11 Distal Femoral Nonunions

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11.1 Introduction

11.1.1 Distal Femur Fractures

Distal femur fractures are defined as those fractures involving the distal 9–15 cm of the femur. They may be entirely extra-articular (AO/OTA Type A), partial articular (AO/OTA Type B) or intra-articular (AO/OTA Type C) [1].

The management of these fractures depends on the type. The type A fractures are generally best managed with either intramedullary (IM) nailing or open reduction and internal fixation (ORIF) [2]. The decision usually is based on the amount of intact distal femur. If there is less than 4 cm, generally ORIF is preferred to obtain adequate fixation in the distal segment. If above 4 cm, then there usually is enough of the distal femur to allow for two interlocking screws with a retrograde nail [3]. Antegrade nailing can be used but meticulous detail must be adhered to, to insure an anatomical restoration of the limb [2]. Type B fractures require ORIF with screws ± small plates as needed since they are partial articular fractures. The type C fractures generally are best managed with ORIF with locking large fragment plates to allow fixed angle fixation or dedicated fixed angle devices; if the intra-articular component is a simple split, direct reduction of the joint with screw fixation and subsequent retrograde nailing can be performed. In all cases, it is important to realign the mechanical axis of the limb.

Open reduction and internal fixation of the distal femur historically required fixed angle devices [4]. The 95° dynamic condylar screw (DCS) and 95° blade plate provided excellent fixation options for all extra-articular distal femur fractures and select type C fractures with simple intra-articular splits. More comminuted articular fractures required other options such as non-locking condylar plates which often times required a second plate medially to provide sufficient support. These gave way to locking plates, with one of the earliest being the *less invasive stabilization system* (LISS) [4]. Early reports of its use in the management of distal femur fractures were encouraging [5, 6]. Weight and Collinge reported a 100% healing rate at 13 weeks [5]. In a larger series of 103 fractures, Kregor et al. [6] reported a healing rate of 93% without adjunctive bone grafting. They had two nonunions.

11.1.2 Incidence of Nonunions

The incidence of nonunions in the management of distal femoral fractures has been reported historically anywhere from 0 to 19% in the literature with variation depending upon the implant used [4]. This was prior to the widespread use of current locked condylar plating

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systems. As locking plate constructs became more widely used, the rate of nonunion seems to have increased with an incidence as high as 32% [7–9]. Additionally, as the population increases, the number of geriatric distal femur fractures has increased with a nonunion incidence of 24% in this subgroup [10].

11.1.3 Ramifications of Nonunions

These distal femoral nonunions can be severely disabling and lead to poor function [11]. Many of these patients have been unable to bear weight through the affected limb for months if not years. These patients also have malalignment that affects the mechanical axis of the lower extremity. They often have a leg length discrepancy due to bone loss from the injury, which is then exacerbated by the multiple procedures that have been performed. However, with proper attention to the principles of nonunion management, repair of the distal femoral nonunion can lead to healing and improved function [12].

11.2 Causes of Nonunions

Chapter 1 reviewed the various risk factors for the development of nonunions. There are, however, factors that have been implicated in nonunion development that are specific to the distal femur. The majority of nonunions are related to the mechanical environment that is created by the fixation construct. Fortunately, the femur has a circumferential soft tissue envelope. However, damage to the soft tissues can occur when the fracture is open. Additionally, periosteal stripping and bone loss can occur in such high-energy injuries. This can provide a significant biological insult and put the patient at risk for the development of a nonunion as well. The surgeon can inadvertently cause additional stripping during fixation. Thus, it is important to minimize soft tissue dissection, especially on the medial side.

11.2.1 Mechanical Considerations

Locked plating has been found to be a potential risk factor for the development of nonunion. Healing problems with the use of locked plates have recently been reported as high as 32% [7–9]. Hoffman et al. [7] reported an 18% nonunion rate with locked plating and a 20% recalcitrant nonunion rate after secondary procedures in this subgroup. Henderson et al. [8] retrospectively evaluated a group of 86 distal femur fractures (82 patients) treated with locked plating and found a nonunion incidence of 20% which was much higher than the reported literature at the time. They felt that callus inhibition was occurring from too stiff of a construct. A similar decrease in callus formation when using locking plates for distal femur fractures was seen in comparison to intramedullary nails [13]. Lujan et al. [14] retrospectively evaluated 64 consecutive patients that underwent osteosynthesis of a distal femur fracture with either titanium plates or stainless steel plates. They found that locking constructs did result in asymmetric callus formation, which was inconsistent. Most notably they found that titanium constructs exhibited significantly more callus formation early on up to 12 weeks. Although no increased risk of nonunion with the use of stainless steel implants was seen in this study, others have indicated a potential relationship. Rodriguez et al. [15], in a multicenter retrospective study, showed that the use of stainless steel plate was an independent risk factor for nonunion. They showed that the probability of intervention for a nonunion was 21% if a stainless steel plate was used initially versus 4% if a titanium plate had been used at the index operation. In a follow-up study, Rodriguez et al. [16] showed a 41% nonunion rate in stainless steel constructs, but only 10% nonunion rate in titanium constructs which was statistically significant. However, the overall nonunion rate was 13.3% indicating that most of the cases in their series were treated with titanium plates (239 T vs. 32 SS). They indicated that the plate material was an independent predictor of nonunion development.

Historically, fixed angle devices, such as the dynamic condylar screw, were the implants of choice for distal femur fractures. The device had excellent results with 0–10% nonunion rates [4]. In a multicenter study by the Canadian Orthopedic Trauma Society, the use of the DCS was revisited [17]. In a prospective randomized controlled trial, the DCS group had a union rate of 91% compared to 52% of the LISS group at 12 months. There was a higher complication and revision rate in the LISS group. A similar implant to the DCS, the 95° angled blade plate was compared to the *locking condylar plate* (LCP) [18]. They showed that the LCP group had more malunions and nonunions, and a statistically higher incidence of complications resulting in significantly more secondary procedures. In a study comparing the use of the LISS plate to that of locking compression plates (LCP), similar nonunion rates were seen—22.1% (LISS) and 20.7% (LCP) [19].

In an effort to determine the cause of the healing issues, Bottlang et al. [20] evaluated the biomechanics of locked plating in the distal femur. They showed that biomechanically there clearly was asymmetric interfragmentary motion, with the least amount of motion at the cortex adjacent to the plate. Clinically, this was seen as inhibition of callus formation and nonunion development of 19% despite intact hardware. In an attempt to promote callus formation and enhance the mechanical environment with locked plating, they described a technique called far cortical locking. In this technique, the screws locked into the plate but did not engage the near cortex and only obtained fixation in the far cortex. Biomechanically, this reduced the overall stiffness of the construct and promoted interfragmentary motion. In an animal model, they compared far cortical locking to standard locking in a tibia gap model. The far cortical locking group had significantly greater callus formation, which was symmetric, had stronger calluses and complete healing. In a biomechanical cadaveric distal femur model, the far cortical locking technique showed an 81% decrease in construct stiffness and enables parallel interfragmentary motion. Specially designed far cortical locking screws were used in a prospective observational study by Bottlang et al. [21]. Thirty-two patients with 33 distal femur fractures were treated with this technique, with thirty-one available for follow-up. They had a statistically significant increase in periosteal callus at weeks 12 and 24 when compared to their previous published historic controls [14]. There was only one nonunion in this series. Despite the promising results, this technique has not gained wide acceptance.

It is clear that too stiff of a construct can inhibit fracture healing, but conversely inadequate stability can lead to failure of the construct and a subsequent nonunion. It has been suggested that by using a longer plate (>9 holes in shaft length but with at least 8 holes proximal to the fracture) can minimize plate failure [20]. In a different study, plate length was not found to be predictor of nonunion [16]. Most likely it is a combination of plate length, the number of screws, plate material and the type of screws placed that modulate the healing response.

11.2.2 Biological Considerations

An open fracture with resultant bone loss or defect can be a predisposing factor to the development of a nonunion [15, 19, 22]. An open fracture was found to increase the probability of an intervention for nonunion from 21 to 52% for a stainless steel plate and from 4 to 14% for a titanium plate [15]. In a separate study, 37% of open fractures required reoperation for a nonunion, compared to only 10% of closed fractures [22].

An open distal femur fracture is the result of a high-energy injury with resultant comminution, which itself has been suggestive of nonunion [11]. It has been suggested that bone grafting of these highly comminuted injuries should be considered early to help prevent failure of the hardware and subsequent nonunion [23]. Barei and Beingessner [24] bone grafted 55% of distal femurs with bone loss in their series at an average of 70 days, all of which achieved union. Those with bone loss, which did not undergo bone grafting, all healed. All of these were found to have posterior cortical continuity. The presence of posterior cortical continuity despite bone loss indicated that bone grafting was unnecessary. These open fractures also have significant soft tissue disruption, and thus, further insult with extensive exposures can further disrupt the already compromised soft tissue envelope.

Infection has been reported in 0–10% after ORIF. Many of the same things leading to a nonunion can predispose one to infection. Infection itself has been shown to be a risk factor for the development of a nonunion [11, 15, 19]. Infection was found to increase the probability of an intervention for nonunion from 21 to 66% for a stainless steel plate and from 4 to 24% for a titanium plate [15]. Thus, it is imperative, when evaluating a nonunion, that infection is ruled out with the appropriate laboratory studies and radiographic imaging (see Chap. 1).

11.2.3 Patient Considerations

Patients with osteoporosis may have tenuous fixation and are at risk for hardware failure. Locked plating can certainly be helpful in such cases. Despite this, the geriatric population has high incidence of nonunion despite the use of locked plates. Moloney et al. [10] performed a multicenter retrospective cohort study of 176 patients. The mortality at one year was 25% with a 24% incidence of nonunion in the survivors. The long-term functional outcome of such injuries in the geriatric population has been very poor as well [25].

Non-compliance with weight bearing may put undue stress on plate fixation and can lead to early failure. Smoking can certainly delay fracture healing and may lead to a nonunion [22]. Diabetes and other endocrinopathies can also lead to a delay in healing or a nonunion [22].

Morbid obesity has also been shown to be a risk factor for the development of a nonunion specifically in distal femur fractures [15, 22]. Obesity was found to more than double the probability of an intervention for a nonunion despite the material of the implant [15]. Ricci et al. [22] found that proximal implant failure was associated with a higher BMI. The implant failure then leads to the development of a nonunion.

11.3 Evaluation and Diagnosis

The general evaluation and diagnosis of nonunions has been covered in Chap. 1. The same principles apply. However, specific points to address in relation to distal femoral nonunions will be discussed below.

11.3.1 History

A clear understanding of the original mechanism of injury can provide information to assist in evaluating the nonunion. It is important to understand the mechanism of injury of the original fracture. Was it a high- or low-energy injury? Was it an open fracture? If it was open, how many surgeries prior to definitive fixation? What was done at the time of the original surgery? This can be hard to ascertain if the patient has undergone several surgeries prior to their presentation. Requesting the medical records from the original surgeon can be enlightening. Did they have any problems after fixation? Obtaining an accurate history regarding any previous infection is paramount. It is important to determine when weight bearing began especially when there is hardware failure. Early failure may indicate non-compliance with the postoperative regimen. A social history should be obtained to include the use of nicotine, narcotics and illicit drugs. A careful medical history, to determine whether any comorbidities contributed to the development of the nonunion especially diabetes, is critical.

11.3.2 Physical Examination

The patient should be evaluated for gross motion at the nonunion site in cases of hardware failure.

The limb should be inspected for signs of infection such as erythema or draining sinus tracts. Knee motion should be assessed as best possible. In cases where the hardware has failed, the patient may have too much discomfort or pain to assess accurate range of motion. A thorough neurovascular exam should be performed. Many of these patients may have concomitant ligamentous injuries of the knee, which may have gone unrecognized. Therefore, a careful knee exam to assess for stability should be performed if possible. Gross motion at the nonunion site may preclude an accurate assessment of knee stability. The patient should be evaluated for leg length discrepancy, as many of these patients will have developed shortening from the numerous previous surgeries [26].

11.3.3 Laboratories

This has been covered previously, but a full evaluation for infection (complete blood count [CBC], erythrocyte sedimentation rate [ESR] and C-reactive protein [CRP]) and metabolic issues should be performed. Vitamin D deficiency should be addressed. Endocrinopathies and other metabolic abnormalities may require evaluation by an endocrinologist. Diabetics should have better glucose control. Osteoporosis should be managed with appropriate medications.

11.3.4 Radiographs

Standard anteroposterior (AP) and lateral radiographs of the entire femur should be obtained. Standing bilateral AP and laterals from the hip to the ankle can help to assess for any associated deformity with the nonunion. This also allows evaluation of the mechanical axis of the limb and to rule out any other associated deformities in the tibia. Stress examination of the nonunion site can be obtained to determine whether any motion is present in the cases of stiff nonunions where clinical evaluation may be equivocal.

11.3.5 Computed Tomography/Magnetic Resonance Imaging

A computed tomography (CT) scan should be obtained to define the nonunion. If there is concern for malrotation, a CT scan of both hips and knees can be obtained to compare the injured side to the unaffected side for a more accurate determination. A magnetic resonance image (MRI) is warranted in select cases where the hardware has already been removed (no metal artifact) and in infected cases to better assess the presence and extent of osteomyelitis. In general, an MRI is not needed for the aseptic nonunion.

11.3.6 Nuclear Imaging

These studies can be useful in evaluating nonunions when there is a concern for infection. If laboratory studies (CBC, ESR and CRP) are elevated, then nuclear medicine studies may add additional information. In the case of aseptic nonunions, these studies are usually not indicated.

11.4 Treatment

In a systematic review of the literature regarding distal femoral nonunions, the most common treatment involved fixed angle plating with cancellous autografting resulting in a 97.4% union rate [11]. It is important to determine whether there are any causative factors which may have contributed to the nonunion. Correctable factors should be addressed such as smoking cessation and vitamin D replacement (which should correct secondary hyperparathyroidism). Treatment is based on a number of factors. The type of nonunion, whether it is hypertrophic or atrophic, will determine whether bone grafting is needed. The presence of intact or failed hardware can influence the treatment of choice. For fractures that were intra-articular, a determination of whether or not the intra-articular portion has healed can determine whether revision ORIF is needed or whether the nonunion is isolated to the meta-diaphyseal region. It is clear from the literature that no clear consensus exists as to the best treatment option for these nonunions [11, 12].

Chapman et al. [27] used either single or double plate fixation with autologous bone grafting in the management of distal femoral nonunions in 18 patients. In their retrospective review, they had 100% union rate. In another study by Bellabarba et al. [28], twenty patients with nonunions were managed with indirect reduction techniques and application of either a 95° condylar blade plate, condylar buttress plate or a locking condylar plate. Only 45% (atrophic and oligotrophic nonunions) underwent adjunctive autologous bone grafting. They reported a 100% union rate. All of these patients had been initially treated with similar plate screw constructs, but none had bone grafting as part of the original fracture treatment. The same authors had used similar techniques in a series of twenty-three patients with femoral nonunions that had been initially treated with intramedullary nailing for their femur fracture [29]. There were only eight distal femoral nonunions. These were all treated with a 95° condylar blade plate and all healed. The overall success rate for all fractures was 91%. Bone grafting was performed on all biologically deficient nonunions. Gardner et al. [12] reviewed a single surgeon case series of 31 distal femoral nonunions treated with a fixed angled implant. Lag screws across the nonunion site were used in all patients as well as bone graft augmentation (71% autologous bone). They had a 97% union rate at 15.9 weeks with return to a pre-injury functional status in 84% of patients. Deformity correction was an important part of the treatment. Wang and Weng [30] treated thirteen patients with distal femoral nonunions with open reduction and internal fixation combined with both cortical allograft struts and autogenous iliac crest bone grafts. They used predominately blade plates or condylar buttress plates and a few antegrade nails. They achieved 100% union at an average of 5 months. Amorosa et al. [31] used 95° angled blade plates to treat 32 cases of distal femoral nonunions. They had a 92.5% healing rate with the one surgery in the 27 patients with follow-up.

An alternative approach to complete revision ORIF has recently been described by Holzman et al. [32], where a medial locking plate is added to a preexisting intact lateral locking plate construct. They treated 22 patients with 23 distal femoral nonunions with either the addition of a medial plate and autogenous bone grafting when the lateral plate was stable (16 cases) or a two-stage procedure where the broken lateral plate was removed and replaced, followed by a medial locking plate and bone graft two months after the first stage (7 cases). They had a 95.2% success rate in the 21 cases with follow-up. They concluded that adding a medial plate in cases with stable lateral fixation was a successful alternative to complete revision surgery.

The use of intramedullary nailing in the management of distal femoral nonunion has also been studied. However, the early supracondylar nails initially developed were fraught with complications due to the multiple hole configurations of these implants. Koval looked at a series of 16 distal femoral nonunions treated with the supracondylar nail and had only a 25% success rate with a high rate of hardware failure and complications [33]. Wu treated 21 distal femoral nonunions with antegrade nails placed in a retrograde fashion and dynamically locked [26]. In the 18 patients followed for an average of 3.3 years, 88.9% healed at an average of 4.2 months. All were bone grafted with autogenous bone graft obtained from the ipsilateral medial tibial condyle at the time of the nailing. In a similar series, Wu also treated 13 distal femoral nonunions where the initial fracture was treated with an antegrade nail [3]. They again utilized an antegrade nail placed in retrograde fashion, locked dynamically with bone grafting from the medial tibial condyle. Plate fixation was added in some cases. They had a 100% union rate at an average of 4.5 months.

Since many of these nonunions have associated leg length discrepancy and deformity, external fixation has been described as an option for the management of distal femoral nonunions.

Ali and Saleh [34] treated 15 cases of distal femoral nonunion in which all had either a leg length discrepancy or malalignment requiring correction. Five of the cases were infected. They had success in 14 of 15 (93.3%) cases with the one case uniting after intramedullary nailing. They were able to correct angular deformities as well as regain length in these patients. The biggest issue was poor motion with an average range of motion of 80°.

As a salvage procedure in patients with a persistent nonunion of the distal femur, especially in the elderly, prosthetic replacement has been described [35–37]. Haidukewych et al. [35] performed a total knee arthroplasty (TKA) in 17 patients (ages 38–86; mean of 66) that had either failed treatment of a distal femur fracture or nonunion. They had a five-year survivorship of 91%. They did have a 29% rate of both intra-operative and postoperative complications. They felt that it provided reliable pain relief as well as functional improvement, but the overall results were inferior to that of primary TKA. In cases of the elderly patient with a persistent nonunion, the use of a megaprosthesis has also been reported [36, 37]. These patients are cited as having poor bone quality, arthritis, joint contractures and previous implant failure. Revision is felt to be a poor option in these elderly patients. Vaishya et al. [37] treated ten patients with a persistent nonunion and arthritis with a megaprosthesis. All knees had satisfactory alignment and range of motion, but two patients had minor wound problems. They felt that this was a viable one-stage salvage procedure for the patient with a difficult nonunion. The advantage for prosthetic replacement is that is allows for early ambulation [36].

Many options exist for the treatment of distal femoral nonunions, and there is no clear algorithm for the best treatment in terms of implant. Revision plating, intramedullary nailing and even circular external fixation are all viable options but need to be based on the stability of the pre-existing fixation as well as the local biology. Prosthetic replacement should be considered in the elderly with poor bone quality and arthritis.

11.4.1 Treatment Based on Nonunion Type

11.4.1.1 Hypertrophic

Hypertrophic nonunions need stability and thus improvement of the mechanical environment is paramount. These do not usually require bone grafting. In the majority of cases, the hardware has failed and revision of the fixation is required. Either plate fixation or retrograde intramedullary nailing has been successful. If a retrograde intramedullary nail is utilized, the intra-articular component must be healed. The nail can address the meta-diaphyseal component only. If the intra-articular nonunion is simple, lag screw compression with bone graft may be needed. The mechanical axis needs to be realigned regardless of the implant used. The hypertrophic nonunion is usually mobile enough to allow for deformity correction. If a nail is used, blocking screws can aid in deformity correction. If plates are used, fixed angle devices can help correct the deformity. Small leg length discrepancies can be tolerated and managed with a shoe lift. Healing of the hypertrophic nonunion is the goal.

11.4.1.2 Atrophic or Oligotrophic

The decision for bone grafting is clear and should be performed in cases of atrophic or oligotrophic nonunions. If the hardware is stable, autogenous bone grafting can be performed without a need for hardware revision. If, however, the hardware has failed, then both revision fixation and bone grafting are required for a successful outcome. As in all cases, the mechanical axis should be re-established. If the joint component is healed, then retrograde nailing with use of the 'reamer–irrigator–aspirator' (Synthes, Paoli PA, USA) for harvesting of autogenous bone graft from the femoral canal can be performed. Fixation with a retrograde nail that has fixed angle capabilities in the distal segment should be utilized. The reamings obtained can be packed into the nonunion site.

11.4.1.3 Infected

In cases of infected nonunions, a two-stage if not three-stage procedure may be warranted. In the first stage, removal of the hardware, debridement of the infected nonunion site, obtaining cultures, application of antibiotic cement into the defect with or without temporary external fixation are performed. Once the infection is cleared, stabilization along with placement of a cement spacer is performed. Fixation can be with either a retrograde intramedullary nail (preferred) or a locking plate or a fixed angle device. In the final stage, bone grafting into the defect is done after the cement spacer is removed (Masquelet technique). If the amount of bone requiring debridement is extensive, the use of circular external fixation and distraction osteogenesis to fill the defect can be considered. This technique is highly specialized and should be undertaken by someone experienced.

11.4.2 Author's Preferred Methods of Treatment

1. *Stable Hardware (Rare) and Hypertrophic*: Adjunctive plate fixation can often provide sufficient stability to promote union. This situation is rare.
2. *Stable Hardware and Atrophic/Oligotrophic*: If the hardware is stable, simply bone grafting the nonunion site should be sufficient to promote union. The harvest site for the bone graft should be based upon the amount of bone graft needed.
3. *Failed Hardware (Common)*: In cases where the initial lateral locked plating has failed, the joint component has healed and the meta-diaphyseal area has gone on to a mobile hypertrophic nonunion, removal of hardware and retrograde intramedullary nailing with a nail allowing for a fixed angle distally works well. The largest diameter nail should be used to obtain stability. With the advent of the reamer–irrigator–aspirator (RIA) system (DePuy Synthes, Warsaw IN, USA), it is easy to obtain autogenous bone graft from the intramedullary canal at the time of reaming. The bone graft can be packed into the nonunion. This technique is our method of choice for most distal femoral nonunions regardless of the nonunion type. Nail stabilization allows for earlier weight bearing. Bone grafting provides a biological stimulant as many of these patients have already had several operations at the time of presentation. Correction of any deformity can usually be accomplished with the nail as most are mobile. If the nonunion site is stiff, a fixed angle device (95° angled blade plate or DCS) to correct the deformity may be a better option as long as the joint injury is healed.
4. *Failed Hardware with Nonunion of Intra-Articular Component*: If the hardware has failed and the joint component is not healed, then complete removal of the previous plate and revision ORIF with restoration of the joint congruity, realignment of the mechanical axis and bone grafting is needed. We prefer to use a locking plate, either the locking compression LISS plate or locking condylar plates after compression and fixation of the joint component.
5. *Use of External Fixation*: Circular external fixation for nonunion management is reserved for those cases where, despite bone grafting to large defects, the nonunion persists. It can also be useful in cases of septic nonunion where internal fixation may be problematic despite debridement. It can also be used in cases of multiplanar deformities in combination with a nonunion, especially when it is a stiff hypertrophic nonunion. The patient must understand the procedure and the length of time such a device will be on as it can be life altering during the time the fixator is on the thigh.
6. *Prosthetic Replacement*: In cases of the elderly patient with a distal femoral nonunion, consideration to a total knee arthroplasty should be given. The ideal candidate should be one with poor bone quality where fixation may be problematic with ORIF. If they also have preexisting arthritis or as a result of the original injury, then a total knee arthroplasty may be preferred. A megaprosthesis (distal femoral replacing) can be considered when the bone stock is deficient and unable to support a standard or stemmed total knee arthroplasty.

11.4.3 Case Discussions

Case 1

Patient is a 50-year-old white male originally involved in motor vehicle accident (MVA) in 2008. Patient sustained a right Grade III A open distal femur fracture AO Type C3. He underwent irrigation and debridement of the open fracture (I&D) and temporary bridging external fixation. He then required several washouts due to the contamination. He subsequently underwent definitive ORIF approximately 2 weeks after the initial injury with a 7-hole LCP-LISS plate. Patient was followed by the original surgeon and then referred for a nonunion, with hardware failure at 5 months with AP and lateral radiographs shown in Fig. 11.1.

The patient was evaluated and found only to have hepatitis C. The patient denied any history of wound problems or infections after the definitive procedure. The patient had not smoked for 30 years and quit drinking 10 years prior to presentation. Laboratory markers were all within normal limits for his white blood cell (WBC) count, C-reactive protein (CRP) and erythrocyte sedimentation rate (ESR). Dual-energy X-ray absorptiometry (DEXA) scan had been obtained by his primary care provider and was normal. He had normal 25-OH vitamin D levels. His physical examination showed well-healed surgical scars as well as traumatic lacerations from the original injury, varus malalignment of the limb at the nonunion site and flexion only to 30°. A CT scan with coronal and sagittal reconstructions (Fig. 11.2) was obtained, which showed healing of the intra-articular component but a clear nonunion of the metaphyseal portion with varus collapse with pullout of screws as well as broken screws.

The patient underwent hardware removal with debridement of all fibrous tissue from the nonunion site. The RIA system was utilized in a retrograde fashion to obtain bone graft from the femoral canal of the affected leg. A retrograde nail with a fixed angle blade component distally was inserted and statically locked proximally with two screws. The RIA bone graft was packed into the nonunion. The postoperative images are shown in Fig. 11.3.

The patient went onto heal the nonunion by 7 months (Fig. 11.4). At this point, he underwent manipulation under anesthesia of his right knee,

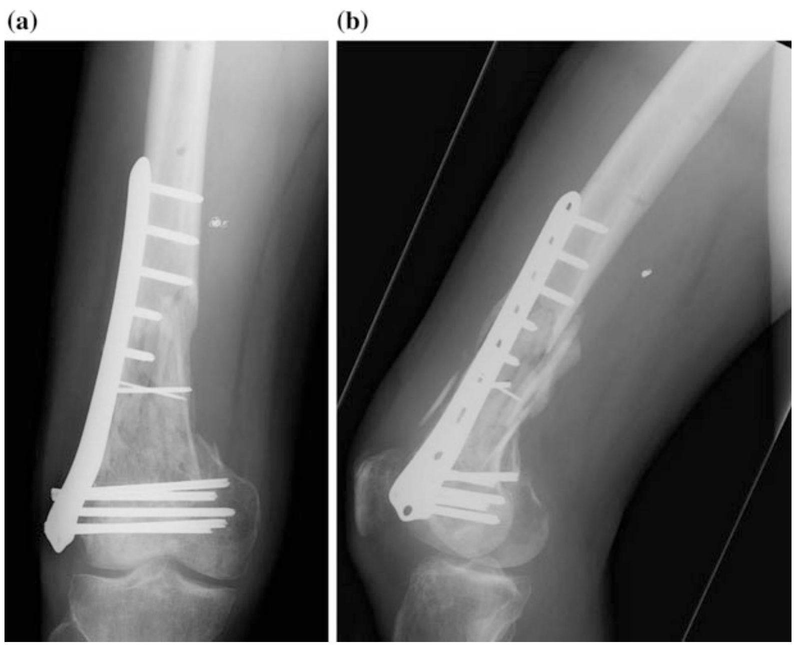

Fig. 11.1 **a** Anteroposterior and **b** lateral radiographs of the right knee showing hardware failure, shortening and varus

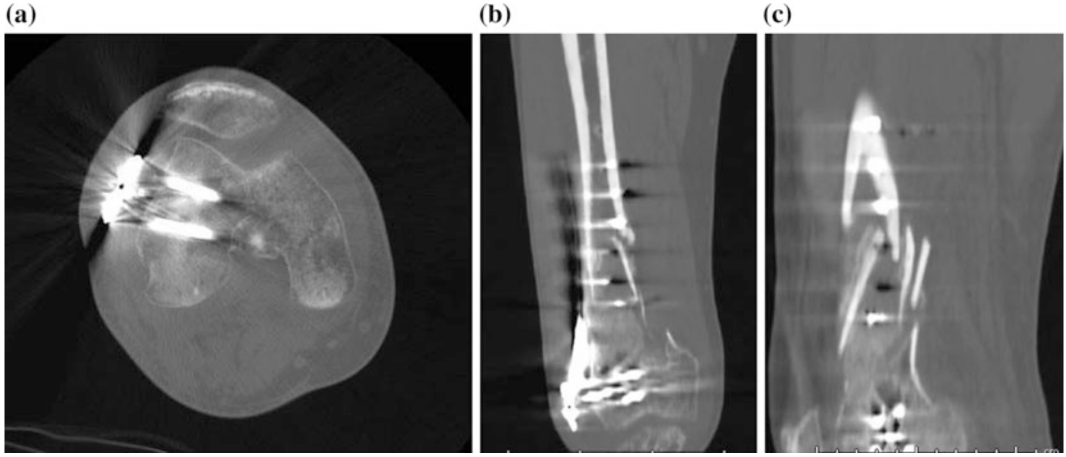

Fig. 11.2 **a** Axial computed tomography (CT) image showing healing of the intra-articular component; the gap between the plate and the bone is well visualized; **b** coronal CT image showing the varus alignment, failure of hardware and the metaphyseal nonunion; **c** sagittal image also showing the nonunion

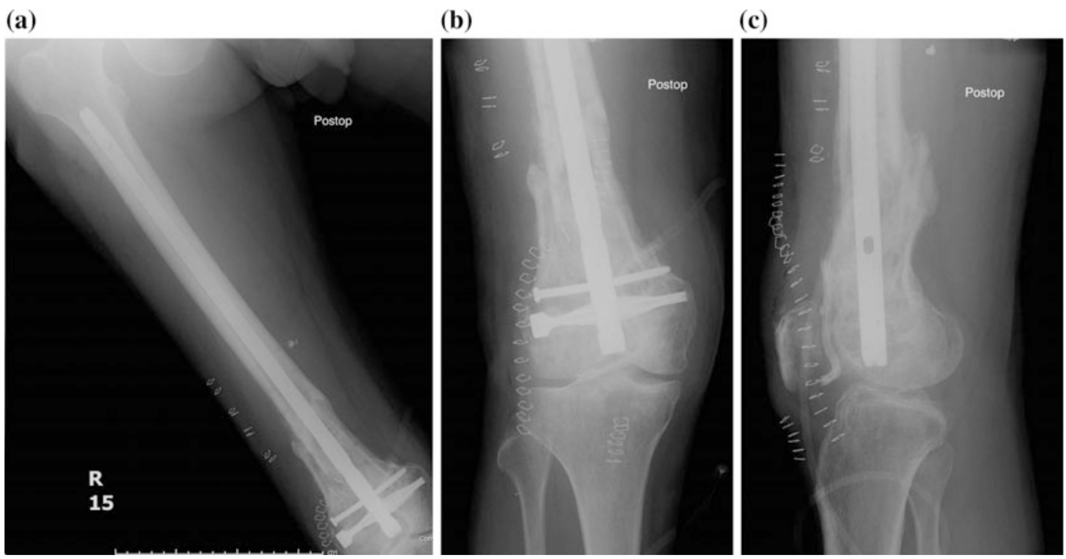

Fig. 11.3 Immediate postoperative images after retrograde intramedullar nailing and bone grafting. **a** Full length right femur showing re-establishment of femoral anatomical axis; **b**, **c** anteroposterior and lateral of the right knee showing the nonunion site with bone graft

quadricepsplasty and an arthrotomy with lysis of adhesions for persistent poor knee motion (0° to 65°). The patient eventually achieved 110° of motion.

The patient did well and returned to his activities, which included downhill skiing. Patient returned 7 years later with complaints of knee pain, which was felt to be consistent with arthritic-like symptoms and probably a degenerative medial meniscal tear (Fig. 11.5). He was also having hardware symptoms distally at the lateral aspect of the knee. Arthroscopic debridement along with hardware removal was discussed with the patient since the patient was going under anesthesia. The patient had arthroscopic debridement of the knee. He was found to

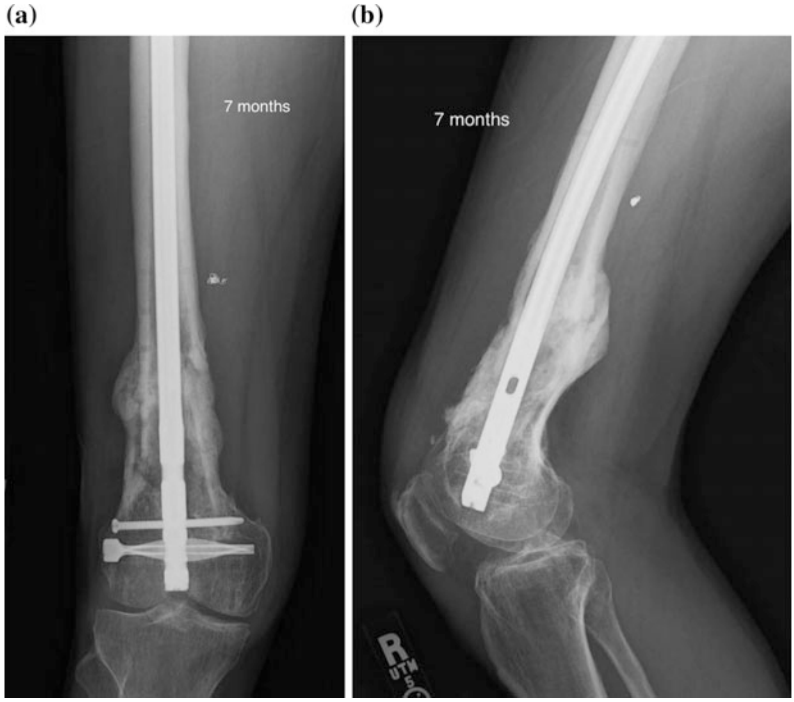

Fig. 11.4 **a** Anteroposterior and **b** lateral radiographs of the right knee at 7 months showing consolidation of the nonunion site

have Grade III medial tibial compartment disease but only Grade I lateral compartment disease. The nail was removed without difficulty (Fig. 11.6). Patient returned to his snow skiing and has improved motion to 120° of flexion and has always maintained his extension.

Case 2

The patient is a 54-year-old Latin American female who sustained multiple injuries in an MVA in 2006. The patient was treated for a left distal femur fracture with ORIF at an outside institution. The patient was followed for approximately 17 months, after which she was told she was healed and discharged. She apparently was fully weight bearing.

She then presented 2 years out from the initial injury with hardware failure and a nonunion of the left distal femur (Fig. 11.7). The patient was unable to give details of the injury as to whether or not it was an open fracture. The patient is morbidly obese. She has diabetes, hypertension and a history of deep vein thrombosis. Her laboratory evaluation showed a normal WBC but an elevated ESR of 74 and CRP of 21.3. Her other laboratory studies were within normal limits. The nuclear medicine studies obtained were negative. Clinically, she did not have any evidence of infection nor did she report ever having any wound problems or any other issues after the index procedure until 22 months later when she noticed the sudden pain. A CT scan was obtained and confirmed the nonunion and hardware failure. The joint was healed (Fig. 11.8).

The patient underwent removal of the hardware, RIA of the femur for bone graft and placement of a retrograde nail with a fixed angle blade component distally. It was statically locked proximally with two screws. Her postoperative images are shown in Fig. 11.9.

The patient was allowed to be immediately weight bearing and went on to heal by 6 months. (Figure 11.10). At her last follow-up of 13 months, she was ambulating fully with the use of a cane for long distances. She was pain-free with 0° to 95° of motion (Fig. 11.11).

Case 3

The patient is a 38-year-old white male who was initially injured in an MVC while working out of

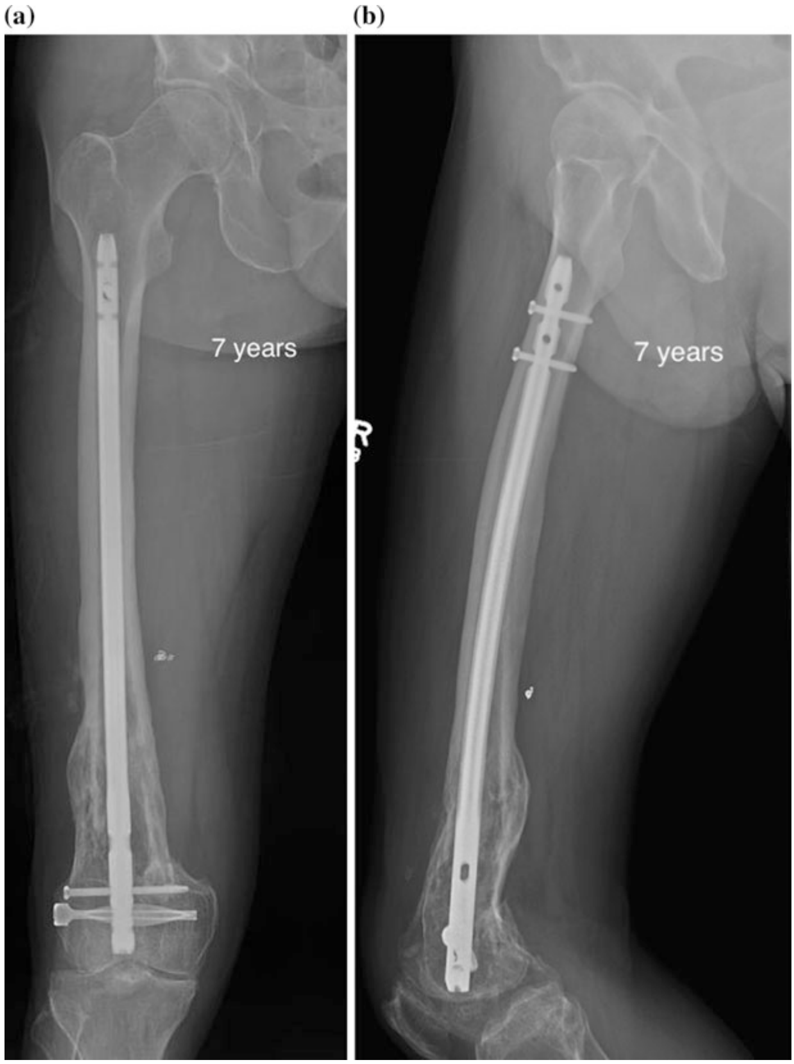

Fig. 11.5 **a** Anteroposterior and **b** lateral radiographs of the right femur at 7 years showing well-healed femur with stable hardware

town. He had sustained a left Grade IIIA open distal femur fracture/dislocation. His operative report indicated that both the anterior cruciate ligament (ACL) and posterior cruciate ligament (PCL) were out, but no indication regarding the status of his collaterals. He had an initial irrigation and debridement with application of a temporary bridging external fixator. He subsequently underwent ORIF at the outside institution. Patient returned to the area and presented to our institution approximately 6 weeks out (Fig. 11.12).

The patient is otherwise healthy. His physical examination at that time showed well-healed incisions and traumatic lacerations. He was followed and felt to be progressively healing (Fig. 11.13; 6 months). He was fully weight bearing, but at 9 months he developed increased pain. The radiographs showed subsidence of the hardware and some collapse (Fig. 11.14). The patient underwent a CT scan (Fig. 11.15), which showed a persistent nonunion of the metaphyseal area as well as part of the intra-articular region. The allograft bone had not been incorporated.

The patient underwent revision ORIF as opposed to nailing because of concern for a persistent intra-articular nonunion. The hardware was removed, and the allograft bone was

Fig. 11.6 **a** Anteroposterior and **b** lateral radiographs of the right femur at 3 months after hardware removal

nonviable and had not incorporated; it was debrided, resulting in the large void shown in Fig. 11.16. The intra-articular nonunion was stabilized with a screw (Fig. 11.17). Bone graft was obtained via the RIA system from the left femur after the hardware was removed. It was done retrograde through the nonunion site (Fig. 11.18). Revision ORIF with a variable angle locked plate was performed and the bone graft placed into the nonunion site with additional bone graft extender (demineralized bone matrix [DBM]) (Fig. 11.19). The final postoperative radiographs are shown in Fig. 11.20.

Patient went onto heal the nonunion with abundant bone around the site and was functioning well at 18 months. His range of motion was 0° to 115°. His last follow-up radiographs are shown in Fig. 11.21.

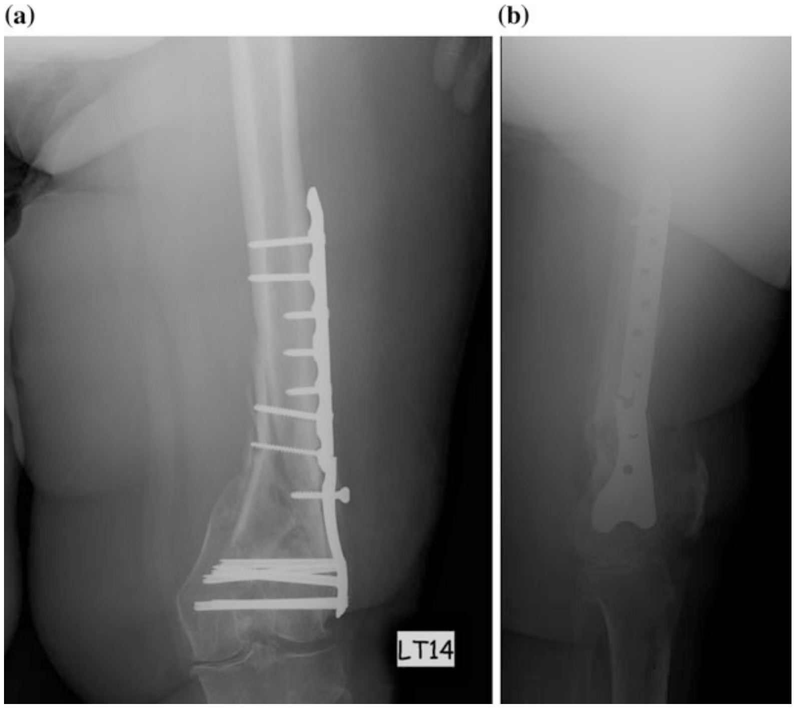

Fig. 11.7 **a** Anteroposterior and **b** lateral radiographs of the left knee 2 years after the initial fixation showing loosening of hardware and nonunion**. a** The loose screw is easily visualized**; b** the break in the plate is well visualized as well as the recurvatum deformity at the nonunion site

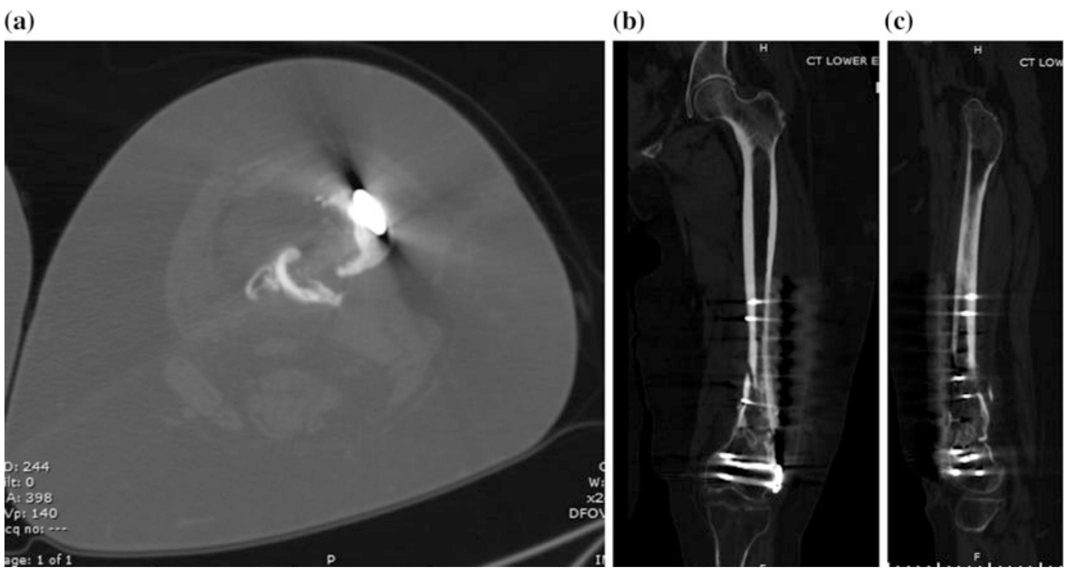

Fig. 11.8 Computed tomography scan images showing the nonunion: **a** axial image showing lack of bone, **b** coronal image showing the varus and nonunion, **c** sagittal image showing the recurvatum deformity and nonunion

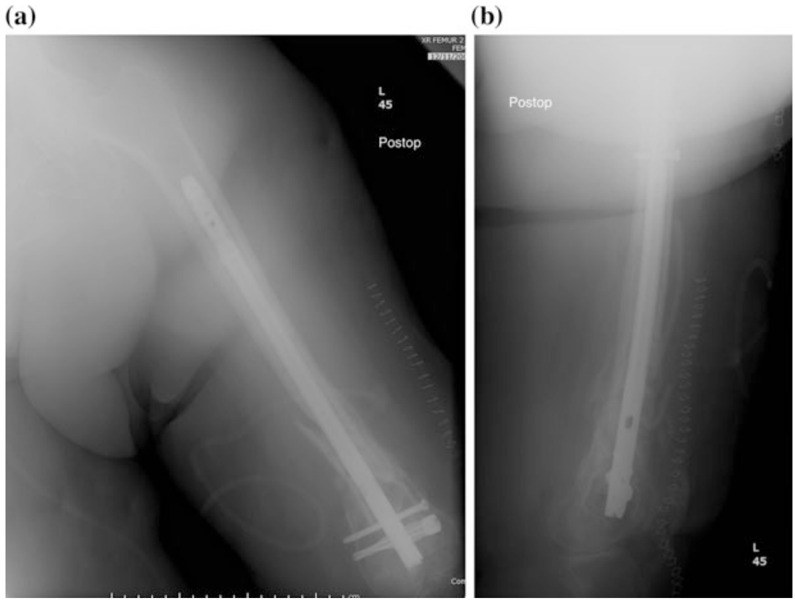

Fig. 11.9 Immediate **a** anteroposterior and **b** lateral postoperative left femur radiographs showing stabilization of the nonunion with a retrograde nail and bone grafting

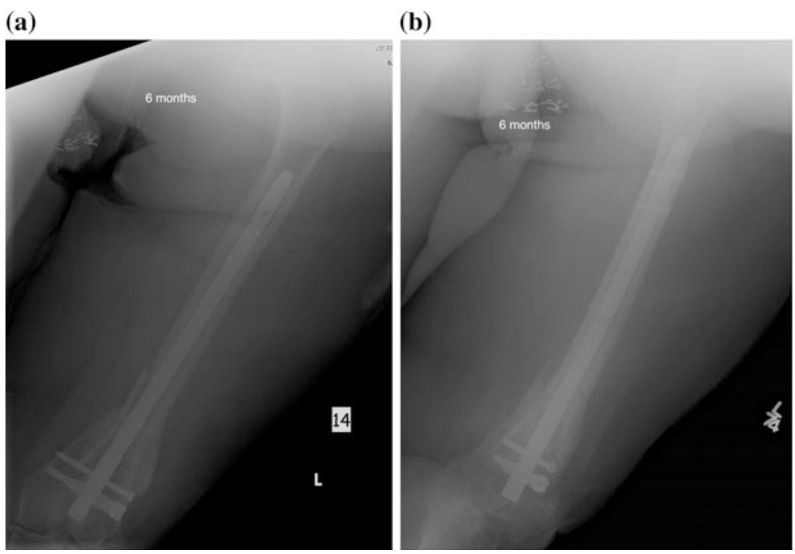

Fig. 11.10 **a** Anteroposterior and **b** lateral left femur radiographs at 6 months showing consolidation across the nonunion site

Case 4

The patient is a 51-year-old morbidly obese woman who is referred for a nonunion of her right distal femur. She is approximately one year out from her initial injury, which was a right grade III A open distal femur fracture. She was managed with ORIF at an outside institution. The radiographs showed bending of the plate and loosening of the screws distally. There was an obvious nonunion of the meta-diaphyseal region (Fig. 11.22).

She reports no immediate complications after her initial surgery and denies any history of infection. Her only medical problem is morbid

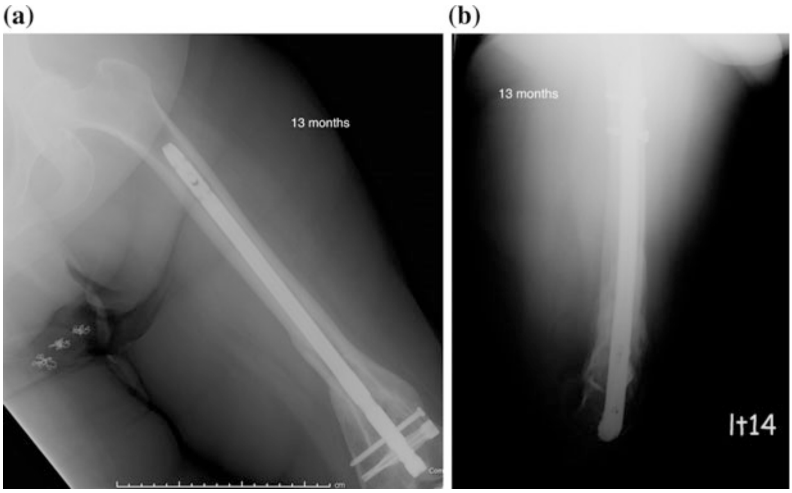

Fig. 11.11 Final follow-up **a** anteroposterior and **b** lateral left femur radiographs at 13 months showing a well-healed femur without hardware complications

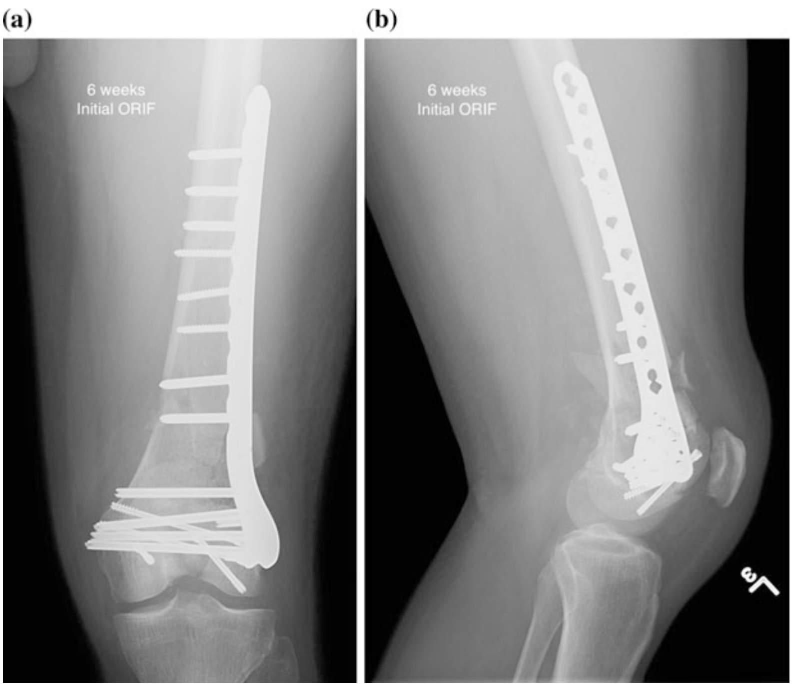

Fig. 11.12 **a** Anteroposterior and **b** lateral left knee radiographs at 6 weeks after open reduction internal fixation. The fracture appears well reduced and restoration of the anatomical axis

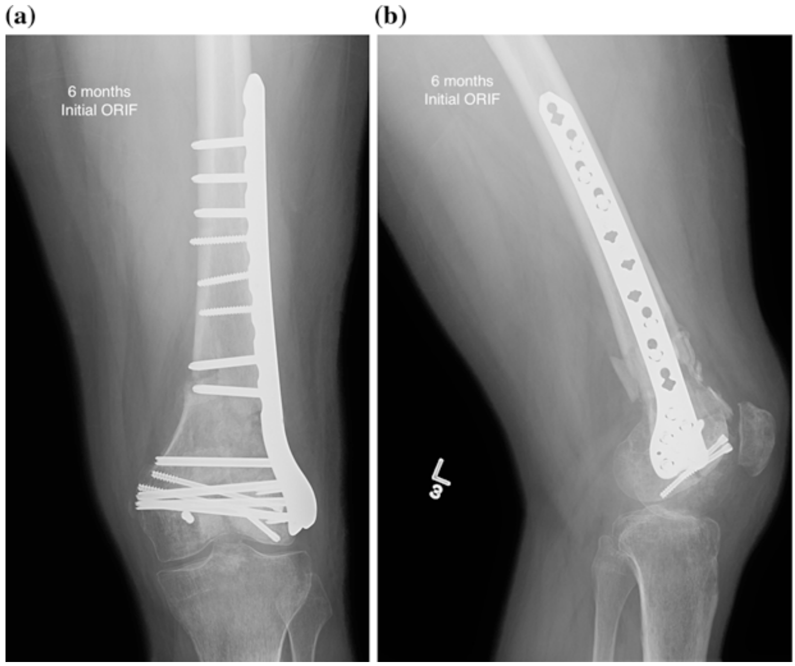

Fig. 11.13 **a** Anteroposterior and **b** lateral left knee radiographs at 6 months. **a** There appears to be some consolidation at the medial cortex as well as in the metaphyseal region, but some subsidence of the plate is seen with collapse at the fracture site but stable hardware; **b** lateral shows increasing consolidation anteriorly

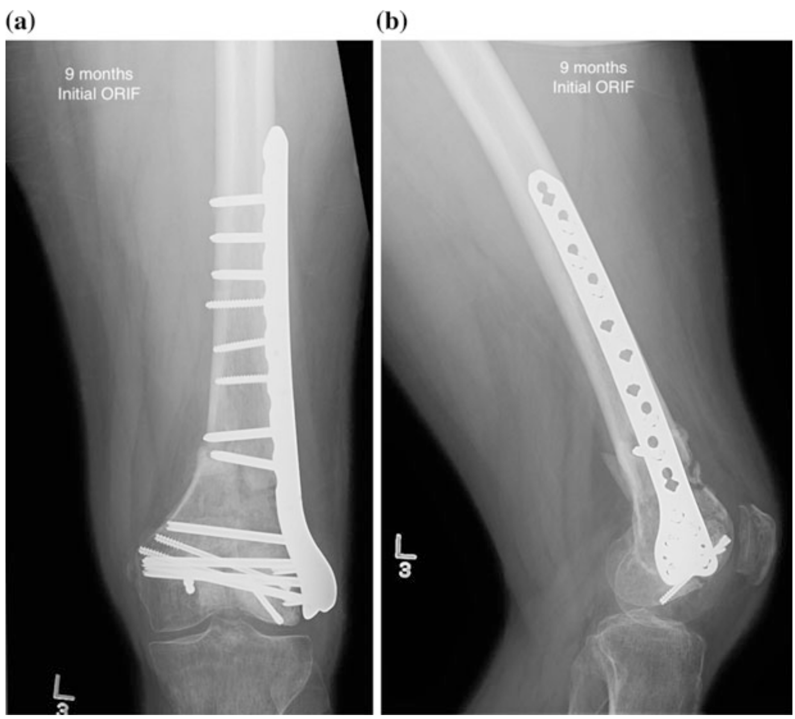

Fig. 11.14 **a** Anteroposterior and **b** lateral left knee radiographs at 9 months. **a** There appears to be further subsidence of the plate and thus collapse at the fracture site; **b** lateral shows increasing consolidation posteriorly and intact plate

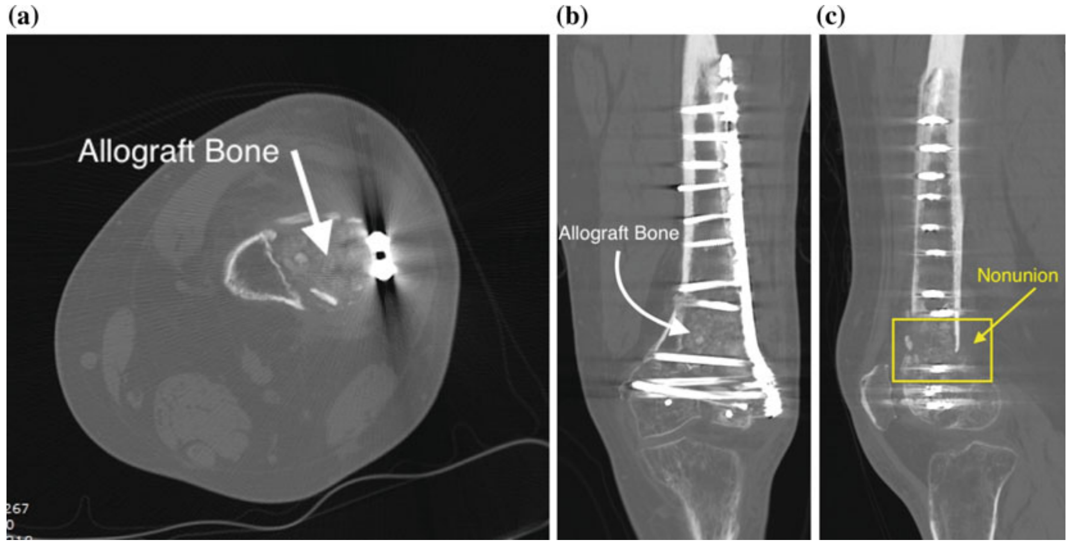

Fig. 11.15 A computed tomography scan was obtained to evaluate the fracture site. **a** Axial image showing the allograft bone still unincorporated and a lack of bridging; **b** coronal image showing again the allograft bone and its lack of incorporation as well as subtle varus collapse; **c** the obvious nonunion is clearly visualized on the sagittal image

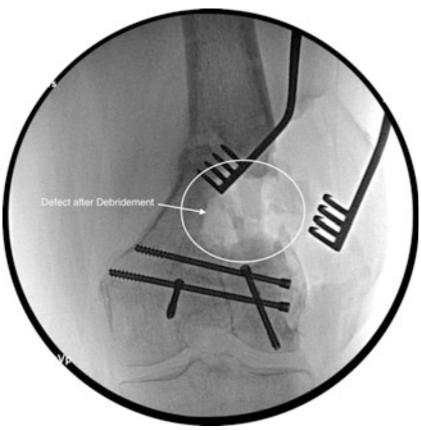

Fig. 11.16 Intra-operative fluoroscopic image after plate removal and debridement of the allograft showing the large void

Fig. 11.17 Intra-operative fluoroscopic image showing the additional partially threaded cancellous screw for lag screw fixation of the articular nonunion

obesity (BMI 64). She is a smoker (half pack per day). Smoking cessation was recommended. She had been previously prescribed an ultrasound unit in an attempt to aid consolidation. Physical examination showed well-healed surgical scars and lacerations without signs of infection. Her range of motion was 0° to 100° compared to 0° to 120° on her unaffected side. Her laboratory evaluation showed her CRP to be 19.5, WBC 11.9 and ESR of 22. Her 25-OH vitamin D was less than 15. She was immediately started on vitamin D2 at 50,000 units weekly. She responded to the dosing with her 25-OH vitamin D increasing to 39. Her nuclear medicine studies showed uptake consistent with degenerative changes in the knee joint but no evidence of infection.

Fig. 11.18 Intra-operative fluoroscopic image showing the reamer for the reamer–irrigator–aspirator (RIA) going retrograde through the mobile nonunion site

Fig. 11.19 Intra-operative fluoroscopic image after stabilization and bone grafting of the nonunion site

The patient underwent repair of her nonunion with removal of all hardware with obvious motion seen at the nonunion site. The nonunion was stabilized with a retrograde nail after obtaining bone graft using the RIA system. We obtained 40 cc of bone graft, which was all placed into the nonunion site and supplemented by demineralized bone matrix. The immediate postoperative images are shown in Fig. 11.23.

The patient was followed and felt to have healed by 6 months with bridging bone (Fig. 11.24). At her last follow-up at four years, she was ambulating without assistive devices, had only a 5 mm leg length discrepancy managed with a shoe insert, and had regained her full knee range of motion (ROM) (Fig. 11.25).

Case 5

The patient is a 48-year-old Latin American female who presents with pain, discomfort and inability to bear weight on her right lower extremity. Radiographs obtained at the time show a right distal femoral nonunion with hardware failure (Fig. 11.26).

Her original injury was 4 years prior at which time she was treated at an outside facility for a right grade IIIA open distal femur fracture. She reports having multiple surgeries (10) afterward for various reasons, including infection. She is morbidly obese and has hypothyroidism (on thyroid replacement). She does not smoke. Her physical examination showed well-healed surgical incisions and lacerations. Her range of motion was 5° to 35°, and it appeared that she had about 30° to 40° of malrotation. She had no signs of infection.

Nonunion evaluation was performed. Her WBC was 9.6, ESR 29 and a CRP 19.9. She also had hypovitaminosis D. Nuclear medicine studies were performed which showed positive bone scan, indium scan but discordant uptake on sulfur colloid scan, indicating a concern for infection (Fig. 11.27). The CT scan showed an obvious nonunion (Fig. 11.28).

Surgical options were discussed with the patient, including staging the definitive management, if there was presence of an infection. At the time of surgery, the nonunion site was evaluated after all the hardware was removed. The native bone appeared normal. There was a significant amount of allograft 'croutons' that were loose and thus were debrided from the nonunion site. Intra-operative cultures were sent as well as a stat Gram's stain, which was negative for bacteria and only 2–3 polymorphonuclear cells (PMN) per high-power field (HPF) on frozen section of the tissue. There was no purulence, just the unincorporated bone graft. The decision was made to proceed with definitive management with the benign appearance of the nonunion site and the negative intra-operative studies. She underwent

Fig. 11.20 Immediate postoperative **a** anteroposterior and **b** lateral left knee images showing the final construct

correction of her deformity through the mobile nonunion site, both angulation and rotation. There was a 50% circumferential defect for a length of about 10-cm. Retrograde nailing was performed after obtaining autogenous bone graft using the RIA system. Reaming to 16 mm was performed, and a 15 mm diameter nail was placed. The defect was packed first around the nail with calcium sulfate beads impregnated with vancomycin (off-label use) after which the autograft was packed on top. The entire defect was filled. Her knee was then manipulated after closure. We were able to passively fully extend her and flex her to 95° (Fig. 11.29).

The patient went on to heal by 8 months as seen in Fig. 11.30. At her three-year follow-up, she maintained her 95° of flexion, had a slight leg length discrepancy of 1.5 cm managed with a shoe lift, and was ambulating with the use of a cane on occasion. She reported only occasional discomfort with weather changes (Fig. 11.31).

Case 6

The patient is a 33-year-old Latin American female who was involved in a head-on MVA and sustained multiple bilateral lower extremity injuries, including a left grade IIIA open distal femur fracture with intra-articular involvement. In addition to damage control management of her other injuries, she underwent I&D and temporary bridging external fixation across the left knee (Fig. 11.32). The patient returned to the ICU and her condition improved.

The patient underwent definitive ORIF of her left distal femur fracture once she was stable. There was extensive comminution and bone loss in the meta-diaphyseal region extending into the trochlear region. The patient also had calcium

Fig. 11.21 Follow-up **a** anteroposterior and **b** lateral radiographs at 18 months after the revision open reduction internal fixation and bone grafting of the left knee, showing consolidation of the nonunion site

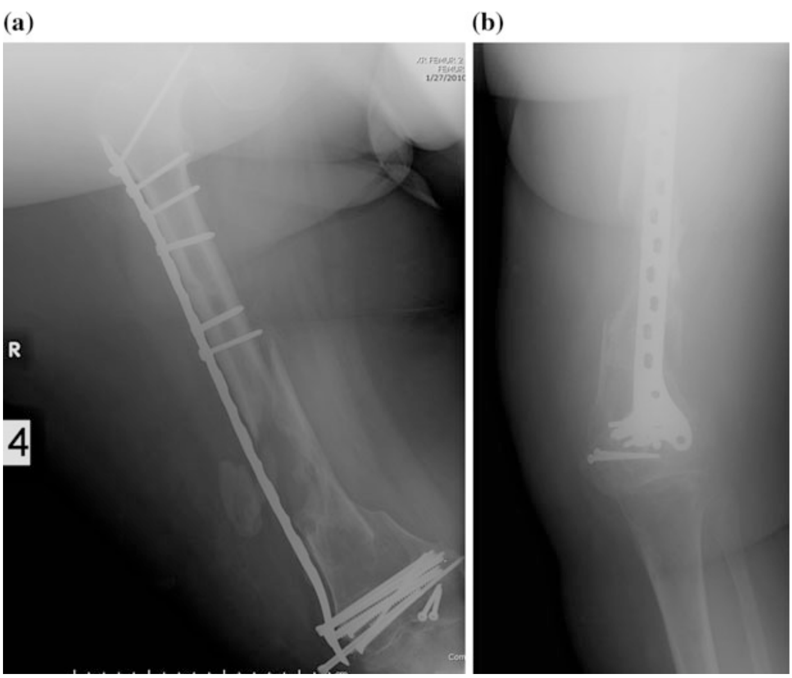

Fig. 11.22 **a** Anteroposterior and **b** lateral radiographs of the right femur showing the bending of the original fixation and loss of fixation distally. The large soft tissue density can also be appreciated

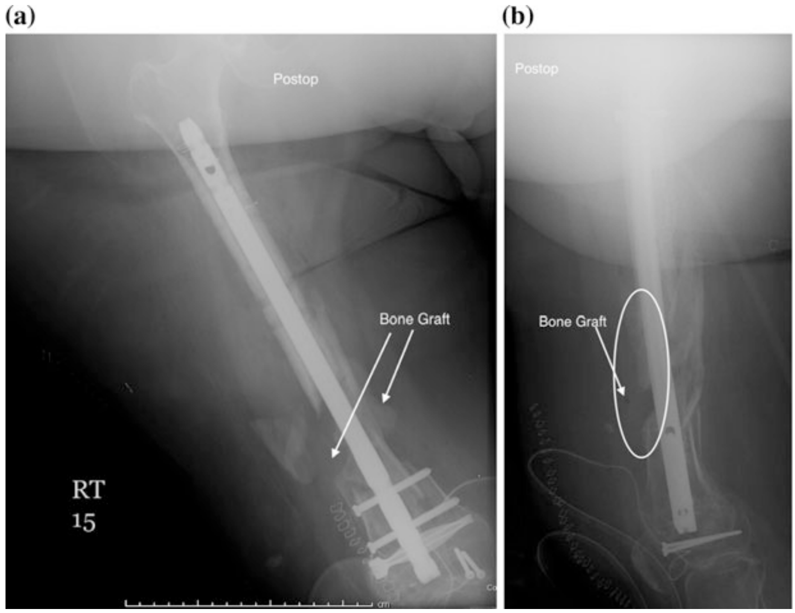

Fig. 11.23 Immediate postoperative **a** anteroposterior and **b** lateral radiographs of the right femur showing stabilization of the nonunion site with a retrograde nail and placement of the bone graft

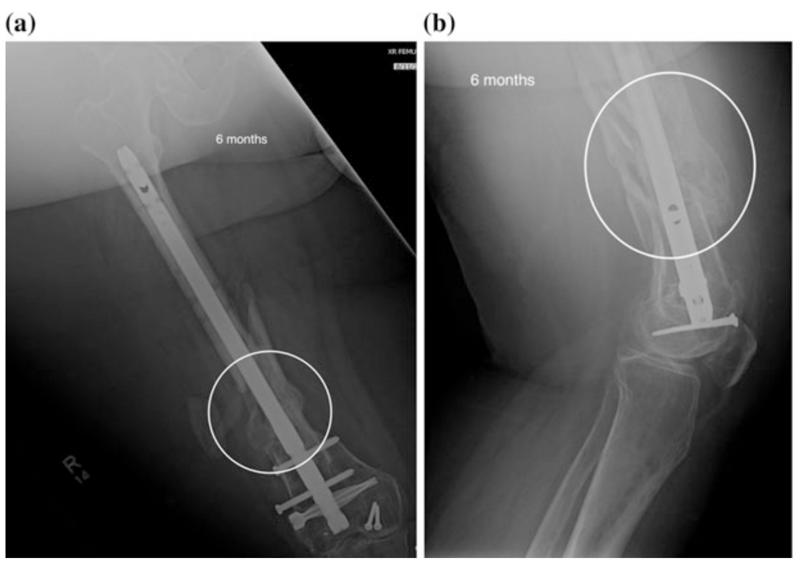

Fig. 11.24 **a** Anteroposterior and **b** lateral radiographs of the right femur at 6 months showing increased consolidation and bridging of the nonunion. Abundant bone formation is visualized within the *marked areas*

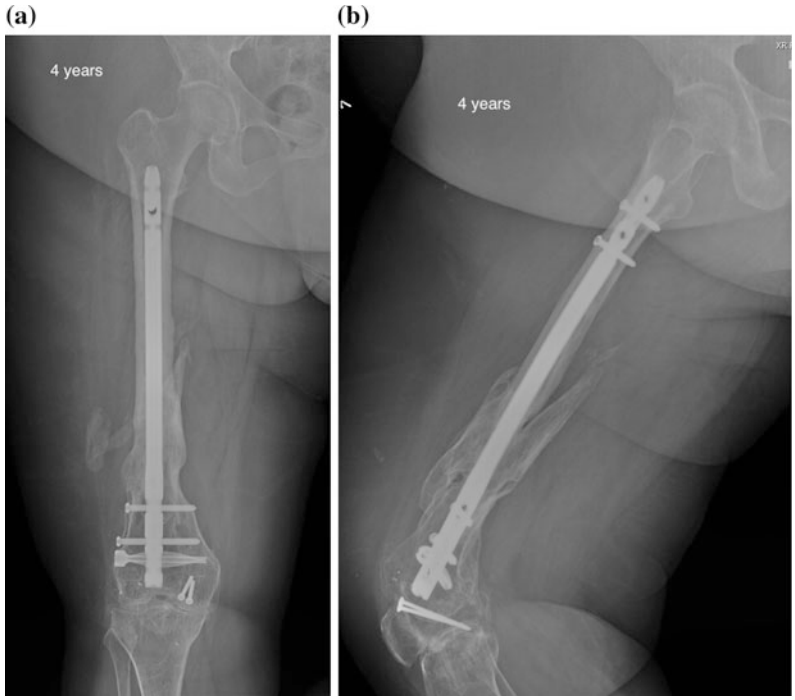

Fig. 11.25 Last follow-up **a** anteroposterior and **b** lateral radiographs of the right femur at 4 years showing resolution of the nonunion and stable hardware. There has been further consolidation across the nonunion site

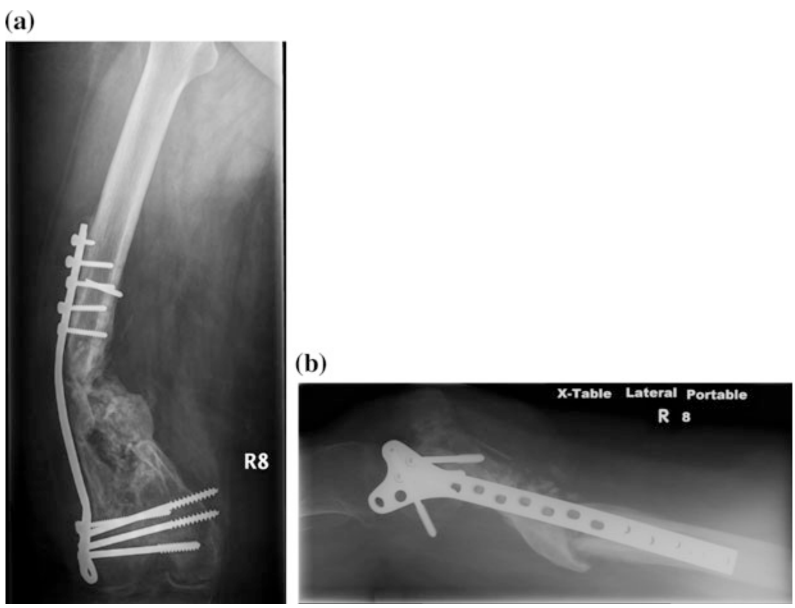

Fig. 11.26 **a** Anteroposterior and **b** lateral radiographs of the right femur showing failed hardware with significant varus deformity, hardware failure and nonunion

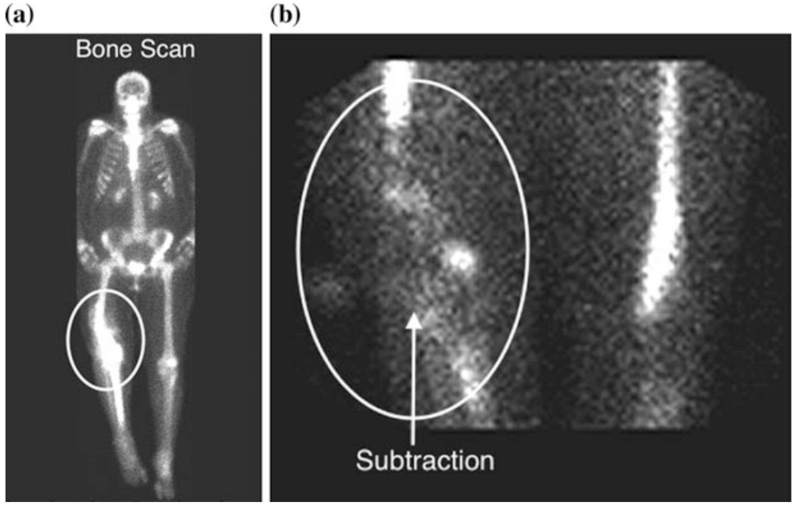

Fig. 11.27 Nuclear medicine studies: **a** bone scan showing increased uptake in the entire distal half of the right femur (*circled*); **b** subtraction image of sulfur colloid from indium showing areas with increased activity indicating discordant uptake and suggestive of infection

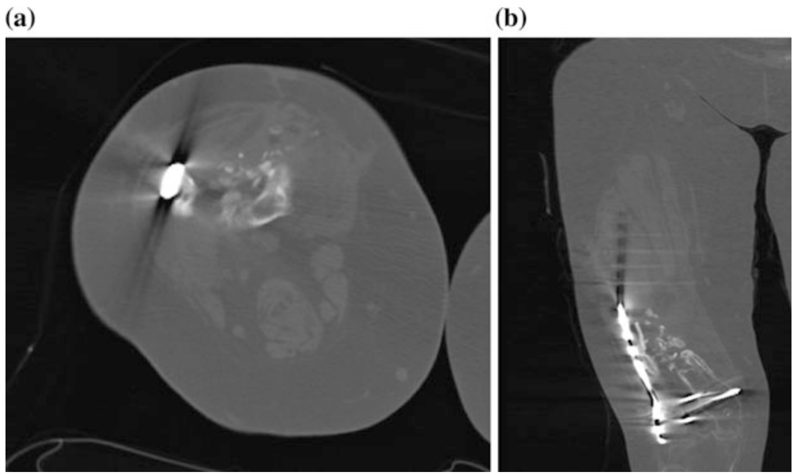

Fig. 11.28 Computed tomography scan images showing the lack of bridging bone and obvious nonunion; **a** axial image; **b** coronal image

sulfate impregnated with vancomycin and supplemented by DBM, placed into this large defect (Fig. 11.33)

The patient was followed and went on to heal all her other fractures, which included a left tibial plafond fracture and right patella fracture. Her femur continued to progress, and the calcium sulfate slowly resorbed with some consolidation. At seven months, she was ambulating with a cane but with some discomfort (Fig. 11.34). Due to concern over incomplete healing, a CT scan was obtained (Fig. 11.35). It revealed a large anteromedial defect with healing of the lateral cortex only. The posterior cortex appeared to

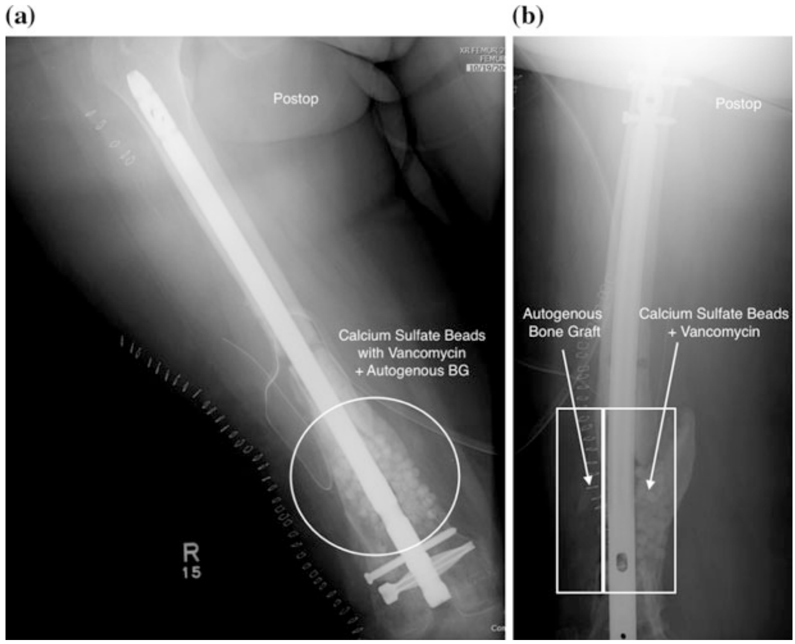

Fig. 11.29 Immediate postoperative **a** anteroposterior and **b** lateral right femur images showing correction of the deformity as well as stabilization of the nonunion with a retrograde nail. **a** The nonunion site is packed with the calcium sulfate beads with vancomycin (off-label use) and the bone graft; **b** the layering of the bone graft on top of the calcium sulfate is better delineated

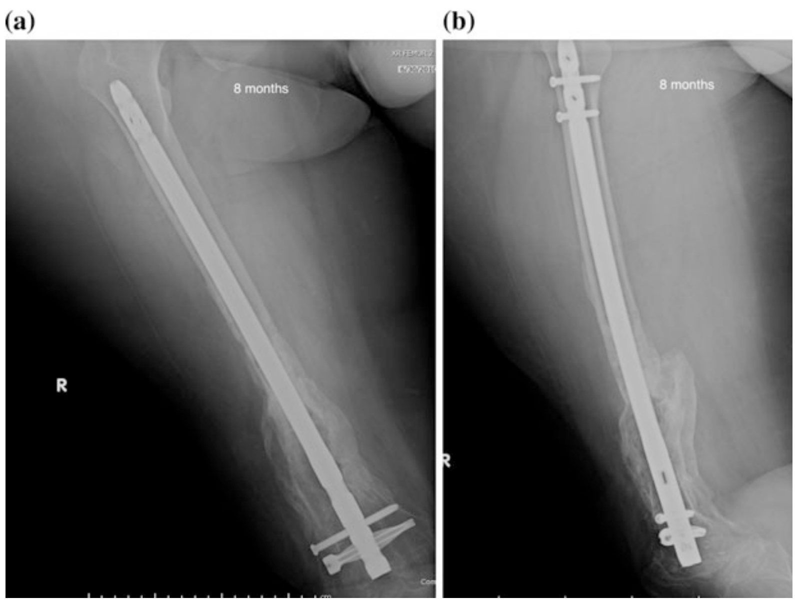

Fig. 11.30 **a** Anteroposterior and **b** lateral radiographs of the right femur at 8 months showing complete bridging of all 4 cortices and stable hardware

Fig. 11.31 Three-year follow-up **a** anteroposterior and **b** and lateral radiographs of the right femur showing continued stable hardware and further consolidation of the nonunion site

have some bridging. The intra-articular component had healed completely. It was felt to be a meta-diaphyseal nonunion.

The patient never had any problems postoperatively in terms of infection and never showed any signs of infection. All of her laboratory studies were within normal limits. She did have limited ROM to only 90° of flexion. Repair of the nonunion was discussed and she underwent surgery. Multiple options were discussed with the patient to include just autogenous bone grafting. She did not want harvesting of bone from any other site. It was decided to remove the plate and screws and

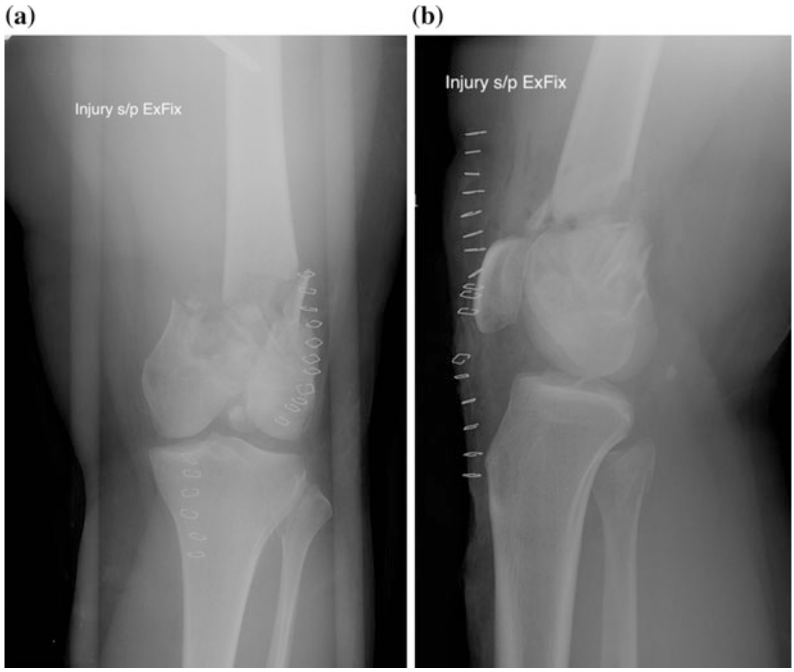

Fig. 11.32 Initial **a** anteroposterior and **b** lateral radiographs of the left knee after irrigation and debridement and bridging external fixation

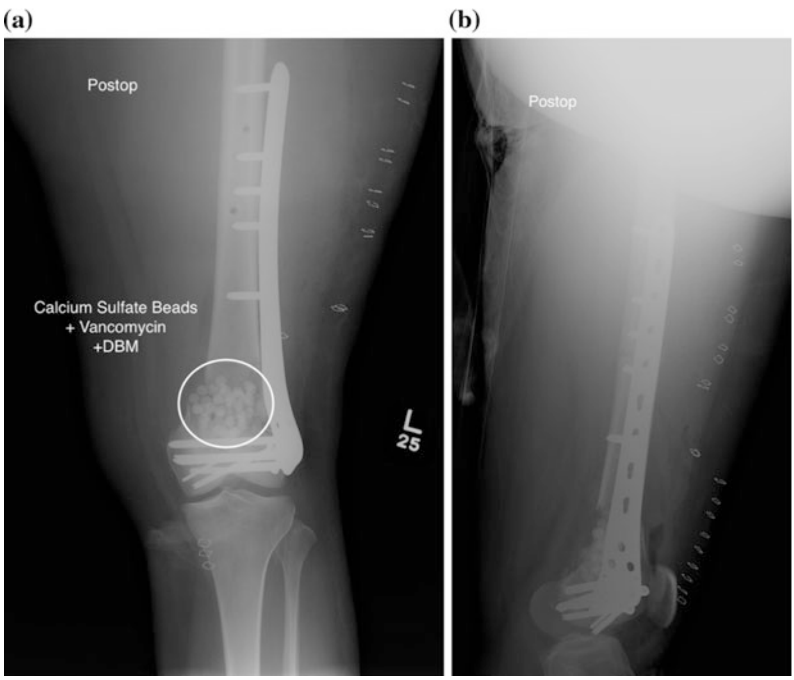

Fig. 11.33 Immediate postoperative **a** anteroposterior and **b** lateral images of the left femur after open reduction internal fixation and placement of calcium sulfate bead with vancomycin (off-label use) and demineralized bone matrix (DBM). A stainless steel locking condylar plate (LCP)—less invasive stabilization system (LISS) plate was used

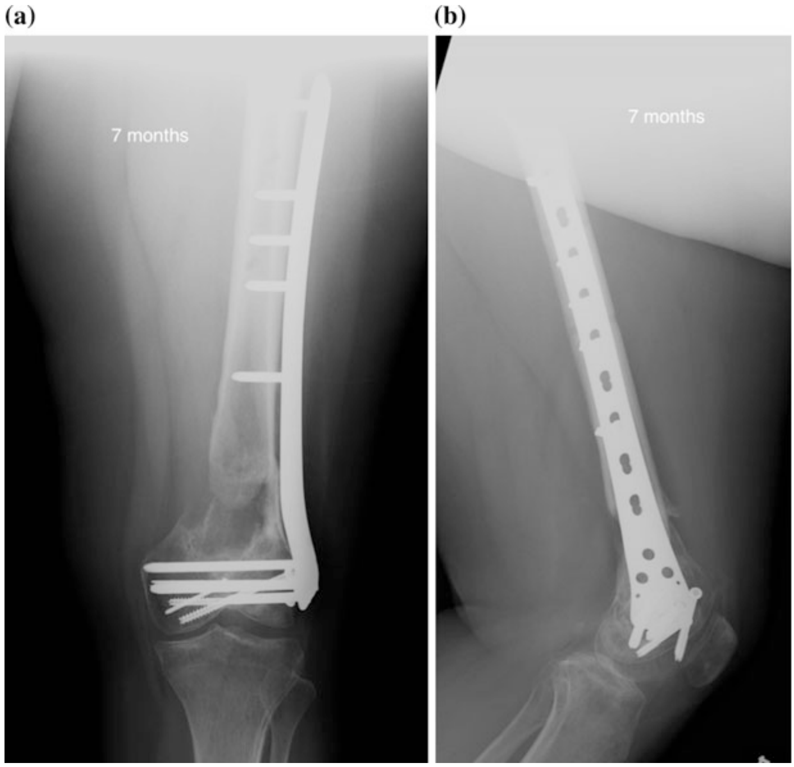

Fig. 11.34 At 7 months, **a** anteroposterior and **b** lateral radiographs of the left femur show complete absorption of the calcium sulfate and bridging laterally. The hardware is stable

place a retrograde nail during which the RIA system would be used to obtain bone graft, which could then be placed into the defect (Fig. 11.36). An open lysis of adhesions was performed while the hardware was removed. After the nail and bone graft was placed, the knee was manipulated and full flexion was obtained. The patient went on to heal by 4.5 months (Fig. 11.37). At her last follow-up (13 months out from her nonunion repair), she had full ROM and was ambulating without assistive devices (Fig. 11.38).

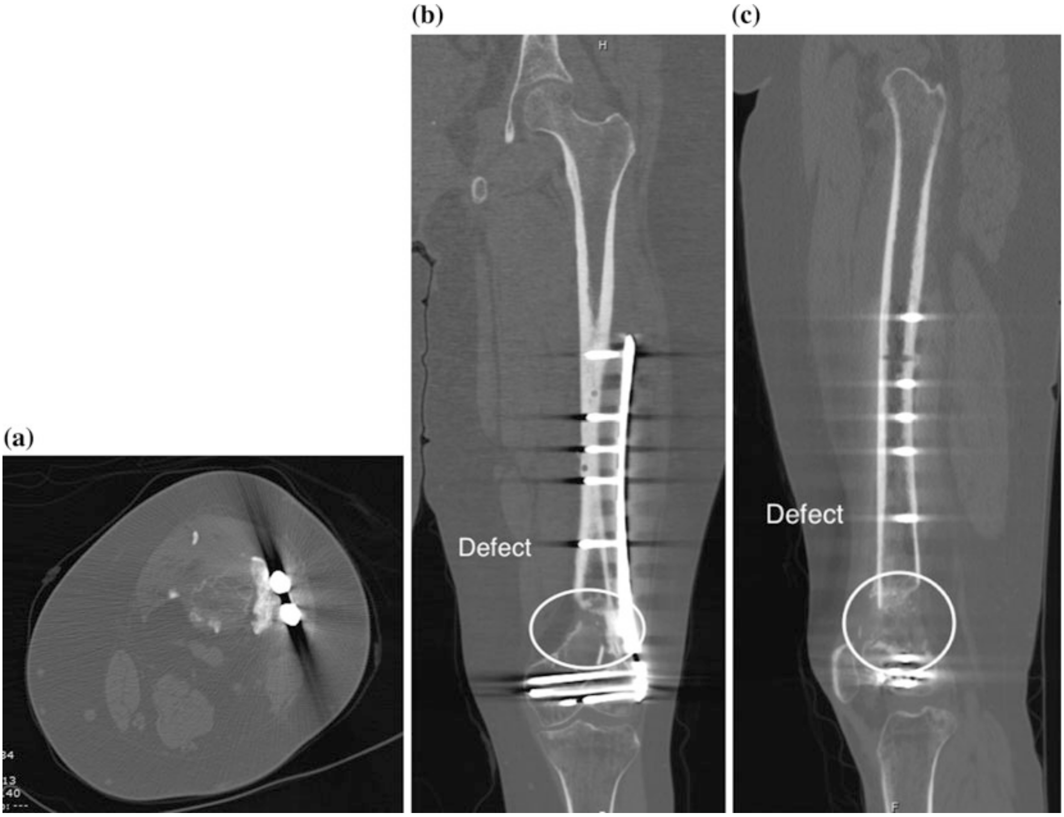

Fig. 11.35 Computed tomography scan images: **a** axial image shows the lateral bridging but the central nonunion; **b** coronal image shows the defect centrally but the healed lateral cortex; **c** sagittal image shows the lack of bridging bone anterior or posterior with central defect

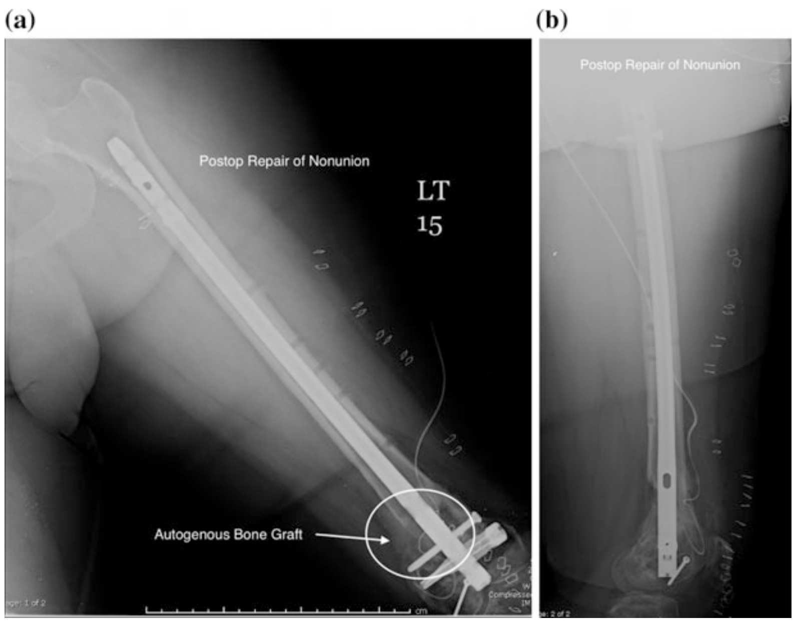

Fig. 11.36 Immediate postoperative **a** anteroposterior and **b** lateral images of the left femur after removal of hardware and placement of a retrograde intramedullary nail with the bone graft

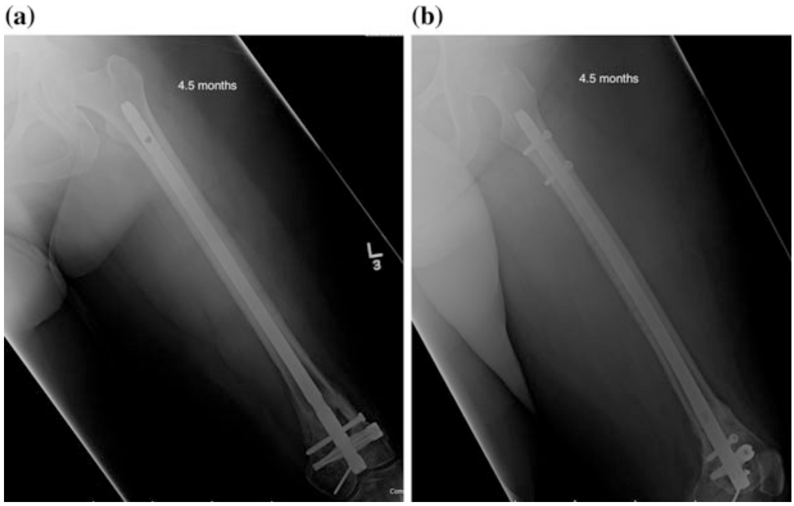

Fig. 11.37 At 4.5 months, the **a** anteroposterior and **b** lateral images of the left femur showed complete bridging of the nonunion site. It was felt that the patient was healed

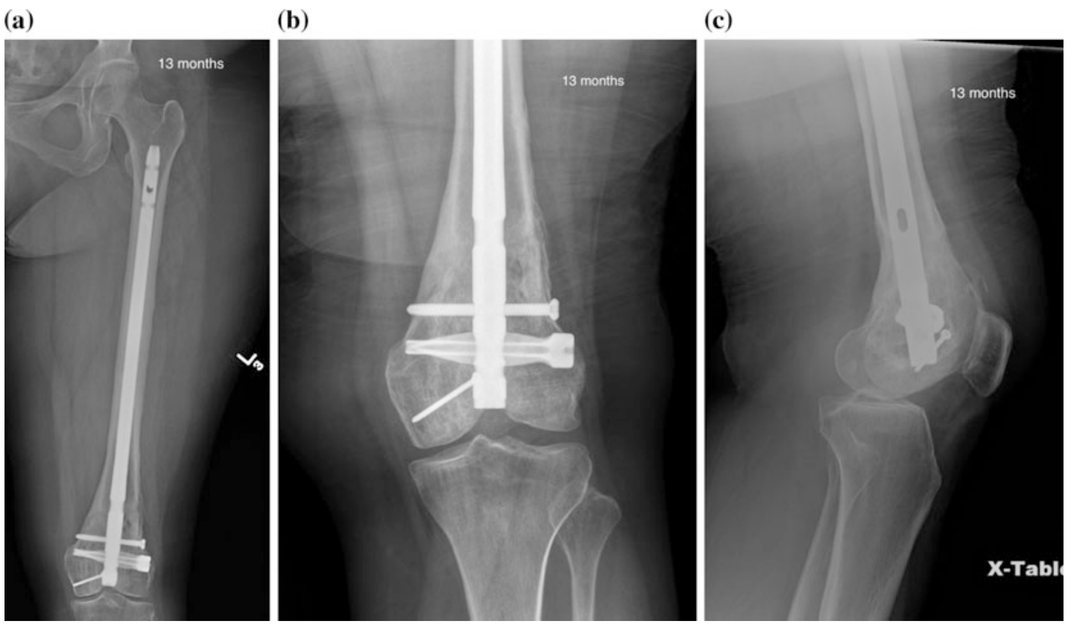

Fig. 11.38 At 13 months, **a** anteroposterior of the left femur and close-up; **b**, **c** anteroposterior and lateral images of the left knee showed solid consolidation of the nonunion site

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