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# Reverse sural flap with simultaneous open bone transport in the leg: A novel method

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**Abstract**

**Background:** Successful management of extensive bony and soft tissue loss in the leg is challenging. The authors would like to describe a novel technique of open bone transport used simultaneously with a reverse-flow sural neurocutaneous flap to achieve limb salvage.

**Method:** A 40-year-old male patient had sustained a Gustilo IIIC left proximal tibial fracture with anterior soft tissue loss following a road traffic accident. Open bone transport was performed together with a reverse-flow sural neurocutaneous flap to close both bony and soft tissue defects simultaneously.

**Results:** We faced challenges of soft tissue invagination and over-distraction during the process. They were overcome by employing the K-wiring technique and the Accordion Manoeuvre respectively. The flap remained healthy and the soft tissue defect gradually healed. The bone transport segment was docked with both injury and corticotomy sites showing good bony healing.

**Conclusion:** Open bone transport was successfully employed with a reverse sural flap to achieve limb salvage in this patient. This technique can be considered in patients with significant bone loss and significant anterior soft-tissue defects which are not amenable to free soft tissue coverage due to single vessel runoff and the risk of vascular steal.

**Keywords:** Limb salvage, open bone transport, reverse sural flap, ring fixator, bone loss

## Introduction

Limb salvage in severe open fractures of the tibia remains a challenge. Historically, significant bone loss was treated with primary amputation. With advances in surgical techniques, the decision for salvage against primary amputation remains difficult [1, 3].

Numerous treatment techniques had been described to manage such injuries. Conventional techniques involved intramedullary fixation, autogenous bone grafting and soft tissue transfer. The Ilizarov method of distraction osteogenesis had revolutionised the management of bone loss and deformities [4, 6]. Other techniques of acute shortening and then staged reconstruction, Masquelet technique [7], Papineau technique [8] and use of vascularised free fibular grafts had also been described in the literature.

We would like to report a novel method of open bone transport used simultaneously with a reverse sural flap to manage a patient with significant bone loss and large anterior soft-tissue defect. This technique which involved segmental open bone transport together with the overlying flap cover to achieve concurrent bony and soft tissue coverage has yet to be described in the available literature.

## Illustrative case

A 40-year-old male patient presented with a left lower limb crush injury after a high-velocity road traffic accident. His left lower limb was crushed by the vehicle dashboard for 20 minutes requiring extrication. He sustained a Gustilo IIIC left proximal tibia fracture. The transected popliteal artery was managed with an inter positional reverse saphenous vein graft on the day of the accident by the vascular surgeons with good results.

Multiple soft tissue and bony debridement were performed. The medial femoral condyle Hoffa fracture was fixed first at 1-week post-injury. K-wires were used to hold bony fragments that were deemed viable at the injury site in the initial setting. They were later removed when these bony fragments showed avascularity. The initial bone gap was 65 millimeters (Figure 1). The wound extended anteromedially from the tibial tubercle to the distal third of the tibia and anterolaterally over the proximal third of the leg.

We applied a circular ring fixator to provide initial fracture stability and temporary wound coverage with a negative pressure dressing at 2 weeks post-injury. (Fig. 2)

The initial plan was for limb salvage via the Masquelet technique [7] through a gastrocnemius flap. This was attempted at 3 weeks post-injury after the wound was assessed to be clean and stable. Unfortunately, the gastrocnemius flap was found to be unhealthy 2 weeks after. The proximal aspect of the distal tibial fragment was also devitalised. All dead tissue was resected. Only about a third of the gastrocnemius flap was left.

The patient still had a large anterior soft-tissue defect with a significant portion of the tibia exposed. Some form of flap coverage would be required. Free flap in this case had a significant risk of microsurgical failure given the extensive zone of injury. This left us with very limited options to achieve limb salvage.

Given the adequate reverse sural donor territory posteriorly and the doppler presence of its supplying peroneal perforators, we elected to perform a delayed reverse-flow sural neurocutaneous flap to first cover the exposed bone and then perform open bone transport together with the overlying flap to close the rest of the defect. This was attempted after all necrotic flap has been debrided and no infection ensued at about 6 weeks post-injury.

The external fixator was then extended. A piggyback circular frame planned for bone transport at a later stage was applied to the distal tibia.

The pins for the external fixator were carefully put in place with special attention to avoid superficial sural neurovascular structures and the posterior skin flap. Doppler ultrasound was used to mark out the position of the peroneal perforators and the sural artery pedicle. The distally-based reverse neurocutaneous flap was raised with its sural nerve and rotated anteriorly over the anterior defect to ensure the adequate length and then tagged back to the donor site to train and delay the flap. (Figure 3) Negative pressure wound therapy was applied to the defect.

6 days later, the partially divided flap was transposed to cover exposed bone on the proximal-distal tibia segment (Fig. 3). The donor site was covered with a split skin graft.

Distal tibia corticotomy and fibular osteotomy were performed a week later. This was at around 2 months post-injury. The tibia was acutely shortened to reduce the soft tissue and bony defects (Figure 4). After ensuring that the flap and skin graft are taken and healthy, open bone transport was initiated. A negative pressure dressing was used to cover any open wounds at any point during bone transport.

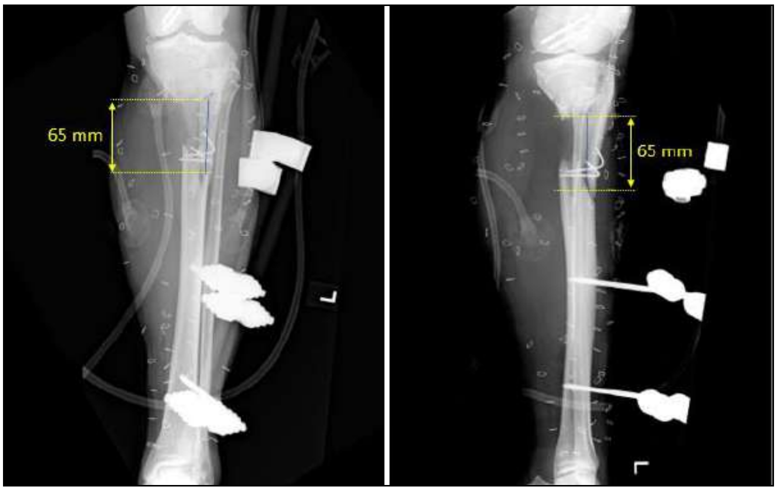



**Fig 1:** Radiograph of the segmental bone defect in the proximal tibia after initial debridement. The bone gap was 65 mm

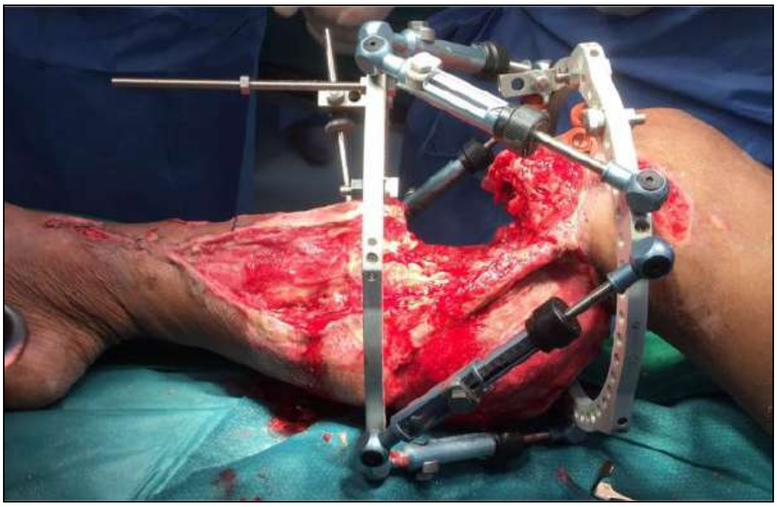


**Fig 2:** Clinical photograph of the wound taken 3 weeks post injury showing the bony and soft tissue defect. Circular external fixator had been applied. Initial plan was for limb salvage via Masquelet technique through a gastrocnemius flap

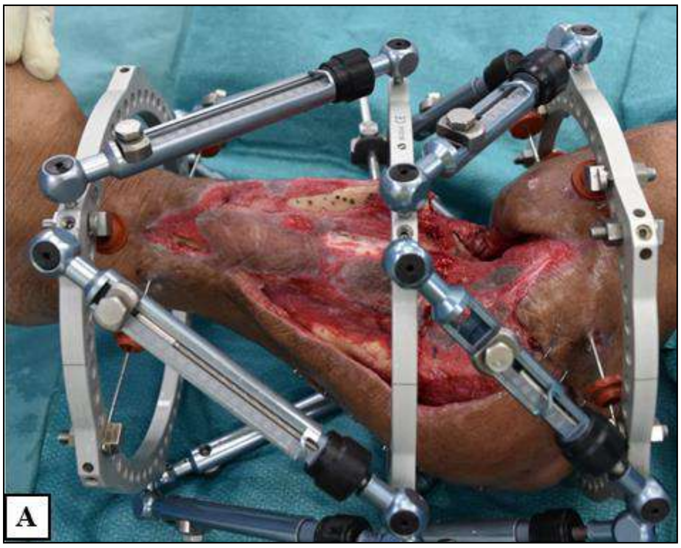



**Fig 3A:** Clinical photograph showing the residual soft tissue and bony defect after debridement of gastrocnemius flap and devitalised tibia. The staged reverse sural flap was raised and tagged back. A piggy back circular frame was applied to the distal tibial segment

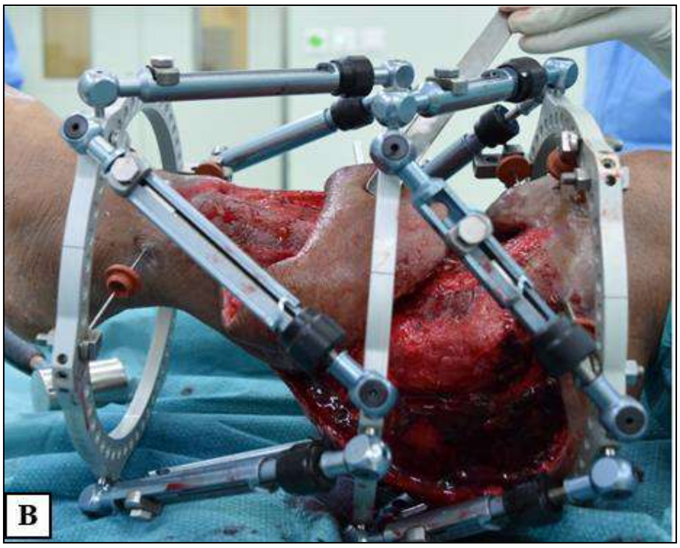



**Fig 3B:** Clinical photograph showing the staged reverse sural flap being transposed to cover the exposed tibia bone on the lateral aspect. the donor site was later covered with split skin graft

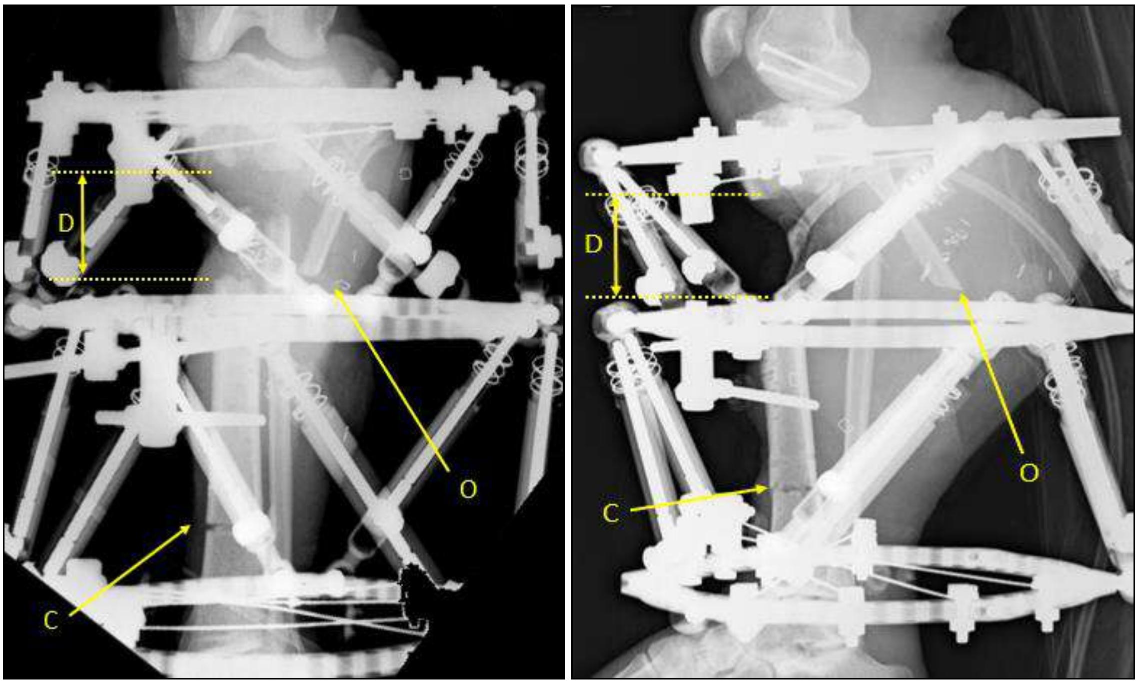



**Fig 4:** Radiographs of the leg showing the bony defect (D), distal tibia corticotomy (C) and fibular osteotomy (O) after acute shortening

**Concept**

The concept of open bone transport is to perform segmental bone transport together with its overlying soft tissue cover. The bony and soft tissue defect will be reduced simultaneously and subsequently closed with the docking of both the bony segment and the overlying soft tissue.

Bone transport was targeted at a speed of 1mm per day. This speed was based on Professor Ilizarov's methodology of distraction osteogenesis [4]. The skin and soft tissue over the corticotomy region were stretched at a similar rate. At the site of the open wound, the soft tissue granulation occurred at a rate of about 1mm per day. (Diagram 1)

**Challenges**

**Over-distraction**

Distraction was controlled by the patient and he was advised to follow treatment targets of 1mm per day. However, due to overzealous distraction, we achieved a distraction of 45mm over 2 weeks, which far exceeded the target of 1mm per day.

This posed 2 problems: poor bone regenerate at the corticotomy site and exposure of bone at the granulation front.

We overcame the first problem by subjecting the corticotomy site to a period of cyclical compression and distraction over a period of 6 weeks. This was following the transformational osteogenesis concept or the Accordion Manoeuvre as described by Professor Ilizarov [9, 10].

The standard protocol for the accordion manoeuvre was not well described [11, 12]. In our patient, each shortening and lengthening phase lasted for 2 weeks at a rate of 1mm per day. This lasted for a total duration of 6 weeks. A foot frame was put on to keep the ankle at neutral during this phase.

The second problem of bone exposure was overcome by mobilising the reverse sural flap again and advanced to cover the exposed proximal bone segment.

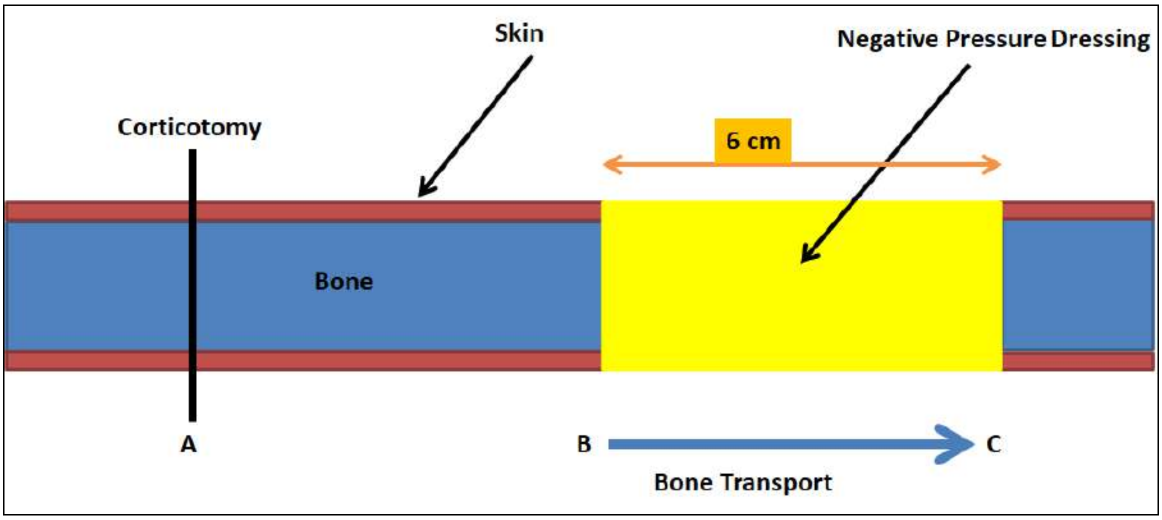
**Soft tissue invagination**

We encountered the problem of soft tissue invagination at the proximal tibia fragment where excess soft tissue overhang into the wound cavity and covered part of the cut surface of the proximal tibia. This would prevent the docking of open bone transport. This problem was encountered due to the delay in docking on the transport segment because of initial over-distraction and need for cyclical compression and distraction.

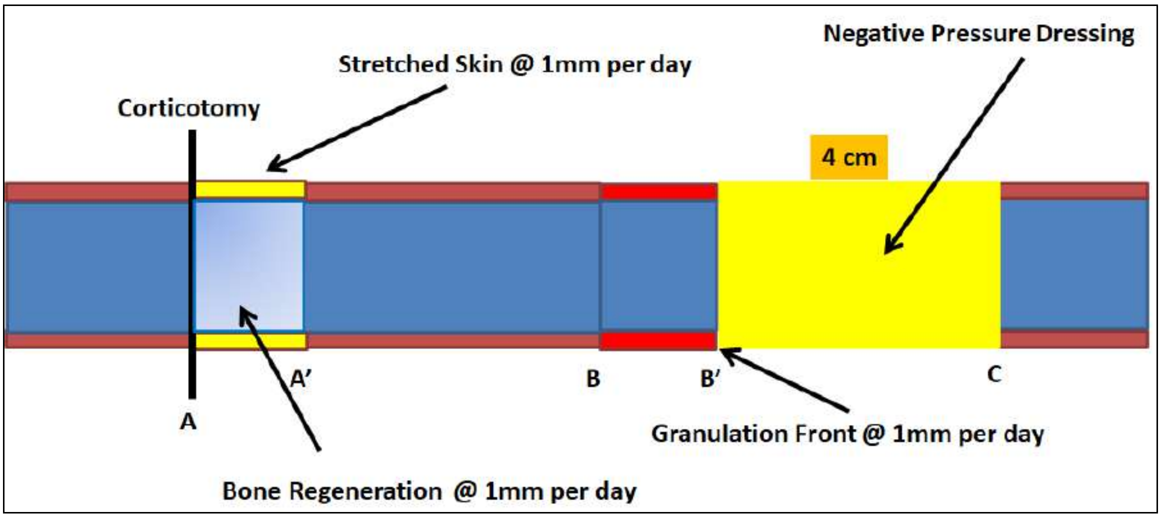
K-wiring technique was utilised to railroad the soft tissue flap away from the bone end. K-wires were inserted into the proximal tibia and fixed to the proximal ring. Because of contracted scarring, a full-thickness midline scar release was necessary to re-elevate the entire soft tissue flap anteriorly and K-wires were used for temporary suspension of the flap. This had helped to preserve the precious soft tissue cover whilst allowing expansion. (Figure 5)

With the resolution of the above challenges, open bone transport was continued until docking of the bony and soft tissue components. The flap remained healthy throughout and the wound reduced markedly in size. (Figure 6) Both injury and corticotomy sites showed good bony healing.

At 1 year the bony regenerate was clearly seen. Length, alignment and rotation had been gradually corrected via the circular external fixator over the period of transport. (Figure 7) The external fixator was removed and internalised with a bridging plate and screws. (Figure 8)




**(A)**

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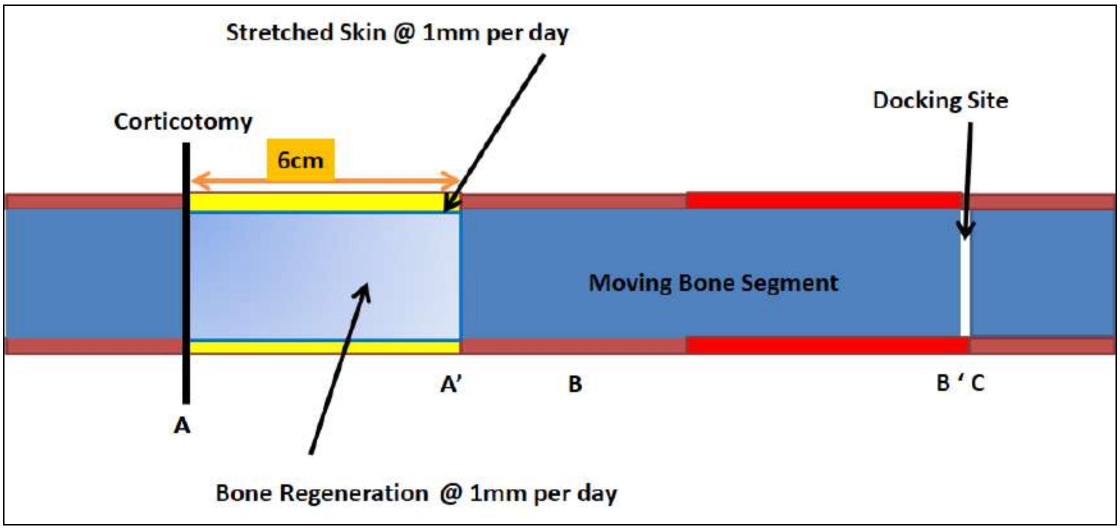


**(C)**

**Diagram 1:** Pictorial representation of open bone transport. A: Corticotomy is performed at site away from zone of injury. B: Bone transport was targeted at a speed of 1mm per day. The skin and soft tissue over the corticotomy region is stretched at a similar rate. At the site of the open wound, the soft tissue granulation occurs at a rate of about 1mm per day. C: Docking of both soft tissue and bony fragment.

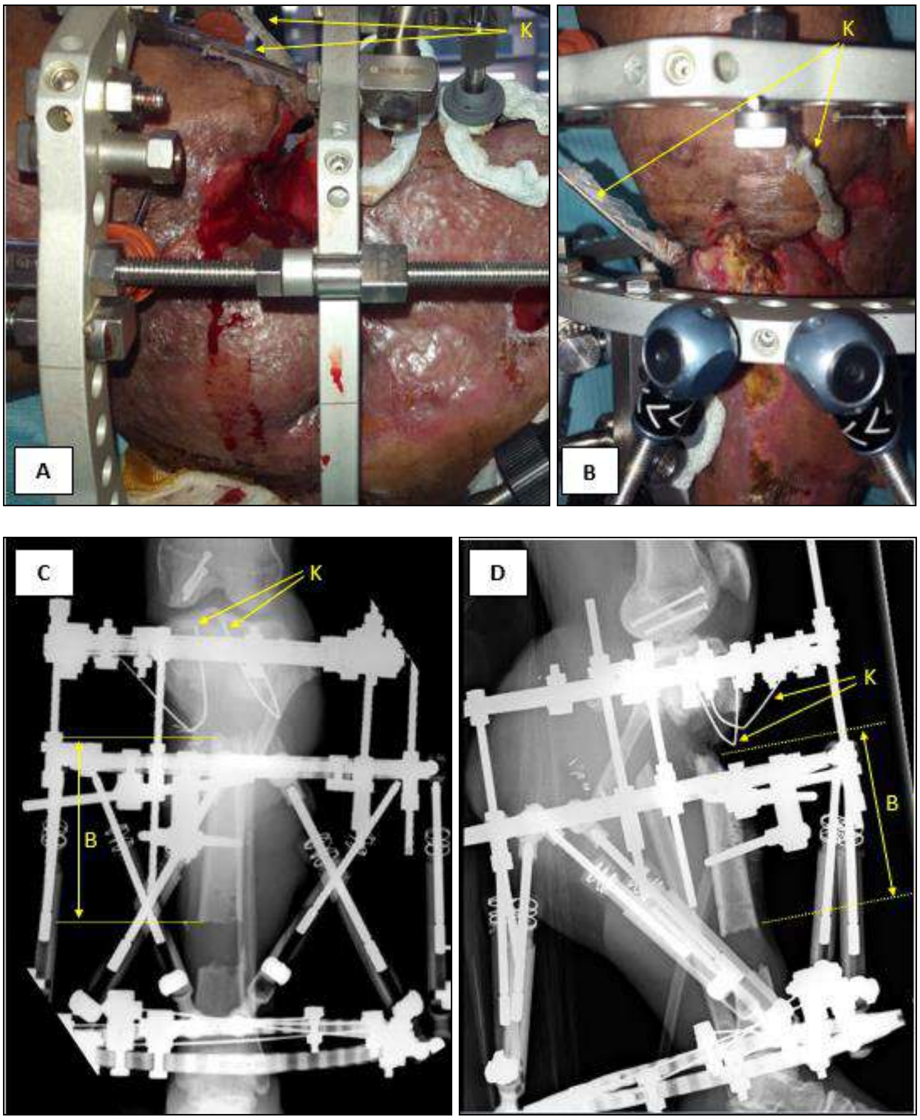


**Fig 5A, 5B:** Clinical photograph showing K-wiring technique being utilised to railroad the soft tissue flap away from the bone end. K-wires (K) were inserted into the proximal tibia and fixed to the proximal ring. In view of contraction, a full thickness midline incision was necessary to raise the entire soft tissue flap anteriorly and then held up with K-wires. Subsequent growth of the flap followed the K-wire path.

**5C, 5D:** Radiographs showing position of the K-wire (K) and the bone transport segment (B).

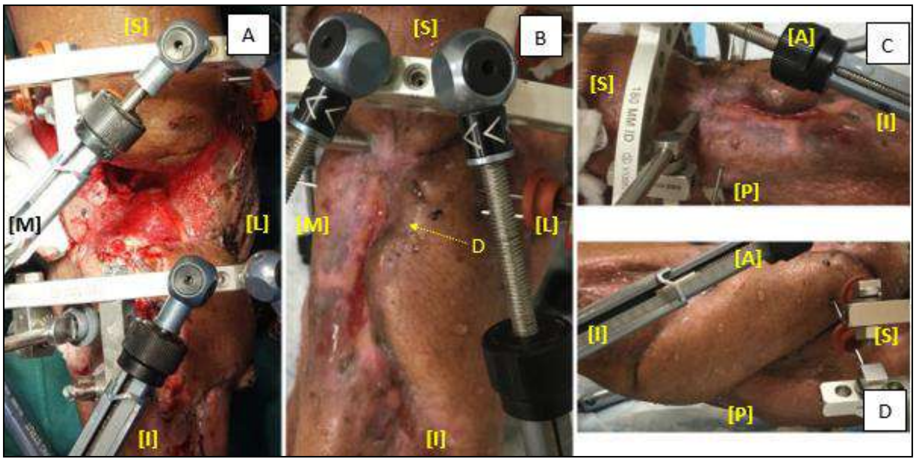


**Fig 6:** Series of clinical photograph showing residual defect after docking. A: Photograph illustrating the initial anterior soft tissue defect with the transposed reverse sural artery flap midway through the bone transport process. B: Photograph showing the same anterior aspect of this defect after docking. D points to tibia docking site. C: Medial aspect of the leg after docking. D: Lateral aspect of the leg after docking. Letters in square bracket indicate perspective of clinical photo. S: Superior; I: Inferior; M: Medial; L: Lateral; A: Anterior; P: Posterior.

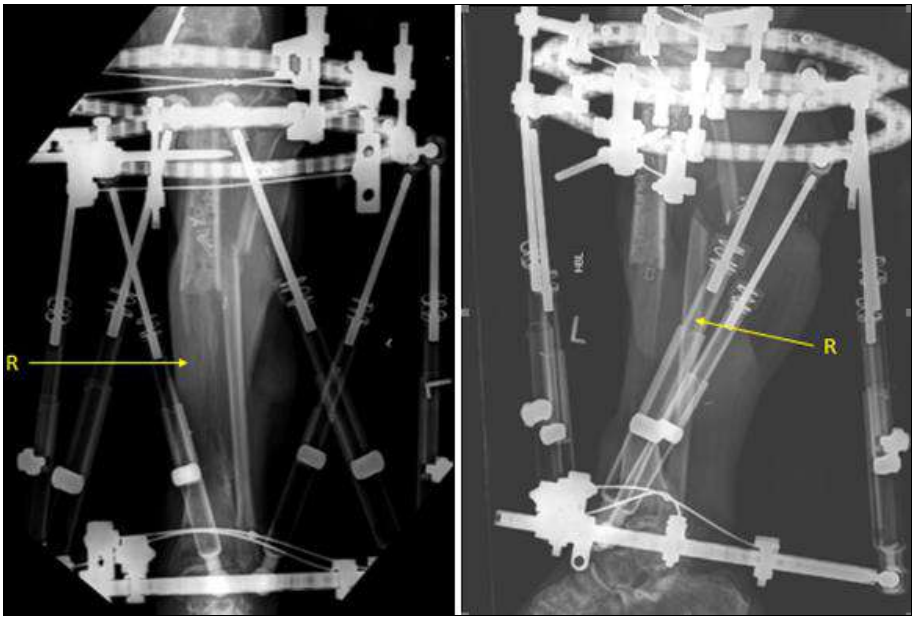


**Fig 7:** Radiographs showing regenerate (R) at 1 year. Length, alignment and rotation had been gradually corrected via the circular external fixator over the period of transport

**Fig 8:** Radiographs showing final internal fixation of tibia post removal of external fixator. Anatomical axis of tibia marked by yellow dotted line

## Discussion

Limb salvage in Gustillo type III open fractures of the tibia remains a challenge [13]. There is no single best method to achieve limb salvage in such injuries. Historically, such injuries with significant bone loss were treated with primary amputation.

Many techniques have been described to salvage such injuries. The conventional technique involved intramedullary fixation, autogenous bone grafting and soft tissue transfer. External fixation offers another option and is the more versatile method for treating these injuries.

The Ilizarov method of distraction osteogenesis has revolutionised the management of bone loss and deformities [4, 5, 14]. The pre-requisite for bone transport is first to have stable fixation at the fracture site. Low energy corticotomy is performed followed by 5-7 days of latency. A distraction rate of 1mm per day is most optimal and should be achieved in 3-4 divided increments per day [4, 6]. There has been much success in achieving limb salvage with bone transport in compound tibial fractures and bone defects [15-18].

Many techniques and adjuncts based on this principle have been described in the literature to increase the chances of limb salvage.
Acute shortening and then staged re-lengthening and reconstruction has also been described [19, 20]. This method can be considered as an advancement of a large vascularised osteocutaneous flap to close the bony and soft tissue defect [19]. The recommended safe limit for acute shortening has been described to be 3cm to avoid neurovascular compromise. Beyond which, defects should be closed gradually [21, 22].
Masquelet technique [7] has gained popularity in the management of bone loss. It involves a 2-step surgical procedure. The first step involved the introduction of a cement spacer in the bone defect followed by the reconstruction of soft tissue. The second step was for interval removal of the cement spacer that had been encased in an induced membrane and filling the defect with bone graft. This technique is effective in achieving bony union [23].
The use of vascularised free fibular grafts has also been described in the literature, though its utilisation has been less common compared to prior mentioned techniques [24, 25].
The Papineau technique first described in 1973 was another staged technique described for treating infected non-union of long bones [8]. It involved initial surgical debridement of necrotic tissue, temporary stabilisation, antibiotic therapy and regular wound dressing. The next step is for the packing of bone defect with autograft. The final step involved soft tissue coverage with a flap or healing by secondary intention. A modern modification has been described with the use of negative pressure dressing [26]. This modern twist has been reported to treat patients successfully with severe open tibial fractures with bone defects [27-29].
Open bone transport had been described by Rozbruch *et al.* [30] They described this technique in patients with significant bone and soft tissue defect and were not candidates of flap coverage. Circular external fixator was used to gradually close the bone and soft tissue defect simultaneously. The majority of wounds in the series were only covered with clean gauze during transport.
In a more recent study by Li *et al*. [31] which included 13 cases were managed with open bone transport. Wounds in this series were covered with negative pressure dressing and aggressive regular dressing and nursing of the wound followed. They described challenges of thin skin formed by traction and sinking of skin with bone migration.
Our technique combines the use of open bone transport together with regional flap coverage. The soft tissue defect in our case was rather extensive with exposed bone. Hence some form of soft tissue coverage was necessary. A free flap was not considered because of high microsurgical failure risk from thrombosis and vessel damage given the extensive zone of injury. The presence of the circular fixator would also make access for free flap microsurgery difficult.
With the failure of the gastrocnemius flap, we had limited options and a reverse sural flap was chosen as it was the only reliable regional flap that was sufficient to cover a large anterior defect and the exposed tibia bone. Open bone transport was then carried out with the overlying flap to achieve limb salvage.
The reverse sural artery neurocutaneous flap was first described by Masquelet *et al*., in 1992. It was based on arteries accompanying the sural nerve and their anastomoses with the peroneal artery in the posterior midline of the calf [32]. The staged procedure for the reverse sural flap improves the blood supply of the flap by opening up choke vessels and increasing perfusion to the most distal part of the flap [33]. This minimizes the risk of flap necrosis. This flap spares the major arteries of the limb.
The reverse sural flap was also a good regional coverage option when working around a frame [34-36]. Pre-operatively, pedicle vascularity was ensured with a doppler ultrasound. Great care was taken preoperatively to avoid piercing the posterior calf, which would compromise the flap. The flap inset was staged and divided 6 days later to reduce the risk of flap tip necrosis. These technical details were crucial in the success of the flap. This was a robust flap that allowed manipulation 6 weeks after it was raised to be further advanced to cover a new area of defect.
We did not experience the skin complications as encountered by Li *et al*., [31] at the traction segment even with over-distraction of the fracture site. The Accordion Manoeuvre was performed following the concept of transformational osteogenesis as described by Professor Ilizarov in our patient [9, 10]. Other than the overhang of soft tissue at the proximal wound site, we did not encounter other skin or soft tissue complications at the distraction site.
The use of K-wires to redirect soft tissue flap growth had not been described in the literature. The proximal soft tissue flap had ingrown into the tibial bone defect as part of the body's healing process. By re-elevating the flap and temporarily suspending with a stiff K-wire scaffold, the thick proximal granulation flap was successfully redirected to allow expansion and docking of the bone ends.
The drawback of our technique was the duration taken to achieve union. This was also partially contributed by initial over-distraction and the need to stimulate the healing of the regenerate. The patient did not encounter significant wound infection or osteomyelitis throughout the course of the transport.

**Conclusion**

This was a challenging case of limb salvage in a Gustilo IIIC tibial fracture with a complex osteoplastic defect. Open bone transport was successfully employed with a reverse sural flap to reduce the soft tissue and bony defect in our patient. This technique can be considered in patients with significant bone loss and with huge overlying soft tissue defect not amenable to once-off soft tissue coverage. In cases where free flaps are not feasible, the reverse sural flap can be considered as a workhorse in the lower limb.

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