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TRAUMA SURGERY

A surgical algorithm for the management of recalcitrant distal femur nonunions based on distal femoral bone stock, fracture alignment, medial void, and stability of fixation

Raja Bhaskara Rajasekaran[1] · Dheenadhayalan Jayaramaraju[1] · Dhanasekara Raja Palanisami[1] · Devendra Agraharam[1] · Ramesh Perumal[1] · Arun Kamal[1] · Shanmuganathan Rajasekaran[1]

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Abstract

Background Recalcitrant distal femur nonunions (RDFN) are a challenge in management due to factors including poor bone stock, multiple surgeries, metaphyseal bone loss, and joint contractures. There are no specific guidelines in the management of cases of RDFN. Based on our experience, we devised an algorithm and we present the results of 62 cases of RDFN managed following it.

Materials and methods Our algorithm was formulated after analyzing 34 cases of RDFN and it involved four factors which were hypothesized to influence outcomes namely: distal femoral bone stock, extent of medial void, alignment of the fracture, and stability of fixation. Each factor was addressed specifically to achieve a good outcome. Between 2012 and 2015, 62 patients with RDFN at a mean age of 47.4 years (26–73) and 2.3 prior surgeries (2–6) were managed following the algorithm.

Intervention 58 patients required revision osteosynthesis to improve alignment and achieve a stable fixation. 4 elderly patients with poor bone stock were managed with arthroplasty. Extent of medial void was found to significantly influence surgical decision making. Five patients without medial void required only cancellous autograft bone grafting, 47 patients with < 2 cm void were treated with an allograft fibular strut inserted in the metaphysis and 6 patients with a void > 2 cm were managed with medial plating.

Outcomes and results 57 patients treated with osteosynthesis achieved union at an average of 7.4 months (6–11) and the 4 patients managed with arthroplasty also had a favourable outcome. One patient who was managed with revision osteosynthesis had a nonunion with an implant failure and needed an arthroplasty procedure. The average LEFS (lower extremity functional score) of all our patients was 67 (51–76) at an average follow-up of 18.2 months (12–33).

Conclusion Our stepwise surgical algorithm would help surgeons to identify the factors that need to be addressed and guide them towards the interventions that are necessary to achieve a successful outcome while managing cases of RDFN.

Level of evidence III.

Level of clinical care Level I Tertiary trauma centre.

Keywords Recalcitrant · Distal femur nonunions · Medial void · Bone stock · Alignment

Introduction

Distal femur fractures account for only 4–6% of all femoral fractures, but have a nonunion rate of up to 20% after surgical intervention [1–4]. Factors leading to nonunion include metaphyseal comminution, poor bone quality, and inadequate fixation [1–3]. If these factors are not properly addressed during revision surgery, there is a higher chance of failure leading to a recalcitrant distal femur nonunion (RDFN) with problems of inadequate bone stock, metaphyseal void, joint contractures, and deformities [3–6]. Although this is a major

✉ Raja Bhaskara Rajasekaran
rajalibra299@gmail.com

[1] Department of Orthopaedics and Trauma, Ganga Medical Centre and Hospitals Pvt. Ltd, 313, Mettupalayam Road, Coimbatore, India

surgical challenge, there is paucity of literature regarding the management of RDFN. We hypothesized that the use of a consistent algorithm to address distal femoral bone stock, medial void of the fracture, fracture alignment, and implant stability would result in successful outcomes.

Materials and methods

Our institution being a tertiary level 1 trauma centre managing about 12,000 trauma surgeries annually gave us the opportunity to come across cases of RDFN on a regular basis. Thirty-four cases of RDFN were retrospectively analyzed by the two lead authors (DJ and RBR) and they hypothesized that four factors namely adequacy of distal femoral bone stock, extent of the medial void, alignment of the fracture, and stability of the fixation had a profound influence over the outcomes. Based on these factors, we formulated an algorithm (Fig. 1) and we managed the following 62 cases of RDFN using the algorithm. Cases which had at least two failed surgical attempts were defined as RDFN. Our study was approved by the Institution Review Board (IRB).

Our algorithm

Our algorithm took into account four important factors necessary to achieve a successful outcome: adequacy of distal femoral bone stock, extent of the medial void, alignment of the fracture, and stability of the fixation.

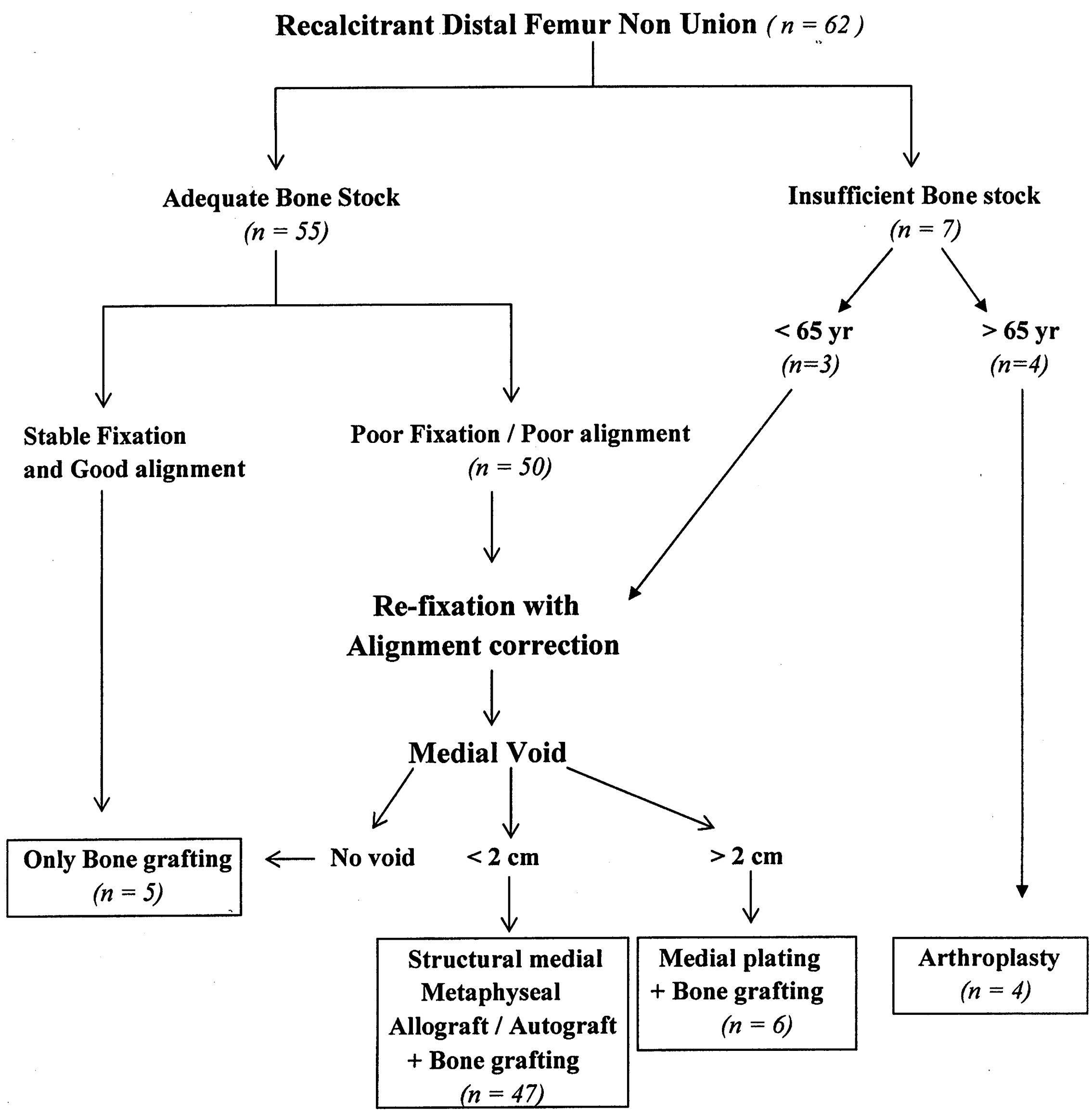

Fig. 1 Our algorithm to manage cases of resistant distal femur nonunions (RDFN). We managed 62 cases of RDFN following this algorithm

The radiographs at presentation of all patients of RDFN were observed and analyzed for the four factors, and they were assessed as follows.

Distal femoral bone stock

Distal femoral bone stock was assessed for the ability to obtain a stable fixation in the distal segment. This was done by drawing a line connecting the articular surfaces of both the condyles and drawing a perpendicular from the intercondylar notch 3 cm into the metaphysis proximally on the AP radiograph and a line from the centre of the condyles up to 3 cm into the metaphysis on the lateral radiograph (Fig. 2a, b). The adequacy of bone within this area to provide stable distal fixation was assessed. In those cases where there was a suspicion for poor stock, it was termed as inadequate.

Extent of medial void

The medial void of the distal femur was defined after correction of alignment as the fracture length between the distal medial cortex of the intact proximal segment and the proximal medial cortex of the intact distal segment. An intra-operative measurement of the gap in the medial cortices was done in centimeters after correction of the alignment of the fracture to determine the medial void (Fig. 2c, d). It is important that the assessment is performed intra-operatively after correction of the alignment.

Alignment of the fracture

The mLDFA (mechanical lateral distal femoral angle) [7] was used to measure the alignment of the fracture on a true AP radiograph of the whole length of the femur. Angle between the mechanical axis of the femur and the line joining both the articular surfaces of the condyles was measured (Fig. 2e). An angle of 87° ± 2° was considered as an acceptable fracture alignment. An increase in the angle was considered as varus and a decrease in the angle was considered as valgus.

Stability of the fixation

A titanium locking compression plate (AO Synthes) on the lateral side with an adequate working length (three times the fracture during comminution and eight times the fracture during a transverse fracture) [8, 9] and adequate screws on the proximal part and distal part of the fracture was considered a stable fixation. Any evidence of screw breakage, screw loosening, and implant breakage or cut-out was considered poor fixation requiring revision.

In the algorithm which we had formulated, patients were analyzed first for adequacy of distal femoral bone stock available for fixation as achieving a stable fixation is crucial for success during revision surgery. Patients above 65 years with insufficient bone stock had a high chance of another failure, and hence, they were managed with total joint arthroplasty. In patients less than 65 years with insufficient bone stock, another attempt of refixation was given with allograft struts to fill the defect combined with osteosynthesis. When the distal bone stock was adequate, further plan depended on the quality of fixation and alignment. Stable fixation and acceptable alignment required only cancellous autograft bone grafting. From our experience, we noted that vast majority of patients of RDFN presented with failed fixation leading to poor alignment. Here, revision fixation with correction of alignment is critical. Following alignment correction and revision fixation, the extent of medial void was addressed using metaphyseal struts in defects less than 2 cm and by adding a medial plate in defects greater than 2 cm.

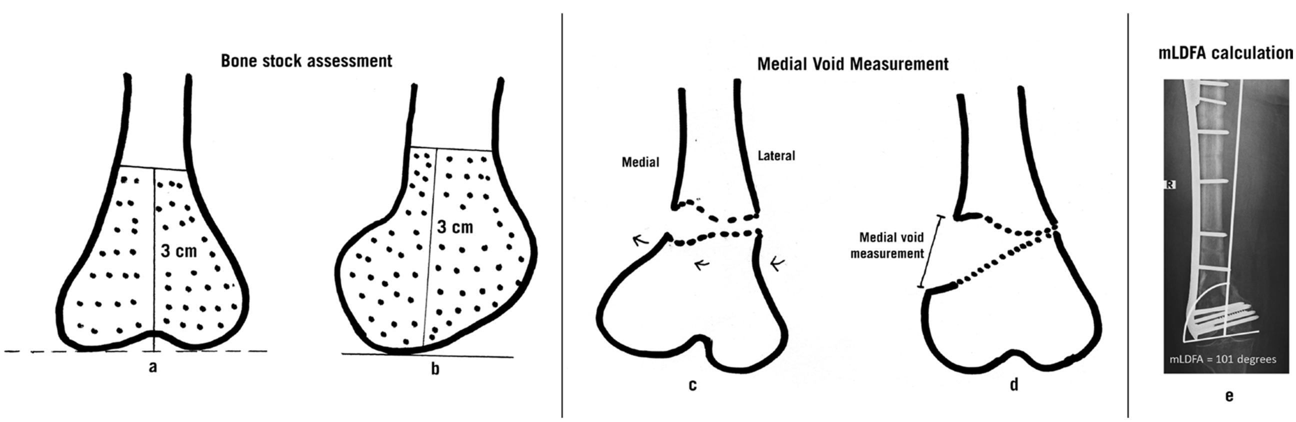

Fig. 2 The dotted area in **a** and **b** showing the region of the distal femur which needs to be assessed for bone stock. Varus collapse in distal femur nonunion (**c**). Medial void seen after restitution of the normal alignment during revision surgery and measurement of the medial cortical discontinuity (**d**) as shown. Measurement of mLDFA on AP radiographs to assess the alignment (**e**)

Poor fixation and poor alignment are related to each other, and in all cases requiring alignment correction, revision fixation was also done and vice versa.

Based on these factors and our algorithm, four different surgeries were performed: only cancellous autograft bone grafting, revision osteosynthesis with medial metaphyseal fibular allograft strut and cancellous autograft, revision osteosynthesis with medial plating, and cancellous autograft or arthroplasty. Iliac crest bone autografts were used in all surgeries except arthroplasty.

Between January 2012 and December 2015, we managed 62 cases of RDFN following our algorithm. Only patients who had at least two previous unsuccessful surgical attempts were defined as RDFN and were included. Patients in our study had an average 2.3 number of surgeries (2–6) previously. Our study group included patients in whom infection was ruled out by clinical examination and blood tests. Cases with evidence of infection were not included in the study. 38 patients in our study were males and 24 patients were females. The average age of our patients was 43.4 years (26–73). Eighteen patients had a history of smoking and 12 patients in our study group were diabetics who were taken up for surgery after appropriate control of sugar levels. 57 patients had primary treatment elsewhere and 5 were follow-up cases from our institution.

Following our algorithm, of the 62 patients, 58 patients were managed with osteosynthesis surgery and 4 patients who were above 65 years with insufficient bone stock were managed with arthroplasty. In addition to revision osteosynthesis, 5 patients received cancellous autograft bone grafting, 47 received a metaphyseal structural allograft strut and cancellous autograft, and 6 received a medial plate and cancellous autograft. Out of the 58 patients managed with revision fixation, 3 patients had insufficient bone stock, but were below the age of 65 years. In these patients, the problem was solved using two fibular allografts combined with careful screw placement.

Following surgery, nonweight-bearing mobilization of the operated limb with walker assistance was given to all patients for 6 weeks followed by partial weight-bearing walking (50%) for the following 6 weeks. Full weight-bearing walking was initiated 3 months following surgery after evidence of callus formation on the radiographs. Knee range of movement was initiated using CPM (continuous passive motion) device immediately following surgery. Knee range of motion was calculated during each visit and all patients were followed up with regular radiographs at 6 weeks, 12 weeks, and 24 weeks from surgery to check for bony union. LEFS score [10] was calculated after evidence of bony union to assess the functional outcome. LEFS is a patient-based questionnaire comprising of 20 questions with a maximum score of 80 with higher scores indicating better outcomes.

Results

Of the 58 patients who were managed with osteosynthesis, 57 patients had a successful bony union at 7.4 months (6–11). We defined bony union as successful bridging bone on three cortices. The 4 patients who primarily underwent arthroplasty following the algorithm had a favourable outcome. At an average follow-up of 18.2 months (12–33), the average LEFS was 67(51–76). The average knee flexion achieved was 100° (60–120).

Complications

One of the patients—46-year-old female—managed with osteosynthesis combined with two allograft struts went on to have another nonunion with implant failure. She was managed successfully with an arthroplasty procedure. Two patients had delayed union at 10 months and 11 months, respectively. No intervention was needed in those cases. Two patients who were diabetics had superficial infection post-operatively and both of them were managed successfully with intravenous antibiotics. One patient who had achieved bony union had removal of hardware at 15 month follow-up due to a recurrence of infection. All the results were tabulated (Table 1).

Discussion

Management of a nonunion requires adequate planning. The level of planning required is even more critical in cases of recalcitrant distal femur nonunions (RDFN) due to issues including poor bone stock, metaphyseal void, multiple surgeries, and joint contracture. Our experience at our busy trauma and limb reconstruction department where we manage nearly 300 nonunion cases annually gave us the opportunity to propose an algorithm and also apply it to 62 RDFNs in a period of 3 years.

Many studies [4–6, 11, 12] have identified (i) metaphyseal bone defect, (ii) inability to obtain adequate bony fixation, and (iii) failure to augment bone grafts to address metaphyseal comminution as important predisposing factors to nonunion of the distal femur after fixation. When there is an inadequate fixation, there is a loss of alignment, frequently an internal rotation deformity, bone loss from toggling implants, and during revision surgery, this contributes to inadequate bone stock and difficulty in obtaining a stable revision fixation which was also emphasized by Schatzker [3].

Stability of fixation is vital for union and this is aided by good quality bone stock. The need to assess the distal

Table 1 Data of all patients in our series

Patients. no.	Bone stock	Age in years	No: of prior surgeries	Implant at presentation	m LDFA	Surgery done	Time to union (months)	Complications	Knee ROM (in degree)	LEFS
1	Adequate	28	2	Distal femur LCP	88	Bone grafting	6	Nil	125	72
2	Adequate	41	3	Fixed angle DCS	86	Bone grafting	6	Nil	100	76
3	Adequate	56	3	Distal femur nail	93	Alignment correction + refixation + allograft strut	7	Nil	110	70
4	Not adequate	23	3	Distal femur LCP	102	Alignment correction + refixation + allograft struts	8	Nil	90	70
5	Not adequate	29	2	Distal femur LCP	102	Alignment correction + refixation + allograft struts	8	Nil	85	69
6	Adequate	52	3	Distal femur Nail	93	Alignment correction + refixation + allograft strut	7	Nil	110	71
7	Adequate	48	2	Distal femur LCP	96	Alignment correction + refixation + allograft strut	8	Nil	105	70
8	Adequate	62	3	Distal femur nail	100	Alignment correction + refixation + allograft strut	6	Nil	110	68
9	Adequate	49	2	Distal Femur Nail	93	Alignment correction + refixation + allograft strut	7	Nil	85	60
10	Adequate	56	2	Distal femur LCP	102	Alignment correction + refixation + allograft strut	7	Superficial infection	95	62
11	Adequate	49	2	Distal femur nail	93	Alignment correction + refixation + allograft strut	7	Nil	110	70
12	Adequate	45	2	Distal femur LCP	88	Bone Grafting	6	Nil	120	71
13	Adequate	52	2	Distal femur LCP	87	Bone grafting	7	Nil	110	75
14	Adequate	62	3	Distal femur Nail	100	Alignment correction + refixation + allograft strut	6	Nil	110	68
15	Adequate	52	2	Distal femur LCP	101	Alignment correction + refixation + allograft strut	7	Nil	105	71
16	Adequate	52	3	Fixed angle DCS	97	Alignment correction + refixation + allograft strut	6	Nil	105	72
17	Adequate	59	2	Distal femur nail	106	Alignment correction + refixation + allograft strut	7	Nil	120	68
18	Not adequate	73	6	Distal femoral Nail	94	TKR	–	Nil	100	72
19	Adequate	50	3	Distal femur LCP	98	Alignment correction + refixation + allograft strut	7	Nil	100	69
20	Adequate	53	2	Distal femur LCP	98	Medial plating	7	Nil	105	59
21	Adequate	46	2	Fixed angle DCS	96	Medial plating	6	Nil	110	68
22	Adequate	32	3	Fixed angle DCS	97	Alignment correction + refixation + allograft strut	6	Nil	105	72

Table 1 (continued)

Patients. no.	Bone stock	Age in years	No: of prior surgeries	Implant at presentation	m LDFA	Surgery done	Time to union (months)	Complications	Knee ROM (in degree)	LEFS
23	Adequate	57	2	Distal femur LCP	102	Alignment correction + refixation + allograft strut	7	Nil	110	68
24	Not adequate	72	3	Fixed angle blade plate	99	TKR	–	Nil	110	70
25	Not adequate	46	2	Distal femur LCP	101	Alignment correction + refixation + allograft strut	–	Nonunion with implant failure – Arthroplasty with Megaprosthesis done	50	54
26	Adequate	52	2	Fixed angle DCS	96	Alignment correction + refixation + allograft strut	7	Nil	105	70
27	Adequate	43	2	Distal femur LCP	87	Bone grafting	8	Nil	110	76
28	Adequate	33	2	Distal femur LCP	101	Alignment correction + refixation + allograft strut	7	Nil	105	71
29	Adequate	51	3	Fixed angle DCS	97	Alignment correction + refixation + allograft strut	6	Nil	110	62
30	Adequate	37	2	Distal femur LCP	102	Alignment correction + refixation + allograft strut	8	Nil	105	71
31	Adequate	42	3	Distal femur LCP	98	Alignment correction + Refixation + Allograft strut	8	Nil	100	69
32	Adequate	35	2	Distal femur LCP	103	Alignment correction + refixation + allograft strut	7	Nil	110	71
33	Adequate	52	3	Fixed angle DCS	95	Alignment correction + refixation + allograft strut	6	Nil	120	68
34	Adequate	33	2	Distal femur LCP	99	Alignment correction + refixation + allograft strut	6	Superficial infection	90	67
35	Adequate	37	2	Distal femur LCP	116	Alignment correction + Refixation + Allograft strut	8	Nil	95	70
36	Adequate	28	2	Distal femur LCP	98	Alignment correction + refixation + allograft strut	6	Nil	110	72
37	Adequate	35	3	Distal femur LCP	102	Alignment correction + refixation + allograft strut	6	Nil	110	64
39	Adequate	31	2	Distal femur LCP	98	Alignment correction + refixation + allograft strut	6	Nil	110	72
40	Adequate	53	3	Distal femur nail	98	Alignment correction + refixation + allograft strut	6	Nil	110	72
41	Adequate	57	2	Fixed angle blade plate	98	Alignment correction + refixation + allograft strut	6	Nil	75	63
42	Adequate	42	2	Distal femur LCP	93	Alignment correction + refixation + allograft strut	8	Nil	105	73

Table 1 (continued)

Patients. no.	Bone stock	Age in years	No: of prior surgeries	Implant at presentation	m LDFA	Surgery done	Time to union (months)	Complications	Knee ROM (in degree)	LEFS
43	Adequate	54	3	Distal femur LCP	92	Alignment correction + refixation + allograft strut	9	Nil	120	71
44	Adequate	46	2	Fixed angle blade plate	99	Alignment correction + refixation + allograft strut	6	Nil	90	59
45	Not adequate	69	3	Distal femoral LCP	94	TKR	–	Nil	110	68
46	Adequate	29	2	Distal femur LCP	105	Alignment correction + refixation + allograft strut	11	Nil	105	72
47	Adequate	25	3	Fixed angle DCS	96	Alignment correction + refixation + allograft strut	7	Nil	120	75
48	Adequate	53	2	Distal femur LCP	98	Medial plating	7	Nil	105	70
49	Adequate	47	2	Fixed angle DCS	95	Medial plating	7	Nil	110	71
50	Adequate	35	2	Distal femur LCP	83	Alignment correction + refixation + allograft strut	7	Nil	105	71
51	Adequate	47	3	Distal femur nail	108	Alignment correction + refixation + allograft strut	8	Implant removal at 15 months post op due to infection	80	67
52	Adequate	40	2	Fixed angle blade plate	96	Alignment correction + refixation + allograft struts	7	Nil	95	70
53	Adequate	39	2	Distal femur LCP	105	Alignment correction + refixation + allograft strut	6	Nil	115	72
54	Adequate	35	3	Distal femur LCP	118	Alignment correction + Refixation + Allograft strut	10	Nil	120	75
55	Adequate	41	3	Fixed angle DCS	96	Medial plating	6	Nil	110	68
56	Adequate	29	2	Distal femur LCP	105	Alignment correction + refixation + allograft strut	7	Nil	85	59
57	Adequate	45	3	Distal femur LCP	101	Alignment correction + refixation + allograft strut	6	Nil	60	51
58	Not adequate	76	3	Distal femur LCP	92	TKR	–	Nil	100	66
59	Adequate	35	2	Distal femur LCP	118	Alignment correction + refixation + allograft strut	8	Nil	105	72
60	Adequate	36	3	Distal femur Nail	92	Alignment correction + refixation + allograft strut	7	Nil	90	53
61	Adequate	49	2	Distal femur LCP	90	Medial plating	7	Nil	110	70
62	Adequate	45	2	Distal femur LCP	104	Alignment correction + refixation + allograft strut	8	Nil	100	69

femoral bone stock is vital and needs experience in assessment. Although CT scans may be useful, there is often image scatter impairing assessment of remaining bone stock. This assessment has to be made on experience and were termed as inadequate bone stock when the senior surgeon felt it be less than 50%. In all our cases, the assessments of bone stock were made by trauma surgeons who had more than 10 years of experience. In our series, 7 patients had inadequate bone stock. In 4 of them who were above the age of 65 years, arthroplasty surgery was done (Fig. 5c, d). In this group, total knee replacement was the best decision to overcome multiple problems of poor bone stock, osteoporosis, and also to mobilize elderly patients as soon as possible. In the 3 patients with inadequate bone stock who were less than 65 years, a revision fixation was planned. Apart from careful positioning of screws to accommodate the bone stock available, we used two fibula strut grafts in the metaphysis to supplement the bone stock, get better screw purchase, and also give stability (Fig. 3c). Of the 3 cases managed by pegging two allografts in the metaphysis, one case went on to have a nonunion and an implant failure (Fig. 6a–e). The radiograph was assessed to have inadequate bone stock, and since she was only 46 years old, osteosynthesis was done with two allograft struts filling the metaphysis combined with autografts. However, she showed no signs of union on regular follow-ups and she presented with implant failure at 5 months. Though she went on to have a favourable outcome following arthroplasty (Fig. 6g, h), we feel that, in younger patients with inadequate bone stock, a trial of osteosynthesis combined with twin allografts to supplement the bone stock can be given. In younger patients, achieving fracture union must be aimed at whenever possible. However, if it fails, arthroplasty with modularity based on the requirement is the only option.

The distal femur fixation has a tendency to fail in varus, especially in cases of comminution [11]. During revision surgery, after restitution of the normal alignment of the fragments, there is a void medially due to the opening up of the fracture. It is biomechanically crucial to restore medial continuity to avoid failure as emphasized by Sanders and Krettek [13, 14]. Various studies [13–24] have shown different methods like only addition of autografts, allograft strut addition, medial plating, or nail pate combination construct, but there is no particular guideline about how to manage these defects. In 5 cases where there was no void during surgery, only de-cortication of the parent bone and iliac crest bone grafting was done which yielded favourable results. We managed defects less than 2 cm by pegging an allograft strut taken from our tissue bank augmenting the metaphyseal column combined with a lateral locking plate fixation and autografts through the same lateral approach (Fig. 3a, b, 4c–f). The use of allograft struts during revision surgery of nonunions of the distal femur has been reported before. Wang in his series of 13 cases [17] showed successful union employing allograft struts and also in our series [19] reported before, and we have shown successful results pegging allografts as they give a good structural stability while addressing distal femur nonunions. Defects greater than 2 cm required a medial plate combined with autografts as an allograft or autograft strut would not be able to mechanically bridge such a large defect alone (Fig. 5a, b). Of the 53 cases with a medial void, 47 cases with defects less than 2 cm were managed with metaphyseal allograft strut support and the 6 cases

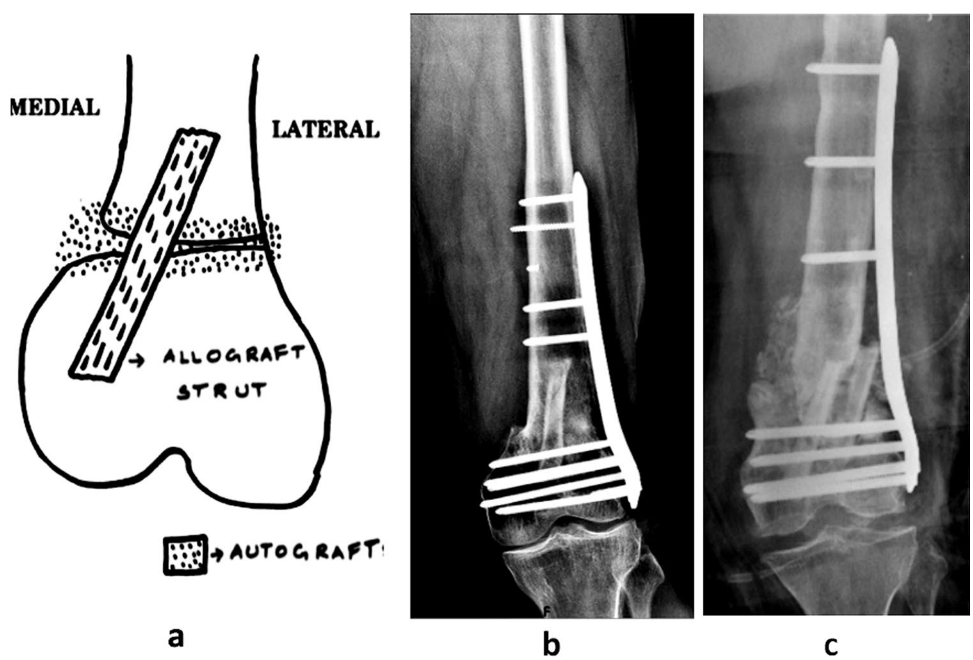

Fig. 3 Preoperative planning of insertion of an allograft strut in the metaphysis in cases of medial void less than 2 cm (**a**). Case managed with allograft strut showing union (**b**). In young individuals with inadequate bone stock, placing of twin allografts in the metaphysis to fill the defect and completing the fixation (**c**)

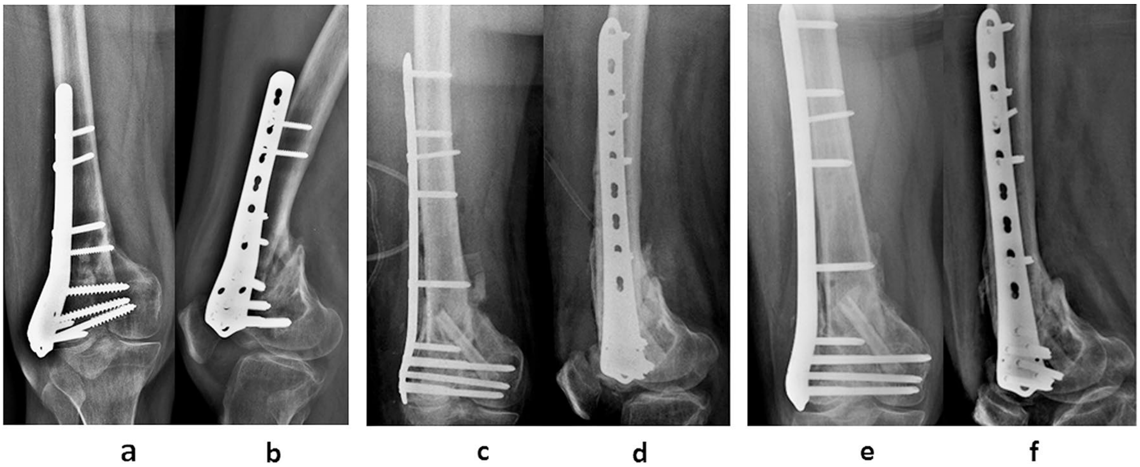

Fig. 4 Illustrative case of a recalcitrant distal femur nonunion with three unsuccessful surgical attempts previously showing nonunion with inadequate fixation in AP (**a**) and lateral (**b**) radiographs. Post-operative radiograph of the case which was managed with alignment correction, allograft strut insertion and refixation with LCP (**c**) and (**d**). Radiographs **e** and **f** showing union at 6 months

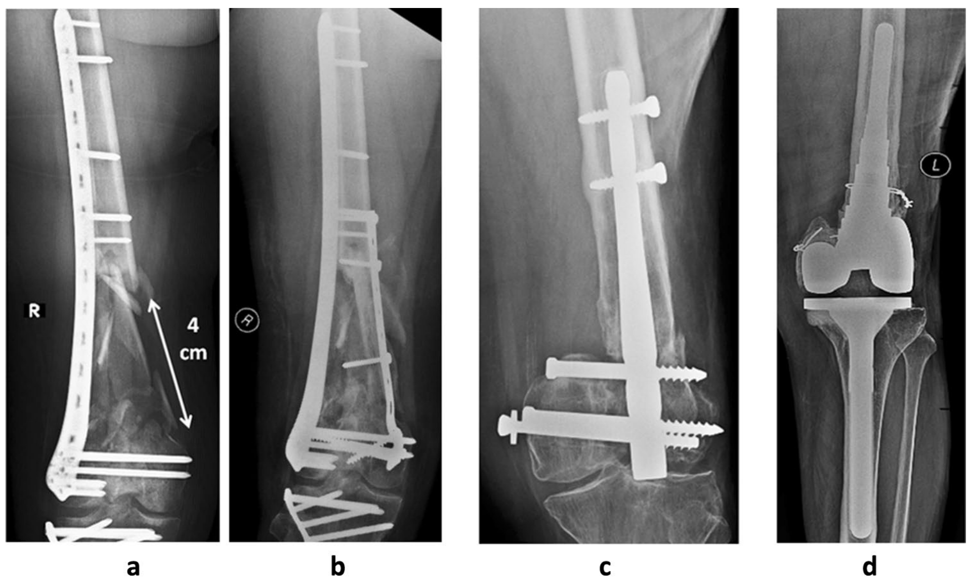

Fig. 5 Illustrative case of a recalcitrant distal femur nonunion with a medial void of 4 cm (**a**) managed successfully with refixation with an addition of a medial plate (**b**). A 73-year-old female with inadequate bone stock and six unsuccessful surgeries previously (**c**) managed successfully with total knee arthroplasty (**d**)

with defects greater than 2 cm were managed with medial plating and bone grafting. In instances of nonavailability of an allograft, we recommend the use of the fibular autograft to supplement the defect.

Proper alignment of any fracture is the key to a successful union. mLDFA gave us an accurate indication of the alignment of the fracture. $87° \pm 2°$ was used as the acceptable value for an ideal alignment. Any alignment in varus ($n = 41$) or valgus ($n = 1$) was not accepted and was subjected to revision surgery. We employed the cable method for analysis of the frontal plane deformity intra-operatively to correct the alignment [14]. By placing an electrocautery cable from the centre of the femoral head to the centre of the tibiotalar joint, we aimed at an alignment of the cable to be in the midline of the patella and completed our fixation. The cable test is a useful method in alignment assessment and correction and we employed it in all our cases.

Inadequate fixation is one of the predominant factors for failure in distal femur fractures [5, 6, 11]. Of the 50 cases identified to have inadequate fixation, 16 cases had inadequate plate length, 6 cases had improper fixation, 5 cases had screws or implant breakage, and the remaining 23 cases had a combination of all the above. All these cases were addressed with removal of the implant and revision fixation with a titanium distal femur locking plate on the lateral side after alignment correction. At least four locking screws were inserted in the distal femur and a minimum of three locking screws were inserted in the femoral shaft after obtaining adequate compression at the fracture site. This helped us achieve a stable fixation. Studies have shown the locking

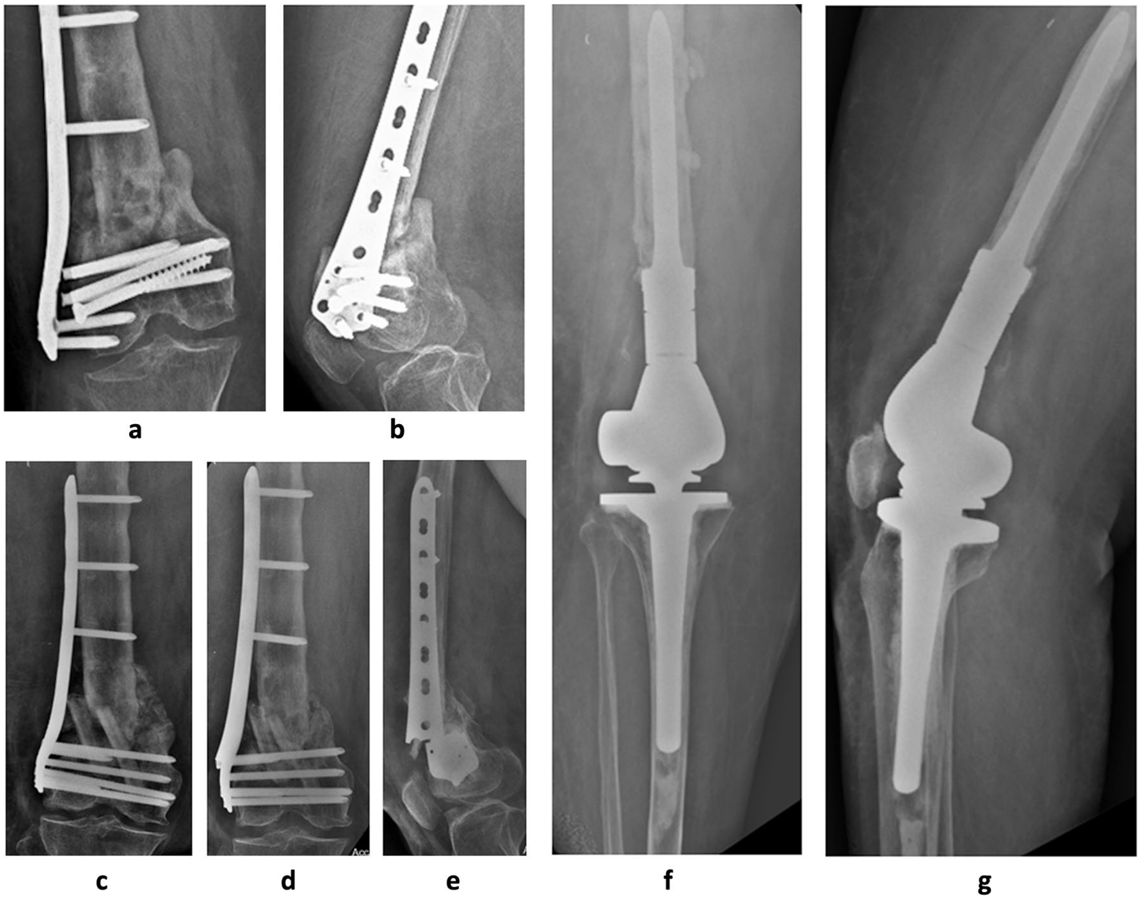

Fig. 6 Illustration of the single failed case in our series after following our algorithm. A 46-year-old female who presented to us with an implant failure following two previous attempts at fixation (**a, b**) was assessed as inadequate bone stock. She was managed by pegging twin allografts (**c**), but, however, she ended up in another RDFN (**d, e**) due to implant failure. She was managed with arthroplasty using a megaprosthesis (**f, g**)

plate to have a better stability and lower irreversible deformation than other fixation modalities [16, 21, 22]. Schatzker and Lambert showed good-to-excellent results in the distal femur; they had managed using a locking plate following AO principles [3].

In cases of RDFN, especially in old age, there are chances of another failure due to osteoporosis and poor bone stock, and in these patients, arthroplasty is a good option. Even in the single case in our series which failed following the algorithm, the patient benefitted from arthroplasty. The same fact was emphasized by Vaishya et al. [23] in their study of 10 patients where they showed arthroplasty to be a one-stage salvage option in cases of RDFN with favourable results. Recently, Kim et al. [24, 25] highlighted the effectiveness of intramedullary nailing combined with enhanced fixation to achieve favourable outcomes in infra-isthmal femoral nonunions. However, all these studies report a small series of patients and are reports of only one treatment modality. RDFNs have multiple problems and one treatment method would not be ideal as there are many factors to be addressed. This problem is overcome by our study where all the important factors are addressed specifically and various intervention options are described to the surgeon based on the need. This is the main strength of our study. Ma et al. [26] formulated a three-stage protocol involving debridement, lengthening with deformity correction, and osteosynthesis to manage RDFNs, but their study had only 10 patients and involved three different interventions. Our sample size of 62 patients is one of the largest series of RDFNs to be reported and our successful outcomes show that our algorithm is a useful tool to guide surgeons (Fig. 6).

Using our surgical algorithm, we achieved a successful outcome in all 61 patients (98.38%) and we strongly feel that it can be used in prospective application for managing challenging cases of RDFN. An illustrative case is shown in Fig. 7.

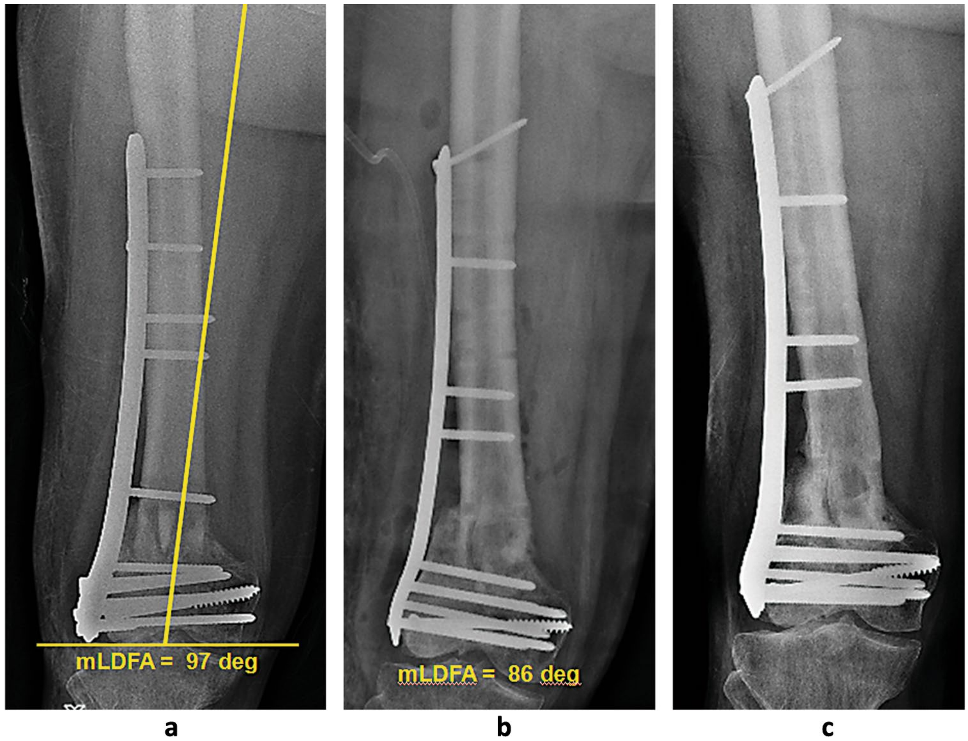

Fig. 7 Illustrative case of a RDFN with 3 prior surgeries in a 38-year male who presented with nonunion and impending implant failure with screw loosening 4 months after the third attempt at fixation. Pre-operatively, the patient had an mLDFA of 97° indicating the alignment to be an unacceptable varus (**a**). He had adequate bone stock and there was no medial void following alignment correction during revision surgery. Following our algorithm, revision fixation and alignment correction with addition of cancellous autografts (**b**) were done leading to a successful bony union at 5 months (**c**)

Limitations

Our study is not without limitations. The main limitation of our study was of it being retrospective in nature. Another limitation of our study is that it is based on the results of only one centre. To validate our algorithm, prospective studies using our algorithm in cases of RDFN in various different centres need to be done. The assessment of distal femur bone stock is subjective and it requires a lot of experience to decide whether sufficient bone stock is available to procure a stable fixation, especially in the presence of an implant. In spite of these limitations, our algorithm serves as an excellent guide to the surgeon to plan in a stepwise manner in addressing each important factor while managing RDFN.

Conclusion

Based on our algorithm, treatment of an RDFN starts with proper assessment of bone stock, medial void, fracture alignment, and stability of fixation. If these are not addressed, then the chance of having another failure is very high. In the 62 cases managed following the algorithm, we had a high success rate (98.38%) and thereby we feel that our stepwise algorithm would serve as a useful tool in managing cases of RDFN.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical standards The study was performed in accordance with the ethical standards in the 1964 Declaration of Helsinki.

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