the tibial plateau) (*short line*)

for osteotomy, different points are chosen to shift the mechanical axis. If performed for the treatment of medial compartment OA, the mechanical axis should be corrected into the lateral compartment: Hernigou recommended correction to 3–6° of mechanical valgus [47]; Fujisawa (among others) preferred a point 62% across the tibial plateau (Fig. 6.4) [23]. If, however, the osteotomy is performed as an adjunct to isolated small lesion cartilage repair, then correction to neutral is preferred, where the mechanical axis is corrected to the center (50%) of the tibial plateau. Finally, if the cartilage repair needed is more extensive, the correction is between the above two examples, e.g., 3°.

By measuring the width of the tibia at the level of the proposed osteotomy, the surgeon can convert the required angular correction into a wedge size (Fig. 6.5) [48]. Furthermore, changes to the posterior slope need to be considered. Generally, opening wedge osteotomy has a tendency to increase posterior slope, unless specific technical steps are undertaken to counteract this tendency (further discussed in the dedicated tibiofemoral osteotomy technique Chap. 25); closing wedge preserves or decreases posterior slope. In the ACL deficient knee, the osteotomy is specifically planned to decrease the posterior tibial slope, which reduces strain on the ACL [49]. Conversely, in the PCL deficient knee, the tibial slope must be increased in order to produce anterior tibial translation and decrease stress on the PCL [50].

For DFO, it has been recommended not to overcorrect into the medial compartment because

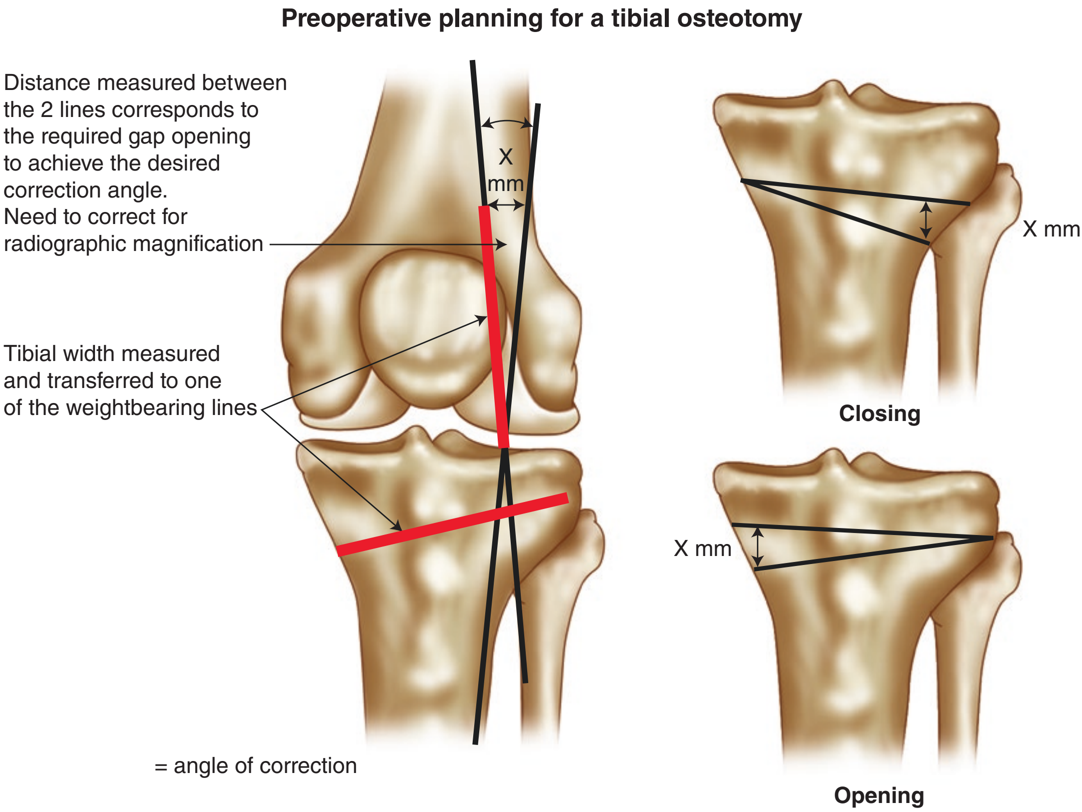

Fig. 6.5 Planning of the correction angle. The tibial width is measured and the length is transferred to one of the weight-bearing lines, as measured from the intersection of the lines at the tibial plateau. At this distance, the width measured between the two lines corresponds to the gap opening required to achieve the desired correction angle

of the high risk of rapid development of degenerative changes (see higher medial compartment forces in a neutral knee discussed earlier) [51]; therefore, the goal is to place the knee in near neutral alignment with the mechanical axis falling near the medial tibial spine.

Results

Outcomes studies of HTO are generally limited to patients treated for unicompartmental OA. In this setting, good and excellent results have been reported in approximately 70–80% of patients at 5–10 years and in 50–60% at 15 years (Table 6.1) [29, 47, 53, 55–63]. A Cochrane systematic review concluded that valgus HTO for knee OA resulted in significantly less pain and improved WOMAC (Western Ontario and McMaster Universities) score [40]. A recent systematic review reported improved mechanical axis alignment and better control over the tibial slope angle change postoperatively with the use of navigation assisted HTO. However, these improvements have not yet been reflected in clinical outcome score [64]. Several studies have found no significant differences between opening and closing wedge HTO [57, 65–67].

The preoperative amount of medial compartment degeneration was negatively correlated with outcomes: Ahlback grade 1 demonstrated good or excellent results in 70% of patients, whereas grades 2 and 3 were only 50% and 40%, respectively [56, 68]. Generally, patients can expect to maintain their level of sporting activity, even though a return to competitive and high-

Table 6.1 Outcomes after HTO

Author	Type of study	Subjects	Follow-up	Complications	Good/excellent % and survivorship
Coventry et al. [52]	Retrospective	87	10 years (3–14 years)	N/A	64% good-to-excellent; 87% at 5 years, 66% at 10 years
Tang and Henderson [53]	Retrospective	67	6.5 years (1–21 years)	5 delayed unions, 2 DVT, 1 peroneal nerve palsy	39% good-to-excellent; 89.5% at 5 years, 74.7% at 10 years
Naudie et al. [54]	Retrospective	106	10 years		73% at 5 years, 51% at 10 years, 39% at 15 years, 30% at 20 years
Sprenger and Doerzbacher [55]	Retrospective	76	10.8 years	11 complications, 7 peroneal palsies	86% at 5 years, 74% at 10 years, 56% at 15 years
Spahn et al. [39]	Observational	84	4 years (2.5–5 years)	3 DVT, 2 infections	70.2% good-to-excellent on KOOS
Noyes et al. [31]	Retrospective	41	4.5 years	None	71% good-to-excellent
Efe et al. [56]	Retrospective	199	9.6 years (1–18 years)	38 (19%) complications, 8 DVT, 1 vascular injury, 6 peroneal palsies, 3 infections, 9 nonunions	64% good-to-excellent; 93% at 5 years, 84% at 10 years, 68% at 15 years
Polat et al. [57]	Retrospective	168	12.4 years (5–22 years)	13 (8%), 1 peroneal palsy, 3 implant failures, 2 delayed unions, 1 nonunion, 3 superficial infections, 1 deep infection, 2 DVTs	93.4% at 5 years, 71.2% at 10 years
Bode et al. [58]	Prospective	51	5 years (60 months)	8.6%, 1 lateral tibia plateau fracture, 3 overcorrections, 2 delayed unions	96% at 5 years
Hui et al. [59]	Retrospective	413	12 years (1–19 years)	16 complications, 5 pulmonary emboli, 8 DVT, 1 peroneal palsy, 1 nonunion	85% of satisfaction; survival rate of 95% at 5 years, 79% at 10 years, 56% at 15 years
Schallberger et al. [60]	Retrospective	71	16.5 years (13–21 years)		Satisfaction index of 80%; survival rate of 98% at 5 years, 92% at 10 years, 71% at 15 years

DVT deep vein thrombosis, *KOOS* knee injury and osteoarthritis outcome score, *N/A* not applicable.

impact activities is rare [69]. Correction of the mechanical axis to 183–186° (3–6° of valgus) appears to be associated with the best outcomes; overcorrection resulted in accelerated degeneration of the lateral compartment, whereas undercorrection led to inadequate pain relief, especially when combined with obesity [47]. Patients with an 8° valgus angle and/or weighing less than 1.32 × ideal body weight (IBW) had 90% survival at 5 years; conversely, patients both weighing more than 1.32 × of IBW and having a valgus angle of less than 8° demonstrated survival of only 38% at 5 years and 19% at 10 years [52]. Lower preoperative patient mental health also negatively affects postoperative HTO functional outcomes and return to work capacity [70]. Lastly, smoking has been identified as a negative outcome predictor [39]. Some studies demonstrated a favorable effect of osteotomy on articular cartilage even in elderly

Table 6.2 Outcomes after DFO

Authors	Type of study	Knees	Follow-up	Complications	Good/excellent % and survivorship
Healy et al. [45]	Retrospective	23	4 years (2–9 years)	2 nonunions, 1 fracture, 2 blade plate removals	83% good-to-excellent
McDermott et al. [72]	Retrospective	24	4 years (2–11 years)	1 failure of fixation, 1 PE, 1 infection	92% good-to-excellent
Terry and Cimino [73]	Retrospective	34	5.4 years (2–19 years)	N/A	60% good-to-excellent
Edgerton et al. [74]	Retrospective	24	8.3 years (5–11 years)	6 nonunions, 5 losses of correction	71% good-to-excellent
Wang and Hsu [75]	Retrospective	30	8.3 years (5–14 years)	1 nonunion, 1 fracture	83% good-to-excellent, 10 years at 87%
Finkelstein et al. [76]	Retrospective	21	11 years (8–20 years)	1 infection, 1 PE, 1 loss of correction	10 years at 64%
Kosashvili et al. [77]	Retrospective	31	15.6 years (6–21.5 years)	N/A	30.3% good-to-excellent, 48.5% failed at 15 years
Backstein et al. [78]	Retrospective	40	10.3 years (3–20 years)	N/A	60% good-to-excellent, 82% at 10 years, 45% at 15 years
Wylie et al. [79]	Systematic review	372	6.5 years (3.75–15 years)	34 (9.1%), 11 losses of correction, 6 fractures, 4 infections, 4 hardware failures, 2 PE	Total reoperation rate of 34% TKA (15%) HWR + others (19%)
Chahla et al. [80]	Systematic review	319	Opening wedge (4.6 years (2.8–6.5 years)) Closing wedge (8 years (2.5–15.1 years))	Opening wedge (0–30%) Closing wedge (0–73%)	Survival rate (64 to 90% (mean 80%) at 10 years, 58% at 15 years, 21.5% at 20 years)

DFO Distal femoral osteotomy, *PE* Pulmonary embolism, *N/A* Not applicable, *TKA* Total knee arthroplasty, *HWR* Hardware removal.

patients, especially with larger corrections [22, 25, 71].

Distal femoral osteotomy for the treatment of lateral compartment OA has been less studied, but generally reports comparable outcomes with approximately 80–90% survival at 10 years (Table 6.2) [78–81].

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