ORIGINAL RESEARCH

Bone Transport with the Taylor Spatial Frame Technique: A Case Series

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Abstract

Aim: Bone transport is a beneficial reconstructive method for bone defects caused by infected non-unions or bone tumours. The Taylor Spatial Frame (TSF) is a three-dimensional corrective external fixator that can be used to achieve bone transport and correct any residual deformities easily at any time. This study reports the results of bone transport using TSF.

Materials and methods: This is a retrospective study of ten patients who underwent bone transport using the TSF. The mean age was 32.3 years; the femur was affected in one case and the lower leg in nine. Bone defects were due to infected non-unions in seven cases and bone tumours in three. The duration of external fixation, bone transport distance, distraction index (DI), alignment at the end of correction, leg length discrepancy, and complications were investigated.

Results: The average bone transport distance was 76.0 mm. The external fixation period averaged 367 days with the DI at 20.8 days/cm. Deformity at the docking site was assessed to have an average 2.6° deformity and 2.0 mm translation in the frontal view, as well as 3.3° deformity and 3.7 mm translation in the lateral view. The mean leg length discrepancy was 10.9 mm and the percentage of the mechanical axis (%MA) was 40.6%. Four patients underwent plate conversion after correction and two required additional surgery for non-union at the docking site. Bone union was achieved in all patients and there was no reaggravation of infection or tumour recurrence.

Conclusion: The TSF allowed for the correction of deformities and translations that occurred during bone transport giving excellent results. However, as with bone transport using this or other devices, additional procedures are often needed to obtain consolidation or docking site union.

Keywords: Bone transport, Bone tumour, Non-union, Plate conversion, Taylor Spatial Frame.

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Introduction

Managing segmental bone defects caused by infected non-union or bone tumours is challenging for orthopaedic surgeons. Bone transport is a reconstructive technique that uses distraction osteogenesis to regenerate living physiological bone.[1,2] Traditionally, the Ilizarov external fixator has been used, however, correction of deformities during reconstruction is difficult; additional surgeries are sometimes required for re-correction. Taylor Spatial Frame (TSF) is a modern multiplanar external fixator; it provides the capability of deformity correction, sequentially or simultaneously, by adjusting six connecting struts.

This study aimed to report our experience in performing bone transport using TSF for segmental bone defects of the lower extremities.

Materials and Methods

The ethics committees of Kanazawa University Hospital approved this retrospective study (No. 2022-161). The infected non-union or bone tumour cases that underwent bone transport at our institution between 2003 and 2017 were evaluated. The cases of infected non-union included patients who were initially treated for trauma at our institution and referred at a later date.

Ten cases were included in the study. The causes of bone defects were infected non-union in seven cases and bone tumour in three. Cases of infected non-union initially included five Gustilo–Anderson grade IIIB and one closed fracture, including one case with unknown details. Cases of bone tumours included two osteosarcomas and one of osteofibrous dysplasia. The reconstructed site was the femur in one case and the tibia in nine. All were reconstructed using a bifocal approach; the hexapod fixator TSF (Smith & Nephew) was used in all cases.

The following variables were recorded: duration of external fixation, distance of bone transport, distraction index (DI), external fixation index (EFI), deformity and translation at the docking site after correction, leg length discrepancy at the last follow-up, percentage of mechanical axis (%MA), complications, and if additional procedures were performed to complete treatment. Deformity and translation at the docking site were measured using the frontal and lateral radiographic images, using the bone axes of each proximal and distal fragment as reference lines.

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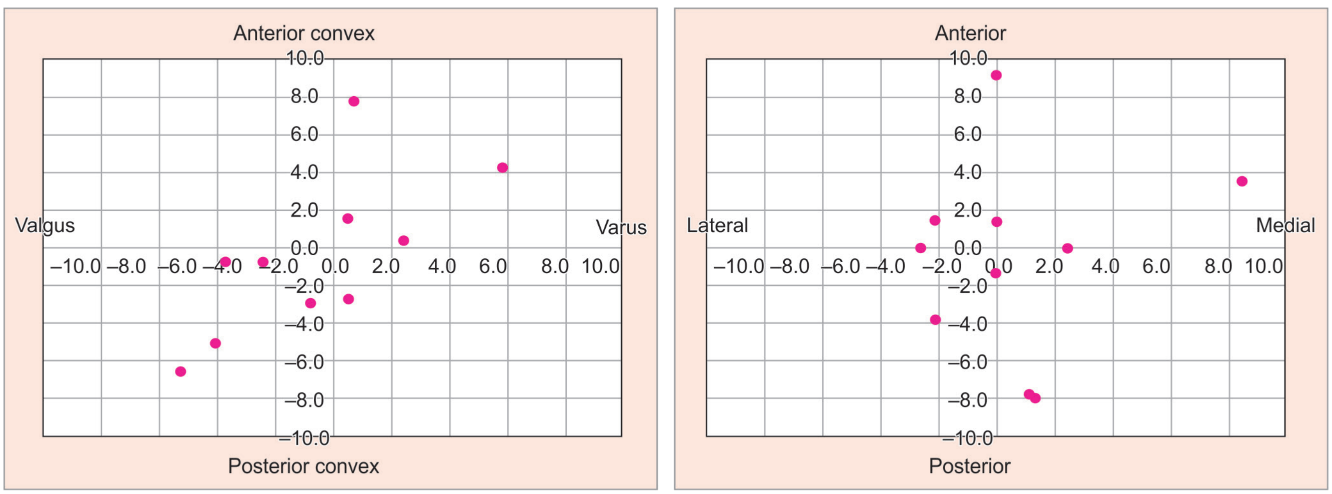
Table 1: Items related to external fixation, postoperative alignment, leg length discrepancy, the number of additional surgeries and complications are shown for each cause of bone defect

	Total	*Infected non-union*	*Bone tumour*
N	10	7	3
Distance of BT (mm)	76.0 (29–125)	66.4 (29–125)	98.3 (80–110)
Duration of EF (day)	367 (102–810)	309.6 (102–646)	503.0 (245–810)
DI (day/cm)	20.8 (12.2–32.9)	22.6 (16.8–32.9)	14.3 (12.2–16.5)
EFI (day/cm)	54.2 (18.5–101.3)	53.7 (18.5–90.0)	55.3 (23.3–101.3)
Leg length discrepancy (mm)	10.9 (0–20)	9.0 (0–20)	14.0 (10–17)
%MA (%)	40.6 (16–60)	44.6 (30–60)	34.0 (16–56)
Plate conversion (*n*)	4	3	1
Recorrection (*n*)	0	0	0
Complication (*n*)	3	2	1

EF, external fixation



	n	*Mean*		*n*	*Mean*
Little (<1°)	4		Little (<1°)	3	
Varus	2	3.6° (2.4–5.8)	Ant. apex	3	4.6° (1.6–7.8)
Valgus	4	3.9° (2.4–5.3)	Post. apex	4	4.3° (2.9–6.5)
Total	10	2.6°	Total	10	3.3°

	n	*Mean*		*n*	*Mean*
Little (<2 mm)	5		Little (<2 mm)	5	
Medial	2	5.5 mm (2.5–8.5)	Anterior	2	6.4 mm (3.6–9.2)
Lateral	3	2.3 mm (2.1–2.6)	Posterior	3	6.5 mm (3.8–8.0)
Total	10	2.6°	Total	10	

Fig. 1: Deformity and translation at the docking site after correction are shown in the graphs and tables underneath

Results

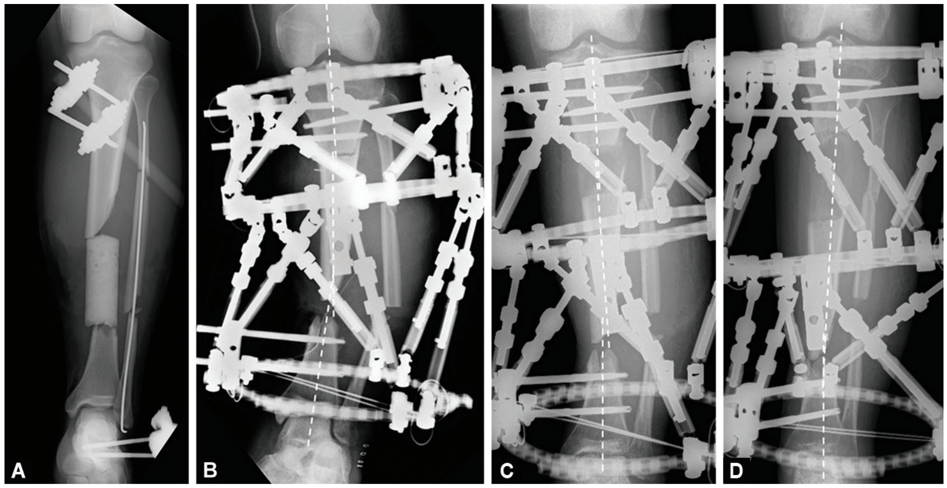
Ten patients had a mean age was 32.3 years (8–60) and included 9 males and 1 female. The mean postoperative follow-up was 84.3 months (22–180 months).

The data reporting the index of external fixation, measurements at the last follow-up, and complications are shown in Table 1. The mean bone transport distance was 66.4 mm (29–125 mm) for infected non-unions, 98.3 mm (80–110 mm) for bone tumours, and 76 mm (29–125 mm) overall. The mean duration of external fixation was 309.6 days (102–646) for infected non-unions, 503.0 days (245–810) for bone tumours, and 367 days (102–810) overall.

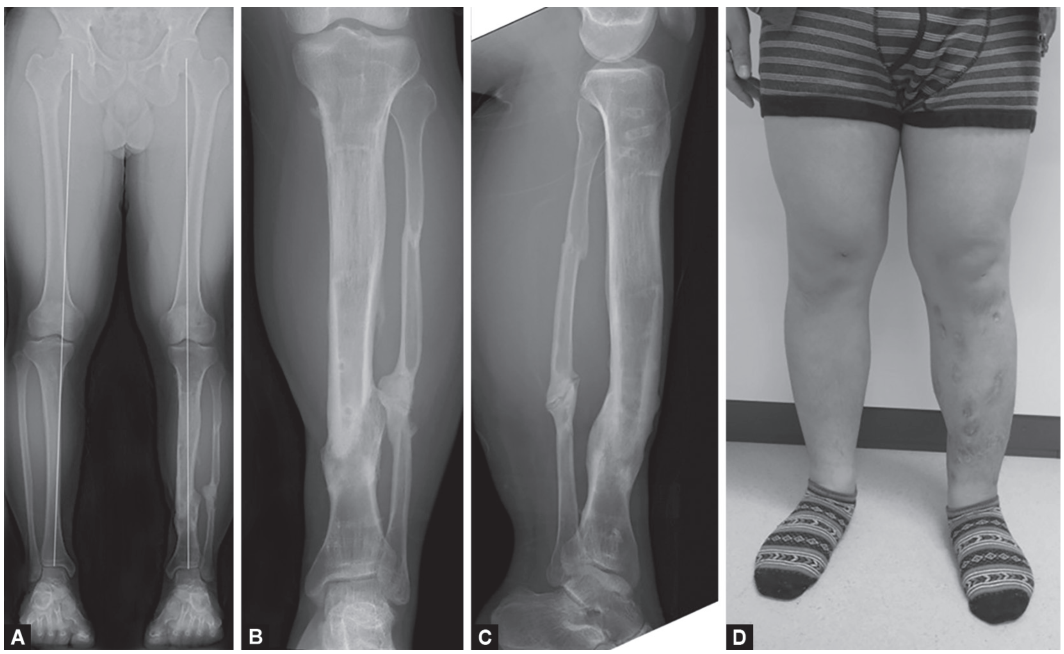
The residual deformity at the docking site (angular and translation) after correction is shown in Figure 1. In the frontal view, four patients had a ≤1° deformity, two had a varus deformity (mean 3.6°), and four had an external valgus (mean 3.9°). In the lateral view, three patients had a ≤1° deformity, three had an anterior convex deformity (mean 4.6°), and four had a posterior convex deformity (mean 4.3°). In the frontal view, five patients had a ≤2 mm translation, two had medial translation (average 5.5 mm), and three had lateral translation (average 2.3 mm). In the lateral view, five patients had ≤2 mm translation, two had anterior translation (6.4 mm), and three had posterior translation (6.5 mm on average). No cases required additional surgery to address the residual deformity after correction had been achieved through the TSF.

The mean leg length discrepancy and %MA were 10.9 mm (0–20 mm) and 40.6% (16–60), respectively. Four patients underwent plate conversion at the end of the correction to facilitate regenerate column union and consolidation.

There were complications of infection, non-union, and skin trouble. One patient with non-union at the docking site underwent hindfoot arthrodesis with an intramedullary nail. In another case,



Figs 2A to D: (A) A radiograph at the time of our referral: The defect was filled with a cement spacer; (B to D) Radiographs showing the bone transport course, performed with appropriate adjustments for deformity and translation



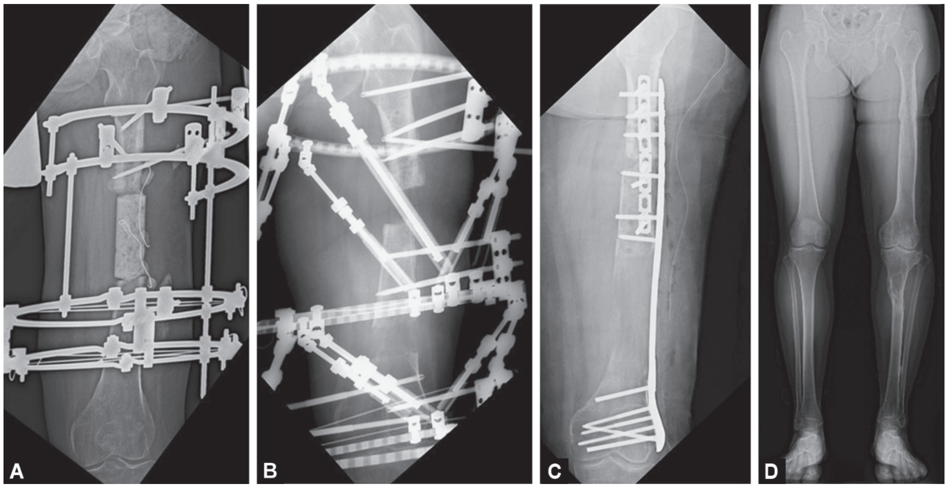
Figs 3A to D: (A to C) Radiographs at latest follow-up: The bone union has been achieved; %MA is 44%; almost passing through the knee centre; (D) Clinical photograph at last follow-up (6 years postoperatively): No recurrence of infection

the TSF was reapplied for the non-union at the docking site, followed by bone graft and plate fixation resulting in bone union. Six patients had superficial pin site infections which were all treated with oral antibiotics. One patient had skin invagination during bone transport and underwent dermatoplasty.

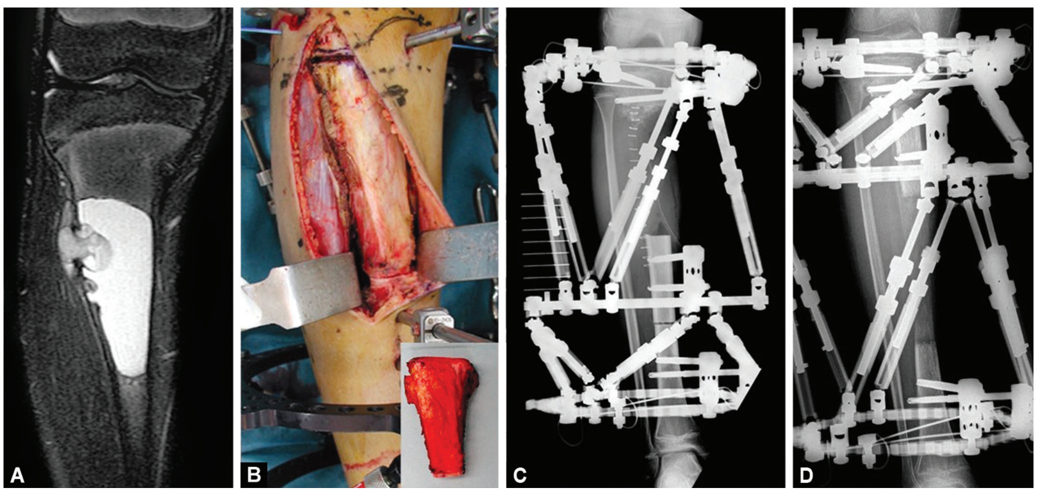
Three Case Presentations

A 21-year-old male patient sustained a Gustilo–Anderson grade IIIB left tibial open fracture in a traffic accident. He was referred to our department after a cement spacer was placed due to an infected non-union (Fig. 2A). The cement spacer was removed, and a TSF was applied for bone transport. During the transport, a correction program was applied to the deformity, and 75 mm of the bone was reconstructed (Fig. 2). After correction, an autologous iliac bone graft was placed at the docking site. Bone union was achieved; the latest follow-up radiographs show that the %MA was 44% with no leg length difference, and the patient could lead his daily life without problems (Fig. 3).

A 31-year-old male patient sustained a Gustilo–Anderson grade IIIB open fracture of the left femur from a car accident leading to an infected non-union after treatment (Fig. 4A). Bone transport with the TSF was performed after segmental resection and 125 mm of the bone was reconstructed (Fig. 4B). The proximal ring interfered with the patient's sitting posture. Plate conversion was performed 2 weeks after the end of the correction program (Fig. 4C). At the final follow-up, an X-ray showed a leg length discrepancy of 8 mm



Figs 4A to D: (A) The defect was filled with a cement spacer; (B) The segmental bone was transported from the distal to the proximal end; (C) A radiograph after plate conversion was performed; (D) Radiographs at latest follow-up (4 years postoperatively): The bone union has been achieved



Figs 5A to D: (A) Preoperative radiograph: the patient presents with osteosarcoma findings on the proximal metaphyseal end of the tibia; (B) Intraoperative clinical photograph: the resected tumour bone is shown in the lower right; (C) Postoperative X-ray: showing osteotomy at the distal side for bone transport; (D) The segmental bone was transported to the proximal end

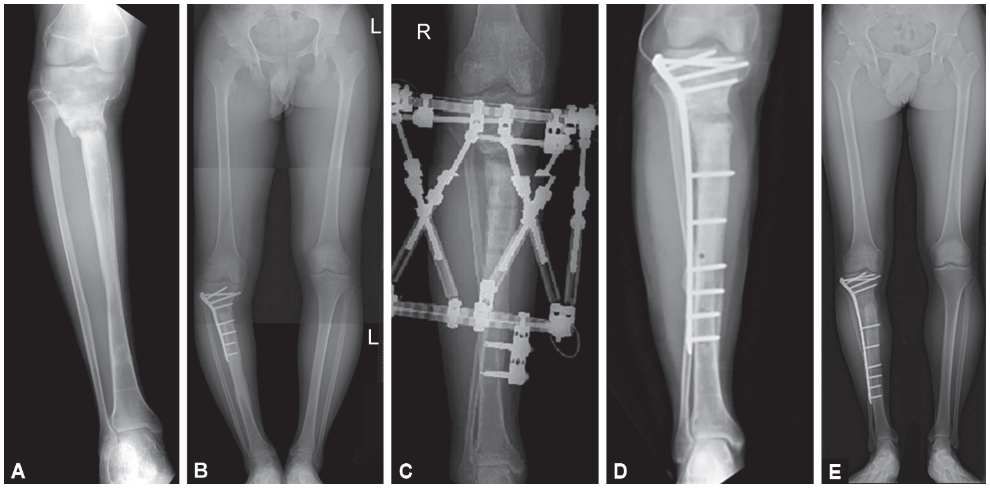
and %MA of 30% (Fig. 4D). Although the knee flexion range of motion remained limited, the patient was able to walk unassisted without pain.

A 12-year-old boy underwent chemotherapy followed by a tumour excision for osteosarcoma of the right proximal tibia (Fig. 5). The 110 mm bone defect was reconstructed by a TSF bone transport (Fig. 5). After correction, a bone graft was placed at the docking site and the external fixator was removed after 454 days. However, a non-union of the docking site was found after fixator removal. Although bone grafting and plate fixation were performed, the residual deformity at the non-union remained (Fig. 6). The TSF was reapplied and correction of this deformity was performed (Fig. 6C). When the external fixator was removed, bone grafting and plate conversion were repeated. Union at the docking site was achieved finally (Fig. 6D). The %MA was 30%, and the leg length difference was 15 mm (Fig. 6E). The patient can walk unassisted and lead his daily life without problems.

Discussion

The treatment of segmental bone defects in the leg, particularly those associated with soft tissue defects or infection at the site of a non-union, is challenging.[3,4] The treatment goals are numerous, including achieving union, soft tissue coverage, correcting limb axis deviation, equalizing limb length discrepancy, treating established infections, and preventing tumour recurrence while allowing for functional recovery.[5–7] Various techniques have been used to treat large segmental bone defects, such as autogenous bone grafts,[8] ipsilateral fibular graft,[9–11] allograft reconstruction,[12] vascularised free fibula transfer,[13,14] Masquelet technique,[15–17] and bone transport. It is essential to consider the advantages and disadvantages of each technique; particularly the procedure's simplicity, bone union rate, extent of reconstruction, donor site invasion, and final bone strength.

Since bone transport is a physiological bone regeneration, it allows for the reconstruction of large bone defects without



Figs 6A to E: (A) After TSF was removed, nonunion of the docking site became apparent; (B) Additional bone grafting and plate fixation were performed, but the varus deformity remained; (C) Recorrection for varus deformity using TSF was performed; (D) Postoperative radiograph: Plate conversion was performed when TSF removal; (E) Radiographs at latest follow-up (15 years postoperatively): The bone union has been achieved, and the %MA was 29%

sacrificing other sites. It is less invasive to soft tissue and improves blood flow in the treated limb. In addition, using a circular external fixator can accommodate early weight bearing; therefore, it is often favoured as a treatment method for preventing loss of motor function. There are several reports of bone transport using the Ilizarov external fixator and the TSF.[18–21] However, frequent frame modifications and the need for sequential correction of deformities during bone transport are the main limitations of the Ilizarov device.[5,22,23] One of the problems is that deformity or translation may occur during transport, particularly in cases with large defects. In such cases, the conventional monolateral rail fixator or classic Ilizarov fixator requires additional procedures or components for correction, depending on the degree of deformity.

The TSF easily corrects such deformities and translations without additional procedures or major modifications to the fixator. In addition, the alignment does not have to be completely reduced at the time of surgery and can be corrected gradually, reducing the additional trauma to the soft tissues caused by acute correction. Numerous studies have reported the advantages of the TSF over the classic Ilizarov fixator.[5,22] Abuomira et al. compared the results of non-union treatment between the standard Ilizarov method and the Ilizarov method with TSF, reporting no statistical difference.[20] However, the reconstruction distance was longer in the cases that used TSF; the use of TSF in treating rotational deformity and the accuracy of the correction are noted in the report. One drawback is that the program is somewhat complicated to input because it requires evaluation at the proximal and distal locations. There is also the risk of contact and impingement between the half pin and the strut between the rings on the side being shortened. Furthermore, there is a risk of the ring-to-ring distance becoming too narrow for the existing struts to accommodate. Therefore, these factors should be considered when deciding how the wires and half pins are inserted into the transported bone fragment and how the correction programme is configured.

In this study, the average length of reconstruction was 76 mm. Although there were many cases of massive defects, the final alignment of the reconstructed bone segment was limited to $\leq$5° deformity and $\leq$ 5 mm translation in half of the cases. There were no cases of recurrence of infection or tumour during the long-term follow-up. The main complication was the non-union of the docking site, consistent with reports by other authors in a certain percentage of cases.[23,24–26] In our hospital, bone grafting to the docking site was performed usually as routine; however, non-union was found in one case in which bone grafting was not performed. Although reports on the rate of performing bone grafting varied,[3,27–30] we believe that bone grafting is beneficial for bone union in cases of infected non-union and malignant bone tumours, where there are concerns about bone healing.

While most of the previous reports of bone transport have been for infected non-unions, we consider bone transport with the TSF as an option for bone reconstruction after bone tumour excision. There are few reports of bone transport in bone tumours; Mizoshiri et al. reported a case of bone transport using a TSF for Ewing's sarcoma,[24] and our reported 22 cases of distraction osteogenesis after excision of bone tumours.[31] This study's results showed that the group with bone tumours had a larger amount of reconstruction and a longer duration of external fixation than the group with infected non-unions. The group with bone tumours had a slightly poorer final alignment and leg length discrepancy. The longer external fixation period may have been due to the larger amount of defect and chemotherapy used prior to reconstruction which may have affected the speed of bone fusion. However, further study is required in a larger number of cases.

In our hospital, plate conversion is performed after reconstruction and correction for patients who wish for external fixation to be removed early. Long-term external fixation increases the patient's physical and mental stress and may cause gait disturbance and limited range of motion. Converting to internal fixation may prevent the recurrence of deformity and re-fracture at the docking site after hardware removal. Therefore, plate conversion after reconstruction has various advantages. Plate conversion is a valuable tool, particularly for cases with an extended period of external fixation and for femoral cases which tend to be prone to limited knee joint range of motion.

The limitations of this study include the small number of cases, the lack of reproducibility because the deformity was evaluated using radiographs, and the lack of comparative studies with the conventional monotube and Ilizarov types. Further studies are needed to confirm the efficacy of TSF bone transport compared to Ilizarov.

Conclusion

Ten cases for which bone transport was performed using the TSF were investigated. The TSF allowed for the correction of deformities and translations that occurred during bone transport, particularly at the docking site, with overall excellent results.

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