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RESEARCH

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# Reconstruction of large post-traumatic segmental femoral defects using vascularised bone flaps: a retrospective case series

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## Abstract

**Background** Large femoral defects after trauma, femoral non-unions, fractures complicated by osteomyelitis or defects after bone tumour resection present high burden and increased morbidity for patient and are challenging for reconstructive surgeons. Defects larger than 6 cm and smaller defects after failed spongioplasty are suitable for reconstruction using a free, eventually a pedicled vascularised bone flap. The free fibular flap is preferred but an iliac crest free flap or a pedicled medial femoral condyle flap can be also used. These vascularised flaps are ideal for bridging defects of long bones and can be also used as osteocutaneous or osteomuscular flaps for coverage of soft tissue defect if present. The patients and their families were informed that data will be submitted for publication and they gave their written informed consent prior to the submission. The study was approved by the institutional ethic committee.

**Methods** We analysed a group of eight patients with large diaphyseal or distal metaphyseal femoral defects. A free fibular flap was used in six patients, a pedicled medial ipsilateral femoral condyle flap was used in two patients and a defect in one patient was reconstructed using an iliac crest free flap.

**Results** All flaps healed completely in all patients and no fracture of the flap was detected during the study period. In one patient, a locking plate broke and was replaced by a compression plate. At the last check-up all patients were able to step on the reconstructed limb with full weight.

**Discussion** Although our study comprises a heterogeneous group of cases, they all have been successfully treated by a similar technique, adapted in each case specifically to the needs of the patient. A major limitation parameter of reconstruction by a free vascularised flap is the size of bone defect needed to be reconstructed. In case of a bone defect longer than 6 cm and a concomitant soft tissue disruption, a vascularised double-barrel fibula is the preferred.

**Conclusion** Large femoral defects can be successfully reconstructed with good long-term results using suitable free or pedicled vascularised bone flaps, especially preferring the free fibular flap.

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**Keywords** Large femoral defect, Non-union, Chronic osteomyelitis, Femoral reconstruction, Free fibular flap, Medial femoral condyle flap, Free iliac crest bone flap, Free tibiofibular flap

## Background

Even today the large post-traumatic segmental femoral defects are challenging for reconstructive surgeons, especially when combined with osteomyelitis or significant soft tissue loss. On the one hand, fortunately the incidence of large femoral defects is very low (approximately 0.05%), but on the other hand due to its rarity we still miss a gold standard method of reconstruction of these defects. The frequently used reconstruction methods for femoral defects are vascularised bone grafting, Masquelet's technique and distraction osteogenesis. Each of them is successfully used by surgeons across the world and has its pros and cons.

## Patients and methods

The aim of the study was to review the clinical outcomes of using vascularised bone grafts for reconstruction of large femoral defects.

From 2000 to 2022, eight patients (four females and four males of Central European origin) with a femoral defect underwent a reconstruction using vascularised bone grafts. A free vascularised fibular flap (FVFF) was used in six patients, a pedicled medial ipsilateral femoral condyle flap (MFCF) was used in two patients. All patients suffered from a large post-traumatic segmental defect, larger than 6 cm.

To enrol the patients for reconstruction using FVFF they had to meet the following criteria: (1) supracondylar femoral defect affecting the medial and lateral pillar of the femur at least 4 cm long; (2) defect longer than 6 cm in the medial part of the femur; (3) good vascular condition of the limb.

The MFCF was used under the two conditions: (1) the bone defect was shorter than 5 cm after the resection of the femoral condyle; (2) the medial side of the femur was intact at the flap harvest site.

Patients' age at the time of surgery ranged from 25 to 59 years. Although most patients were not young, they all had no comorbidities that could adversely affect healing and most of them had a good compliance. The reconstruction surgery was performed after extensive debridement and complete bacterial eradication. Recipient site preparation included scar tissue excision, resection of damaged bone and dissection of recipient vascular structures. Detailed information about patients and reconstructions are presented in the Table 1.

## Results and case series

A case-series of eight patients is presented and characteristics of the used flaps are presented in the Table 2. No patients had flap failure, all defects healed completely without major complications, only one patient had a fracture of the osteosynthetic splint. Also, in all patients, the limb could be fully weight-bearing after a number of months. The attached tables describe the individual defects as well as the surgical technique and long-term outcome. The detailed course and outcome of each case is then described in further detail within the case series.

### Case 1

A 33-years-old female polytraumatic patient with a medial diaphyseal femoral fracture featured a 9-cm-long femoral defect. It was primarily fixed by an external fixator and after four weeks, when general condition of the patient was stabilised, a reconstruction with a double-barrel fibular flap was performed primary due to extensive bone loss. A defect of this size could have not been solved in any other way. A microanastomosis to femoral vessels using a great saphenous vein graft end-to-side was created (Fig. 1a and b) and the result was satisfactory after three years (Fig. 1b).

### Case 2

A 45-years-old male patient suffered a medial diaphyseal femoral fracture with 10-cm-long interfragment. The reason for non-healing and non-union was an avascular necrosis of the central fragment with subsequent osteomyelitis which resulted in a huge bone defect after radical debridement necessary for final reconstruction with a vascularised bone graft. Multiple procedures were performed on the femur, including the application of gentamicin beads into the medullary cavity. Ten years after the injury, the femoral intersegment was radically resected and extensive debridement of the soft tissues was performed. Reconstruction of the defect was performed by a free fibular double-barrel flap and a free musculocutaneous anterolateral thigh flap. The fibula was divided transversely and longitudinally into four parts to achieve a larger contact area between the femur and the flap (Fig. 2a and b).

### Case 3

A 35-years-old male polytraumatic patient with a cerebral contusion and supracondylar femoral loss fracture featured a 12-cm-long distal femoral defect. It was primarily fixed by an external fixator. After stabilised general condition of the patient a locking plate osteosynthesis

**Table 1** Characteristics of the patients and their defects

| Patient | | | | | | Defect | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| No | Sex/age | Comorbities | | | | Cause | Size | Localisation | Osteomyelitis | Nonunion |
| | | DM | PAD | Smoking | Other | | | | | |
| 1 | F / 33 | - | - | - | - | Car accident | 9 cm | Medial diaphyseal defect | - | - |
| 2 | M / 45 | - | - | - | - | Motorcycle accident | 10 cm | Medial diaphyseal defect | + | + |
| 3 | M / 35 | - | - | + | - | Car accident | 12 cm | Distal diaphyseal defect | - | + |
| 4 | M / 59 | - | - | + | - | Car accident | 6 cm | Distal femur, supracondylar defect | - | + |
| 5 | F / 53 | - | - | - | - | Car accident | 7 cm | Distal diaphyseal defect | - | + |
| 6 | M / 25 | - | - | - | - | Motorcycle accident | 8 cm | Medial diaphyseal defect | - | + |
| 7 | F / 58 | - | - | + | - | Car accident | 6 cm | Distal femur, supracondylar defect | - | + |
| 8 | F / 55 | - | - | + | - | Car accident | 6 cm | Distal femur, supracondylar defect | - | + |

Legend: DM – diabetes mellitus; PAD – peripheral arterial disease

was performed and after one week a reconstruction with a double-barrel fibular flap based on the soleus muscle and covered by a dermo-epidermal skin graft was done. Again, the bone defect was huge and unsuitable for further reconstruction. A microanastomosis to femoral vessels using a great saphenous vein graft end-to-side was created (Fig. 3a and b).

### Case 4

A 59-years-old male patient with a supracondylar distal femoral fracture was primarily treated with a locking plate. Due to the lack of compression after the primary ostesynthesis, which resulted in a non-union, several spongioplasties had to be performed together with a new osteosythesis. However, the terrain was not suitable for proper healing and it was decided to use a vascularised bone graft for better bone healing. A reconstruction with a double-barrel fibular flap was performed. A microanastomosis to descending genicular vessels was created without help of a vein graft (Fig. 4a and b). The patient was checked 4 years later (Fig. 4c).

### Case 5

A 53-years-old female patient with a distal diaphyseal femoral fracture was primarily treated with a locking plate. Because of non-union a reconstruction with a pedicled medial condyle femoral flap was performed (Fig. 5a and b). The reason for failure and its solution are identical with the Case 4.

### Case 6

A 25-years-old male polytraumatic patient suffered a medial diaphyseal femoral fracture. Multiple reoperations were performed including intramedullary ostesynthesis, spongioplasty with locking plate augmentation and cement spacer insertion. After eight years of unsuccessful treatment, he was referred to our centre with lack of detailed medical history, the exact reason of the situation was not fully known. A reconstruction by a free fibular double-barrel flap was performed. A microanastomosis to femoral vessels was created using a great saphenous vein graft end-to-side (Fig. 6a and b). Unfortunately, during parachute jump from the airplane the plate was broken, exchanged and checked after 10 months (Fig. 6c). Then the patient disappeared.

### Case 7

A 58-years-old female patient with a supracondylar distal femoral fracture was primarily treated with a locking plate. Again, a primary application of the plate without a good compression was followed by a failed spongioplasty due to the lack of quality of the surrounding tissue and bone activity. Because of non-union and given location, a pedicled medial condyle femoral flap was used to finally solve the situation (Fig. 7a and b).

### Case 8

A 55-years-old female patient with a supracondylar distal femoral fracture was primarily treated with a locking plate. Because of non-union following a failed ostesynthesis due to the lack of compression and subsequent repeated unsuccessful spongioplasties in poorly vital terrain, a reconstruction with a pedicled medial condyle femoral flap and a free osteomyocutaneous iliac crest flap was performed simultaneously after five months. The reason for the use of both flaps was that the medial condyle of the femur directly encroached on space of the non-union and despite the maximum possible bone mass of the medial condyle of the femur, the defective part of the bone would still not be sufficiently filled. The bony part of the iliac crest flap measured $6 \times 3 \times 3$ cm, the part of the obliquus externus abdominis muscle $6 \times 3 \times 1$ cm and the skin island lying above it $20 \times 6$ cm. Femoral re-osteosynthesis was performed with an angularly stable plate from a lateral approach. Flap microanastomoses to the femoral vessels were created end-to-side (Fig. 8a and b).

**Table 2** Characteristics of the used flaps

| Flap | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Patient№** | **Flap** | **Period between trauma and reconstruction** | **Pedicle length (cm)** | **Pedicle diameter (mm)** | **Recipient artery** | **Recipient veins** | **Vein graft** | **Time of reconstruction (min)** | **Flap survival** | **Complications** | **Full weight bearing (weeks)** |
| 1. | Fibula | 3 weeks | 20 | 3 | Femoral artery E-S | Femoral vein E-S | +, great saphenous vein | 250 | + | - | 36 |
| 2. | Fibula +ALT | 10 years | 18<br>23 | 3<br>3 | Femoral artery E-S Descending branch of lateral femoral circumflex artery E-E | Femoral vein E-S Descending branch of lateral femoral circumflex vein E | +, great saphenous vein | 300 | + | - | 36 |
| 3. | Fibula | 1 year | 25 | 3 | Femoral artery E-S | Femoral vein E-S | +, great saphenous vein | 270 | + | Locking plate fracture | 36 |
| 4. | Fibula | 6 months | 23 | 3 | Descending genicular artery E-S | Descending genicular vein E-S | - | 300 | + | - | 36 |
| 5. | Fibula | 8 years | 26 | 3 | Femoral artery E-S | Femoral vein E-S | +, great saphenous vein | 240 | + | - | 36 |
| 6. | MFCF | 1 year | 25 | 3 | Pedicled flap | Pedicled flap | Pedicled flap | 180 | + | - | 36 |
| 7. | MFCF | 5 months | 8 | 3 | Pedicled flap | Pedicled flap | Pedicled flap | 230 | + | - | 36 |
| 8. | ICBF +MFCF | 5 months | 20<br>10 | 3<br>3 | ICBF femoral artery E-S MFCF pedicled flap | ICBF femoral vein E-S MFCF pedicled flap | - | 260 | +<br>+ | - | 36 |

Legend: ALT – anterolateral thigh flap; ICBF – iliac crest bone flap; MFCF – medial femoral condyle flap; E-E – end-to-end; E-S – end-to-side

## Discussion

The currently available treatment strategies of bone loss are based on autologous, allogeneic or xenogeneic bone transplantation as well as synthetic biomaterials [1]. Successful bone augmentation procedures should include an osteoconductive scaffold with sufficient mechanical stability, an osteo-inductive stimulus to induce osteogenesis, and should enable osteo-integration and vascularity [2, 3]. One essential parameter is adequate vascularisation that ensures the vitality of the bone grafts thereby supporting the regeneration process. However, deficient vascularisation presents a frequently encountered problem in current management strategies. Furthermore, many of these grafting approaches fail due to the lack of adequate vascularisation. Insufficient vascularity of the fracture site reduces the exchange of gas, nutrients and waste between the tissue and the blood system as well as the delivery of cells to the site of injury, leading to inner graft necrosis [4, 5].

The vascularised bone flap contains the patient's own cells, growth factors and a vascularisation bed thereby

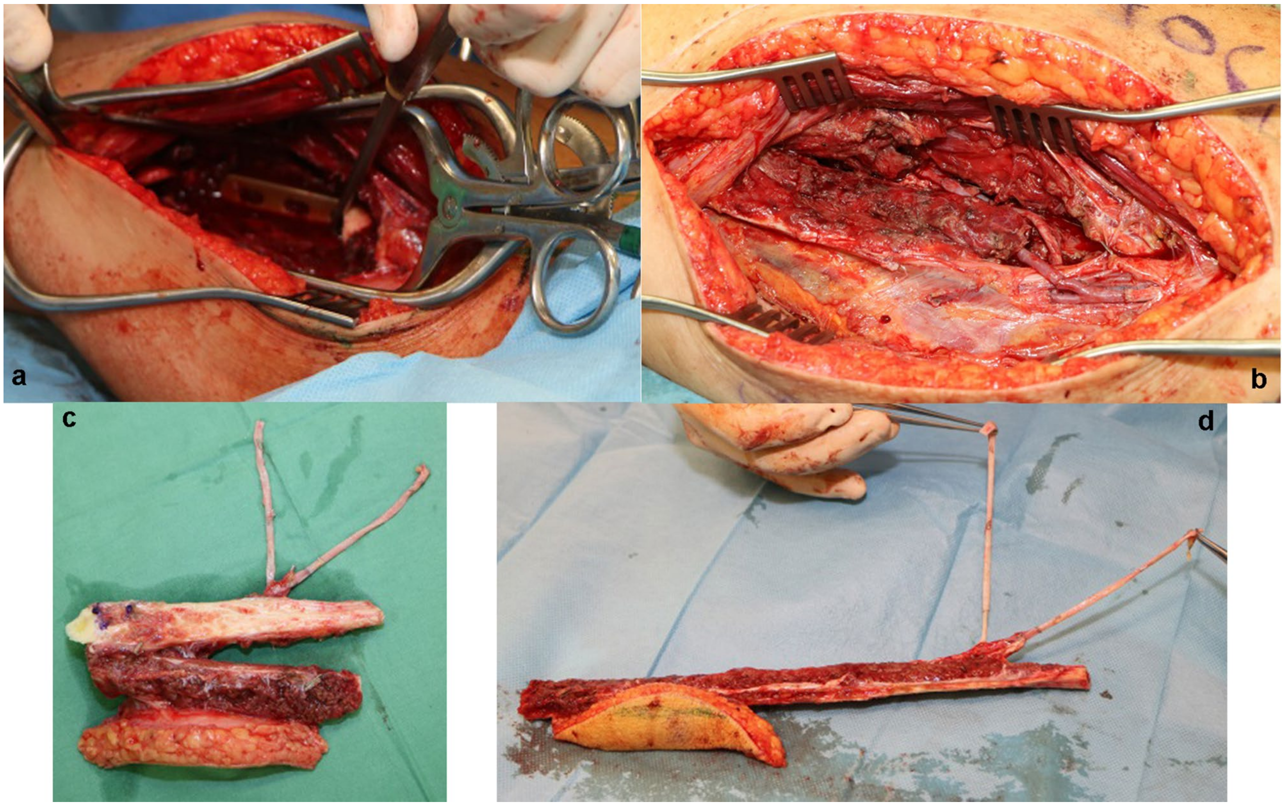


**Fig. 1a** A 33-years-old female polytraumatic patient with a medial diaphyseal femoral fracture (**a**) femoral defect; (**b**) double-barrel fibular flap insertion in femoral defect; (**c**) free double-barrel fibular flap; (**d**) harvested fibular osteocutaneous flap

reducing graft resorption, enhancing healing and permitting better diffusion of antibiotics. A major limitation parameter of reconstruction by a free vascularised flap is the size of bone defect needed to be reconstructed [6]. The main risks of this kind of reconstruction are postoperative vascular thrombosis leading to flap loss and possible donor site complications due to the additional surgical intervention at the bone harvest site [1]. In case of a bone defect longer than 6 cm and a concomitant soft tissue disruption, a vascularised fibula is a more appropriate solution. Due to the disproportion of the width of the femur and the fibula, the use of a double-barrel fibula is the preferred option. To cover the soft tissue defect, flexor hallucis longus and soleus muscles can be used simultaneously with the fibula.

The main advantage of the so-called "out-of-box "solutions (allografts, xenografts, synthetic biomaterials, etc.) is their immediate availability in different sizes and shapes. All of them have osteo-inductive and osteoconductive properties but due to lack of their vascularisation, they have lower osteogenic potential compared to vascularised autografts [7–10]. The other disadvantage is the allograft resorption by creeping substitution that increases the risk of mechanical instability. The similar disadvantage also applies to a free non-vascularised autograft [11–14].

Concerning the Masquelet's technique, the main goals of an induced membrane are reducing the resorption of bone graft, and supporting vascularisation and corticalisation. The main complications of this technique are infection, refracture, non-union and severe bone graft resorption [15–18]. Morelli et al. conducted a systematic review of the Masquelet's technique involving 427 adults [19]. Complications were high (49.6%) amongst all studies, occurring in 15–100% of patients and the ultimate union rate after revision surgeries was 89.7% of cases. There was a failure of one of the steps (persistence of infection or non-union) in 18% of patients with a subsequent requirement for further surgery in 26.7% of cases [19]. In Masquelet's own series, there was an overall 45% complication rate, with a 29% failure rate (nine patients) and 13% refracture rate [15]. Aurégan et al. in their systematic review of the Masquelet's technique in 69 children observed an overall complication rate of 42% of cases. The mean bone union rate after a single induced membrane technique was 58%, which improved to 87% after revision surgeries. The main complications noted were non-union (23%), graft resorption (9%) and fracture (9%) [20].

The Ilizarov's osteodistraction technique also offers the possibility of an axis defect reconstruction, and allows a lengthening of the limb, however, it has associated

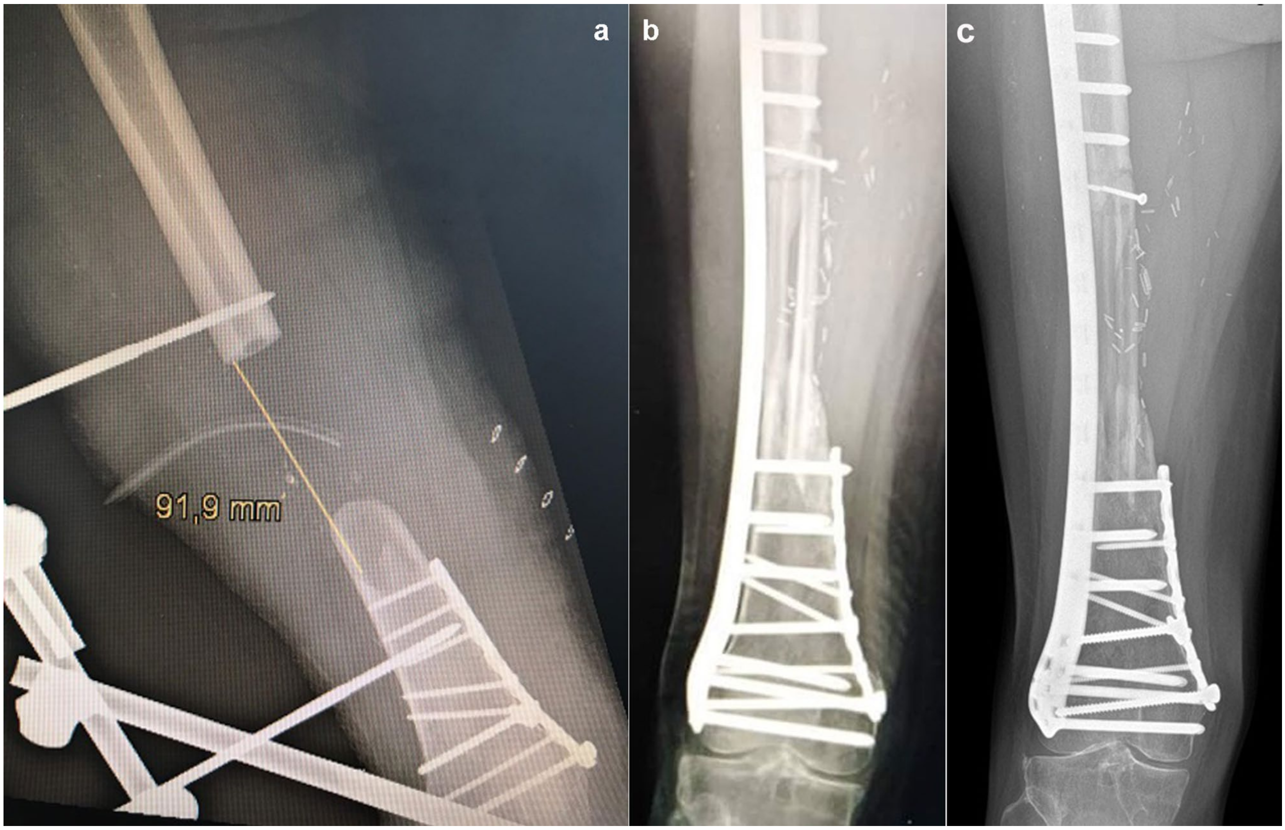


**Fig. 1b** A 33-years-old female polytraumatic patient with a medial diaphyseal femoral fracture – result after 12 months. X-ray before (**a**) and after (**b**) and result after 3 years (**c**)

drawbacks such as several months or even years of healing large segmental defects, with extended hospital recovery and discomfort for patients as well as risks of osteomyelitis along the transcutaneous wires [21].

Yin et al. conducted a systematic review of the Ilizarov's method in the treatment of infected non-unions of the tibia and femur [22]. In a total of 590 patients spanned over 24 studies, the average bone union rate was 97.26% of cases in all included studies. The mean bone defect was 65–67 mm in patients with infected tibial non-unions and 80 mm in patients with infected femoral non-unions. The rate of refracture was 4%, malunion 7%, deep infectious recurrence 5% and knee stiffness 12% of cases. The rate of superficial pin site infection varied between 10% and 100%, with the mean external fixation time 10.69 months and the mean external fixation index 1.70 months/cm in the patients.

This case-series could also involve the case of a defect in a female patient with a distal diaphyseal femoral fracture suffered from a blast injury as a result of an exploding bomb in Baghdad. After two years of non-effective treatment, it was reconstructed using an iliac crest bone flap and a microanastomosis between the femoral vessels and the tibiofibular trunk (proximal segment of the posterior tibial artery) was created end-to-side with the great saphenous vein graft [23]. Although our study comprises a heterogeneous group of cases, they all have been successfully treated by a similar technique, adapted in each case specifically to the needs of the patient and we suppose that the compiled information can contribute to further enhancement and development of treatment protocols in such complicated injuries.

Future directions in large bone defect reconstruction such as in vivo bioreactor, 3D printing, 3D bioprinting techniques and stem cell technologies brings the potential of producing a customised and vascularised living bone graft, but a lot about this technique is still under development and it has not enough clinical evidence yet [23–27].

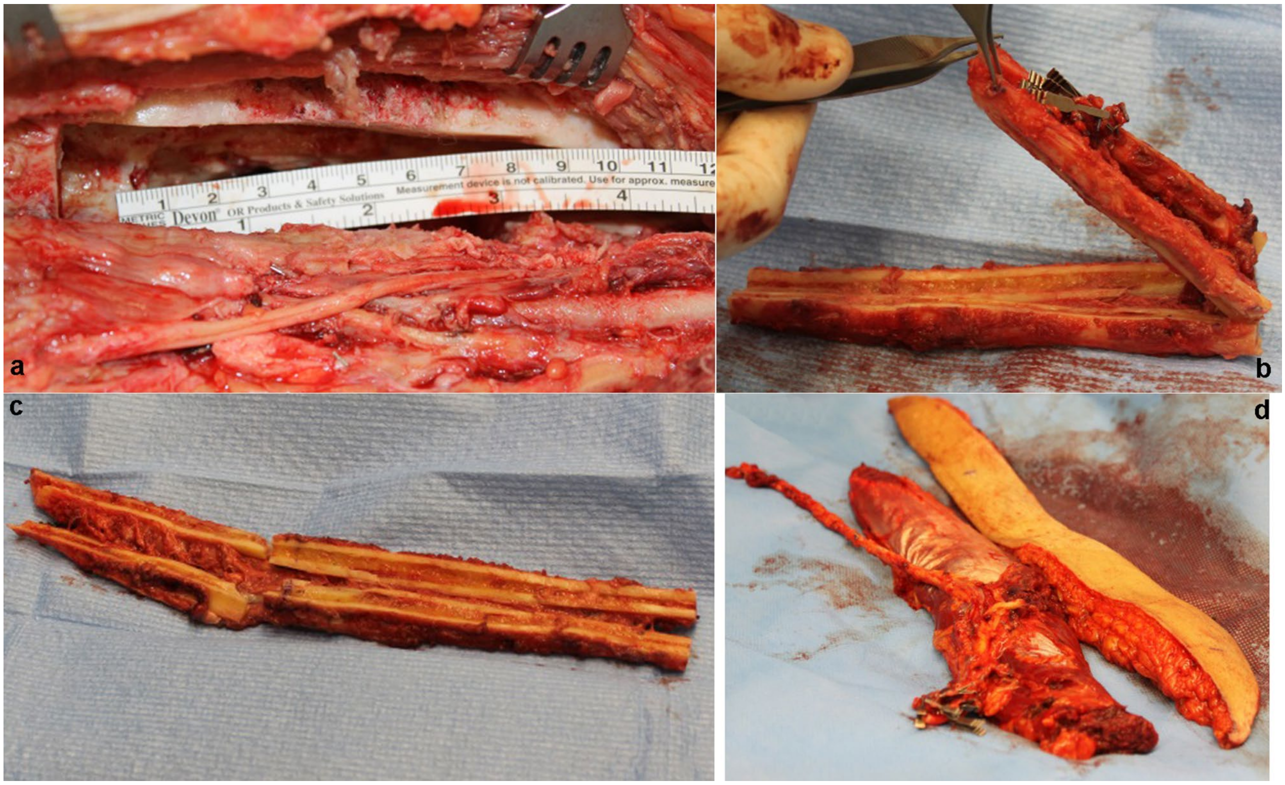


**Fig. 2a** A 45-years-old male patient with a medial diaphyseal femoral fracture with 10-cm-long interfragment. (**a**) femoral defect; (**b** and **c**) free fibular double-barrel flap, fibula is sawn transversely and longitudinally; (**d**) free musculocutaneous ALT flap

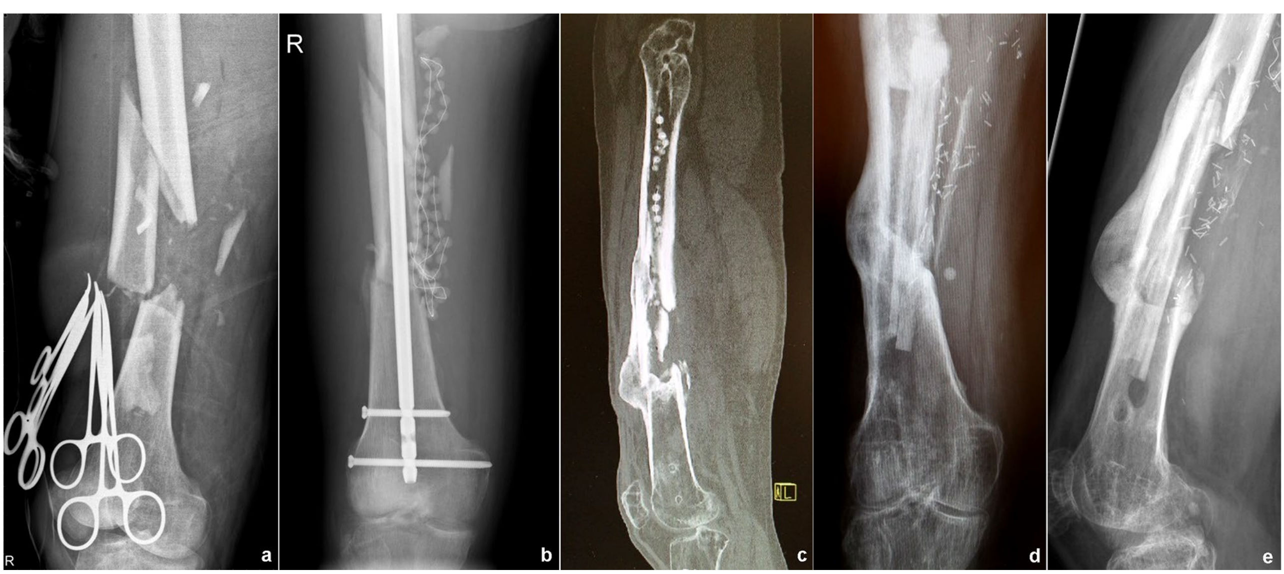


**Fig. 2b** A 45-years-old male patient with a medial diaphyseal femoral fracture with 10-cm-long interfragment – result after 3 years. X-ray before (**a**–**c**) and after (**d**, **e**). (**a**) medial diaphyseal femoral fracture with a 10-cm-long interfragment; (**b**) intramedullary osteosynthesis with gentamicin beads; (**c**) complication healing by chronic osteomyelitis with non-union; (**d** and **e**) result after 3 years

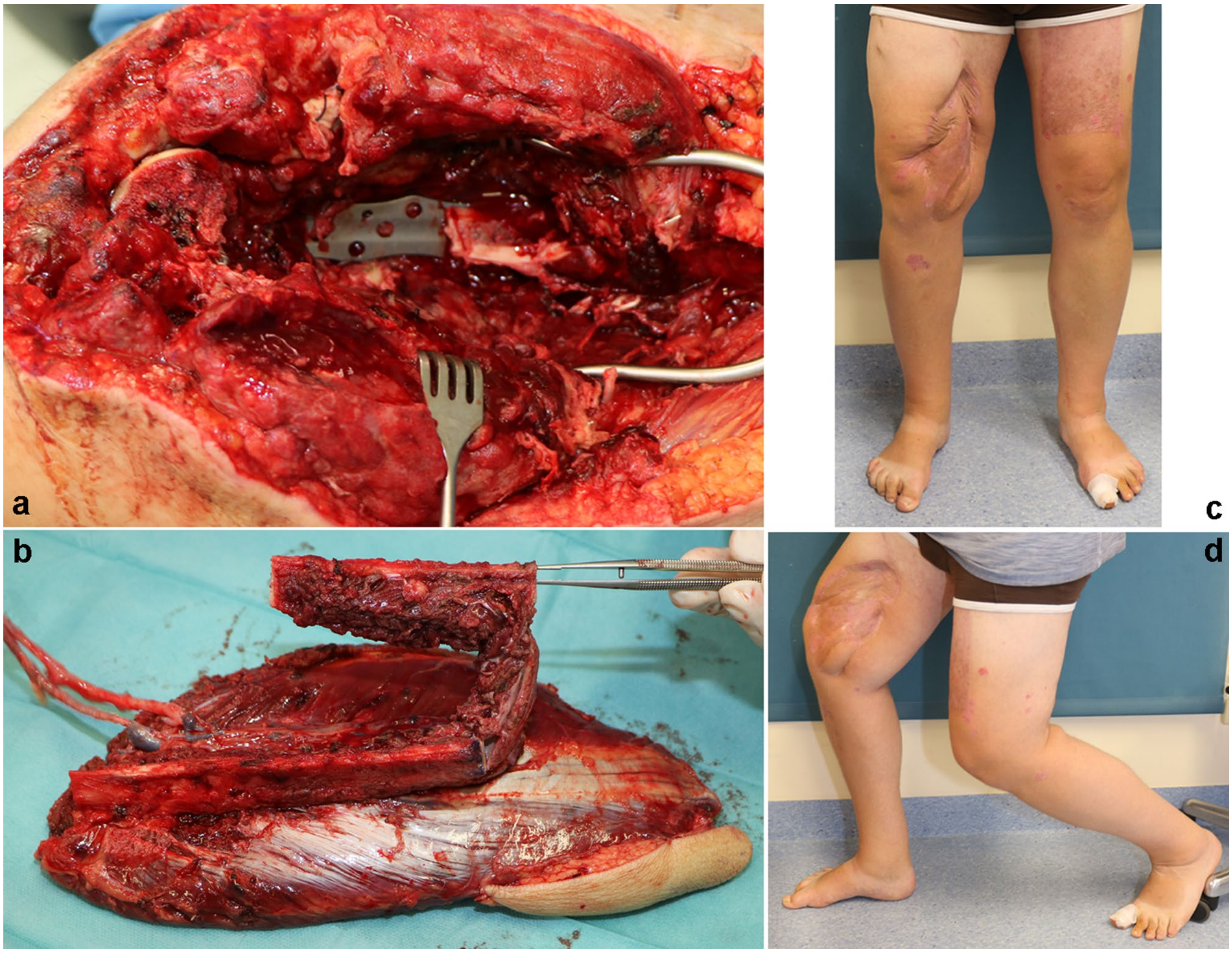


**Fig. 3a** A 35-years-old male polytraumatic patient with supracondylar femoral loss fracture and a 12-cm-long distal femoral defect. (**a**) femoral defect; (**b**) free fibular double-barrel osteomyocutaneous flap (soleus muscle); (**c** and **d**) result after 9 months

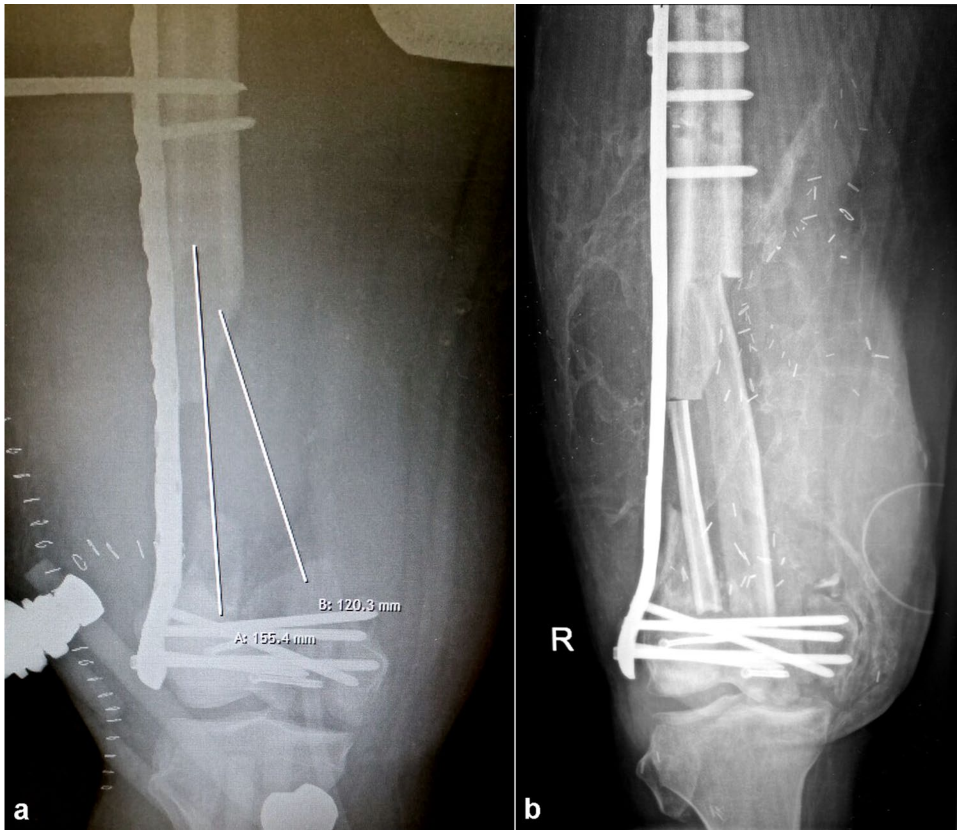


**Fig. 3b** A 35-years-old male polytraumatic patient with supracondylar femoral loss fracture and a 12-cm-long distal femoral defect. X-ray before (**a**) and after (**b**). (**a**) femoral defect; (**b**) result after 9 months


**Fig. 4a** A 59-years-old male patient with a supracondylar distal femoral fracture. (**a**) femoral defect; (**b**) free fibular double-barrel flap; (**c** and **d**) result after 24 months

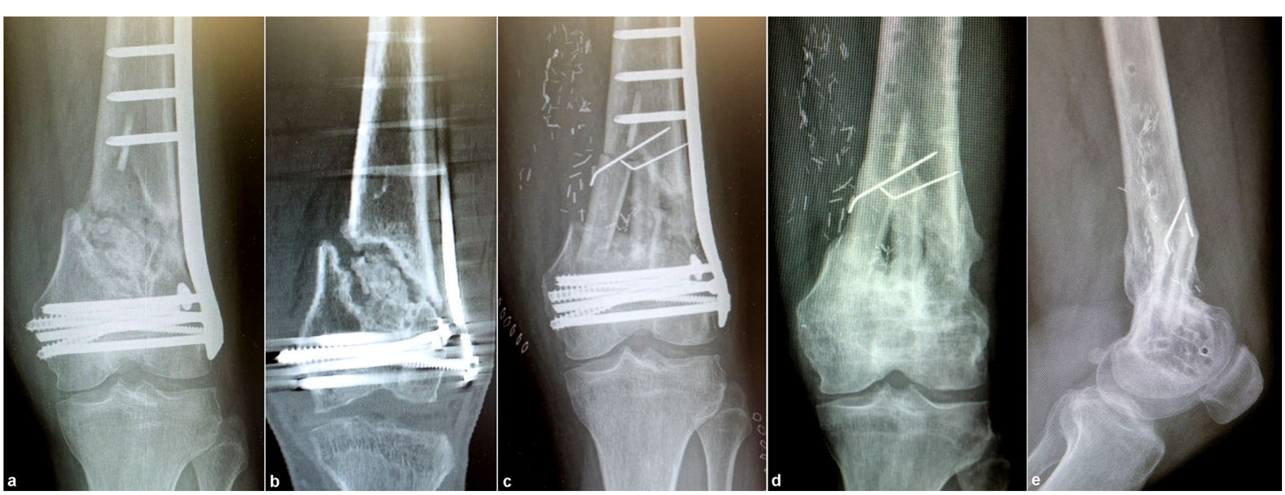


**Fig. 4b** A 59-years-old male patient with a supracondylar distal femoral fracture. X-rays (**a** and **b**) non-union after treating by a locking plate osteosynthesis; (**c**) result after 3 months; (**d** and **e**) result at 24 months

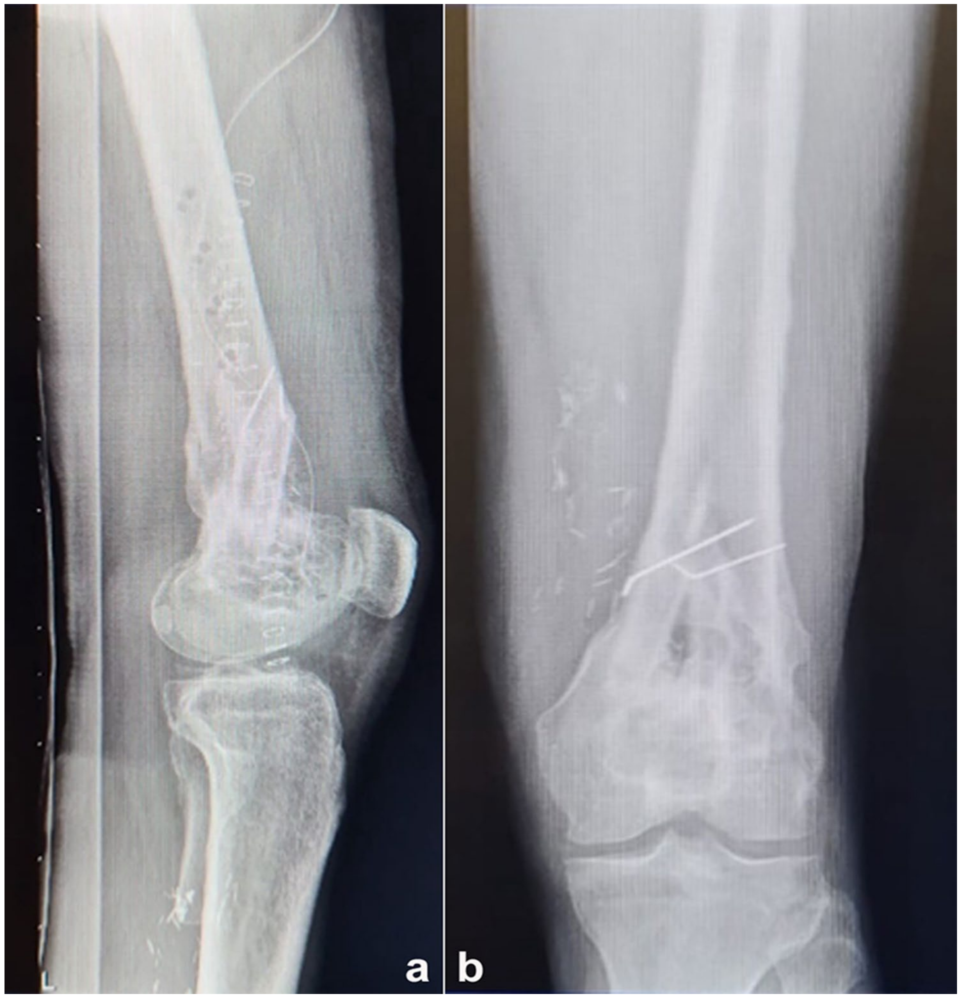


**Fig. 4c** A 59-years-old male patient with a supracondylar distal femoral fracture. X-rays 4 years after the procedure in lateral (**a**) and anteroposterior (**b**) projections

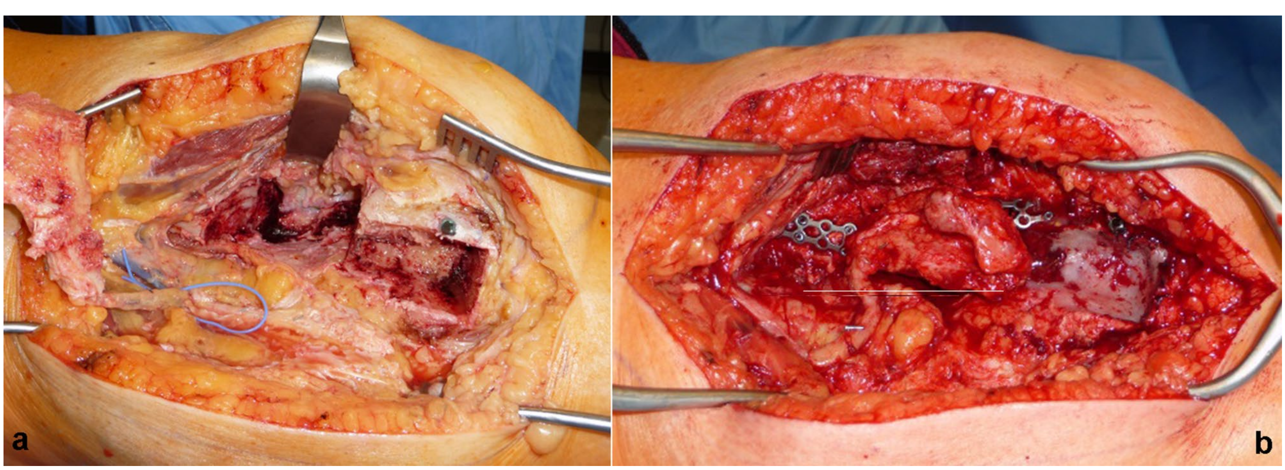


**Fig. 5a** A 53-years-old female patient with a distal diaphyseal femoral fracture. (**a**) femoral defect and harvested pedicled MFCF; (**b**) MFCF insertion in femoral defect

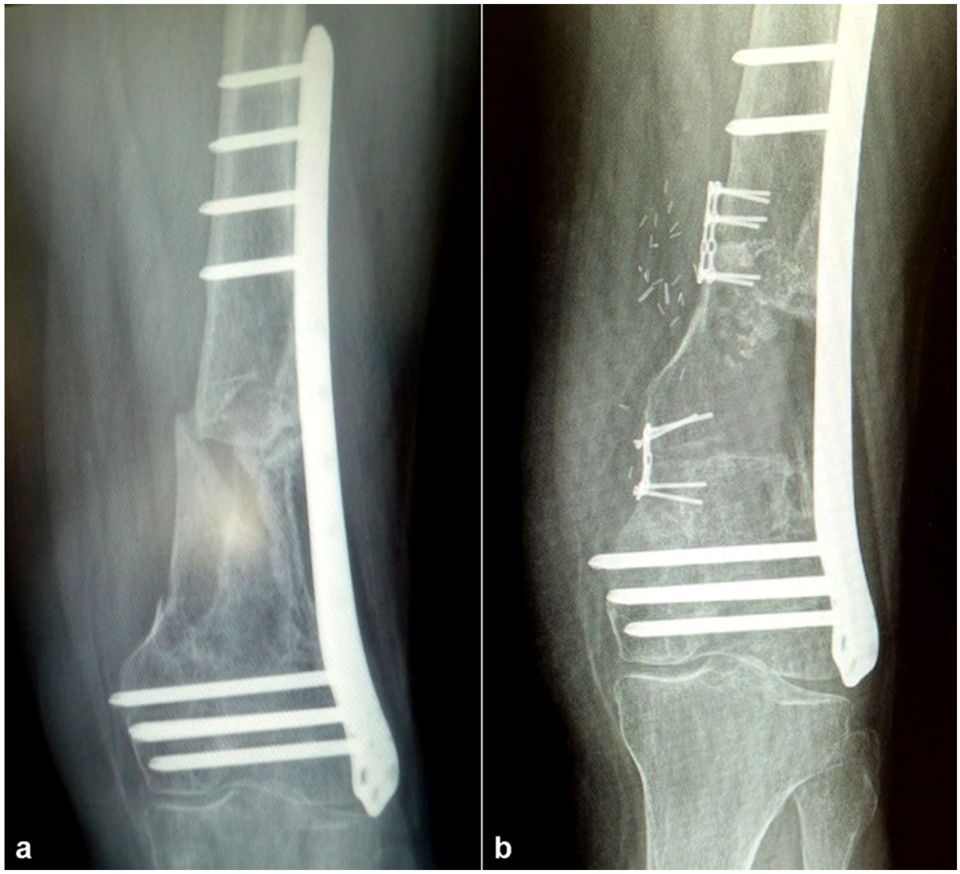


**Fig. 5b** A 53-years-old female patient with a distal diaphyseal femoral fracture. X-rays before (**a**) and after (**b**). (**a**) non-union before reconstruction; (**b**) result after 3 months (after the reconstruction by MFCF)

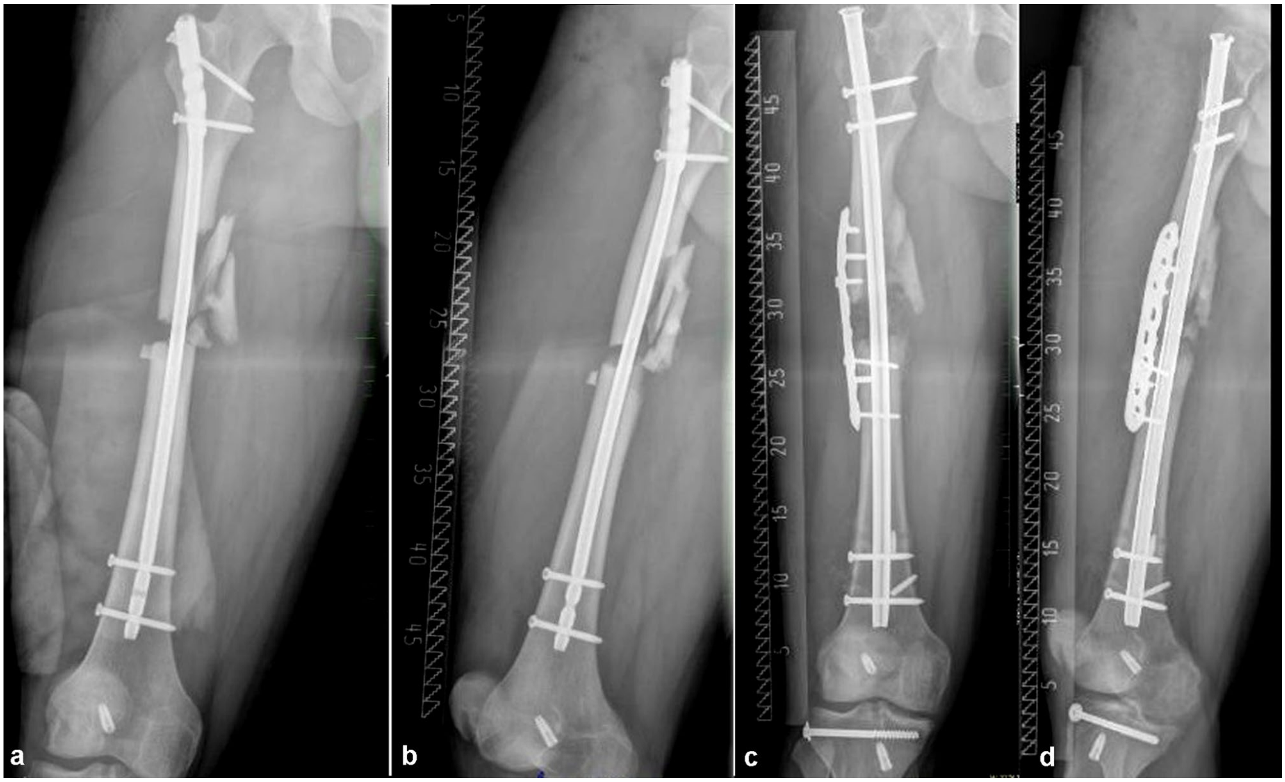

**Fig. 6a** A 25-years-old male polytraumatic patient with a medial diaphyseal femoral fracture. X rays (**a** and **b**) intramedullary osteosynthesis; (**c** and **d**) intramedullary osteosynthesis supplemented with spongioplasty and locking plate

**Fig. 6b** A 25-years-old male polytraumatic patient with a medial diaphyseal femoral fracture. X-rays (**a** and **b**) locking plate osteosynthesis with a cement spacer (white arrows); (**c**) non-union after 9 months; (**d** and **e**) result at 3 months after reconstruction by a double-barrel free fibular flap


**Fig. 6c** A 25-years-old male polytraumatic patient with a medial diaphyseal femoral fracture after reconstruction by a double-barrel free fibular flap. X-rays (**a** and **b**) broken plate after parachute jump from the airplane; (**c**) exchanged plate; (**d**) result after 10 months

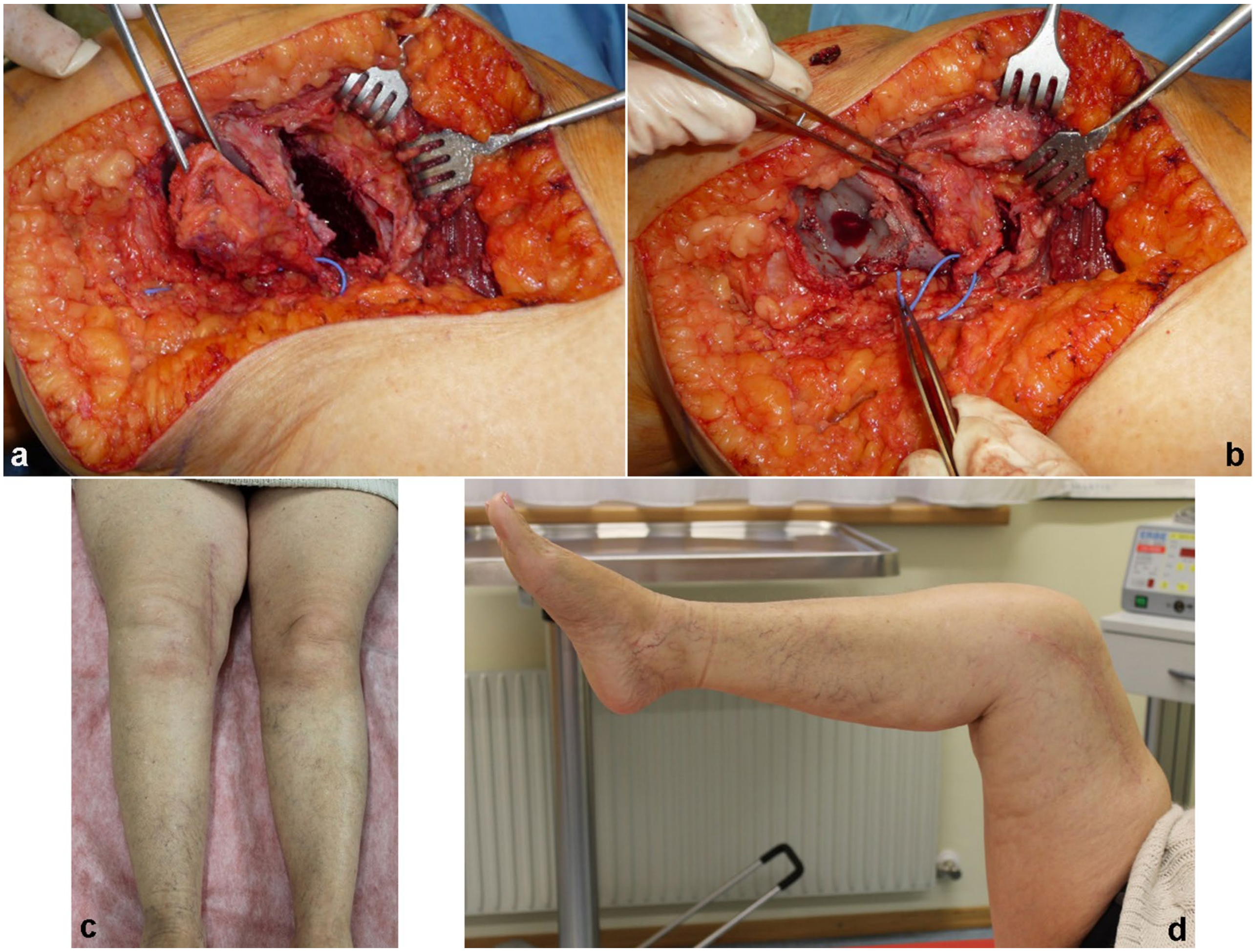

**Fig. 7a** A 58-years-old female patient with a supracondylar distal femoral fracture. (**a**) femoral defect and harvested pedicled MFCF; (**b**) MFCF insertion in the femoral defect; (**c** and **d**) result after 9 months

**Fig. 7b** A 58-years-old female patient with a supracondylar distal femoral fracture. X-rays before (**a**) and after (**b**). (**a**) non-union before reconstruction; (**b**) result at 9 months after the reconstruction using MFCF

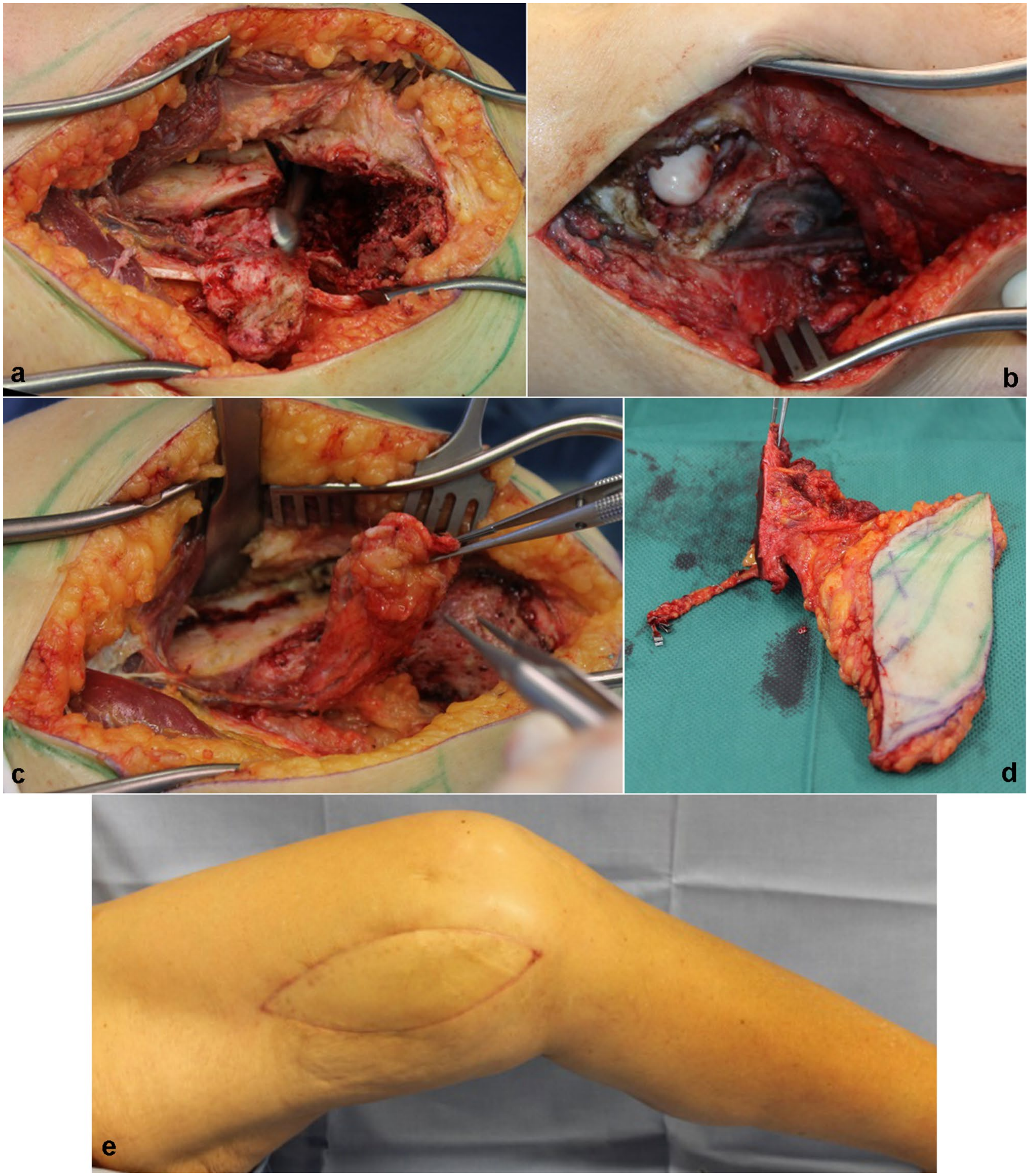


**Fig. 8a** A 55-years-old female patient with a supracondylar distal femoral fracture. (**a**) medial view of the through femoral defect; (**b**) lateral view of the through femoral defect with finger insertion; (**c**) pedicled MFCF; (**d**) free osteomyocutaneous ICBF; (**e**) result after 12 months

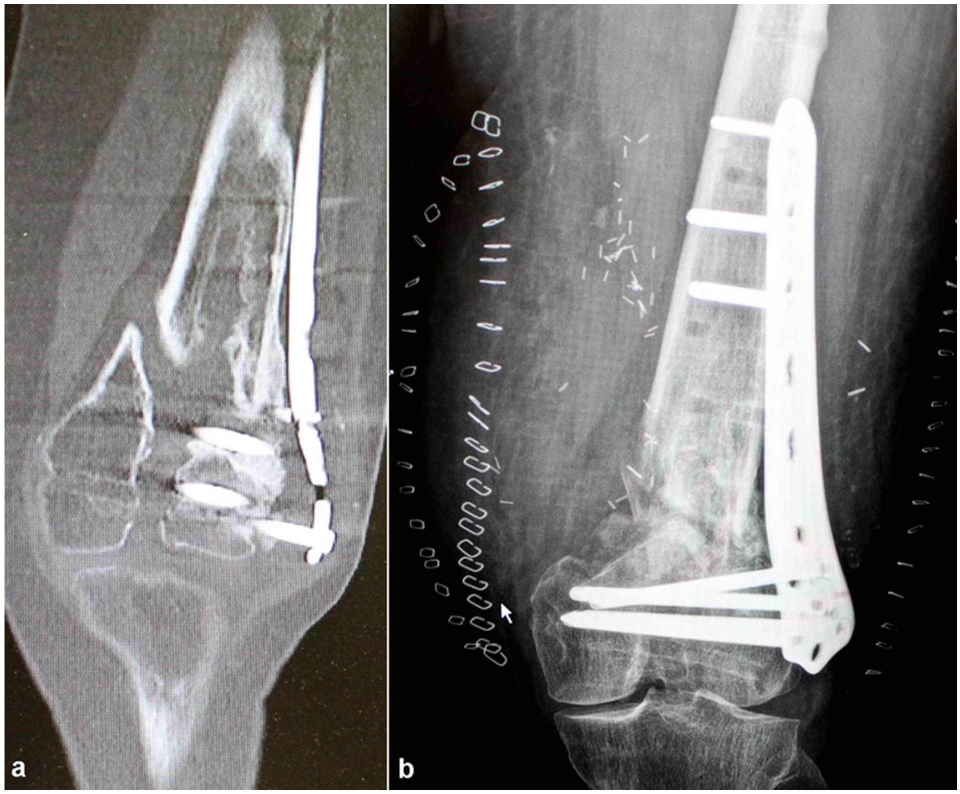


**Fig. 8b** A 55-years-old female patient with a supracondylar distal femoral fracture. X-rays before (**a**) and after (**b**). (**a**) non-union; (**b**) result at 12 month after reconstruction

## Conclusion

Large femoral defects can be successfully reconstructed with good long-term results using suitable free or pedicled vascularised bone flaps, especially with a free fibular flap. Currently, there are no perfect graft and ideal method for the reconstruction of large segmental femoral defects, they all have disadvantages and limitations in use. We believe that in the future with the development of science and technology the ideal graft could be developed. Successful repair depends on osteogenic cell survival and tissue viability after transplantation to the recipient site, while vascularisation and neovascularisation play a determinant role, therefore, nowadays the best option for reconstructing large femoral defects is a vascularised bone flap.

### Abbreviations

FVFF Free vascularised fibular flap
MFCF Medial ipsilateral femoral condyle flap
3D Three–dimensional


### Acknowledgements

The patients and their families were informed that data will be submitted for publication. They gave their written informed consent for their personal or clinical details along with any identifying images to be published prior to the submission. The work has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) and its later amendments, and in accordance with laws of the country where it was conducted. It was approved by the institutional ethic committee.


### Author contributions

T.K.: Surgery, Investigation, Visualization, Writing - Original Draft. J.H.: Surgery, Investigation, Visualization, Writing - Review & Editing. J.P.: Surgery, Investigation, Visualization, Writing - Review & Editing. O.Š.: Surgery, Investigation, Visualization, Writing - Review & Editing. T.V.: Surgery, Investigation, Visualization, Writing - Review & Editing. D.K.: Formal analysis, Supervision, Writing - Review & Editing. J.P.: Surgery, Methodology, Supervision, Validation, Resources, Data Curation, Writing - Review & Editing.


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### Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

## Declarations

### Ethics approval and consent to participate

The work has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) and its later amendments, and in accordance with laws of the country where it was conducted. It was approved by the local institutional ethic committee (Hospital Nove Mesto na Morave Ethic Committee). The patients and their families were informed and gave written informed consent for their enrolment into the study.

### Consent to publication

The patients and their families were informed that data will be submitted for publication. They gave their written informed consent for their personal or clinical details along with any identifying images to be published prior to the submission.

### Clinical trial number

Not applicable.

**Competing interests**
The authors declare no competing interests.

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