



Original Article

How to perform minimally invasive tibial cortex transverse transport surgery

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ABSTRACT

Background/objective: The tibial cortex transverse transport (TTT) surgery has been reported for the treatment of severe diabetic foot ulcers with satisfactory clinical outcomes. TTT surgery can effectively regenerate the microvascular network in the lower limbs of these patients to promote ulcer healing and increase the chance of limb salvage.

Methods: In this report, the authors provide a technical guide to perform minimally invasive TTT surgery through the use of a specially designed external fixation frame and tibial corticotomy guide plate.

Results: This minimally invasive technique utilizes smaller skin incisions and preserves the local blood supply.

Conclusion: Our minimally invasive TTT surgery technique is a simple procedure that significantly increased the efficacy and reduced the complications of TTT surgery.

The Translational potential of this article: This report provides a step-by-step guide on how to perform minimally invasive TTT surgery. The use of specially designed external fixator and corticotomy guide plate are the key factors for a reproducible and successful TTT surgery. This report will serve as a reference guide for surgeons to perform TTT surgery.

Background

Diabetic foot ulcer (DFU) is a severe complication of diabetic mellitus, which is associated with high mortality and high cost [1,2]. Severe DFU are often deep and large and frequently complicated by cellulitis, osteomyelitis and gangrene. Although endovascular procedure and bypass surgery are the current standard treatment for ischemia foot ulcers, 40% of DFU patients with severe limb ischemia cannot meet the requirements for these options [1,2]. Nearly 90% of severe DFU patients at Wagner III above unfortunately end up with amputation of limb due to failure responses to conventional treatments [3, 4]. For patients with ulcers successfully treated by conventional treatments, the recurrence rate is about 40% within 1 year, and 65% within 5 years [5]. Therefore, better, novel, cost-effective treatments are needed to promote the healing of DFU and increase the rate of limb salvage.

Tibial cortex transverse transport surgery (TTT surgery) is based on Ilizarov's law of tension-stress, which states that slow and gradual

distraction of bone activates and enhances the regenerative potential of living tissues. This technique provides a new alternative for treating chronic diabetic foot ulcers and peripheral vascular disease [6, 7]. Clinical studies have shown that the TTT technique can induce microvascular network regeneration in the lower extremity of diabetic patients and significantly reduces the overall risk of diabetic foot ulcer complications, especially the rate of amputations [6]. However, the TTT method has not yet been utilised as a mainstream treatment and there is still a lack of mechanistic studies. To date, there is no detailed technical report on how the TTT surgery is performed.

In the early days TTT surgery was carried out without proper guideline and standards, involving a relatively big cortex window on the tibia shaft and using assembled external fixators that were not purposely designed for TTT surgery, hence the incidents of skin necrosis at the treatment area, tibial shaft fracture and lack of patients' cooperation were sometimes encountered, which prevented the wider acceptance of

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employing TTT surgery in DFU management [8]. The authors describe here how to perform TTT surgery with mini-incisions and a smaller tibial cortical window (5 cm long x 1.5 cm wide), with a specially-designed external-fixator frame for cortical bone chip transverse transport (movement). The authors will describe the surgical technique of TTT.

Step-by-step surgical instruction for transverse tibial transport surgery

1. Patient Selection

Patients with severe DFU who meet the following criteria: (1) Wagner III and above, who received standard therapy over 2 months with no obvious improvement. (2) The patients shall have at least one anterior or posterior tibial artery still present and functional. (2) No other medical conditions that affect the surgery and patient cooperation. For more details of the patient's selection, standard treatments before TTT surgery, etc. please consult the newly published Chinese Association of Orthopaedic Surgeons (CAOS) clinical guideline for the treatment of DUF using TTT technique [8].

2. The Protocols of TTT Surgery

The minimal invasive TTT surgery is performed using a specially-designed external frame together with tailor-designed guide metal plate. The recommended surgical protocols are just published in Chinese Association of Orthopaedic Surgeons (CAOS) clinical guideline for the treatment of diabetic foot ulcers using tibial cortex transverse transport technique (Version 2020) [8]. For the details of the step-by-step surgical protocols of TTT surgery, please consult the above guideline paper [8].

Here we provide a step-by-step visual guide on how the minimally invasive TTT surgery is performed through a series of illustrations as follows:

Fig. 1 illustrated how the corticotomy site was chosen, positioned and the cortex window corticotomy was performed using a specially-designed external frame together with tailor-designed guide metal plate in step-by-step fashion [Fig. 1].

Fig. 2 showed the x-ray examination during the TTT surgery that confirms the position of the cortex window and the completion of the corticotomy [Fig. 2].

Fig. 3 showed that how the purposely designed external fixator for TTT surgery was applied properly; the detailed locations of the small incisions used for the corticotomy were also shown [Fig. 3].

Fig 4 showed how the wound shall be dressed following TTT surgery, which was also important to prevent potential infections at the surgery and pin sites [Fig. 4].

3. Postoperative Management and Outcome Assessment

The recommended protocols for postoperative management and outcome assessment following TTT are just newly published in Chinese Association of Orthopaedic Surgeons (CAOS) clinical guideline for the treatment of diabetic foot ulcers using tibial cortex transverse transport technique (Version 2020) [8]. For the details of these protocols please consult the above guideline paper [8].

Discussion

Chen Y et al. have reported the use of TTT surgery for management of severe DFU with remarkable clinical outcomes [6]. By 6 months, a higher proportion of ulcers healed in the TTT group than the control group (93% versus 41%); at 2 years' follow up, only 2.9% patients in the TTT treatment group had amputation and recurrences in contract to 23% (amputation) and 17% (recurrences) in the control group respectively [6]. The TTT surgery has significantly promoted angiogenesis by increasing the density of small vessels and the blood flow which was evident by quantitative measurements 3 months after the surgery. Hence the TTT surgery is a novel method to enhance healing and limb salvage as well as decreasing the recurrence of severe DFU [6].

For the TTT surgery protocol, Chen Y et al. reported the following procedures: (1) A 4-cm medially curved incision was made 1 cm from the tibial crest and 2 cm distal to the tibial tuberosity. (2) The soft tissue was retracted with blunt dissection and the periosteum was exposed; (3) Corticotomy was performed by drilling multiple holes in a rectangle (5 cm × 1.5 cm) in one side of the cortex. (3) After osteotomy, two 3-mm drill holes were made in the osteotomized cortex followed by the insertion of two anchor pins (through two cortices) to stabilize the external frame. (5) The holes were connected by osteotome to separate the piece of cortex from the tibial shaft. We found the procedures described above are difficult to follow and there are some serious concerns as followings: (1) The skin cut: the curved 4-cm skin cut is necessary to allow the drillings for the corticotomy on the cortex. Despite the careful dissection, it is inevitable to damage most of the periosteum covering the piece of cortex which will be drilled around. Therefore, the piece of corticotomized cortex was severely deprived periosteal and subcutaneous tissue blood supply and the only blood supply left (which in theory is for the inner 2/3 cortex) is from intramedullary arterial branches. However, during the corticotomy procedure, an unexperienced surgeon may cut the piece of cortex off from the tibial shaft and the cortex flap becomes freely moveable, which could seriously (if not completely) destroy the only remaining blood supply from the intramedullary source. Thus, the reported procedure although worked well in the hands of experienced surgeons as reported by Chen Y et al. [6, 7], it may lead to potential risks

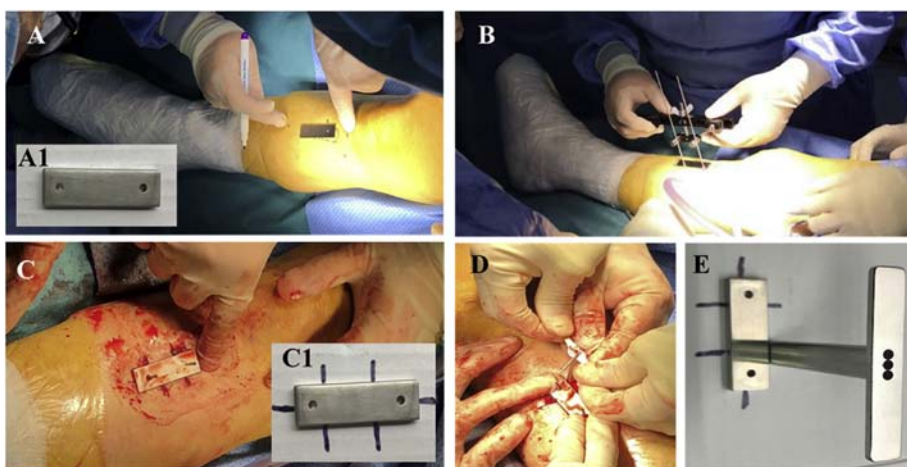


Figure 1. Illustration of the surgical procedures for TTT surgery. **A.** The guide plate is used as a guide to position the corticotomy site at the medial side of the tibia, 5 cm below the tibial tuberosity, right in the middle line. **A1.** The metal guide plate, 5 cm long, 1.5 cm wide, with 2 holes (3 mm in diameter). **B.** Use the external fixator as a reference to make sure the guide plate is placed at the center of the tibia and insert the two half-pins into the guide plate holes. **C.** The guide plate is secured in place by the two half-pins penetrated through one side of the tibial cortex. Six 1-cm cuts are then made perpendicular to the guide plate at all sides. **C1.** Illustration to show where and how the small skin cuts are made around the guide plate. **D.** The drilling jig is then inserted into the skin cut and drill holes continuously to connect around the guide plate. **E.** Illustration to show how the drill jig is used to drill multiple holes around the guide plate. The drilling jig has 3 connecting holes, each hole has a diameter of 3 mm.

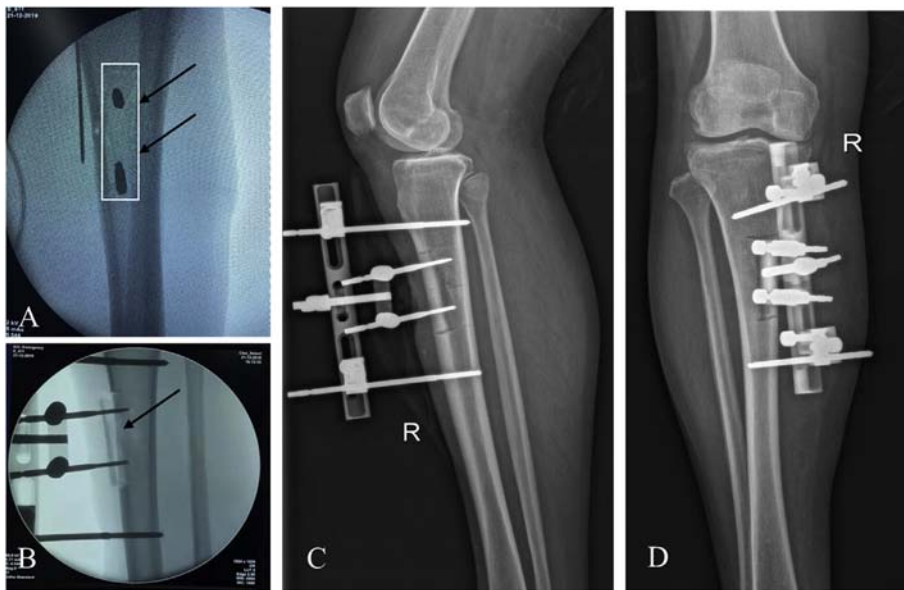


Figure 2. A. X-ray is taken during the surgery to check the guide plate position and make sure it is at the middle of the proximal tibia and the other two anchor half-pins should also be on the middle line of the tibia. B. After the corticotomy is completed, take an X-ray to check if the corticotomised cortical piece can move with the external fixator. C (Lateral view) and D (Front view) of x-ray before the cortex transverse transport starts, showing the position of the two anchor pins (through two cortices) and the two pins at the corticotomy site (through one cortex).

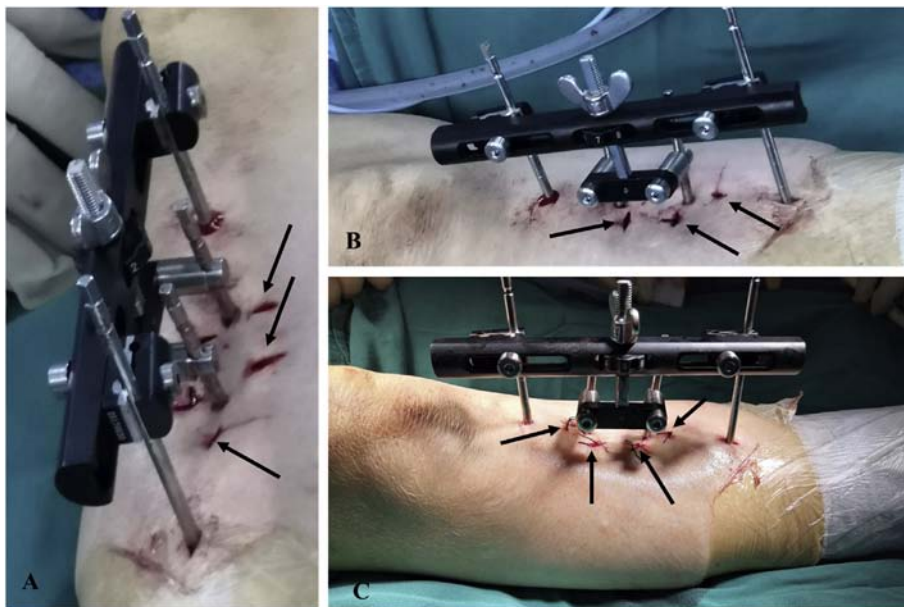


Figure 3. Photos showing the apparatus for tibial cortex transverse transport in place. A. Longitudinal view of the external fixator in place during surgery, the arrows show the 1-cm cuts that have been made around the guide plate. B. Lateral view to show how the external fixator is put in place, the arrows show the skin cuts from where the drilling jig was used to make multiple holes around the guide plate and the corticotomy. C. Lateral view to show the external fixator position when the surgery is completed, arrows show that all the 1-cm skin cuts have been closed with one single suture each.



Figure 4. Photos showing when the TTT surgery is completed. A. Photo shows the position of the external fixator and how the foot is covered during the surgery. B–D. Photos at various angles to show how the wound shall be dressed after the TTT surgery. The entire wound area shall be covered with two large self-adhesive thick gauzes, cuts are made at the edge of the gauzes to cover around the pins, and all pin holes should be covered as shown. The dressings shall be changed 12 hrs after surgery and then daily.



Figure 5. Serial images to show the healing of a severe DUF patient after TTT surgery. **A.** A 62-year old female with Wagner III DUF, the foot ulcer appearance before the debridement. **B.** The ulcer wound appearance after debridement; the wound was pale and no sign of healing 1 week after debridement (above), and the appearance at the operation table right after the TTT surgery (below). **C.** 1 week after TTT surgery, there was fresh and healthy granulation tissues formation at the wound site, the patient reported warm feeling at the foot and reduced pain. **D.** 2 week after TTT surgery, size of the wound reduced to almost half of the size before surgery, the patient was very happy and encouraged to eat nutritious foods to aid healing. **E.** 4 week after TTT surgery, the wound was completed closed and healing went well, dressing was changed daily with only warm saline gauzes to keep the wound moist. **F.** 6 week after TTT surgery, the wound was completely healed, the external fixator was removed and patient discharged, she could partially weight bear the foot and was very happy with the results.



Figure 6. A case of TTT surgery performed on the contralateral limb that promoted DFU healing on the other limb. **A.** 62-year old male with diabetes for over 4 years, who developed skin ulcer on the lower left tibia that persisted for more than 1 month. Because the skin condition on the left tibia was very poor, and it has potential infection risk, the TTT surgery was therefore performed on the right tibia with patient's full consent. **B.** Close up image shows the skin ulcer size which was 2×2 cm at the time of surgery. **C.** 1 week after the TTT surgery, 4 days after the transport started, the ulcer size reduced to 1×1 cm. **D.** Photo shows both legs at 4 weeks after TTT surgery, the size of the ulcer was further reduced. **D1.** Close up image shows the skin ulcer size which was 0.5×0.5 cm at 4 weeks after TTT surgery. **E.** At 6 weeks after the TTT surgery, the ulcer on the left tibia was completely healed and the external fixator on the right tibia was removed.

of skin necrosis at the surgery site, delayed or non-union of the piece of corticotomized cortex for beginners of TTT surgery. (2) The way to perform corticotomy: according to the published TTT protocol, the corticotomy is formed using multiple holes drilling on the cortex free-handed, which is quite difficult to operate for beginners. Even for an experienced orthopaedic surgeon, to drill multiple holes in a line free-handed on a slippery surface is a challenge. The heat and torque forces generated during the drilling will damage the periosteum all around the cortex piece. If the multiple holes were misaligned, it may cause fracture to the cortex piece during later pin insertion or osteotome cut. There are real concerns that we and other surgeons encountered during the TTT surgery following the previous published protocols [6] and here we reported a modified TTT surgery procedures to make the surgery easier to perform for beginners.

In our protocol, we use a modified external fixator with a custom-designed drill guide to accurately position the frame and the site of corticotomy. As shown in Fig. 1A, the drilling guide represents the exact size of the corticotomized piece, using this and the external fixator together as guides, it is easy to position the correct site for the corticotomy. Our guide plate is designed as such that the two holes on it match with the two central pins for the external fixator, so that the two half-pins inserted through these two holes will be used to move the corticotomized cortex piece later (Fig. 1B). Thus, we insert the two half-pins using the guide plate through one side of cortex first, which completely avoids any

risk of fracture or misalignment. For the skin cuts, we make several 1-cm skin cuts using sharp knife perpendicular to the guide plate at all sides as shown in Fig. 1C. Thus, we have maximally preserved the subcutaneous tissue blood supply to the corticotomy piece, and the perpendicular cuts to the guide plate means that the effects on skin cut healing was minimal during the bone transport, further reducing the risk of skin necrosis that may cause by longitudinal cuts and excessive tension during bone piece transport (Fig. 1C). For the corticotomy, we have used a custom-designed drilling jig, with three drilling holes (each hole has a 3 mm diameter) joined together as shown in Fig. 1E. The guide plate is used as a ruler, which is already secured in place by the two half-pins already. Through the 1-cm skin cuts, we put the drilling jig on top of the periosteum, and drill the first uni-cortical hole using the jig. Then insert a 2-mm K wire through the first hole to keep the drilling jig in position and drill the rest of the two holes using the drilling jig as shown in Fig. 1E. When completed the 3rd hole, insert another 2-mm K wire, remove the first K wire from the first hole, then rotate the drilling jig around the inserted K wire and continue to drill the holes all around the guide plate in the same fashion. Hence, drilling on the cortices in our protocol is much easier, reproducible and faster and there is no need to worry about the position and fracturing the cortex piece at all.

The main innovation of our TTT surgery protocol are: (1) accurate positioning using the guide plate and (2) mini-skin cuts for corticotomy using multiple drilling jig. The use of a specially designed external fixator

with pairing guide plate and jig, makes the protocol user friendly and easy to standardize and promote TTT surgery. The small size corticotomy (5×1.5 cm) in our procedure is the same as this recent report [6], and this has further reduced the rare risk of tibial shaft fracture, yet it is sufficient to promote the microcirculation and angiogenesis. Most of the patients have immediate relief of pain, fresh granulation tissue formation within 1–2 weeks after TTT surgery, the wound healing is rapid comparing to conventional treatments, and almost all can heal without further medication or intervention except regular dressing changes as shown in Fig. 5.

Currently, it is well recognized with clinical and laboratory evidences that TTT surgery could effectively promote angiogenesis [6] and may also enhance systemic recruitment of healing stem cells and modulate local inflammation status. We report one case who had a recurrent and slow healing diabetic ulcer (2×2 cm) in the left tibia for over a year, and due to the poor soft tissue conditions in the left tibia, we performed TTT surgery on the contralateral right tibia [Fig. 6A]. Interestingly, the size of the ulcer in the left tibia also reduced to 1×1 cm at 2 weeks [Fig. 6B and C]; 0.5×0.5 cm at 4 weeks [Fig. 6D] and completely healed at 6 weeks [Fig. 6E]. This case suggested that TTT surgery has systemic effects in promoting regeneration and may be applied to the contralateral limb to promote diabetic ulcer healing when the local conditions did not allow the surgery on the diseased side. The exact underlying mechanisms on its systemic effects still need further investigation.

Conclusion

In this technical report we provided a step-by-step visual guide on how to perform minimally invasive TTT surgery, which is modified from the reported TTT surgery protocol. The use of purposely designed external fixator and tailor-made corticotomy guide plate are the key factors for a reproducible and successful minimally invasive TTT surgery. Of course the current protocol is still subject to further refinement and improvement with continuous endeavor and enthusiasm from the colleagues in the field, to promote TTT surgery for the benefit of diabetic and other patients worldwide.

Conflict of Interest

The authors have no conflict of interest to disclose in relation to this article.

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