Management of complex distal femur fractures with bone loss using the 'three-in-one technique'

Abdullah Khaled[a], Mahmoud El-Rosasy[b], Ahmed Shafik[a], Osama El-Gebaly[a]

[a]Department of Orthopedic Surgery, Faculty of Medicine, Tanta University, Egypt, [b]Orthopedic Surgery and Traumatology Chief of Limb Lengthening & Reconstruction and Paediatric Orthopaedics Department of Orthopedic Surgery, Faculty of Medicine, Tanta University, Egypt

Correspondence to Abdullah Khaled, Msc, Department of Orthopedic Surgery, Faculty of Medicine, Tanta University, Egypt.
Tel: +201156695276;
e-mail: abdallah_khaled92@yahoo.com

Received: 01 August 2023
Revised: 21 August 2023
Accepted: 25 August 2023
Published: 10 November 2023

The Egyptian Orthopaedic Journal 2023, 58:159–168

Purpose
The reconstruction of complex distal femur fractures with bone loss is a surgical challenge. The aim of the present study was to evaluate the effectiveness of the 'three-in-one' surgical technique, which combines a retrograde nail linked to a lateral locked plate with defect reconstruction using a bone graft in a synthetic scaffold.
Materials and Methods
A prospective study was conducted at a level 1 trauma centre from 2016 to 2021. Comminuted distal femur fractures (OTA/AO type 33A3, 33C2, or 33C3) with bone loss in skeletally mature patients were included. The 'three-in-one' surgical technique was used in all cases.
Results
The present study comprised 14 cases with a mean age of 28 years (range, 18–58 years). The bone defect sizes ranged from 3 to 8 cm. Ten cases (71%) had open fractures. Operative duration ranged between 150 and 210 min (Average 175 min). Excellent, good and fair outcomes according to sanders score were achieved in eight (57%), five (36%) and one case (7%), respectively. There were no cases of implant failure or varus collapse. Postoperative follow-up ranged from 12 to 53 months (mean 27 months).
Conclusion
Management of complex distal femur fractures using the 'three-in-one technique' (retrograde nail fixation augmented by anatomical lateral locked plate and reconstruction of the bone defect using autologous bone grafts in a scaffold of synthetic oxidised cellulose gauze) for complex distal femur fractures provides a stable biomechanical construct that allows fracture healing and early rehabilitation in a single stage through a single approach.

Keywords:
bone loss, distal femur, Nail- plate construct, oxidised cellulose, synthetic scaffold

Egypt Orthop J 2023, 58:159–168

1110-1148

Introduction

The reconstruction of comminuted distal femur fractures is a challenging surgical problem, particularly when associated with bone loss, medial column comminution, osteoporosis, or a short distal fragment. Comminuted distal femur fractures are typically the result of high-energy trauma in young adults or low-energy trauma in osteoporotic bones [1]. Several approaches for the management of comminuted distal femur fractures have been described, including single-locked plate fixation, retrograde nailing, double plating and distal femur replacement [2–5]; however, there is currently a lack of consensus regarding the optimal management of such cases.

As distal femur fractures are subjected to considerable muscular forces, single lateral plate fixation may be inadequate in complex cases leading to varus collapse or nonunion [6,7]. Further, retrograde nailing may provide inadequate fixation if the distal fragment is comminuted or short [3,8]. Inadequate fixation may result in a range of complications and morbidities that necessitate surgical revision, thereby contributing to a high economic burden and long hospital stays. Inadequate fixation may also delay rehabilitation and early weight bearing and compromise postoperative rehabilitation protocols that may end in a stiff knee. Double plating allows adequate biomechanical fixation and prevents medial varus collapse. However, double plating requires further soft tissue dissection that may violate bone biology [9,10]. Acute distal femoral replacement may be reasonable in carefully selected cases, particularly in elderly patients [5,11].

The presence of bone loss in complex distal femur fractures requires careful management of the inherently unstable fracture and bone defect. Several reconstructive

approaches have previously been described ranging from simple to complex procedures including the induced membrane technique (Masquelet technique), Ilizarov bone transport, and free vascularised bone transfer [12–15].

Oxidised cellulose is a synthetic absorbable haemostatic scaffolding agent that has been widely used in surgery [16], with previous experimental studies demonstrating oxidised cellulose has osteoinductive properties [17,18].

As complex distal femur fractures lead to both biomechanical and biological problems, management approaches should aim to reconstruct the bone defect and provide adequate fixation to allow early rehabilitation and enhanced bone healing.

We hypothesised that the management of comminuted distal femur fractures using the 'three-in-one technique' (retrograde nail fixation augmented by anatomical lateral locked plate and reconstruction of the bone defect using autologous bone grafts in a scaffold of synthetic oxidised cellulose gauze) for complex distal femur fractures provides a stable biomechanical construct that allows fracture healing and early rehabilitation in a single stage using a single approach.

Patients and Methods

This prospective study was conducted at a level 1 trauma centre at a university hospital from 2016 to 2021. The study group comprised skeletally mature patients (minimum 18 years old) with comminuted distal femur fractures (OTA/AO type 33A3, 33C2, or 33C3) with bone loss. Exclusion criteria were as follows: associated neurological injury; extensive soft tissue loss; vascular injury; pathological fractures and infection. All cases with multiple trauma and other associated injuries were treated according to our institutional protocols that follow the damage control orthopedics principles. Open fractures were debrided with the administration of systemic antibiotics and temporary immobilisation using splints or spanning external fixation. Index surgery was performed when the general condition of the patient and local soft tissue were considered suitable for intervention. Ethical clearance was obtained from our local ethical committee. Federal Wide Assurance (FWA 00022834) IRB (0010038) Approval reference number (36069). Written informed consent was obtained from all participants or their caregivers.

Surgical technique

All procedures were performed with the patient in the supine position on a radiolucent operating table. A radiolucent triangle was placed underneath the knee to flex it with fluoroscopic imaging from the contra lateral side of the table. All procedures were performed under general or spinal anaesthesia. The injured limb and the iliac crest donor site were prepared and draped. Prophylactic antibiotics were administered preoperatively. All the cases were approached using the standard anterolateral approach to the distal femur.

Downgrading the fracture pattern

In cases with intra-articular fracture extension, the aim was to downgrade the fracture pattern from (33-C to 33-A) with anatomical reduction of the articular surface and fracture fixation using screws. Special care was taken during this step to ensure that the trajectory of the screws did not interfere with the trajectory of the retrograde nail. In cases with intra-articular sagittal plane fractures, screws were inserted from the lateral to the medial side and anterior to the trajectory of the nail under fluoroscopic guidance in the lateral view. Screws head were buried to prevent subsequent interference with the lateral plate. In cases with associated coronal plane fractures, screws were inserted perpendicular to the fracture line while ensuring screws did not cross the midline or interfere with the trajectory of the nail. Screw placement was confirmed in the Antero-posterior view [Fig. 1].

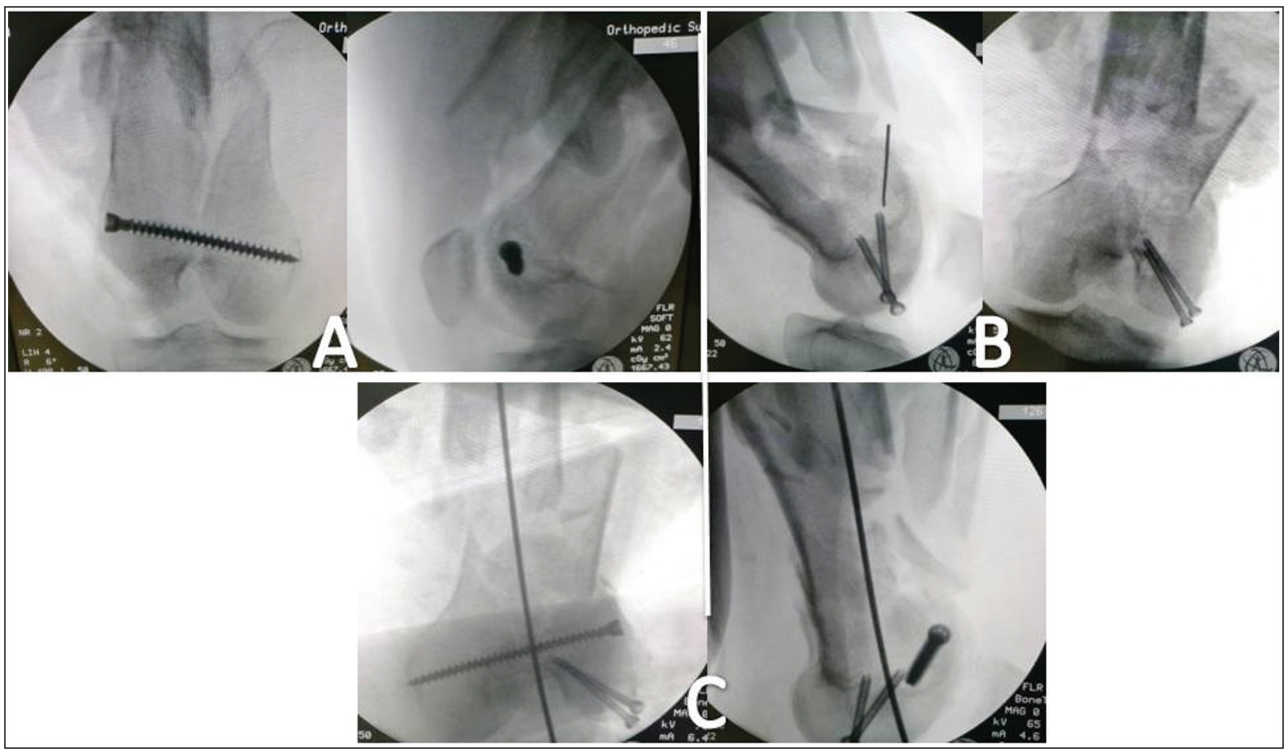
Preparation for intramedullary nailing

A guidewire was inserted in the appropriate trajectory prior to reaming of the medullary canal. Nail length and diameter were then measured. In cases with metaphyseal comminution, confirmation of an appropriate nail length was performed while the assistant applies traction to the injured limb and it was compared with that of the contra lateral limb under fluoroscopic guidance.

Preparation of the nail-plate construct

The nail-plate construct was assembled on a side table. After determination of nail size and diameter; the plate length was determined according to the extension of the metaphyseal comminution and size of the bone defect. In cases with high proximal comminution, where nail and plate length could be matched, the nail-plate was a single construct, where possible, with at least one distal locking screw able to pass through the distal locking hole of the plate and one proximal locking screws of the plate able to pass through the proximal locking hole in the nail. In cases with a low comminution level in which the plate was shorter than the nail, the intent was to place at least two distal interlocking screws passing through the plate locking hole and the distal holes in the nail. The proximal locking screw of the plate was placed anterior or posterior to the nail or with uni-cortical placement. The compatibility of the nail-plate construct was confirmed on the side table. [Fig. 2]

Figure 1:



Downgrading the fracture pattern from 33C into 33A3. A: in the sagittal plane fractures the screws were placed from lateral to medial and anterior to the trajectory of the nail under fluoroscopic guidance in the lateral view. B: In coronal plane fractures the screws were perpendicular to the fracture pattern and not interfering with the trajectory of the nail. C: Notice the screws in both planes were not interfering with the trajectory of the nail

Figure 2:

Illustration of the nail-plate constructs from two different views demonstrates how both the nail and the plate can be linked together as a one construct

Nail-plate combination application

After insertion of the retrograde nail along the guidewire in the appropriate trajectory, the target device was mounted on the nail to prepare for the locking screws. Proper alignment and restoration of femur length under traction was performed prior to the drilling of the locking holes. Submuscular and extraperiosteal sliding of the chosen plate was performed through the distal anterolateral incision. A proximal locking hole was then drilled and the plate was adjusted to allow the drill bit to pass through the locking hole in the plate and nail. Holes for distal locking screws were drilled using a method that allowed the drill bit to pass through the holes of both the plate and nail then insertion of both the proximal and the distal screws. Further screws were inserted through both the plate and the nail when possible. Other screws in the plate were inserted either anterior or posterior to the nail. [Fig. 3]

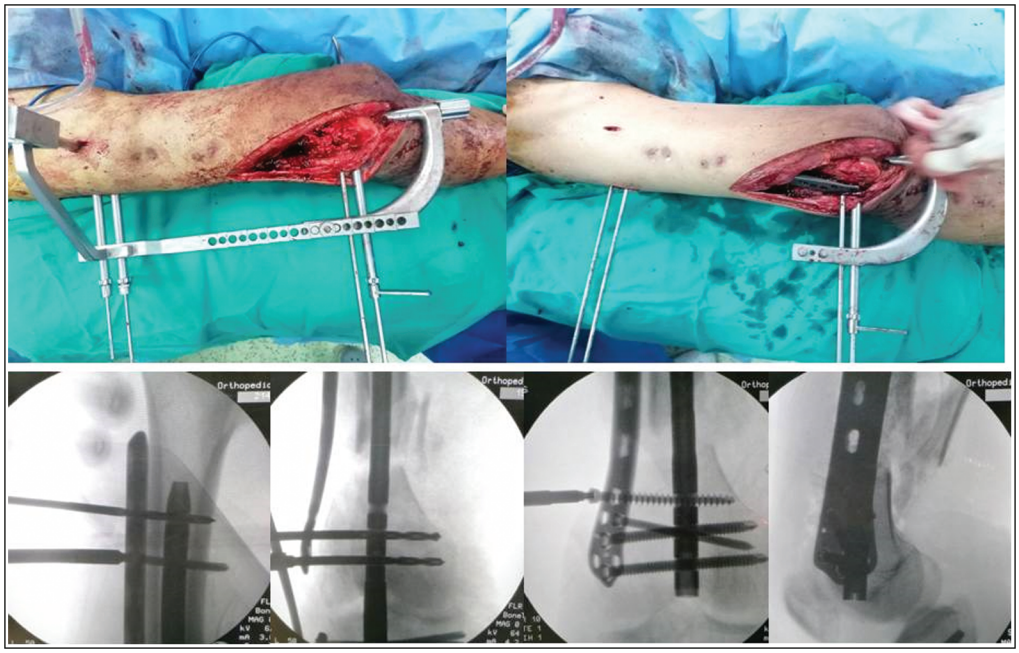
Synthetic scaffold preparation

SURGICEL® NU-KNIT absorbable hemostats were prepared on the side table and tied together using Vicryl 2 sutures to match the defect size. A stay suture was placed at each of the four corners of the performed sheath. Two stay sutures were then circumferentially placed around the bone and tied to the stay sutures on the opposing side to create a cylindrical pouch to contain the graft. [Fig. 4]

Graft preparation

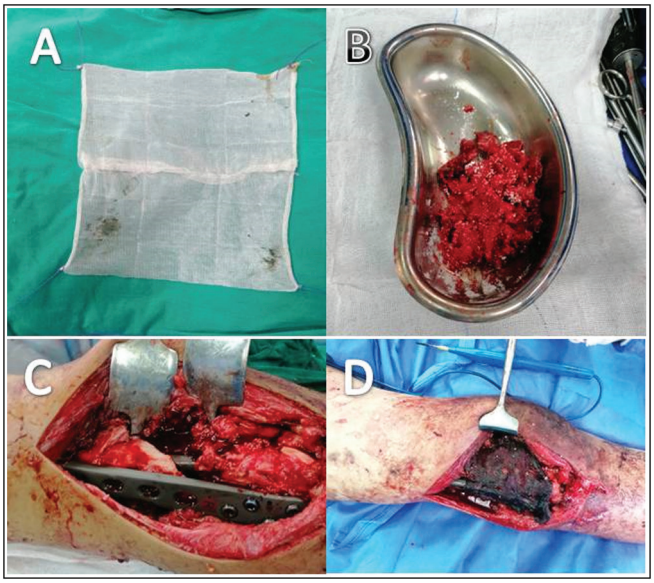
Autologous iliac crest bone grafts were harvested in all cases. In cases with large bone defects, synthetic bone

Figure 3:



Nail- plate construct application in the way that the locking screw of the nail can pass through both nail and plate holes. And the locking screw of the plate can pass through both holes

Figure 4:



A: Preparation of the surgicel gauze with stay sutures at each corner. B: Bone graft preparation. C: The defect after nail-plate application D:After filling the defect with the graft in Surgicel Scaffold

grafts were added as expanders for the autologous graft. The ratio between the iliac crest bone graft and the synthetic graft was 3:1.

Rehabilitation protocol

Patients were encouraged to start the passive range of knee motion from the first postoperative day and use the active range of knee motion with strengthening exercises thereafter. Patients were allowed to mobilise with crutches with touchdown only then progress to partial weight bearing as tolerated based on the progress of bone healing observed in the follow-up radiographs.

Evaluation of the results

Results were assessed using both objective and subjective criteria according to Sanders score based on knee flexion-extension range, pain, walking and stair climbing ability, presence or absence of shortening or deformity and ability to return to work [19].

Results

The present study comprised fourteen patients after the exclusion of two cases who did not fulfill the inclusion criteria. One patient was treated using the masquelet technique due to the presence of infection at the site of the fracture. The second case was treated with the 'three-in-one' technique; however, was excluded due to neurological affection as a consequence of associated second lumbar vertebra fracture. The mean age of the included cases was 28 years (range 18–58 years). Bone defect sizes ranged from 3 to 8 cm (mean 4.5 cm). Eleven cases (79%) were due to road traffic accidents and three cases (21%) were due to falling from height. Ten cases (71%) were open fractures. Operative time ranged from 150 to 210 min (mean 175 min). The synthetic bone graft in combination with iliac crest bone graft was used in ten cases (71.4%). The synthetic bone graft was composed of Hydroxyapatite and B tricalcium phosphate. In 4 cases (28.6%) only

Table 1: Demographic and clinical data

Case	Age (years)	Sex	Side	Etiology	Bone defect (Cm)	Open*/ closed	Associated injuries	Classification (AO/OTA)	Co-morbidities	Operative time (minutes)	Time to union (weeks)	Range of knee (°)	Follow-up (months)	Complications	Sanders score at final follow-up
1	22	M	RT	RTA	3	Open (IIIA)	Contra lateral BBL	33A3	Smoker	180	16	0–130	12	Superficial infection	37
2	26	M	RT	RTA	4	closed	-	33C2	smoker	150	18	0–130	18		39
3	32	M	RT	RTA	3	closed	-	33C2	-	180	24	0–120	12		32
4	58	M	LT	RTA	6	Open (IIIA)	fracture base of skull- fracture ribs	33C3	HTN	160	28	0–90	53	knee stiffness	23
5	24	M	RT	RTA	3	Open (II)	-	33A3	NA	200	20	10–130	24		32
6	20	F	RT	FFH	6	Open (IIIA)	-	33C2	NA	160	32	0–140	18		40
7	24	M	LT	RTA	5	Open (II)	contra lateral BBF	33C3	NA	180	16	0–120	30	LLD:2 cm	33
8	26	M	LT	RTA	6	Open (IIIB)	IPFF	33A3	Smoker	180	24	5–110	48	knee stiffness	36
9	41	M	RT	RTA	5	Open (II)	fracture ribs-IPFF	33C2	Smoker	170	32	0–140	20		40
10	24	F	RT	RTA	3	closed	Ipsilateral comminuted LER	33C3	-	210	15	5–130	24		38
11	28	M	LT	FFH	3	Open (IIIA)	fracture ribs-Ipsilateral comminuted LER	33A3	-	200	16	0–130	24		38
12	21	M	RT	RTA	5	Open (IIIB)	contra lateral femur without bone loss -contra lateral BBL-Ipsilateral BBL	33C2	-	160	20	0–120	30	Superficial infection	30
13	18	F	RT	FFH	8	Open (IIIA)	-	33C2	-	150	32	0–140	18	LLD:1 cm Deep infection	39
14	28	M	LT	RTA	3	closed	fracture ribs-hempneumothorax	33A3	Smoker	170	16	0–130	48	LLD:1 cm	30

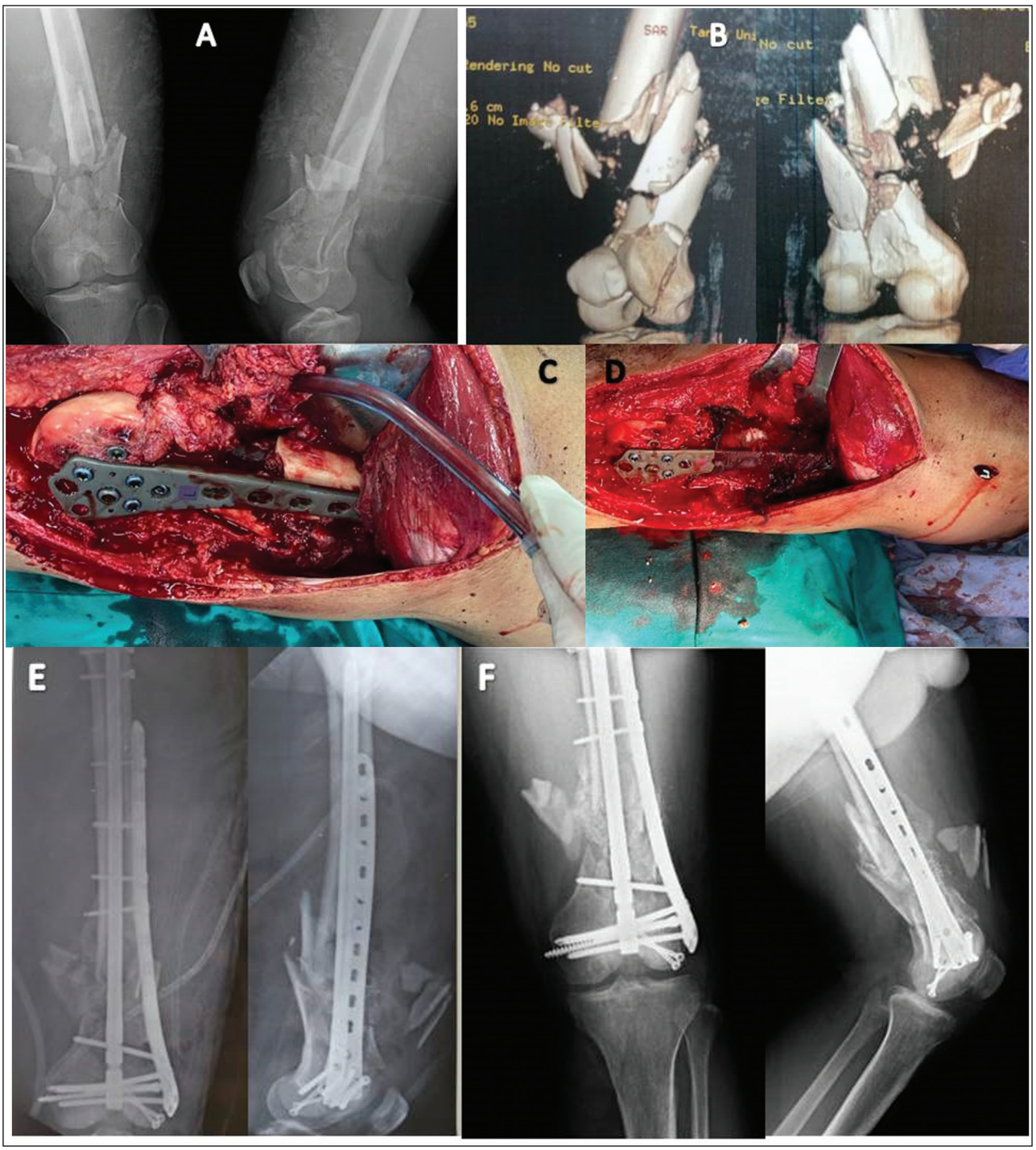
*BBF: Both Bone Forearm; *BBL: Both bone leg; *FFH: Falling from height; *IPFF: Intra peritoneal free fluid; *LER: Lower end radius; *LLD: Limb length discrepancy; *Open fractures: are further classified according to Gustilo Anderson classification; *RTA: Road traffic accident.

the iliac crest bone grafts were harvested without the need for synthetic bone graft expanders. Clinical and demographic information is presented in [Table 1].

Successful reconstruction was achieved in all cases (100%) without the need for further surgery. The average time to radiological bone union was 22 weeks (range 16 to 32 weeks). Satisfactory results were achieved in 13 out of 14 cases (93%). Eight cases (57%) achieved an excellent outcome and five cases (36%) achieved a good outcome according to the sanders classification. One patient (7%) had a fair result due to knee stiffness with a flexion range of 90°, occasional pain, restricted walking, and the need to change employment. No poor results were observed in the present study [Figs. 5 and 6; Table 2].

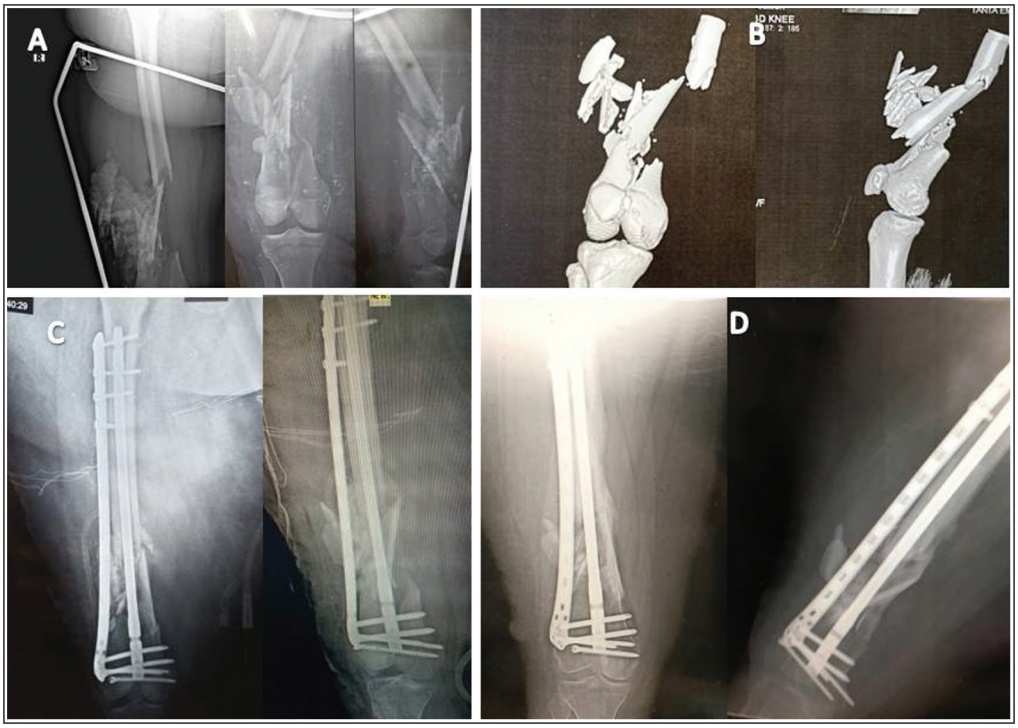
Superficial wound infection occurred in two cases (14%) and was managed conservatively with local wound care and systemic antibiotics. Deep infection

Figure 5:



A case of complex distal femoral fracture with bone loss managed by the (Three-in-One) technique in one stage through a single approach with immediate postoperative rehabilitation. A: Pre X-ray B: 3D CT scan C,D: reconstruction of the defect with surgicel scaffold. E: Postoperative radiograph F: Follow-up radiographs show radiological bone healing and consolidation

Figure 6:



Another case illustrates the (Three-in-One) Technique in a highly comminuted distal femoral fracture in one stage without need for further surgeries. A: Preoperative radiographs. B: CT with 3D reconstruction C: Postoperative radiograph. D: follow-up radiographs show radiological bone healing and consolidation

and wound dehiscence occurred in one case (7%) that necessitated debridement and intravenous antibiotics. The infection resolved and the fracture united without the need for further surgeries in this case. Two patients (14%) had severe knee stiffness, which improved after physiotherapy in one case. There were no cases of implant failure or varus collapse in the present study. Three patients (21%) had a residual limb length discrepancy of less than two cm. Postoperative follow-up ranged from 12 to 53 months (mean 27 months). The results are summarised in [Table 3].

Discussion

Our prospective study evaluated the effectiveness of the novel 'three-in-one technique' in the treatment of complex distal femoral fractures with bone loss. The three-in-one technique' combines a retrograde nail linked to a lateral locking plate and bone graft contained in a synthetic osteoinductive scaffold.

We hypothesised that this technique could provide an effective biomechanical construct and biological environment to allow fracture healing with reconstruction of the bone defect and promote early postoperative rehabilitation. Further this technique comprises a single stage using a single approach with minimal soft tissue dissection.

There are minimal reports regarding the use of nail-plate constructs in the management of distal femoral fractures. However, all studies to date have reported a high union rate with early weight bearing and rehabilitation without loss of alignment [20,21].

Galante *et al*. [22] used nail-plate construct on 14 patients with distal femur metaphyseal and articular comminution in their retrospective study. All the cases achieved full radiological healing at 12 months follow-up except for one with septic nonunion. There was no implant failure or secondary displacement in their series.

Garala *et al*. [21] conducted a comparative study between single plate fixation (40 patients) versus nail-plate construct in distal femur fractures (27 patients). There were seven cases (18%) complicated with implant failure in the single lateral plate versus no failure in the nail-plate group. Also, all the fractures in the nail-plate group were united versus nonunion in 11 fractures (28%) in the single lateral plate group. Only 17/40 patients were allowed full weight bearing postoperatively in the lateral plate group compared to 26/27 patient in the nail-plate group. In our study also all the fractures had been united with no implant failure and the patients were allowed for early weight bearing as much as tolerated.

Table 2: Objectives and subjective outcome measures according to sanders score

Result	Flexion	*N* (%)	Extension Lag	*N* (%)	Pain	*N* (%)	Deformity (°)	*N* (%)	Shortening (Cm)	*N* (%)	Walking	*N* (%)	Stairs climbing	*N* (%)	Return to work	*N* (%)	Final score	*N* (%)
Excellent	>125°	9 (64.3%)	0°	11 (78.6%)	None	8 (57.1%)	0	12 (85.7%)	0	11 (78.6%)	Normal	9 (64.3%)	No limitation	8 (57.1%)	return to pre injury job	9 (64.3%)	36–40	8 (57.1%)
Good	100°–125°	4 (28.6%)	<5°	0 (0%)	Occasional	6 (42.9%)	<10	2 (14.3%)	<1.5	2 (14.3%)	30–60	4 (28.6%)	Holds rail	5 (35.7%)	Return with difficulty	4 (28.6%)	26–35	5 (35.7%)
Fair	90°–99°	1 (7.1%)	5°–10°	3 (21.4%)	With fatigue	0 (0%)	10–15	0 (0%)	1.5–2.5	1 (7.1%)	<30	1 (7.1%)	One stair at a time	1 (7.1%)	Altered full time job	1 (7.1%)	16–25	1 (7.1%)
Poor	<90°	0 (0%)	>10°	0 (0%)	Constant	0 (0%)	>15	0 (0%)	>2.5	0 (0%)	Little none	0 (0%)	Elevator only	0 (0%)	Part time or unemployed	0 (0%)	0–15	0 (0%)

Several biomechanical studies have demonstrated the combined use of a retrograde nail and anatomical locking plate increases resistance to the axial and torsional loads, thereby improving survivability and resistance to failure [23,24].

In the present study, the intramedullary nail was linked to the plate as a single construct using the holes in the plate and nail. We hypothesised that linking the nail and plate would allow for smoother transference of forces across the nail and plate to provide greater stability with reduced rigidity. This construct would thereby allow a degree of micromotion at the fracture site and equalisation of the load on both the nail and the plate to prevent early construct failure. Furthermore, linking the nail and plate allows the use of a larger nail diameter and simultaneous fixation of the plate with bicortical screws. Moreover, the locking screws of the nail in linked nail-plate constructs do not interfere with the placement of the plate. Wright *et al*. demonstrated that nail diameter significantly impacts on construct stability in distal femoral fractures [25]. However the use of a large nail diameter may be technically challenging when using non-linked nail-plate constructs and may interfere with adequate plate fixation.

To the best of our knowledge, no biomechanical studies have previously evaluated the effectiveness of linked nail-plate constructs. To study the effectiveness of linking the nail with the plate and using large nail diameters, we recommend further biomechanical studies comparing linked with non-linked nail-plate constructs with the evaluation of the survivability of both constructs.

The reconstruction of bone defects remains a significant surgical challenge. The induced membrane technique is a relatively simple procedure that depends on the activity of the biological membrane; however, this approach requires a two-stage procedure[12].

Oxidised cellulose is a synthetic absorbable haemostatic agent that has been widely used in surgery. Experimental studies demonstrated the osteoinductive properties of Oxidised cellulose [16–18]. A number of studies have reported the use of oxidised cellulose as a chamber to house autologous grafts in cranio-maxillofacial and spinal surgeries with promising results [26,27]. Recently Abdelkhalek *et al*. [28] used oxidised cellulose as a scaffold in the treatment of segmental femur defects using a single lateral plate and fibular strut graft with a high union rate.

In the present study, the patients were allowed to use a passive range of knee motion and touchdown using crutches from the first postoperative day and gradually

Table 3: Summary of the result

Total number of cases	14	100%
Age (years)	mean 28 years	
	range:18–58y	
Gender	Males:11	78.6%
	Females:3	21.4%
Side	RT:9	64.3%
	LT:5	35.7%
Etiology	RTA:11	78.6%
	FFH: 3	21.4%
Bone defect (cm)	mean 4.5 cm	
	range: 3–8Cm	
Open/closed (open: Gustillo Anderson classification)	Open:10/ GII (3) GIIIA(5) GIIIB (2)	71.4%
	Closed:4	28.6%
Classification (OTA/AO)	33A3:5	35.7%
	33C2:6	42.9%
	33C3:3	21.4%
Operative time	mean 175 min	
	range:150–210 min	
Time to union (weeks)	mean 22 weeks	
	range: 16–32 weeks	
Complications	Knee stiffness:2	14.3%
	LLD:3	21.4%
	Deep infection: 1	7.1%
Final outcome (Sanders score)	Excellent:8	57.1%
	Good:5	35.7%
	Fair:1	7.1%
	Poor: 0	0%
Follow-up (months)	mean:27 months	
	range:12–53 months	

*FFH: Falling from height; *LLD: Limb length discrepancy; *RTA: Road traffic accident.

increase weight bearing as bone healing was observed on follow-up radiographs. This approach allowed for early rehabilitation, improved psychosocial status and early engagement in the community. Immediate weight bearing was allowed in other studies using nail-plate construct without related complications [29,30].

The nail-plate construct has multiple advantages other than providing a stable biomechanical construct. The presence of an intramedullary component in addition to the surface component reduces the surface area of the defect and the required graft, thereby decreasing donor site morbidity. Furthermore, the nail-plate construct acts as a skeleton over which Surgical gauze can be wrapped and filled with the graft to permit bone regeneration.

The main disadvantage of our technique is that linking of the nail to the plate was time-consuming in some cases, particularly when the holes of the nail and the plate were mismatched. Manufactured nail-plate constructs in which the plate can be anchored to the target device of the nail may overcome this limitation. This could guarantee the best match between the nail and plate, thereby decreasing operative duration as the insertion of the locking screw and plate fixation can be performed simultaneously.

The main limitation of the present study is the small number of cases. Further multicenter studies comparing the 'three-in-one technique' with previously described techniques are required to validate the efficacy of this technique. We also recommend further biomechanical studies to examine the effectiveness of linking the nail to the plate compared to other constructs, which may promote the development of off-the-shelf nail-plate constructs.

In conclusion, the 'three-in-one technique' (retrograde nail fixation augmented by anatomical lateral locked plate and reconstruction of the bone defect using autologous bone grafts in a scaffold of synthetic oxidised cellulose gauze) for complex distal femur fractures provides a stable biomechanical construct that allows fracture healing and early rehabilitation in a single stage through a single approach.

Acknowledgements
Nil.

Financial support and sponsorship
The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Ethics approval
This study was approved by the local institutional review board. Federal Wide Assurance (FWA 00022834) IRB (0010038) Approval reference number (36069).

Consent to participate
written informed consent was obtained from all the participants included in our study.

Consent to publish
Written informed consent was obtained from the participants in our study regarding publishing their data and photographs.

Availability of data and materials
The datasets generated during and/or analysed during the current study are available from the corresponding author on request.

Code availability
Not applicable.

Authors contributions
The research idea and hypothesis was developed by AK, All the authors contributed to the study design. All the cases were operated by AK, AS, OG. Data collection and analysis were performed by AK and MR. The first draft of the manuscript was written by AK and revised by MR. All the authors read and approved the final manuscript.

Conflicts of interest
The authors have no relevant financial or non-financial interests to disclose.

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