Four cases of abdominal expander implantation in adult chronic osteomyelitis of lower extremity with soft tissue defect and literature review

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Abstract
In this study, we intend to explore the clinical efficacy of abdominal expander implantation combined with flap technique in adult chronic osteomyelitis of lower limb with soft tissue defects, and to provide the basis for the promotion of the technique in clinical practice. Four patients diagnosed with chronic osteomyelitis of lower extremity with soft tissue defect were enrolled in this prospective study. Evaluation indicators included state of flap survival, state of abdominal incision, surrounding of abdominal wound scar, satisfaction of the patient, state of flap survival half a year after surgery, whether the 3D prosthesis is successfully implanted and limb movement. Four patients had complete flap survival, two of whom had a small amount of skin graft survival disorder in the vascular pedicle area, which improved after 1 month of dressing change. The expander had an average expansion time of 31.5 days, an average water injection of 525 mL, and an average skin volume taken of 159 cm². No incision exudation, incision dehiscence, subcutaneous exudate and other complications occurred. The mean Vancouver Scar Scale score at 3 months after surgery was 3.5 (range from 3 to 6) points. Four patients showed good flap survival at six-month follow-up. 3D printed prosthesis were all successfully implanted. The treatment of adult chronic osteomyelitis of lower extremities with lower abdominal implantable expander combined with flap technique can effectively increase the skin harvesting area, reduce the suture tension of abdominal skin harvesting area and the scar hyperplasia of abdominal skin harvesting area.

Keywords
chronic osteomyelitis, expander, lower extremity, soft tissue defect
Key Messages
- Chronic osteomyelitis is a recurrent and persistent infection, with a higher incidence in lower limb bones such as tibia and femur.
- Achieving effective wound coverage is a difficult clinical problem in the treatment of chronic osteomyelitis.
- Our study aimed to explore the clinical efficacy of abdominal expander implantation combined with flap technique in adult chronic osteomyelitis of lower limb with soft tissue defects.
- The treatment of adult chronic osteomyelitis of lower extremities with lower abdominal implantable expander combined with flap technique increases a time of abdominal surgery,
- It can effectively increase the skin harvesting area, reduce the suture tension of abdominal skin harvesting area and the scar hyperplasia of abdominal skin harvesting area, and improve the possibility of free skin graft survival.

1 | INTRODUCTION

Chronic osteomyelitis is a recurring persistent infection,\(^1\) with a high incidence of lower extremity bones such as tibia and femur.\(^2\) The incidence of this kind of infection within 3 months of open fractures has been reported to be as high as 27% and the incidence of chronic osteomyelitis in adults is increasing year by year.\(^3\) Chronic osteomyelitis is characterised by low-grade inflammation, dead bone formation, new bone attachment, and fistula formation,\(^1,4\) and the clinical treatment is mainly focused on controlling infection, filling dead space, and repairing local bone and soft tissue defects.\(^5,6\) Achieving effective wound coverage is a clinical challenge in the treatment of chronic osteomyelitis. With the development of microscopic techniques, the design of various flaps has been continuously improved. Commonly used flaps for chronic osteomyelitis of the lower extremity include gastrocnemius trophic flap,\(^7\) anterolateral thigh flap,\(^8\) peroneal artery perforator flap,\(^9\) posterior dilated arterial perforator flaps,\(^10\) and ilioinguinal flaps.\(^11\) Although studies\(^12\) have shown that skin flaps, myocutaneous flaps and omentum transplantation can effectively repair complex wounds of the lower extremities caused by a variety of reasons. However, the secondary wounds after flap transplantation for chronic osteomyelitis of lower extremities often cannot be sutured directly, and skin tissue needs to be transplanted. In breast plastic surgery, tissue expanders have been maturely used, which can effectively expand skin tissue. The skin of the ilioinguinal area is loose, elastic, and hidden. There is only a linear scar after skin extraction, and no large area of patchy scars will be left, which is more friendly to the skin extraction area. The full-thickness skin of the ilioinguinal region is not prone to contracture and has good shape and texture, and is often the first choice for free skin grafting for secondary wounds of the lower extremities. If the expander can be implanted in the patient's ilioinguinal region during the first debridement, the skin extraction area can be increased to some extent by rapid dilation.

Herein, our study aimed to explore the clinical efficacy of abdominal expander implantation combined with flap technique in adult chronic osteomyelitis of lower limb with soft tissue defects, and to provide the basis for the promotion of this technique in clinical practice.

2 | MATERIALS AND METHODS

From June 2020 to June 4, 2021 patients diagnosed with chronic osteomyelitis of lower extremity with soft tissue defect in our hospital were enrolled in this prospective study. This study protocol was formulated in accordance with the requirements of the Declaration of Helsinki of the World Medical Association. This study was approved by the ethical committee of our hospital. Written informed consent was obtained from each subject prior to participation.

2.1 | Inclusion and exclusion criteria

Inclusion criteria: (a) Age \(\geq 18\) years; (b) Definite diagnosis of lower limb chronic osteomyelitis with bone defects; (c) Impaired incision closure after bone cement or 3D printed prosthesis placement, with varying degrees of local soft tissue defects; (d) Abdominal expander placement time \(\geq 1\) month;

Exclusion criteria: (a) Chronic osteomyelitis in acute inflammatory phase; (b) other causes of local soft tissue wounds or defects, such as skin and soft tissue malignant tumours; (c) other causes of bone defects, such as bone tumours, bone tuberculosis, etc; (d) accompanied by
serious complications such as grade IV heart failure, severe immune dysfunction; (e) missing follow-up data;

2.2  |  Treatment protocol

All surgical procedures were performed by the same senior plastic surgeon, and all the perioperative care was done by the same medical team.

According to the evaluation of the senior plastic surgeon, once the following indications for the implantation of the expander were met, the ilioinguinal area expander was placed simultaneously with debridement. First, the tissue defect wound cause closure disorder; Second, it is necessary to replace the hyperplasia scar tissue which can affect the implant placement; Third, at the first debridement, extensive soft tissue motility is poor, which is expected to lead to impaired wound closure. The expander (cylindrical expander, C400, 400 mL, Guangzhou Wanhe Plastic Materials Co., Ltd.) was implanted through an incision of about 3 to 4 cm above or below the anterior superior iliac spine, the skin and subcutaneous tissue were sharply cut to determine the level of dissection, and the subcutaneous dissection was performed by a combination of blunt and sharp instruments. Immediately after the implantation was finished, 80 to 120 mL of water was injected; Then the rapid expansion method with water injection every other day was used, and the volume of 15%–20% of the capacity of the expander was injected at each time. The specific amount of water injection is determined according to the tension and colour of the expanded skin. Until the wound conditions were suitable for flap transplantation, the expansion period was terminated. The flaps selected for this study included gastrocnemius neurovascular flaps and perforator flaps. The full-thickness skin was appropriately cut and transplanted freely on the secondary wound. Diffuse gauze bandages were performed. If necessary, plaster brackets were given for fixation and immobilisation.

Debridement: normal saline was used to wash the wound surface, and throat wipes were scratched to obtain wound secretion and were sent for bacterial culture and drug sensitivity test. Incision secretion, pus and other samples were taken multiple times in strict accordance with the “Specifications for the Collection of Samples for Clinical Examination.” The culture methods included identification of general bacterial and fungal smear, culture and drug sensitivity test of general bacterial and fungal, culture and drug sensitivity test of anaerobic bacteria and aerobic bacteria. Samples were submitted for culture within 2 hours after collection. Subsequently, after samples were submitted, a 50 mL syringe was used with a needle to pressurise and flush the gap between internal fixation and tissue, a large amount of normal saline, 3% hydrogen peroxide and 2.5% iodophor were used to repeatedly flush the scratched wound surface and removed the necrotic or infected tissue. 2.5% iodophor solution was used to immerse the wound surface for 10 to 15 minutes. Vacuum sealing drainage (VSD) (size 15 × 5 cm/15 × 10 cm, Wuhan Weidi Medical Technology Co., Ltd.) was placed in the wound. Debridement surgery was performed at intervals of 5–14 days according to the degree of wound cleanliness.

2.3  |  Data collection and evaluation indicators

General information: Gender, age, BMI, operative information, wound condition, etc.

Evaluation indicators: State of flap survival; State of abdominal incision healing, including infection, haematoma, incision dehiscence, etc. Generally, wound infection and dehiscence occur about 11 days after surgery. Surrounding of abdominal wound scar, which was evaluated by Vancouver Scar Assessment Scale the abdominal scar 3 months after surgery; Satisfaction of patient; State of flap survival half a year after surgery; whether the 3D prosthesis is successfully implanted;

Lower Extremity Functional Scale (LEFS) was used to evaluated the functional status of lower limbs. The LEFS score includes daily life (including 6 items), stationary activity (including 4 items), motor activity (including 4 items), and heavy physical activity (including 6 items), with a total of 20 items in 4 dimensions. Each item is scored from 0 to 4 points, with a total score from 0 to 80 points. The score indicates better lower limb function.

2.4  |  Statistical analysis

All the data collected in this study were analysed using SPSS 20.0 software. Normally distributed measurement data were expressed as mean (range from minimum to maximum), while non-normally distributed measurement data were expressed as median (interquartile range), and the comparisons were examined by Student-t test and Mann–Whitney test (non-parametric distribution). The categorical data were expressed as n (%), and the differences between the two groups were examined by chi-square analysis or Fisher’s Exact Test. The statistical significance level was set at 0.05 for a two-sided test.

3  |  RESULTS

From June 2020 to June 2021, a total of 7 patients were diagnosed as chronic osteomyelitis of lower extremity
TABLE 1  General patient information and evaluation indicators

| Number of patient | Gender | Age  | BMI (kg/m²) | Past medical history | Location of the wound (cm²) | LEFS in preoperative (points) | Area of wound (cm²) | Types of skin flap | Type of bacteria infected | Area of second wound (cm²) | Expander fill volume (ml) | Duration of expansion (day) | Area of skin harvested (cm²) |
|------------------|--------|------|-------------|----------------------|-----------------------------|-----------------------------|--------------------------|------------------|-----------------------------|-----------------------------|-----------------------------|----------------------------|-----------------------------|
| Patient 1        | Male   | 38   | 23.15       | No                   | Right knee                  | 39                          | 20*15                    | Right lateral thigh perforator flap | Staphylococcus aureus | 15*10                      | 680                         | 45                         | 21*6                       |
| Patient 2        | Male   | 56   | 23.12       | Diabetes             | Right anterior tibia        | 45                          | 30*8                     | Right gastrocnemius neurovascular flap | Staphylococcus aureus | 30*10                      | 450                         | 32                         | 35*8                       |
| Patient 3        | Male   | 34   | 24.61       | Smoking history      | Left anterior tibia         | 41                          | 20*6                     | Left gastrocnemius neurovascular flap | Klebsiella pneumoniae | 22*7                       | 600                         | 31                         | 30*5                       |
| Patient 4        | Male   | 25   | 28.32       | No                   | Right anterior tibia        | 43                          | 12*15                    | Right gastrocnemius neurovascular flap | Staphylococcus aureus | 16*14                      | 400                         | 30                         | 28*6                       |

| Number of patient | Vancouver scar scale score (points) | Lower limb wound healing time (months) | LEFS in postoperative (points) | Patient satisfaction (0–10 points) |
|------------------|------------------------------------|----------------------------------------|-------------------------------|-----------------------------------|
| Patient 1        | 3                                  | 6                                      | 39                            | 9                                 |
| Patient 2        | 6                                  | 36                                     | 45                            | 8                                 |
| Patient 3        | 4                                  | 12                                     | 41                            | 9                                 |
| Patient 4        | 3                                  | 2                                      | 43                            | 9                                 |

Abbreviations: BMI, body mass index; LEFS, lower extremity functional scale.
with soft tissue defect and were treated in Peking University Third Hospital. According to the inclusion and exclusion criteria, a total of 4 patients were included, 2 patients were excluded for that the abdominal expander placement time is shorter than 1 month; 1 person was excluded for the missing follow-up data. Finally, a total of 4 patients with chronic osteomyelitis were enrolled in this study. All patients were male. The mean age of the patients was 38.25 (range from 25 to 56) years. Two patients had a history of smoking and 1 patient had diabetes mellitus. The infecting organism was Klebsiella pneumoniae in one patient and Staphylococcus aureus in the remaining three. The average LEFS score in preoperative was 9.25 (range from 6 to 12) points. Four patients had complete flap survival, two of whom had a small amount of skin graft survival disorder in the vascular pedicle area, which improved after 1 month of dressing change.

The expander had an average expansion time of 31.5 (range from 30 to 45) days, an average water injection of 525 (range from 400 to 680) mL, and an average skin volume taken of 159 (range from 126 to 280) cm$^2$. The abdominal skin harvesting areas healed by first intention, and the stitches were removed in 2 weeks. No incision exudation, incision dehiscence, subcutaneous exudate and other complications occurred. The mean Vancouver Scar Scale score at 3 months after surgery was 3.5 (range from 3 to 6) points. (Table 1).

Four patients showed good flap survival at six-month follow-up. 3D printed prosthesis were all successfully implanted. The average LEFS score in postoperative 6 months was 42.0 points (from 39 to 45 points). The function of lower limb was significantly improved ($P < .001$). Patient satisfaction 3 months after surgery was 8.75 (range from 8 to 9) points, with a maximum score of 10 points. (Table 1).

### 3.1 Typical case presentation

A 34-year-old man presented with a left tibial fracture due to trauma 1 year ago. Open reduction and internal fixation was performed in another hospital, and persistent ulceration and exudation of the incision occurred 1 month after surgery. Internal fixation was removed from another hospital, followed by multiple debridements with poor

**FIGURE 1** One typical case presentation. (A) The non-healing wound on the left side spread before debridement, with high incision suture tension; (B) Soft tissue defect with cement exposure after first debridement; (C) Initial debridement with lower abdominal expander placement; (D) The expander was implanted, and 120 mL of water was injected immediately after surgery; (E to G) Intraoperative design of gastrocnemius neurovascular flap; (H) After 31 days of continuous rapid expansion, the skin range was designed; (I) Remove the lower abdominal expander completely; (J) Free full-thickness skin graft of lower abdomen to secondary wound; (K) The flap survived well 2 weeks after operation; (L) Skin transplanted survived well 2 weeks after operation; (M) The abdominal skin incision healed 2 weeks after operation.
results and severe soft tissue destruction. Staphylococcus aureus infection was considered in wound secretion culture for many times.

The patient was diagnosed with chronic osteomyelitis with soft tissue defect in another hospital, and bone cutting, bone cement filling, and VSD covering the wound were performed. After admission to our hospital, a wound about 20 cm in length was observed on the left lower leg, covering the VSD. The skin around the wound was slightly dark in colour, mildly swollen, and the dorsalis pedis pulse was good. Patients were then given the standard treatment regimen described in the study. Figure 1 showed the subsequent treatment process. Six months after the flap was repaired, the antibiotic polymethyl methacrylate (PMMA) bone cement was replaced with a 3D-printed prosthesis, followed by rehabilitation exercise (Figure 2).

4 | DISCUSSION

Chronic osteomyelitis is more common in adults with post-traumatic osteomyelitis. The incidence of deep infection after open fractures ranges from 2% to 50%. The tibia is the most common site of open fractures and chronic osteomyelitis. In 1985, Cinery-Mader developed the adult chronic osteomyelitis classification system, which divided the anatomical types of local injuries of chronic osteomyelitis into four types and the physiological status of patients into three layers according to the characteristics of local injuries as well as the general condition of patients. This guideline effectively guided the surgical management, and the higher the grade of chronic osteomyelitis, the more difficult the treatment was, and the worse the prognosis was. Thorough debridement is the key to the treatment of chronic osteomyelitis. Some studies believed that the focus of the treatment of chronic osteomyelitis is the complete removal of necrotic substances. However, Esterhai believe that it was difficult to determine the extent and size of lesion removal. At present, most experts and scholars believed that debridement should achieve the removal of all suspected infectious materials, including implants, dead bones and foreign bodies at the infection site. Excision of the surrounding infected soft tissue should be performed as large as possible, and the bone surface should be removed until there is fresh bleeding. Multiple debridement procedures can lead to local scar contracture, and long-term slow inflammation can make local soft tissue hardening as well as reduced elasticity, which can lead to difficulty in local soft tissue coverage. Plastic surgical flap transfer repair technique plays an important role in the repair of complex wounds of the lower extremities. At present, the flaps used to repair soft tissue defects of the lower leg and foot in clinical practice include medial plantar flap, gastrocnemius neurotrophic flap, peroneal artery perforator flap, and spreading posterior artery perforator flap, with significant clinical results (Figure 3).

The secondary wound after flap transfer repair for chronic osteomyelitis of the lower extremities often cannot be directly sutured and requires transplantation. Optional skin grafts include anterior and lateral thigh split-thickness skin, ilioinguinal full-thickness skin, and scalp split-thickness skin. The skin in the ilioinguinal region is flaccid, elastic, and cryptic, and there is only a linear scar after skin harvesting, which does not leave a large area of patchy scar and is relatively friendly to the skin harvesting area. Full-thickness skin in the ilioinguinal region is not easy to contracture and has a good shape and texture, and is often used as the first choice for free skin transplantation of secondary wound surfaces of the lower extremities.

The primary implantable expander can make full use of the debridement time and complete the expansion of soft tissue in the ilioinguinal region. Adult lower limb chronic osteomyelitis often requires multiple debridements, which is time-consuming. Our study found that if the expander can be implanted in the ilioinguinal region...
FIGURE 3  (A) The scar of the harvesting area in the abdomen at 3 months after the operation in one case; (B) The survival of the skin grafting at 3 months after the operation in one case; (C to E) The survival of the transplanted skin flap at 3 months after the operation

FIGURE 4  (A, B) The survival of the transplanted skin flap at 3 months after the operation in one case; (C) The survival of the skin grafting at 3 months after the operation in one case; (D) The scar of the harvesting area in the abdomen at 3 months after the operation in one case
of the patient at the time of the first debridement, the skin harvesting area can be increased to a certain extent through rapid expansion. On the basis of meeting the skin volume required for secondary wound coverage, the incision tension in the donor site was small, the scar length was short, and the patient satisfaction was high (Figure 4).

The rapid expansion technique plays a significant role in chronic osteomyelitis of the lower extremities with soft tissue defects and can provide sufficient skin to meet the coverage of secondary wounds in a short period of time. Conventional skin expansion methods have a long cycle, generally 8 to 12 weeks, and high cost. In early 1990s, Schmidt and Cole began to study continuous rapid expansion methods. Animal studies have shown that there is no significant difference in the thickness of dermis and fat layer between continuous rapid expansion and conventional expansion, and the difference was that the shrinkage rate of the skin layer after conventional expansion was lower than that after continuous rapid expansion. Musatoe showed that the skin area increased by 34.4% at 2 weeks of rapid expansion and by 35.8% at 6 months of conventional expansion, and there was no significant difference in the quality of expanded skin between the two groups.

In addition to reducing the tension and scar in the donor site, another advantage of the expanded free skin graft is that it is not prone to contracture. The expanded skin epidermal layer thickens, the dermis thins, and the thickness of the dermis decreased by about 20% and depends on the rate of expansion. The collagen fibres in the dermis layer were thickened and increased, the arrangement direction was gradually parallel to the expansion mechanical stress direction, the fibre gap was increased, and the broken and loosely arranged collagen fibres were observed, which became a loose reticular structure, making the expanded skin not prone to contracture.

Expanded skin for free grafting is more conducive to free skin graft survival. Studies have shown that the nuclear membrane of dermal fibroblasts became uneven from flat and smooth at rest after expansion, indicating that dermal fibroblasts were activated and had the ability of collagen synthesis; in addition, in expanded fibroblasts, the presence of a large number of mitochondria and endoplasmic reticulum can also be observed, further indicating that fibroblasts were activated and have the ability of extracellular matrix synthesis, which was conducive to the regeneration of expanded skin. Previous studies have shown that a large number of new capillaries can be seen in the dilated skin, the calibre of blood vessels was thickened, the area of vascular bed was increased, and the number of dilated dermal blood vessels was thickened and increased. Cherry used radiography to show that pigs after 5 weeks of dilatation had an increased number of skin vessels, dilated dermal vessels, enhanced dermal blood supply, and a 117% increase in the length of viable flaps after expansion compared with the control group. By means of vascular casting, Pietrarmggi found that the calibre of vessels with expanded skin increased but the thickness became uneven and the curvature increased, while the spatial arrangement tended to be in the direction along the line of force, indicating that mechanical stress remodelled the vessels. The increase in skin vessels after expansion promoted the survival of skin transplanted.

The disadvantages of implanting expander in the lower abdomen focus on two aspects. On the one hand, it increases a time of abdominal surgery, prolongs the operation time to a certain extent, and additionally increases the operation cost of expander placement; on the other hand, the expander rapidly expands after surgery, causing local swelling pain, which leading to patient discomfort and affecting the patient's activity and quality of life to a certain extent.

One of the limitations is that this study with a small sample size, which lacks a control group, may weaken the generalisability of the results. We will continue to include more cases for analysis. Another limitation was that the maximum follow-up time is half a year, which lacked long-term follow-up data.

5 CONCLUSION

Although the treatment of adult chronic osteomyelitis of lower extremities with lower abdominal implantable expander combined with flap technique increases a time of abdominal surgery, it can effectively increase the skin harvesting area, reduce the suture tension of abdominal skin harvesting area and the scar hyperplasia of abdominal skin harvesting area, and improve the possibility of free skin graft survival. This technique significantly benefits patients and is worthy of reference and promotion.

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CONFLICT OF INTEREST

The authors declare that they have no competing interests.

AUTHOR CONTRIBUTIONS

Xinling Zhang, Yujie Che, Xin Yang and Zhenmin Zhao outlined the study designed. Xinling Zhang, Yujie Che, Guanhuiier Wang and Pengbing Ding performed
implementation and data collection. Xinling Zhang and Yujie Che contributed to data analysis. Xin Yang and Zhenmin Zhao contributed to both the draft and final versions of the manuscript. All authors read and approved the final manuscript.

ETHICS STATEMENT
This study was approved by the ethical committee of Peking University Third Hospital (No. M2018174).

INFORMED CONSENT
Written informed consent was obtained from each subject prior to participation.

DATA AVAILABILITY STATEMENT
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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