11 Malunions of the Distal Femur

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11.1 Introduction

11.1.1 Distal Femur Fractures and Types of Malunions

Fractures of the distal femur are considered to be those occurring within the distal 15 cm of the femur [1, 2]. Depending on the fracture pattern (i.e., extra-articular, partial articular, or complete articular) and relative level of comminution and/or bone loss, the introduction of risk for various types and combinations of malunions will undoubtedly present themselves in the treatment process. Commonly accepted categories of distal femur malunions include malrotation, coronal plane deformity, sagittal plane deformity, limb length discrepancy, intra-articular malunion, and multiplanar deformities [3]. Varying criteria for malunions of the distal femur are found throughout the literature, but it is generally accepted that symptoms begin to occur with coronal plane deformity >5°, sagittal plane deformity >10°, rotational deformity >10–15°, and limb shortening >2 cm [4–7].

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There is a relative paucity of literature regarding distal femur malunions compared to the remainder of the femur and lower extremity. Rather, much of the available literature concerning distal femur fractures tends to focus on acute management, prosthetic replacement, and nonunion treatment [1]. Aside from the studies regarding deformity correction of the distal femur, the crossover of concepts to other lower extremity malunions, native deformities, and nonunions allows for extrapolation. It is important to note, however, that distal femur malunions can be much more variable with regard to treatment due to dependence on the proximity to the articular surface, available bone for fixation, surrounding muscular envelope, and unique deforming muscular forces.

11.1.2 Incidence of Malunions

Distal femur fractures account for 3–6% of all fractures of the femur with an estimated annual incidence of 37 per 100,000 person-years [2, 8–11]. Malunions of the distal femur are overall a fairly rare event [3], the exact incidence of which is difficult to decipher among the literature given the various types of malunions, differing parameters for malunion, and variability of treatment options. Evaluating the different types of malunions individually perhaps provides a better idea of their incidence based on available literature. In a series of 59 distal femur fractures

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treated with various methods, Zehntner et al. reported varus/valgus deformity >5° in 26% of fractures, procurvatum/recurvatum >5° in 22% of fractures, and rotational deformity >5° in 19% of fractures [12]. Rotational malunions of the femoral shaft exceeding 15°, including the distal one-third femur, have been shown to have reported rates between 20% and 30% when treated with intramedullary nailing [13, 14]. With minimally invasive plate osteosynthesis (MIPO) of distal femur fractures, the incidence of rotational malunions >10° has been reported to be as high as 35–43% [6, 15, 16]. Varus collapse >5° has been observed to occur in 42% of patients treated with lateral condylar buttress plate alone [17]. Intra-articular malunions can be difficult to quantify unless intraoperative identification or radiographic malunion deformity or step-off is confirmed. There is a reported incidence of 23–36% of post-traumatic arthritis following intra-articular distal femur fractures [18–20]. However, in addition to intra-articular malunion as a cause for these high rates, mechanical damage during the traumatic event, chondrocyte death and dysfunction, and inflammatory cell-mediated response all present potential confounders to the development of post-traumatic arthritis [18, 20]. Despite the etiology, distal femur fractures represent a relatively common fracture with numerous potential complications. In a systematic review of 1670 distal femur fractures, the rate of secondary surgery for all causes was 16.8% including 6% for nonunion alone, whereas malunions were not specifically distinguished [21].

11.1.3 Ramifications of Malunions

Distal femoral malunions to a significant degree can undoubtedly have detrimental effects to the patient's function with possible cosmesis issues. All of the various types of malunions can result in altered knee biomechanics and/or contact pressures and result in eventual post-traumatic osteoarthritis. Rotational malunions ≥15° are typically noticed by patients and are associated with articular cartilage deterioration, distortion of knee biomechanics, and overall decreased function [5, 6]. Rotational malalignment of the femur is also associated with a higher trend in difficulty with stairs, running, and sports [5]. On computer-generated models, femur rotational malunions of any degree cause posterior displacement of the weight-bearing axis, and supracondylar rotation greater than 30° to 45° results in frontal plane malalignment and knee joint malorientation [22]. In addition, patellofemoral contact pressures have been found to increase nonlinearly with increasing rotational deformities over 20° [23]. With coronal plane deformity, varus or valgus malunion of the distal femur leads to increased contact forces in the medial or lateral compartments of the knee, respectively, which can eventually cause deterioration of the articular cartilage and premature osteoarthrosis [24, 25]. Sagittal plane deformity leading to genu recurvatum or genu procurvatum can result in pain, loss of knee flexion or extension, feelings of instability, and muscle weakness [26]. Additionally, distal femur procurvatum can lead to a limp as a result of restricting the swing phase of gait, while recurvatum deformity can cause a posterior thrust and painful gait [27]. Symptomatic leg length discrepancies >2.0 cm can be associated with quadriceps weakness, gait asymmetry, feeling of imbalance, and low back pain [28]. Lastly, intra-articular malunions can conceivably lead to direct mechanical destruction of the involved articular surface and contribute as well to the aforementioned 23–36% rate of post-traumatic arthritis following intra-articular distal femur fractures [18–20].

11.2 Causes of Malunions

The etiology of malunions of the distal femur is multifactorial with varying levels of contribution from the surgery itself, the implant factors, and patient factors. Oftentimes, the contributing etiology can be retrospectively identified, though this may not always be the case. In a series of 22 distal femur malunions by Rollo et al., the etiology of malunion was attributed to poor fracture reduction in almost 60% of the total cohort, highlighting the importance of the index surgery [3].

Iatrogenic factors certainly play a role, which may be as simple as not utilizing some of the preventative strategies discussed below when indicated for rotational, length, and mechanical axis assessment (See Sect. 11.2.1); however, implant type, choice, and application can contribute as well to malalignment in the index surgery.

Implant choice for distal femur fractures remains a controversial topic. A recent meta-analysis comparing the outcomes of 279 patients treated with retrograde intramedullary nailing versus plating revealed no clear superiority of one implant choice over another with regard to malunion [29]. However, different types of distal femur fractures may dictate implant type, as not all fractures are amenable to retrograde intramedullary nailing [30]. When utilizing a lateral distal femur locking plate for these fractures, it is important to note that plate-bone mismatch is still a problem, even with the modern designs of the available pre-contoured plates. Thus, sole reliance on the plate as a reduction tool may itself contribute to malreduction [31]. A recent study of 53 patients with atraumatic femora underwent digital templating with superimposed distal femur plates from four common manufacturers, which all demonstrated mismatch secondary to under-contouring of the plates, even worse so after total knee arthroplasty [32]. Additionally, there are several common mistakes when utilizing lateral distal femur locking plates that have been identified as contributors to malunion. The much-discussed “golf-club” deformity with medialization of the distal femur can be a result of plate placement too distal and/or too posterior on the lateral femoral condyle [27, 30, 33]. Procurvatum and recurvatum deformity can be induced by plates applied in a flexed or extended fashion, respectively [27]. Failure to align the distal screw trajectory parallel to the distal femoral condyles in certain plate designs can lead to valgus application of the plate and coronal plane deformity [27]. Even after fixation with a laterally based plate, the aforementioned study by Davison showed a postoperative varus collapse in excess of 5° prior to union in 42% of patients treated in his series of 26 comminuted distal femur fractures [17].

Minimally invasive techniques and poor preoperative planning have also been associated with malunions of the distal femur. Minimally invasive plate osteosynthesis (MIPO) technique for distal femur fractures has been shown to be advantageous from a soft tissue preservation aspect [34]; however, several recent studies have shown it to be significantly associated with rotational malunions [6, 15]. One study of 13 femoral shaft fractures and 38 distal femur fractures treated with MIPO technique demonstrated satisfactory rotational alignment in only 56.9% of patients on postoperative CT scans [15]. Additional care to evaluate rotational profile compared to contralateral radiographs as described below can help to perhaps mitigate this risk (See Sect. 11.2.1). As for intra-articular malunions, poor visibility can contribute to poor reduction, as can unrecognized complexity of the fracture. Coronal plane “Hoffa” fractures of the femoral condyle(s) have been described to be associated in about 40% of intercondylar distal femur fractures [35], highlighting the need for preoperative CT scans and appropriate preoperative planning and fixation.

Malunions identified as a result of collapsed nonunion or delayed union emphasize patient factors important to consider as causes of eventual malunion. These have been well described in the literature and include diabetes, obesity, smoking, poor bone quality, and the presence of an open fracture [36–38]. Recognition of these factors may necessitate alternative treatment strategies or heightened vigilance for early recognition and intervention if necessary.

11.2.1 Preventative Strategies for Malunion

Timely healing of the fracture and restoration of the length, alignment, rotation, and articular reduction are paramount to the prevention of malunions. Unfortunately, this may be difficult to directly visualize, particularly in AO type C3 fractures due to comminution and introduction of multiplanar deforming forces [12, 39]. There are, however, several techniques to assist in prevention of the various types of malunions in distal femur fractures that have been proposed.

Rotational malunions represent an unfortunately common type of deformity following treatment of femur fractures. Numerous methods have been theorized to assess intraoperative and postoperative rotational profile. Many of these methods rely on an intact contralateral femur with an absence of preexisting deformity. A 3D CT study of ten randomly selected patients with atraumatic femora showed symmetrical rotational and translational profiles when bilateral femurs were superimposed [40]. Reliance on contralateral imaging is the hallmark of the most commonly employed method for rotational assessment – the lesser trochanter profile (LTP). This method involves obtaining a true AP of the uninjured knee, which can be obtained after 90° C-arm rotation from true lateral with superimposed condyles, followed by an AP of the uninjured hip with leg held in rotation. These views should be saved on the c-arm. An AP of the affected knee should be obtained first after reduction and temporary stabilization of the fracture and then similarly an AP of the injured hip is obtained. This AP of the uninjured hip is then compared to the then subsequently obtained AP view of the injured hip [41]. At this point, any differences in the LTP should be addressed as needed. A recent study evaluated this technique with 19 matched pairs of sectioned cadaveric femora. The authors found that the size of the lesser trochanter was a reliable approximation of rotation with 10% differences in lesser trochanter size correlating to approximately 7° of malrotation [41]. Another method known as the true lateral technique (TLT), originally described by Tornetta et al., can be done by obtaining a true lateral of the knee, then recording the degrees of rotation needed of the C-arm to obtain a true lateral of the hip [42]. A recent survey of 85 surgeons analyzing images of cadaveric femora, however, found only 53% of responders able to identify a 20° malrotation with the TLT method, compared to 67% accuracy utilizing the LTP method [43]. Nevertheless, either or both methods can be employed as another piece of information to help mitigate the risk of rotational malunion.

Prevention of coronal plane malunion can be done with proper plate placement by avoiding the pitfalls as discussed above (see Sect. 11.2) and with reliance on restoration of the mechanical axis. This can be measured with an intraoperative radiopaque thread or rigid guidewire or stretched flexible wire (i.e., Bovie cord) from the center of the femoral head to the center of the ankle joint [44]. In standard cases, this line should pass just medial to the tibial spine of the fully extended knee [45]. However, baseline mechanical axis can be variable among patients, especially those with preexisting knee osteoarthritis. Comparison to the contralateral mechanical axis measured in a similar fashion provides an accurate comparator assuming there is no presence of a contralateral deformity. With retrograde nailing where knee extension is not possible with the nailing jig in place, ipsilateral mechanical axis can be estimated or even calculated by measuring the angle between the plane of the distal articular surfaces of both the medial and lateral femoral condyles and the nail attachment stem of the retrograde nail. In normal cases, this should be a valgus angle of 5–7°, correlating to the average difference in the anatomic intramedullary axis of the femur and the mechanical axis of the lower extremity [45]. This can be estimated radiographically or if the femoral condyles are accessible with the chosen surgical approach can be done with a flat surface spanning both condyles or, alternatively, a goniometer. And lastly, a full-length femur portable X-ray can be used to assess gross coronal plane deformity difficult to accurately detect with fluoroscopy or other means.

Sagittal plane deformity is perhaps the most difficult malunion to accurately prevent. The deforming forces of the gastrocnemius on the distal condylar segment frequently will try to induce a recurvatum deformity and must be resisted with either direct manipulation of the distal segment, a posterior bump under the knee, and/or manual downward traction [46]. Lateral fluoroscopic images may be misleading and may even be partially obstructed by fixation implants or jigs. Obtaining perioperative true lateral images of the contralateral femur with overlap of the distal and posterior aspects of the condyles with the diaphysis in the field of view can be helpful to recreate the flexion/extension component of the injured distal femur relative to the shaft. The relationship of Blumensaat's line to the long axis of the femur or, alternatively, the anatomic posterior distal femoral angle (aPDFA) can be estimated or measured on the lateral femur view from the relationship of the sagittal distal femoral joint line to the long axis of the femur compared to the contralateral [25, 46]. Depending on the proximal extent of the fracture and relative comminution, fluoroscopy may be unreliable if the intact portion of the femur proximal to the fracture is unable to be visualized in the same field of view, and a lateral portable X-ray may be needed to assess the position and sagittal rotation of the articular surface to the intact femoral diaphysis. Finally, an anteroposterior (AP) fluoroscopic view of the distal femur may also provide a hint of sagittal deformity needing correction with the appearance of a "paradoxical notch view" distally [46].

The risk of leg length discrepancy via femoral shortening, or rarely lengthening, can be mitigated by one of two methods if direct fracture reduction is not achievable for reference, which is often the case in highly comminuted fractures. Comparison of limb length based on the palpated level of bilateral patellae, heel pads, and/or medial malleoli can provide a rough estimate of symmetrical limb length. This is dependent on symmetrical positioning of the femoral heads relative to the operative table axis and can be done with the contralateral limb prepped in or under the surgical drapes. When utilizing a retrograde nail for primary or additional fixation, this method may not be useful prior to removing the nailing jig secondary to obstruction of knee extension and migration of the patella during nailing. Use of an intraoperative radiopaque ruler to measure the contralateral and ipsilateral femurs at proximal and distal reference points (i.e., tip of the greater trochanter to the medial femoral condyle distal articular surface) provides the most accurate reproduction of symmetrical femur length assuming pre-injury symmetry.

Adequate surgical exposure for direct visualization or, at minimum, direct palpation of the articular portion of an intra-articular distal femur fracture is critical to avoid step-off and intra-articular malunion. Preoperative identification of articular fractures, via CT scan, that require reduction is key as they may dictate which main surgical approach is preferred. In some cases, these may require an additional direct medial, direct lateral, or parapatellar exposure to confirm reduction and properly place implants. Sole reliance on fluoroscopic imaging for reduction of posterior coronal plane condyle fractures such as Hoffa fractures should be done with caution and only when necessary, such as when concomitant soft tissue injuries prevent exposure. Otherwise direct exposure and visualization, or at a minimum, palpation, is preferred for articular reduction.

11.2.2 Patient Considerations

The biologic, socioeconomic, and behavioral factors of a patient are vital considerations when choosing whom to revise safely, how extensive the revision can or should be, and identifying conditions amenable to preoperative optimization. Obesity, diabetes, smoking, and preoperative reduced albumin levels have all been shown to be independent risk factors for surgical site infection and failure in distal femur fractures [36, 47]. Treating distal femur fractures acutely will likely not allow for considerable modification of these risk factors, but in consideration of deformity correction, smoking, nutritional status, weight loss, and diabetes typically can be addressed and/or counseled. Depending on the level of deformity, timing of reconstruction may be limited and thus, preoperative planning may need to be adjusted to compensate. For instance, obesity results in a conceivable increased demand on implants with increasing patient body weight and perhaps should merit more robust fixation options for any revision surgery if weight loss is not achieved or possible in the timeframe. Patient compliance and need for faster return to work may or may not be modifiable but warrant the opportunity for counseling and shared decision making and perhaps a patient agreement for "buy-in" of the planned treatment. Age and life expectancy are non-modifiable risk factors that deserve central attention as well. With the goal of faster ambulation and return to activities of daily living to avoid complications as a result of immobilization, prosthetic replacement becomes a reasonable option for complex distal femoral malunions or nonunions in the elderly or those with a life expectancy less than 10 years [48–50].

11.3 Evaluation and Diagnosis

11.3.1 History

As with any orthopaedic evaluation, a detailed history can be the most important tool in the assessment and diagnosis of distal femur malunions. A good history should start from the beginning with questions regarding baseline health, smoking status, illicit drug use, comorbidities, housing status, pre-injury activity level, occupation, and hobbies. This can help to better assess patient outcome expectations and provide insight for later discussions regarding the management of realistic expectations. In the setting of an initial consultation for malunion, the mechanism of injury and a thorough timeline should be established. The timeline should highlight the timing of surgery, time to full weight-bearing status, initial identification of gross deformity or symptoms associated with malunion, and timing and duration of rehabilitation thus far. Any history of wound healing difficulty, open fracture, drainage, postoperative oral antibiotic therapy, or any additional surgeries, procedures, or treatments to the incision should be further explored and raise flags for potential infectious contributions to malunion. Compliance with postoperative protocol should be assessed and any inconsistencies in the above history, especially when compared to available documentation, may suggest possible noncompliance that needs to be further explored. Patient self-assessment of function and/or deformity is critical to evaluate and will likely coincide with their chief complaint. In the setting of gross deformity, the chief complaint may be related to cosmesis, but frequently patients with malunions will tend to report difficulty with ambulation, feeling of imbalance or unequal leg length, easy fatigue of knee extensors or flexors, tripping over their feet, and/or anterior knee pain. In the absence of obvious deformity, any of these above symptoms may be reported in isolation or in combination and will likely have persisted despite proper rehabilitation.

11.3.2 Physical Examination

Following a thorough history, the physical examination should begin with inspection of the overall patient appearance, hygiene, and body habitus. Full inspection of gait and simultaneous evaluation of bilateral lower extremities while supine and standing should be performed. The location and appearance of incisions and/or wounds should be noted. Gross deformities may be obvious, but more subtle deformities may need to be pointed out by the patient. The proximity of the medial aspect of the knee joints may clue the examiner into varus or valgus deformity of the affected extremity. The position of the feet should be noted in relation to one another while both supine and standing. Quadriceps atrophy may be obvious, but a cloth ruler to measure bilateral thigh circumference at a given reference point (i.e., 10 cm above the superior patellar pole) will provide more objective and reproducible data.

Rotational malunions can be additionally examined with seated assessment of bilateral hip internal and external rotation, with care to note any differences if observed. If body habitus allows, the trochanteric prominence angle test (TPAT) can be a reliable method to objectively measure bilateral femoral anteversion and thus any rotational abnormalities [51]. This is performed in the prone position by palpating the greater trochanter with the knee flexed to 90°. With gentle internal and external hip rotation, the rotation which yields the most lateral prominence of the palpated greater trochanter is held in place. The resulting angle of the tibial axis relative to a midline imaginary vertical line is recorded. This can be measured with a goniometer or roughly estimated compared to the angle observed in the contralateral extremity.

Leg length can be assessed while lying supine on the examination table and comparing the heel pads and medial malleoli position during full knee extension and with comparative patellae palpation during equal knee flexion to 90°. While standing, the height of the patellae and palpated spatial relationship of the iliac crests should also be noted. If leg length discrepancy is suspected, utilization of varying thicknesses of blocks under the sole of the shortened extremity will provide an objective measurement for perceived limb length discrepancy when the patient reports the feeling of equality. Care should be taken to note any ipsilateral knee flexion contracture or sagittal deformity as this may exacerbate perceived limb inequality [52]. Knee range of motion should likewise be examined bilaterally as well as any detected crepitus, mechanical blocks to motion, hyperextension, or flexion contracture. A ligamentous knee exam should be performed to evaluate for any concomitant ligamentous knee injuries or even laxity secondary to malunion. Strength testing of bilateral lower extremities should be tested entirely to include hip, knee, and ankle motor grades. Bilateral lower extremity neurovascular examinations may also be helpful to assess for nerve injury, neuropathy, and vascular status.

11.3.3 Laboratories

Malunions frequently occur in the setting of normal lab values. If any red flags for infection are noted in the above history and physical, baseline infection labs should be obtained such as complete blood count (CBC), erythrocyte sedimentation rate (ESR), and C-reactive protein (CRP). History of delayed union or late collapse of fracture prior to union should merit additional nonunion lab workup such as complete metabolic profile (CMP), vitamin D, calcium, and endocrine labs if suspected. Hemoglobin A1C values should be obtained for all diabetic patients or those with significantly abnormal glucose values in standard preoperative labs. Strict glucose control is imperative to limit infectious complications and optimize treatment outcomes. Nutritional labs for healing potential, even in obese patients, such as albumin and pre-albumin levels should be strongly considered and any abnormalities addressed preoperatively.

11.3.4 Radiographs

Standard anteroposterior (AP) and lateral X-rays of the femur, hip, and knee should be obtained as part of the initial workup. Kellgren-Lawrence grade of arthrosis can be roughly determined on plain radiographs of the knee for consideration of patients with significant grade III and IV preoperative osteoarthrosis [53]. Standing full-length bilateral lower extremity anteroposterior X-rays with the patellae facing forward and midline radiopaque ruler (i.e., X-ray scanogram) can be obtained for quantification of deformity and objective measurement of limb length discrepancies if applicable. Mechanical femorotibial angle (mFTA), mechanical axis deviation (MAD), and mechanical lateral distal femoral angle (mLDFA) can be likewise measured on full-length standing anteroposterior X-rays [25, 54]. The mLDFA is measured as the angular difference between the femoral mechanical axis and the femoral joint line [55] and can be used to define the magnitude of the coronal plane distal femur deformity, with a standard value of 87° +/− 3° [25, 54]. The anatomic posterior distal femoral angle (aPDFA) can be measured on a lateral femur X-ray to assess for the degree of sagittal plane deformity (mean normative value of 83°) by the relationship of the sagittal distal femoral joint line to the long axis of the femur [25]. The center of rotational angulation (CORA) can be obtained radiographically for preoperative planning with plain X-ray technique at the point where the radiograph shows intersection of the proximal mechanical axis and the distal mechanical axis [54].

11.3.5 Computed Tomography and Magnetic Resonance Imaging

Computed tomography (CT) is the advanced imaging study of choice for additional deformity quantification and preoperative planning. CT scan of the involved extremity can help evaluate for healing, consolidation, canal patency, and bone stock in addition to deformity. Anteversion CT of both lower extremities can be used to objectively measure rotational alignment and degrees required for derotation [15]. A CT scanogram can offer quantifiable mechanical axis deviation (MAD) measurements utilizing the malalignment test if desired [54]. CT scans that include the entire distal femoral articular surface can also be used to evaluate for any intra-articular malunion or subchondral/articular deficit [25]. However, any existing hardware may result in artifact preventing complete visualization and metal suppression techniques should be employed. Magnetic resonance imaging (MRI) is rarely needed unless suspicion of infection based on history and/or abnormal inflammatory laboratory values. If MRI is obtained for any reason, however, the degree of cartilage thickness can be assessed according to the modified Noyes classification for prognostic data or consideration of arthroplasty if indicated [56, 57].

11.4 Treatment Based on Malunion Type

11.4.1 Rotational Malunion

In the absence of other deformities, isolated rotational malunions can be relatively easily addressed through a variety of methods. With any technique employed, it is imperative that the degree of axial derotation be determined preoperatively with CT imaging or anteversion CT protocols of both lower extremities. Fixation of the derotational femoral osteotomy can be done with either intramedullary nail, distal femoral locking plate, or external fixation depending on the canal patency, level of osteotomy, preexisting hardware, and quality of bone available for distal fixation [58–60]. In some rare occasions, intact existing hardware (such as a femoral nail) can be retained and used for stabilization of the derotational osteotomy after removing and replacing proximal screws in the corrected position [34]. The site for the derotational osteotomy can be selected according to surgeon preference and amenability of soft tissues without a definitive superiority of one technique. This can be carried out through the supracondylar region of metaphyseal bone or metadiaphyseal junction or through the prior fracture site [58–60]. The technique for osteotomy can be performed closed via intramedullary saw (if available) or in an open fashion with multiple drill holes completed with osteotome, akin to the De Bastiani technique, or oscillating saw. Muckley et al. evaluated a series of 30 derotational femoral osteotomies carried out with either a closed intramedullary saw technique (n = 18) or an open drill hole/oscillating saw technique (n = 12). In both groups, percutaneous Kirschner wires above and below the osteotomy site were used to gauge derotation and fixation was performed with intramedullary compression nailing. There were no statistically significant differences noted in complication rates between the two groups, though two cases of insufficient correction occurred in the closed technique [58]. Stahl et al. reported on a series of 14 patients with rotational femur malunions utilizing an intramedullary saw for a closed osteotomy technique followed by static intramedullary nail placement after derotation. Amount of necessary derotation was determined preoperatively by CT scan, and intraoperative assessment of derotation was also made by rotation of two percutaneously placed Kirschner wires in the femoral neck and transversely across the femoral condyles. Postoperative CT scans revealed less than 4° of residual deformity in all of the patients in their series. Average time to consolidation was 10–12 months and, notably, 12 out of 14 patients were able to return to work [60].

11.4.2 Coronal Plane Malunion

The end goal of coronal plane deformity correction is re-establishment of the mechanical axis of the lower limb to its normative value [61]. The degree of correction should first be determined by what is needed to restore the center of the mechanical axis to the center of the knee or just medial to the tibial spine [45]. This can be determined with mathematical calculations or through digital templating software if available, such as TraumaCad (Brainlab Inc., Westchester, IL, USA). Calculation of the mechanical axis deviation (MAD) and mechanical lateral distal femoral angle (mLDFA) can quantify the degree of coronal plane deformity and the correction needed to return to the contralateral limb mLDFA or its normative value of 87° +/− 3° [25, 54]. Identification of coexisting deformities, such as limb-length inequality or complex multiplanar deformity, are common and should be carefully scrutinized as they may require different treatment strategies (see Sect. 11.4.5).

Options to achieve coronal plane correction include medial opening wedge osteotomy (for varus), lateral closing wedge osteotomy (for varus), medial closing wedge osteotomy (for valgus), lateral opening wedge osteotomy (for valgus), dome osteotomy, oblique osteotomy in the sagittal plane, double oblique osteotomy as described by Miranda et al. (See Sect. 11.4.5), and osteoplasty in the method of Ilizarov with gradual correction [39, 54, 56] (Fig. 11.1). The pros and cons of opening and closing wedge osteotomies are well described and frequently extrapolated from native knee deformities or high tibial osteotomy (HTO) literature [54, 55, 62–64]. It is important to consider that closing wedge osteotomies offer improved bony contact for stability and to promote union [55], but at the cost of potential femoral shortening [39]. This may be advantageous in those patients who are at higher risk of nonunion with the sacrifice of leg length or in the rare case of patients with overlengthening following index surgery. Opening wedge osteotomies are inherently less stable with less bony contact at the site of correction and may require more robust fixation and usually with augmentation with bone grafting (autogenous, allograft, or bone void fillers) [25, 62]. Supracondylar dome osteotomies and oblique sagittal plane osteotomies of the supracondylar femur offer the potential advantages of improved bony contact without significantly altering the length of the extremity, though their documented use in malunions of the distal femur is lacking [39, 54, 63, 64]. Advantages for these single-stage osteotomies over that of osteoplasty with Ilizarov style frames include avoidance of prolonged time in external fixation, pin site infections, additional knee stiffness, and psychological and social difficulties associated with Ilizarov frame treatment [65, 66]. In the setting of a diagnosis of infection or history suggesting infectious contribution, external fixation can provide an advantage with avoidance of hardware placement directly in the zone of infection [4].

In a series of 15 patients with distal femur varus malunions, He et al. utilized a medial opening wedge supracondylar osteotomy with dual plate fixation medially and laterally. Single and biplanar osteotomies were carried out according

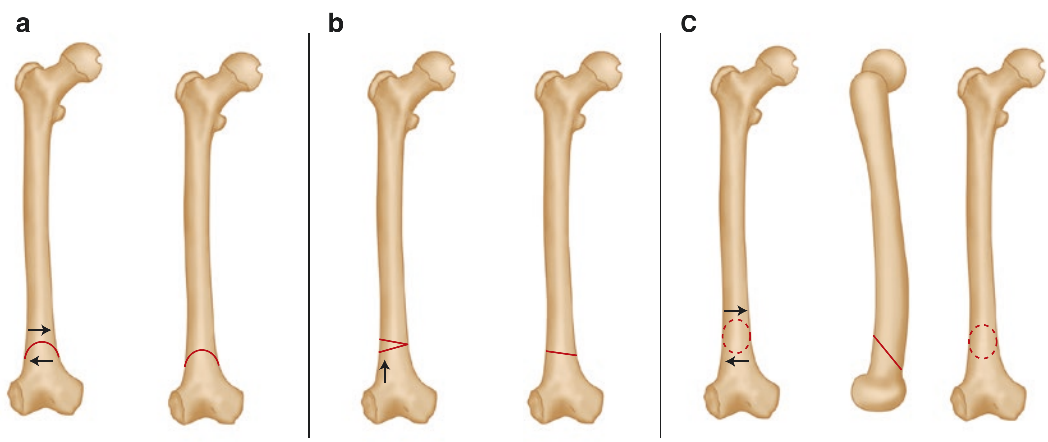

Fig. 11.1 Example of various types of osteotomies for varus coronal plane deformity correction (*A* = dome osteotomy, *B* = lateral closing wedge osteotomy, *C* = sagittal oblique osteotomy)

to preoperative templating and osteotomy sites were guided intraoperatively by placement of supracondylar Kirschner wires. Average mLDFA was corrected from 102.3° to 85.2° and any coexisting limb length discrepancy (LLD) corrected from 3.38 cm to 0.8 cm. Time to union was 4.1 months (range, 2.5–6 months). They reported overall good functional outcomes and no fixation failures or secondary surgeries with average long-term follow-up of 7.4 years [25].

Native varus or valgus deformities of the distal femur resulting in ipsilateral unicompartmental knee osteoarthrosis overshadow much of the remaining literature regarding coronal plane correction. In a series of 15 patients with 16 native distal femur varus deformities, van der Woude et al. utilized lateral closing wedge osteotomies of the distal femur in single and biplanar techniques with lateral plate fixation (n = 12) or medial plate fixation (n = 4) based on surgeon preference. Correction was achieved in all but one patient. Average time to union was 4 months for biplanar closing wedge osteotomy compared to 6 months for uniplanar [55]. Two additional series utilized femoral dome osteotomies for correction of native coronal plane deformity, one of which (n = 16) used external fixation and the other series (n = 12) with a single lateral distal femur locking plate. The first of these series reported good correction and functional outcomes and average union time of 19.4 weeks in 14 patients, with two patients excluded for infection and arthroplasty conversion [63]. The latter series reported full correction with no failures or reoperations and improvement in functional outcome metrics with good patient satisfaction. Average time to union was 13.8 weeks [54].

Though a rare but serious complication, peroneal nerve palsy can be associated with correction of severe valgus deformity especially with significant chronicity of the malunion. A recent cadaveric force transducer study showed significant reduction in rigidity of the peroneal nerve after prophylactic decompression and varus correction with no difference in tension before and after deformity correction [67]. Simultaneous prophylactic peroneal nerve decompression in these select patients with severe chronic valgus deformities should be considered [67, 68].

11.4.3 Sagittal Plane Malunion (Procurvatum/Recurvatum)

Many of the above principles discussed in coronal plane correction (see Sect. 11.4.2) apply similarly to sagittal plane deformities. Determination of the degree of deformity and quantification of the necessary correction must be made preoperatively and can be estimated intraoperatively with the assistance of anterior to posteriorly placed Kirschner wires proximal and distal to the osteotomy site. Preoperative measurement of the anatomic posterior distal femoral angle (aPDFA) can be done on a lateral femur X-ray or CT scan of the entire femur to assess for the degree of sagittal plane deformity. As previously described, the relationship of the sagittal distal femoral joint line to the long axis of the femur should be restored to either a mean normative value of 83° or equal to the contralateral femur aPDFA [25]. Recurvatum is typically the more common presenting deformity secondary to the deforming force caused by the gastrocnemius muscle [27]. Opening or closing wedge osteotomies present similar pros and cons in the sagittal plane as in the coronal plane with accompanying limb lengthening or shortening, respectively, as well as differences in stability. Osteoplasty in the method of Ilizarov can likewise be done, but again may introduce additional risks associated with prolonged external fixation compared to single-stage osteotomy and internal fixation [65, 66].

In a series of 22 distal femur malunions by Rollo et al., which included five patients with procurvatum deformities and 17 patients with recurvatum deformities, osteotomies were performed at the prior malunion site and stabilized with lateral condylar blade plates. Osteotomy sites were augmented with allograft bone struts as well as morselized bone graft and “bone paste” in the opening wedge gap if present. Nine complications were noted to include death (n = 1), deep infection (n = 1), delayed wound healing (n = 3), deep vein thromboembolism (n = 2), and broken hardware (n = 2). Average time to union of the osteotomy was 34.7 weeks with good improvement of functionality following union. However, average persistent leg length discrepancy following deformity correction and union was 3.3 cm [3].

11.4.4 Leg Length Discrepancy

Preoperatively identifying an objective measurement of limb inequality must be done to determine the amount of lengthening required. This can be done with full-length standing radiographs of the lower extremity and either direct measurement with radiopaque ruler, digital templating software, or with blocks under the ipsilateral foot until leveling of the pelvis is observed on X-ray [68]. Symptomatic leg length discrepancies greater than 2 cm requiring lengthening of the malunited femur can be corrected through the process of distraction osteogenesis. This process has been both well described and accepted among the literature, but does require reliable patient compliance. Ilizarov's principles for this method classically involve gradual controlled lengthening through an osteotomy site at a rate of 1 mm per day followed by a consolidation phase [69]. Multiple techniques for distraction osteogenesis have been described in addition to newer Ilizarov style frames alone such as the Taylor spatial frame (Smith and Nephew Inc., Memphis, TN, USA). Lengthening over the nail (LON) technique represents one such method combining external fixation via Ilizarov style frame or monolateral rail frame with an intramedullary nail to guide the bone during distraction osteogenesis [70]. Results for several such series have shown this to be a successful method with less total time in the external fixator, as the intramedullary nail can be locked and external fixator removed during the consolidation and remodeling phases [70, 71]. This method does, however, require additional surgical procedures and relies on the presence or ability to establish a patent medullary canal for nail insertion. Recently, magnet-operated telescopic internal lengthening nails such as the PRECICE nail (NuVasive, San Diego, CA, USA) have gained traction with less required total surgeries, better tolerance, and less minor complications, such as pin site infections commonly associated with external fixation [72, 73]. These devices do require regular motorized lengthening appointments and may not be an ideal option for patients with profound femoral bows given the straight design of the nail. The cost of magnetic lengthening nails (MLN) has also been a concern; however, a recent cost comparison showed no statistical difference between the LON technique (n = 19) and MLN (n = 39). This was largely attributable to fewer overall procedures with the MLN. And notably, the MLN method was found to have a statistically significant shorter time to union (100.2 versus 136.7 days) [74].

11.4.5 Multiplanar Deformity

Many malunions of the distal femur represent a heterogeneous deformity requiring the surgeon to simultaneously address deformities in differing planes with or without limb inequality. Patient considerations merit central attention in multiplanar deformity when determining the appropriate treatment pathway, as prosthetic replacement may be a more reasonable option in the elderly, terminally ill, or those with significant preoperative osteoarthritis. When assessing the deformity for planned correction, identification and quantification of the deformities in each plane can be done manually or, rather, with digital templating software, such as the aforementioned TraumaCad (Brainlab Inc., Westchester, IL, USA). Depending on the degree of deformity, options for treatment of multiplanar malunions consist of osteoplasty with Ilizarov style frame, double oblique osteotomy, biplanar osteotomy, and prosthetic replacement typically involving a distal femoral megaprosthesis.

Circular frame treatment of deformities in the method of Ilizarov affords the opportunity to compress or distract in differing planes and, thus, can allow for multiplanar correction. Corrections can additionally be fine-tuned throughout the treatment process prior to consolidation [75]. However, careful patient selection and counseling of complications is a necessity when engaging into deformity correction via circular frame application. Fixation of rings to the femur requires traversing through the thick muscular envelope which surrounds the bone, resulting in restricted range of motion and inevitable degree of knee stiffness [68]. In addition to this, nearly all patients treated with the Ilizarov style frame will experience wire or pin site infections, plus an additional major complication rate up to 33%, even in experienced surgeons [65]. However, there is an advantage to the variability in ring fixation methods, as they allow for distal fixation in a relatively short segment of bone. If correction must be done in close proximity to the articular surface, extension across the knee joint may be required [76]. The site of osteotomy should be weighed for appropriate capability of correction according to preoperative templating and to allow the most variability of distal options for fixation of the distal ring. Prior to performing the osteotomy, stable fixation of the proximal and distal rings should be performed according to preference with preliminary placement of non-obstructing struts [68, 75]. Osteotomy can then be performed with multiple drills holes completed by an osteotome as described previously. After final construct and spatiotemporal data have been obtained, gradual correction of deformities and/or lengthening at 1 mm/day can then ensue according to vendor software after an initial latency period, usually about 1 week [68]. Weight-bearing as tolerated can typically be allowed immediately after surgery.

Another option for correction of multiplanar deformities is the single-stage double oblique osteotomy, described by Miranda et al. Based on preoperative templating, three total osteotomies are made. These include two oblique osteotomies above and below the deformity to create a wedge of metadiaphyseal bone allowing for medialization and length if needed, followed by a closing wedge osteotomy to correct additional coronal deformity. According to their technique, fixation can be obtained with an angled blade plate, condylar buttress plate, or dynamic condylar plate. In their series of eight distal femur malunions, correction was able to be achieved in all patients to normative values. Average time to union was 4.25 months for the malunion cohort, with one patient requiring an additional bone grafting procedure [39].

The process of decortication and osteotomy for multiplanar correction has also been described for femoral diaphyseal malunions by Middleton et al. In their series of seven patients, they describe careful periosteal flap elevation at the osteotomy site with creation and preservation of attached cortical bone chips, followed by osteotomy and correction of length and deformity. A lateral locking plate was utilized so as to not disrupt the endosteal blood supply, per the authors. Full correction of deformity was achieved in only five out of seven patients, with a staggering time to union of 16.3 months. An average of 1.5 operations per patient were required to achieve union, with one patient having a refractory nonunion at the osteotomy site despite multiple revisions [77].

If parameters allow, some multiplanar deformity may also be simply addressed through a biplanar osteotomy as described by He et al. For simultaneous correction of varus deformity, flexion deformity, and leg length discrepancy, for instance, the authors describe a biplanar medial opening wedge osteotomy with eccentric distraction of the osteotomy gap to open more posteriorly in addition to medially [25].

In the elderly, special considerations must be made regarding function, life expectancy, and time of immobilization. With the exception of Ilizarov style frames, the other described methods of multiplanar malunion correction are typically associated with prolonged periods of immobilization [39]. Acute distal femur fractures in the elderly have been shown to already have poor outcomes with only 18% return to unassisted ambulation and higher perioperative mortality rates when compared to other fragility fractures [78]. With some authors even advocating for primary distal femoral replacement in acute fractures of the elderly [79, 80], substantial consideration should be made for prosthetic replacement in the setting of malunion. Immediate full weight-bearing can be allowed to minimize additional complications related to either immobilization or external fixation. Several series report on megaprosthesis as a viable option for elderly distal femur nonunions, with the majority of surviving patients returning to acceptable functional outcomes and activities of daily living [48–50]. Patient longevity must be carefully weighed with that of the implant; however, as a recent long-term follow-up 144 non-oncologic distal femur replacements revealed an all-cause 10-year revision rate of 27.5% [81].

11.4.6 Intra-articular Malunion

If an intra-articular step-off or loss of reduction is diagnosed early with advanced imaging, correction prior to union is paramount and should be considered with regard to patient age, functional status, and soft tissue conditions. If identification of a healed intra-articular malunion is made prior to the development of premature osteoarthritis, every effort should be made to correct the deformity if possible. Sasidharan et al. and Iwai et al. have described case reports of young patients in their 30s with malunited coronal plane Hoffa fractures treated with osteotomy and cannulated screw fixation at 9 and 6 months post-injury, respectively [82, 83]. Both of these case reports showed reasonable to good short-term outcomes within a year, but long-term and high-quality data are lacking for this salvage operation. Unfortunately, however, the majority of intra-articular malunions may not be discovered until the process of posttraumatic osteoarthritis has already begun. Salvage of articular surface incongruence at this point is difficult given the degeneration of the knee joint, leaving arthroplasty as a reasonable option if age appropriate. Haidukewych et al. presented a series of 17 patients with a mean age of 66 that underwent total knee arthroplasty as a salvage procedure following failed distal femur fracture treatment all of which were nonunions. Three of these patients went on to fail, but they reported an 83% 5-year overall survivorship free of any revision. The authors concluded that total knee arthroplasty does provide reliable pain relief and functional improvement for the majority of the patients in their series, but intraoperative and postoperative complications were common [84]. Lonner et al. reported on a series of ten patients with complex distal femur malunions that underwent simultaneous total knee arthroplasty with distal femur osteotomy and deformity correction. Extra-articular osteotomy sites were fixed with either angled blade plate, retrograde nail, or long press-fit femoral stems. At average follow-up of just under 4 years, no revisions had been performed. Overall function and range of motion had significantly improved from preoperative levels, despite one osteotomy nonunion spanned by a press-fit femoral stem [85].

11.5 Author's Preferred Methods of Treatment

The definitive treatment can often be dictated by the previous fixation implants, surgical approaches used, and any soft tissue considerations along with the patient's expectations and desires. In most cases, treatment requires removal of preexisting hardware either as a staged procedure or simultaneously with the treatment depending on the type of hardware and method of treatment, either of which is acceptable. Our preferred technique is to remove preexisting hardware as a first stage, followed by a second stage for definitive treatment. The interval can allow for further evaluation as well as to ensure that no underlying subclinical infection is present.

1. *Asymptomatic Malunions*

Unless degree of deformity is concerning for malorientation of the knee joint and development of premature osteoarthritis is likely, no treatment is necessary with follow-up X-rays and clinical exam in 6–12 months to evaluate for joint stability/congruence.

2. *Rotational*

Derotational supracondylar osteotomy is made with drill holes and osteotome, K-wires proximal and distal to osteotomy site to evaluate for degrees of correction, with fixation utilizing static retrograde intramedullary nail, irrespective of the type of preexisting hardware. Previous plate fixation requires complete removal. Previous nail fixation can possibly be retained with osteotomy, removal of the proximal locking screws, followed by correction and proximal relocking. In some cases, previously well-fit nails may require complete removal to obtain the rotational correction.

3. *Coronal Plane*

Open exposure lateral closing wedge osteotomy for varus deformity without the presence of additional limb length inequality. Medial opening wedge osteotomy for varus deformity with limb length inequality <3.0 cm. For valgus deformity, lateral opening wedge or medial closing wedge depending on respective concomitant limb length inequality. Fixation typically with intramedullary nail (if plausible route) or lateral distal femur locking plate, contoured to accommodate for corrected deformity.

4. *Sagittal Plane*

For recurvatum deformities (most common), lateral approach with anterior opening wedge osteotomy versus posterior closing wedge osteotomy, decision based on bone quality, healing potential, and concomitant limb length inequality. For procurvatum deformity, anterior closing wedge osteotomy versus posterior opening wedge osteotomy. Fixation typically with intramedullary nail (if plausible route) or lateral distal femur locking plate.

5. *Leg Length Discrepancy*

Distraction osteogenesis is a reliable process to gradually correct leg length malunions. Patient disposition, competency, compliance, and understanding of options for various treatment methods for distraction osteogenesis are critical. Magnetic lengthening nail is preferred if the indications and anatomy allow, otherwise lengthening via Ilizarov style frame. Osteotomy site is typically at the metadiaphyseal junction via drill holes and osteotomy.

6. *Multiplanar Deformity*

Biplanar osteotomy in the case of "simple" multiplanar deformity; otherwise, osteoplasty in the method of Ilizarov with Taylor spatial frame (Smith and Nephew Inc., Memphis, TN, USA) and gradual correction.

7. *Prosthetic Replacement*

All elderly patients with symptomatic malunions merit consideration for prosthetic replacement unless immediate weight-bearing will be allowed. In patients with poor bone quality, limited life-expectancy, and/or presence of advanced post-traumatic osteoarthritis, arthroplasty is also the preferred option. If deformity permits correction with bone cut adjustments or simple augmentation(s), primary or revision total knee arthroplasty components can be utilized, otherwise megaprosthesis with distal femoral replacement if necessary.

8. *Intra-articular Malunion*

In the rare case of a patient with early malunion prior to development of post-traumatic osteoarthritis, salvage osteotomy and cannulated screw fixation +/− bone graft is a reasonable attempt to delay premature osteoarthritis and need for early arthroplasty. In older patients, and those with existing or worsening signs of post-traumatic osteoarthritis or worsening preexisting osteoarthritis, total knee arthroplasty is preferred.

11.6 Case Discussions

11.6.1 Case 1

The patient is a 56-year-old male restrained driver status post high-speed motor vehicle collision in 2016. The patient sustained a left distal femur fracture with metadiaphyseal comminution and intercondylar extension, AO type C2, as well as an ipsilateral basicervical proximal femur fracture, AO type A1 (Fig. 11.2). Initial workup revealed a history of coronary artery diseases status post bypass, hypertension, and a current one pack per day smoking history. The day after presentation, the patient underwent fixation distally with three percutaneous 7.3 mm partially threaded cannulated screws across the intercondylar fracture line followed by long antegrade cephalomedullary locked nail (Fig. 11.3). He was

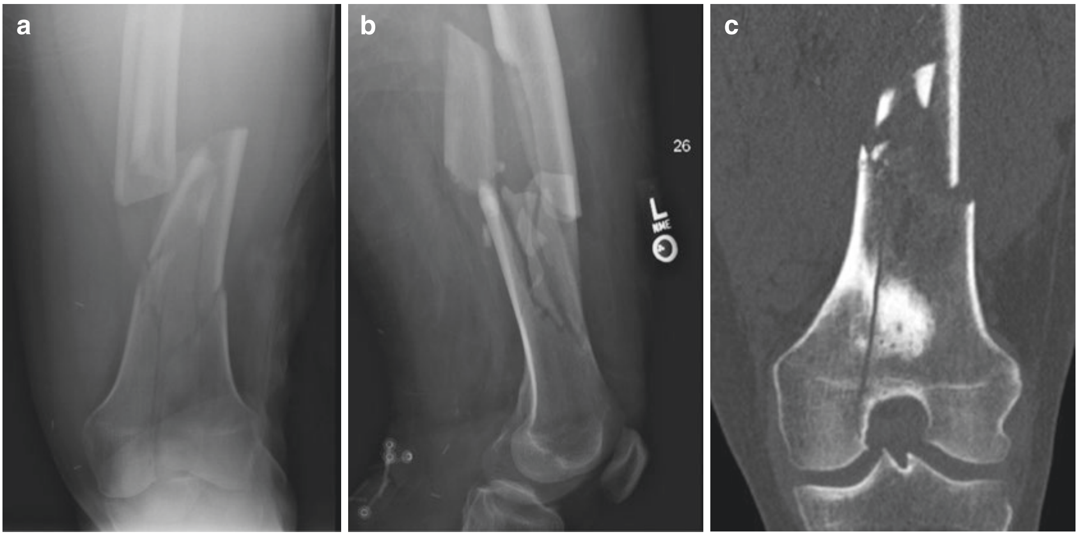

Fig. 11.2 (**a**) Anteroposterior and (**b**) lateral injury radiographs and (**c**) coronal CT slice of the left distal femur showing metadiaphyseal comminution with intercondylar extension, AO type C2

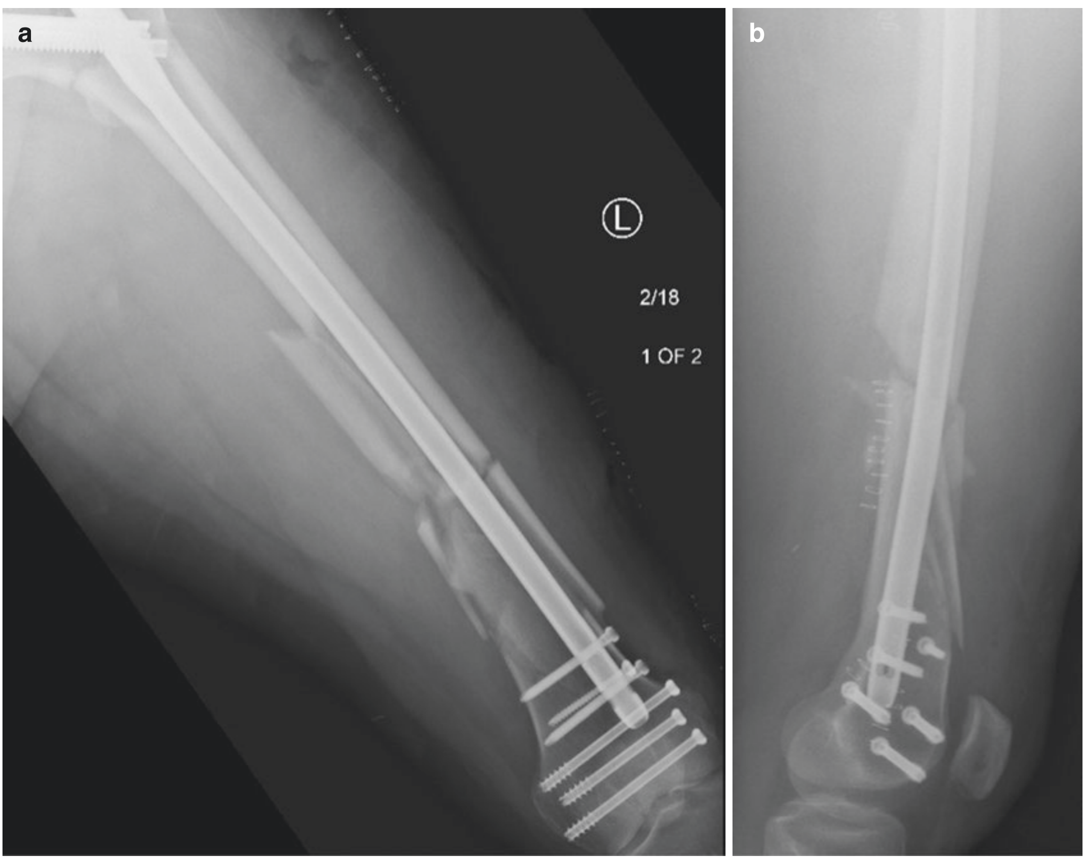

Fig. 11.3 (**a**) Anteroposterior and (**b**) lateral immediate postoperative radiographs of the left femur

discharged to inpatient rehabilitation on post-op day 3, but readmitted and taken back to the OR at 2 weeks post-op for persistent drainage from the proximal hip incision with methicillin-sensitive *Staphylococcus aureus*-positive cultures. Appropriate intravenous antibiotics were tailored to cultures and he underwent two additional washouts over the next several weeks before eventually clearing the infection. X-rays at his 3-month postoperative visit began to show signs of medial translation and several degrees of varus collapse of the comminuted metadiaphyseal component of the distal femur fracture with backing out of several of the distal interlock screws (Fig. 11.4). The patient was then subsequently taken back to the operating room where fracture mobility allowed for valgus stress to re-establish the mechanical axis of the extremity through the fracture site. Several distal intercondylar screws were exchanged, and a blocking screw was utilized laterally to confine the distal tip of the nail while the distal interlock screws were replaced (Fig. 11.5). Postoperatively, he was kept non-weight-bearing for a period of 10 weeks. Union of three out of four cortices was achieved 8 months after revision, but the varus deformity had recurred and a nonunion of the proximal femur persisted. Malunion evaluation with X-ray

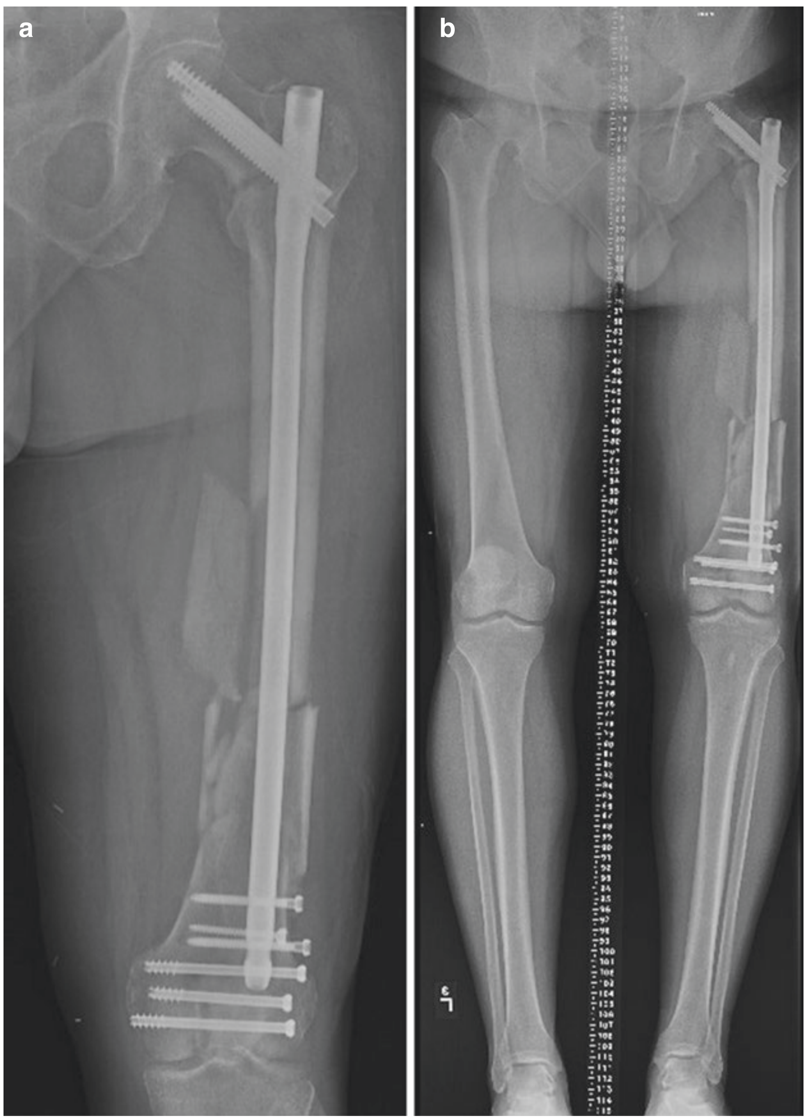

Fig. 11.4 Three-month postoperative (**a**) anteroposterior femur radiograph and (**b**) X-ray scanogram demonstrating varus collapse and distal interlock screws backing out

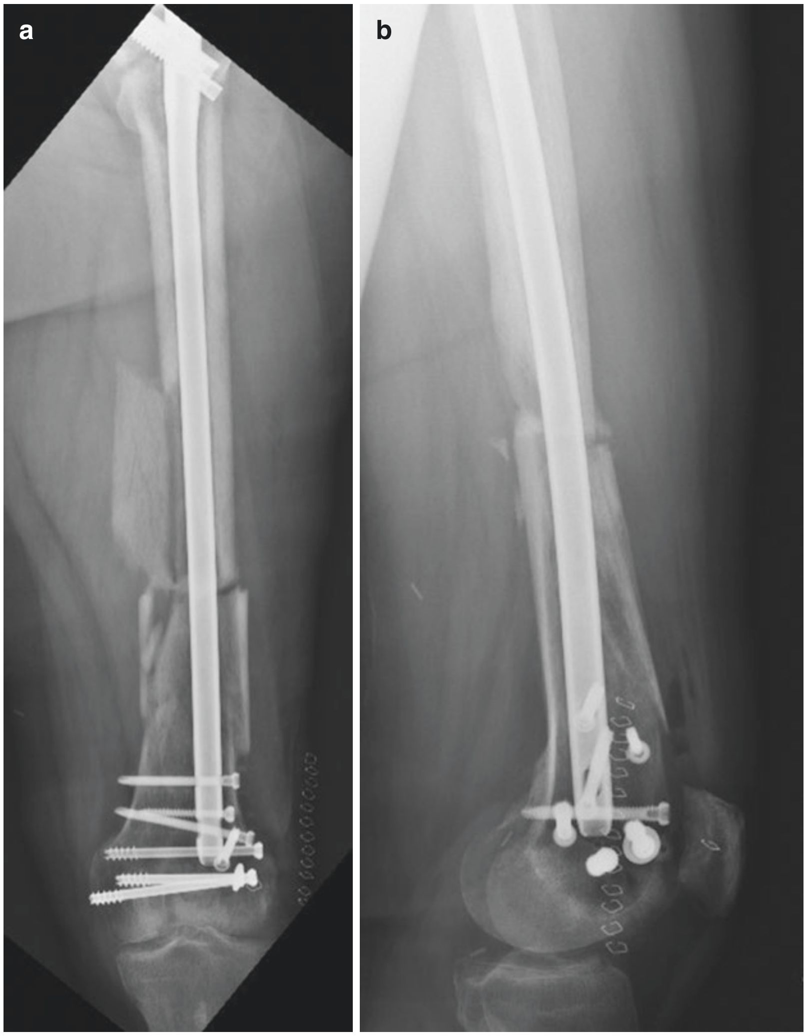

Fig. 11.5 Immediate (**a**) anteroposterior and (**b**) lateral distal femur postoperative radiographs after valgus manipulation and distal screw exchange

scanogram (see images 8/22/18) showed mechanical axis deviation (MAD) of 30 mm, varus deformity of 6°, mLPFA 94°, and mLDFA 93° (Fig. 11.6). Preoperative templating utilizing TraumaCad (Brainlab Inc., Westchester, IL, USA) software calculated a planned 7 mm medial opening wedge osteotomy.

The patient underwent malunion correction with medial opening wedge osteotomy at the previous fracture site according to preoperative templating. Multiple drill holes were utilized at the osteotomy site, completed with a straight osteotome. Compression of the lateral cortex was achieved with drill holes on either side of the osteotomy and pointed reduction forceps. Local biologic augmentation was provided at the osteotomy site with a bone void filler. A second lateral distal femur blocking screw was then placed. Open reduction and bone grafting of the proximal femur nonunion were simultaneously performed, and a long revision cephalomedullary nail was placed bypassing the osteotomy site. Distal interlock screws were placed distal to the osteotomy site (Fig. 11.7).

The patient did well postoperatively. He achieved solid union of the distal femur osteotomy at 6 months postoperative from final revision and was ambulating without assistive devices. He reported he was able to return to 300-pound leg press weightlifting following union at last follow-up 18 months postoperative from last deformity correction (Fig. 11.8).

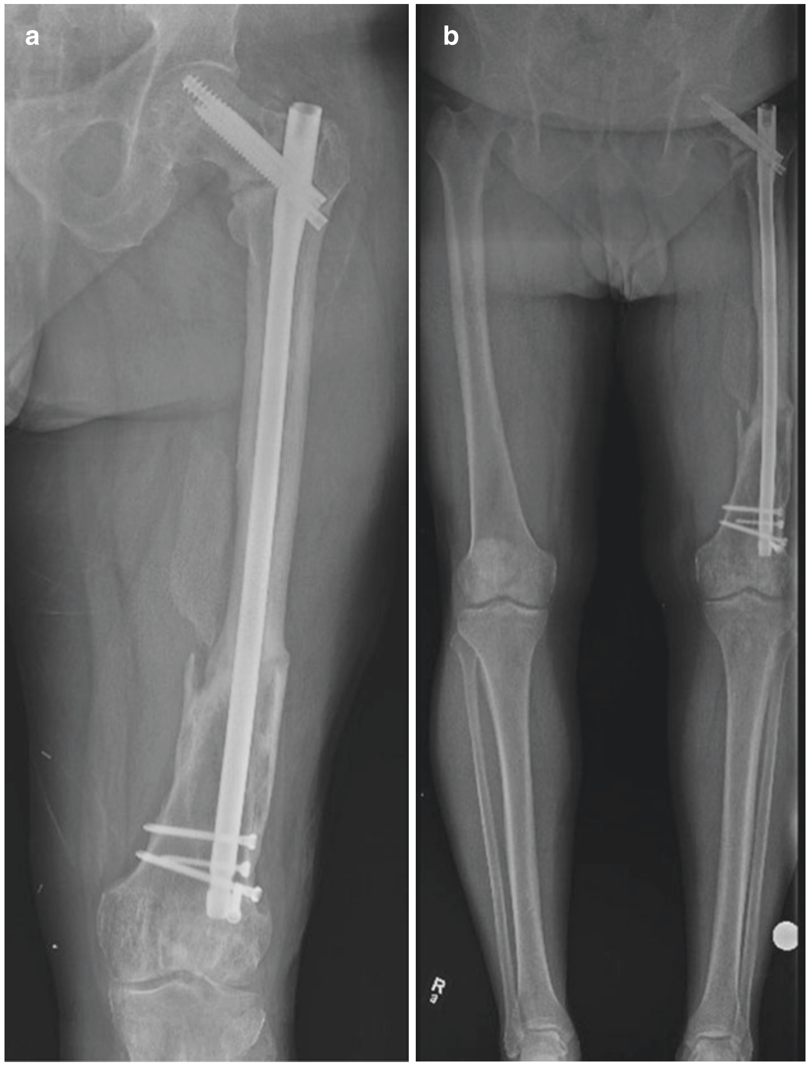

Fig. 11.6 (**a**) Anteroposterior and (**b**) X-ray scanogram following union of the distal femur showing varus malunion

11.6.2 Case 2

The patient is an 18-year-old otherwise healthy male referred to our clinic following treatment of a pediatric right distal femur fracture at the age of 12. He reportedly sustained a Salter-Harris type 3 fracture of the lateral distal femur epiphysis that was treated by an outside provider with open reduction internal fixation via distal femur partially threaded screws, followed by subsequent hardware removal. He went on to develop a gross valgus deformity with internal rotation of the distal femur and a leg length discrepancy of 3 cm (Fig. 11.9). He reported difficulty with strenuous activities as well as a visible deformity. After discussion of the options, the patient elected to proceed with Ilizarov style frame and osteoplasty for simultaneous correction of leg length discrepancy and valgus deformity. Preoperative templating utilizing TraumaCad (Brainlab Inc., Westchester, IL, USA) revealed mLDFA of 73 and planned lengthening of 2 cm with 12.8° correction.

The patient underwent Taylor spatial frame (Smith and Nephew Inc., Memphis, TN, USA) application utilizing hybrid fixation of 6 mm hydroxyapatite-coated pins and Ilizarov tensioned wires. A metadiaphyseal osteotomy site

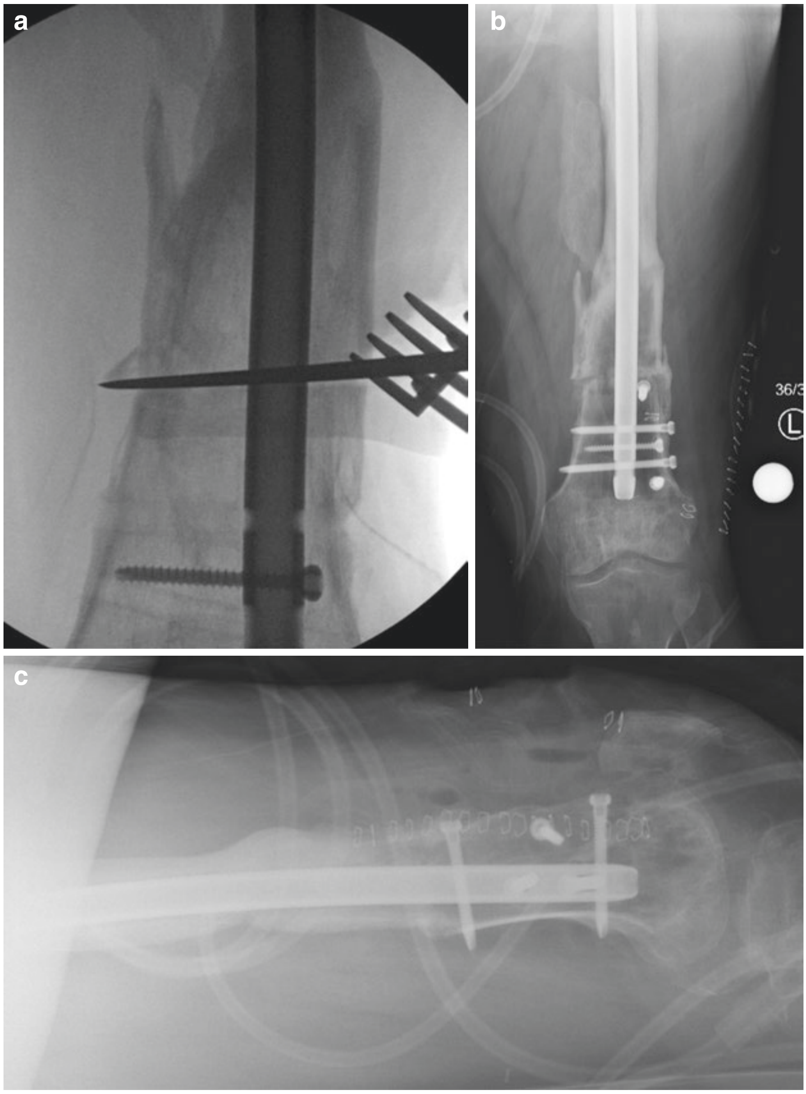

Fig. 11.7 (**a**) Intraoperative fluoroscopic view of completion of metadiaphyseal osteotomy with osteotome and immediate postoperative (**b**) anteroposterior and (**c**) lateral distal femur radiographs following deformity correction

was chosen and carried out with drill holes, completed with osteotome (Fig. 11.10). Gradual distraction and osteoplasty was performed over the following 50 days (Fig. 11.11), with consolidation phase of 100 days after completion of correction (Fig. 11.12). He did experience proximal pin site infections toward the end of the consolidation phase that were treated with oral antibiotics without issue. His frame was removed at 5 months postoperative. Continued weight-bearing with crutches was allowed following removal.

The patient was doing well at his follow-up 6 months after initial frame application, after which he was unfortunately lost to follow-up (Fig. 11.13). He had returned to normal activities and reported feelings of symmetry. He was ambulating without pain and without assistive devices, though he did have ipsilateral knee stiffness and range of motion 0–80° at last follow-up.

11.6.3 Case 3

The patient is a 66-year-old female with well-controlled type 2 diabetes mellitus who is status post primary left total knee arthroplasty by an

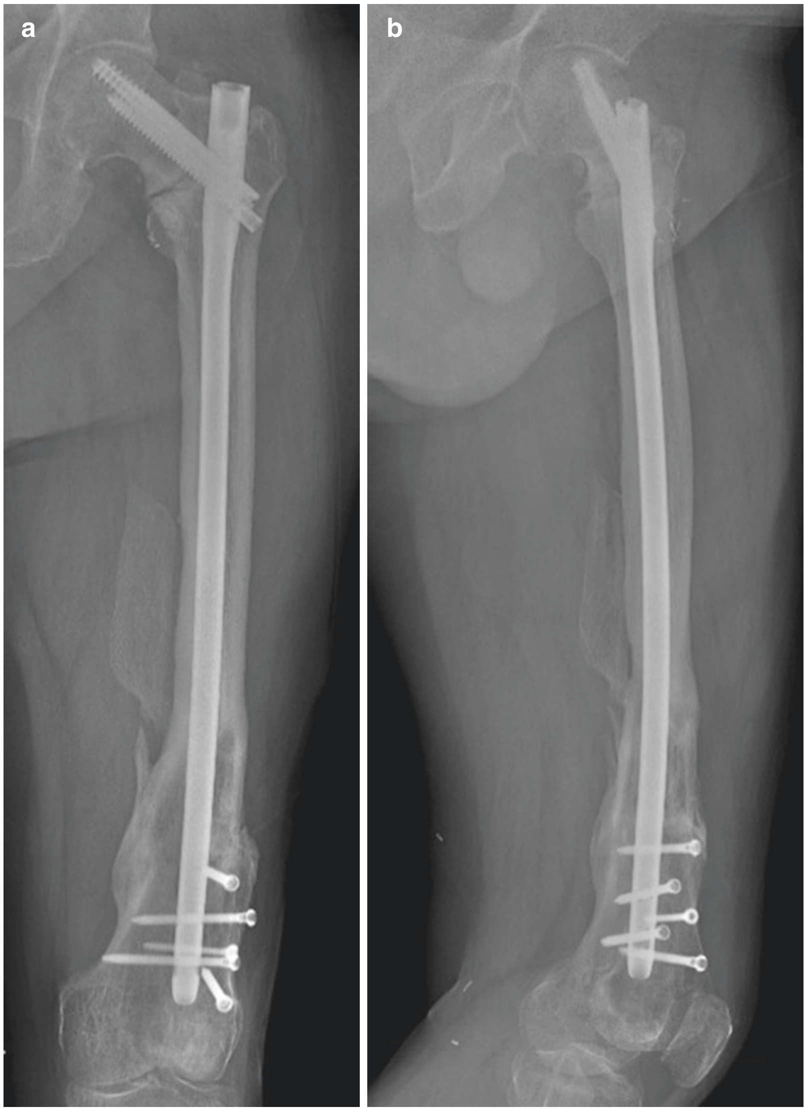

Fig. 11.8 (**a**) Anteroposterior and (**b**) lateral radiographs of the left femur at 18 months postoperative from deformity correction

outside provider 2 years prior to presentation. Three months after surgery, the patient's postoperative course was complicated by a fall and subsequent periprosthetic distal femur fracture treated with open reduction internal fixation utilizing a lateral distal femur locking plate. She reported gross varus deformity several months after fracture fixation and continued pain in the knee. She was referred to our clinic 21 months after fixation with imaging consistent with collapsed malunion in 16° of varus (Fig. 11.14). There was no history of wound healing difficulties, antibiotic use, or additional procedures related to the incisions. Preoperative lab work revealed normal inflammatory markers (CBC, ESR, CRP) and hemoglobin A1C < 7.

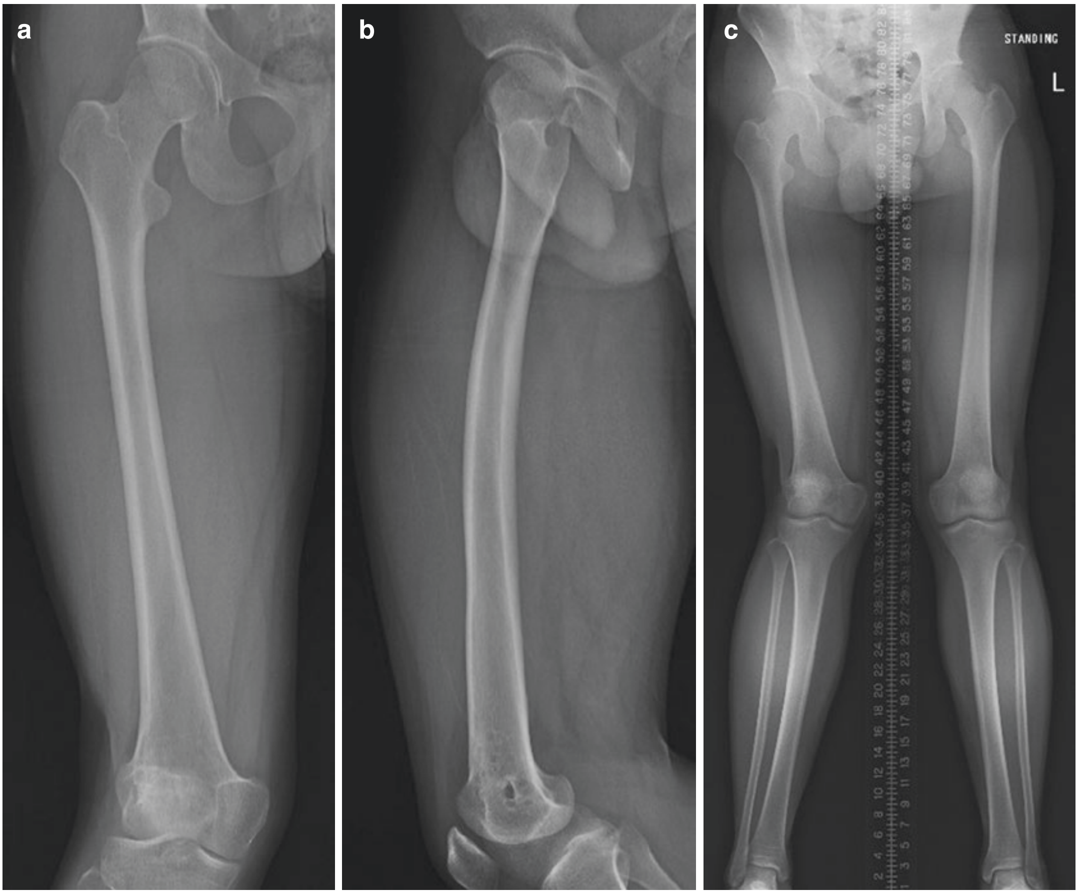

Fig. 11.9 (**a**) Anteroposterior and (**b**) lateral radiographs of the right femur and (**c**) X-ray scanogram at time of consultation showing valgus deformity of the right femur and leg length discrepancy

Following appropriate workup and clearance, she underwent cemented distal femoral replacement with removal of the lateral distal femoral plate/screws and osteotomy above the site of the malunion (Fig. 11.15). Immediate weight-bearing and rehabilitation was allowed. She did well in the early postoperative phase, but unfortunately sustained a fall with therapy 6 weeks postoperatively and was found to have a patellar tendon avulsion off the tibial tubercle and dislocation of the tibial post (Fig. 11.16). Subsequent open reduction of the prosthesis was performed with heavy #5 Ethibond (Johnson & Johnson, New Brunswick, NJ, USA) suture repair of the patellar tendon avulsion. Immediate weight-bearing was again allowed with hinged knee brace locked in extension. Three months following repair, she was found to have recurrent patella alta on radiographs and continued discontinuity of her extensor mechanism on exam. The patient desired no further surgeries and at 6 months postoperatively was ambulating in an extension brace with a rolling walker without significant pain (Fig. 11.17).

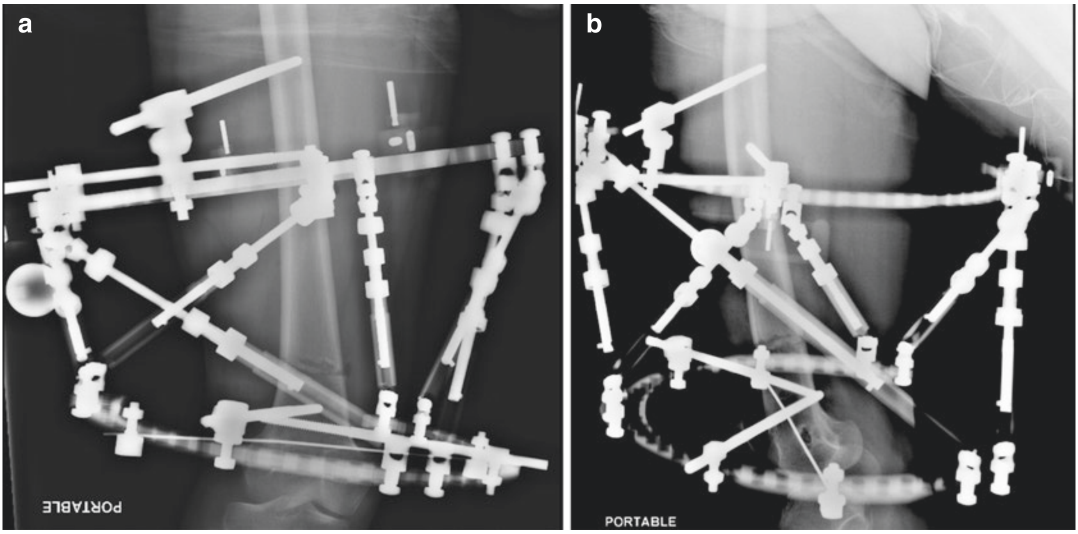

Fig. 11.10 Immediate postoperative (**a**) anteroposterior and (**b**) lateral radiographs of the right distal femur after osteotomy and spatial frame application

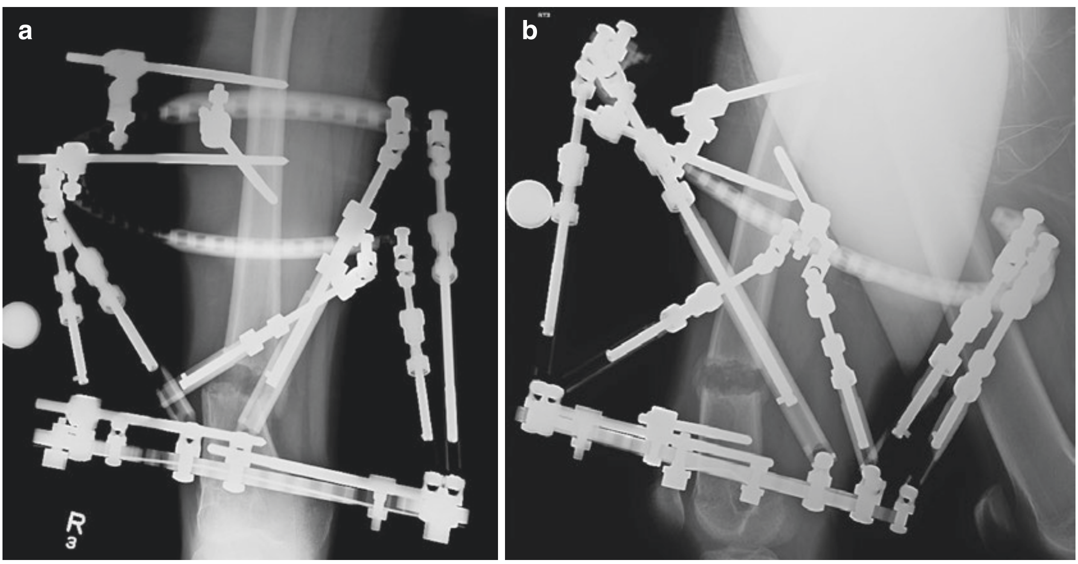

Fig. 11.11 (**a**) Anteroposterior and (**b**) lateral radiographs of the right distal femur at end of correction phase, 50 days postoperative

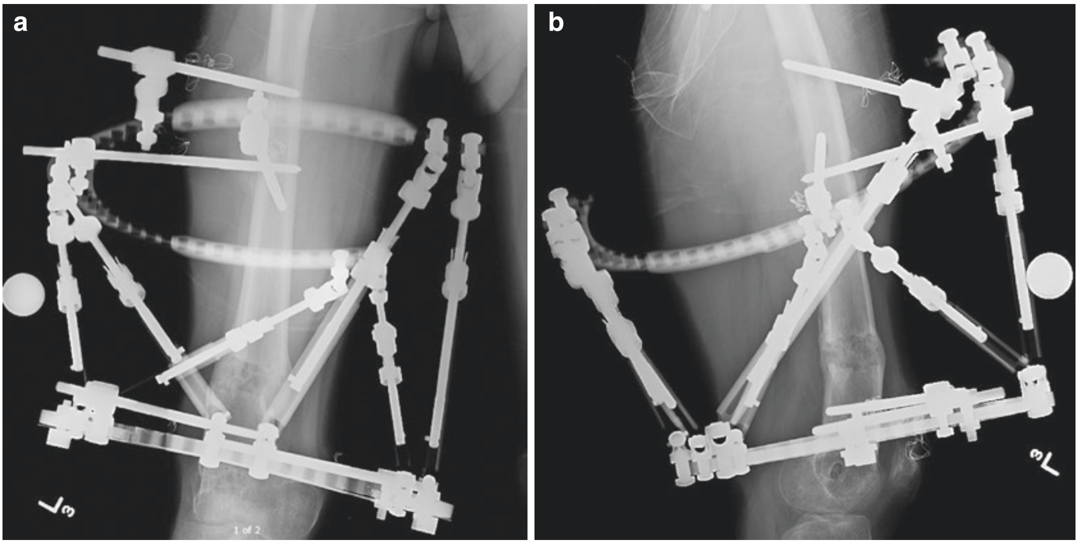

Fig. 11.12 (**a**) Anteroposterior and (**b**) lateral radiographs of the right distal femur at end of consolidation phase, 5 months postoperative

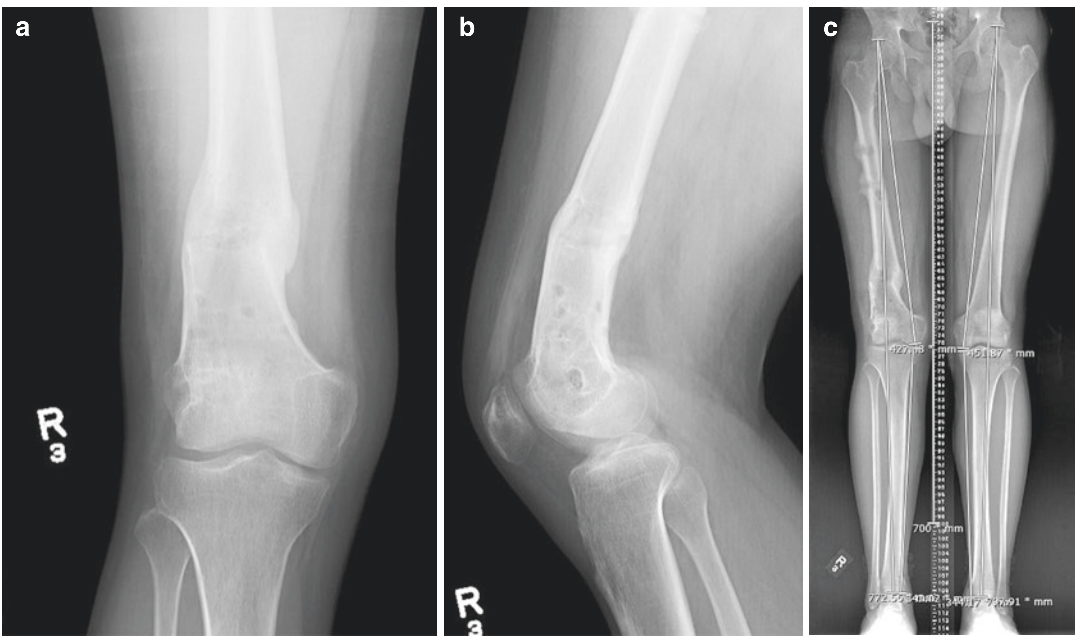

Fig. 11.13 (**a**) Anteroposterior and (**b**) lateral radiographs of the right distal femur and (**c**) X-ray scanogram at final follow-up, 6 months postoperative

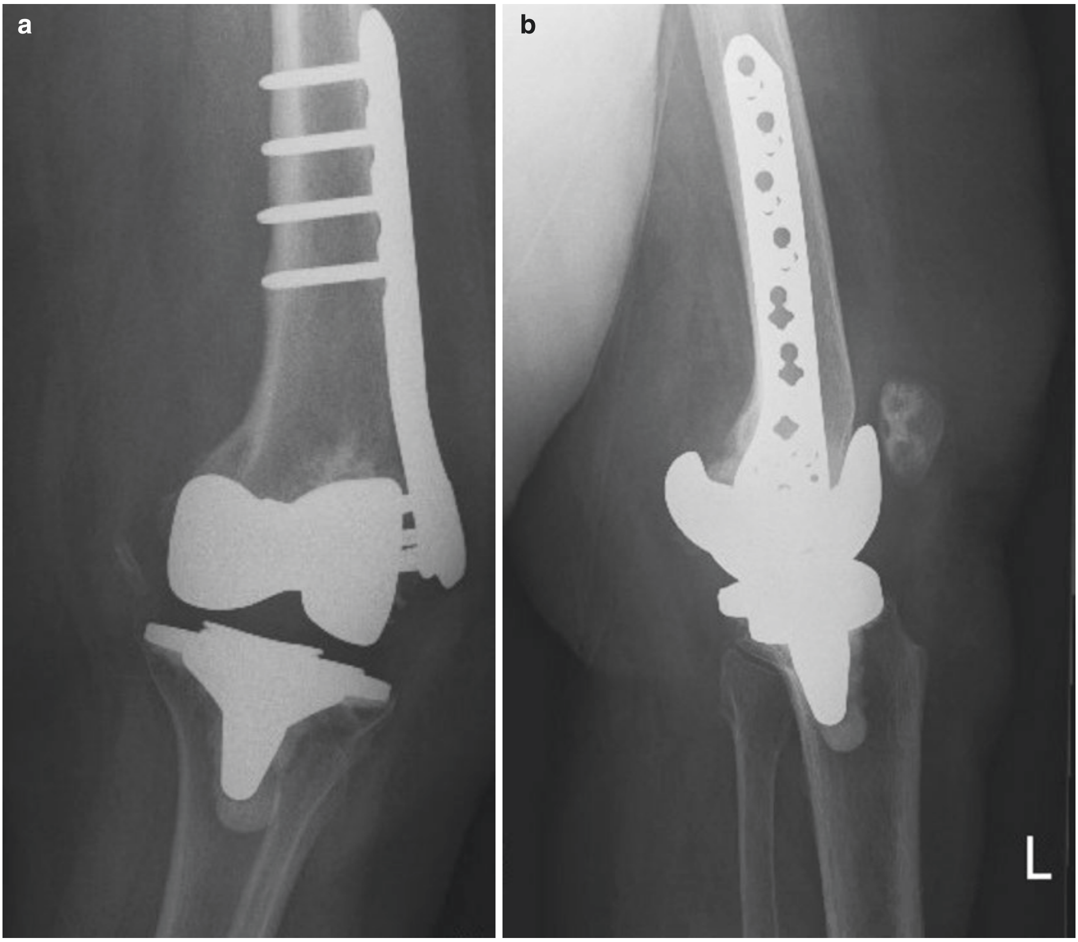

Fig. 11.14 (**a**) Anteroposterior and (**b**) lateral radiographs of the left knee at time of consultation demonstrating varus periprosthetic malunion

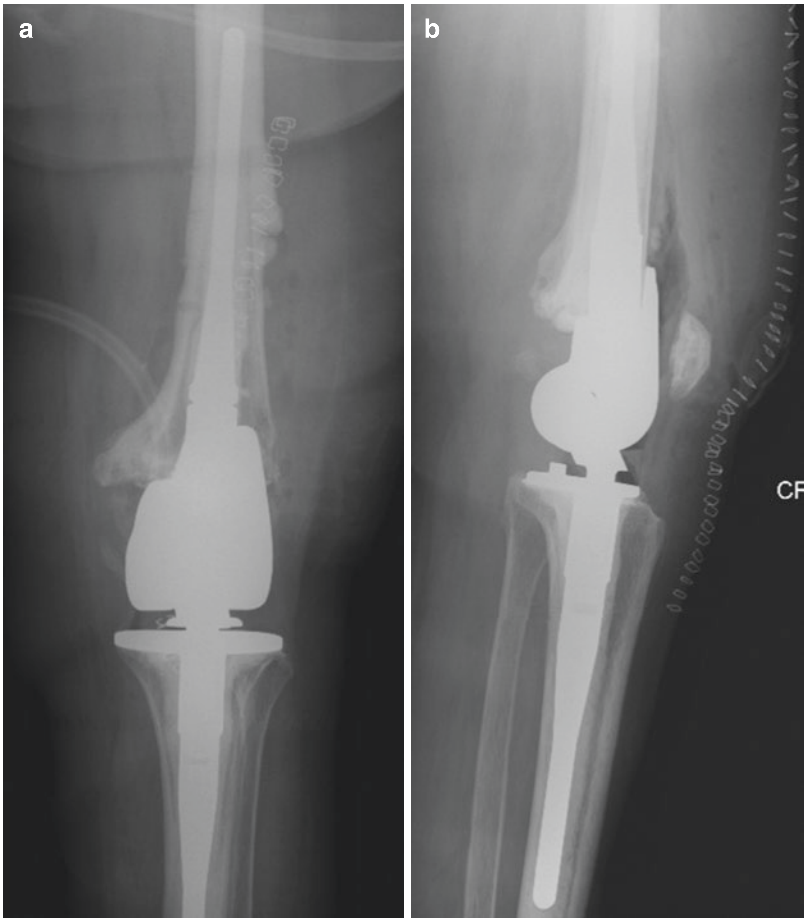

Fig. 11.15 (**a**) Anteroposterior and (**b**) lateral radiographs of the left knee immediately postoperative following left distal femur replacement with resection of malunion

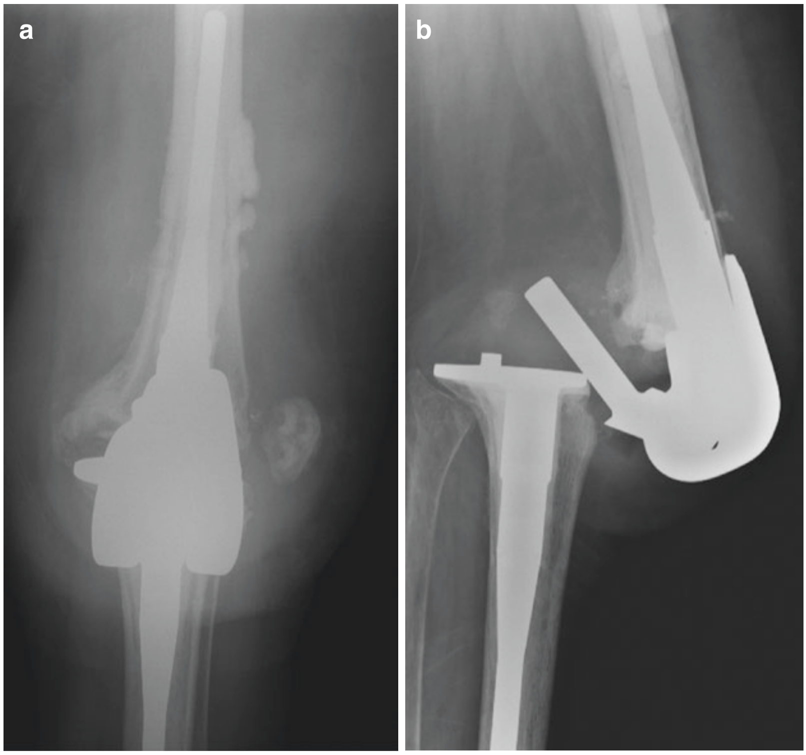

Fig. 11.16 (**a**) Anteroposterior and (**b**) lateral radiographs of the left knee 6 weeks postoperative after fall with dislocation of the tibial post and patellar tendon avulsion

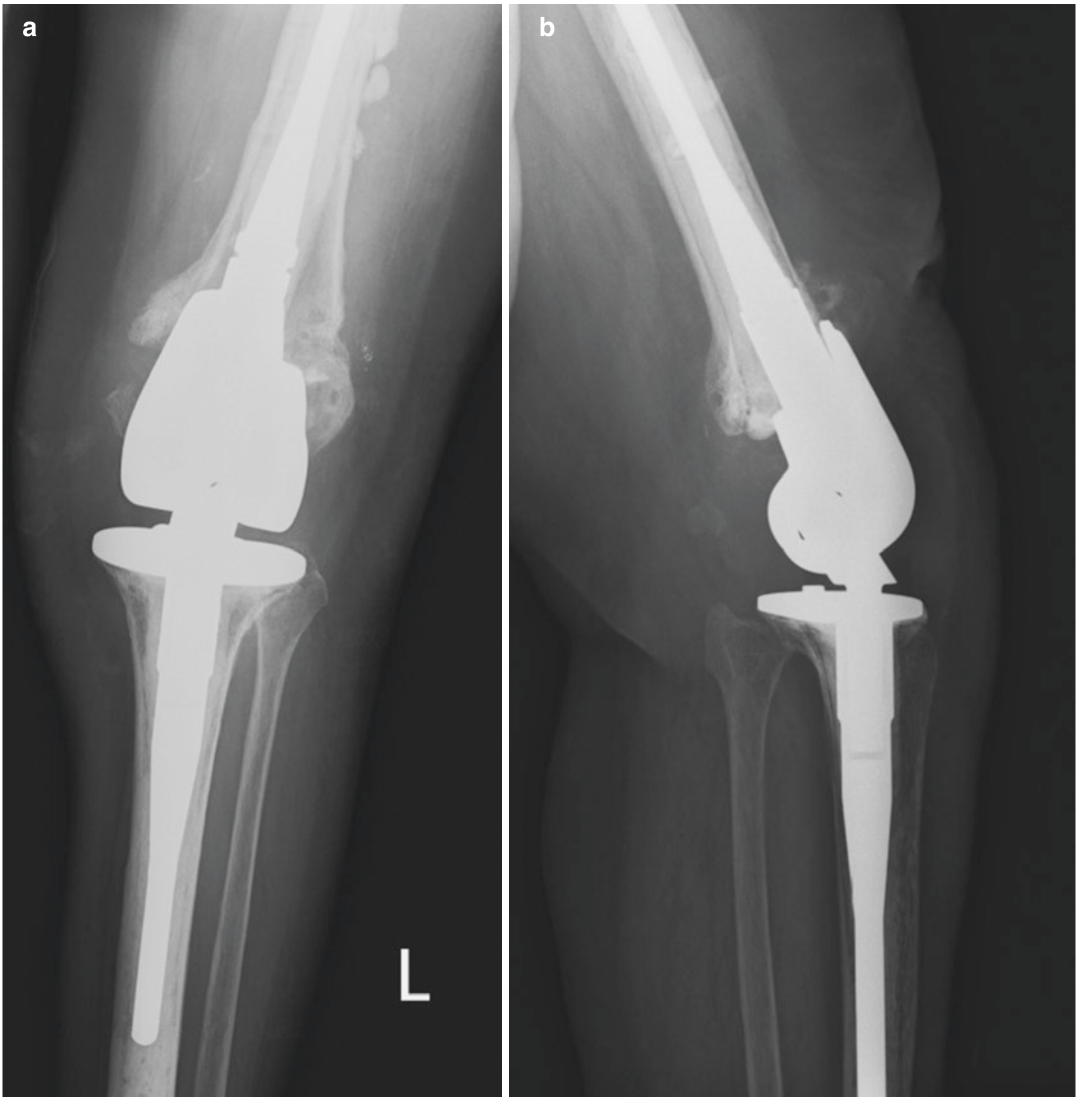

Fig. 11.17 (**a**) Anteroposterior and (**b**) lateral radiographs of the left knee at last follow-up, 6 months postoperative

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