

Retraction and force analysis of transporting bone segment during Ilizarov bone transport

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Abstract

Background: Previous research rarely reported the cause and relevant factors of retraction of transporting bone segment (TBS). The purpose of this study is to analyze the force and cause of retraction of TBS during Ilizarov bone transport after removal of its fixator.

Methods: 37 cases with tibial bone defect treated by Ilizarov bone transport, in whom the fixator of TBS was removed before mature of mineralization of the distraction callus or union of the docking site, were analyzed retrospectively. Bivariate correlation was used to analyze relationship between retraction distance of TBS and age, gender, disease course, length of bone defect, times of pre-operation, size of TBS, transport distance, cause of removal, timing and time interval of removal of TBS fixator. Risk factors with significant level were further identified using multivariate linear regression.

Results: Bivariate correlation analysis showed the timing of removal was negatively correlated while the time interval, cause of removal, transport distance and size of TBS were positively correlated with the transport distance (all $p < 0.05$), however the age, gender, disease course, length of bone defect and times of pre-operation were not correlated with the transport distance ($p > 0.05$). Multivariate linear regression analysis showed the timing of removal, transport distance and size of TBS were significant risk factors for the retraction distance ($p < 0.05$), of which, the timing of removal had the greatest impact, followed by the transport distance and size of TBS, however the cause of removal and time interval were not significant for the retraction ($p > 0.05$).

Conclusion: The traction force of the TBS endured from soft tissue, not from the distraction callus, is elastic and can induce a retraction of TBS when its fixator is removed in advance. The retraction distance is related to the size of TBS, transport distance and timing of removal, especially the timing of removal is an independent risk factor.

Introduction

Callus distraction (distraction osteogenesis) is to perform slow bone transport or lengthening using external distraction system or intramedullary distraction system after osteotomy by Ilizarov's method has been an effective technique to reconstruct large bone defect and correct discrepancies of limbs [1-3], of which, external distraction system is more common in clinic. Removal of external fixator is usually performed after mature of mineralization of the distraction callus and union of the docking site in conventional Ilizarov bone transport. However, conventional Ilizarov bone transport presents high rates of delayed union and nonunion of the docking site and pin-track infection or loosening, inconvenience for rehabilitation and nursing, and psychological disorder induced by long-term external fixation [3-6]. These complications and defects have become the bottleneck for the development of this technique. Some scholars [7-9] reported modified Ilizarov bone transport to avoid difficult healing of the docking site, in which the external fixator was removed when the docking site is closing and then plate or intramedullary nail was used as a relay internal fixation (bone graft may be performed at the same time). Sometimes,

the external fixator must be removed in advance in situations of pin-track problem (pin-track infection or associated with loosening) is not effective for conservative treatment or patient can't tolerate long-term external fixation, then a relay internal fixation was used. In these cases, 1-2 weeks or more time are needed for the healing of the pin-track before implantation of relay internal fixation. During the period between removal of total external fixator or TBS fixator and new implantation of relay internal fixation, retraction of transporting bone segment (TBS) may occur even if plaster cast was used. The retraction of TBS has adverse effect on the healing of the docking site. Previous literatures paid more attention to the bone healing and complications in distraction osteogenesis, rarely reported the cause and relevant factors of retraction of TBS [10-12]. The clinical data of 37 patients with removal of TBS fixator in advance during bone transport process in our hospital from January 2009 to December 2018 were analyzed retrospectively to investigate the force and cause of retraction of TBS.

Materials And Methods

Inclusion and exclusion criteria

The inclusion criteria were ① Patients with tibial defect were treated by Ilizarov bone transport; ②TBS fixator or total external fixator was removed before mature of mineralization of the distraction callus or union of the docking site. The exclusion criteria were ①Patients with incomplete radiographic data; ②Age less than 15 years old;③Another external fixator was used after TBS fixator or total external fixator was removed. This study was approved by the ethics committee of Wuxi No.9 People's Hospital and Shuyang People's Hospital, and written informed consents were obtained from all participants.

Patients

The present retrospective study was approved by the Ethics committee of Wuxi Ninth People's Hospital (Wuxi, China, No. LW2018-2-003) and Shuyang People's Hospital (Changzhou, China, No. LYCZ2018031). Between January 2009 and December 2018, 37 cases were included in the study who were traumatic fractures with tibial bone defect. Before bone transport, all patients with bone defect were fixed with ring or single arm external fixator, among them, 5 cases were simultaneously treated by shortening of the affected limb. There were twenty-three males and fourteen females, ranging in age from 15 to 71 years old with an average age of 39.95 years old.

Observation indexes

Retraction distance: the maximum retraction length measured by radiograph before and after removal of TBS fixator. The course: the days from traumatic bone defect to bone transport. Times of operation: the number of operations performed before bone transport. Cause of removal: modified Ilizarov bone transport (M) was performed to avoid difficult healing of the docking site or pin-track and external fixator related problems (P) were ineffective for conservative treatment or patient can't tolerate. Timing of removal of TBS fixator: months from the beginning of bone transport to the removal of TBS fixator. Size of TBS: length of the TBS. Time interval: days from removal of TBS fixator to radiograph showing retraction of TBS. The retraction distance was 7.46 ± 7.30 mm. Ten risk factors seen table 1.

Table 1. General data of patients and result of bivariate correlation analysis

Variables	\pmS/ratio	P-value
Age(yrs)	39.95 \pm 14.83	0.475
Gender(M/F)	22/15	0.907
Disease course(days)	40.54 \pm 25.65	0.140
Cause of removal(M/P)	29/8	0.001
Size of TBS(mm)	9.68 \pm 2.24	0.012
Length of defect(mm)	6.41 \pm 1.16	0.940
Time interval(days)	10.54 \pm 4.07	0.027
Timing of removal(Mons)	7.47 \pm 1.94	0.000
Times of operation(Num)	1.65 \pm 0.82	0.060
Transport distance(mm)	6.82 \pm 1.17	0.005

Statistical analysis

Data analysis was performed using SPSS 20.0 statistical software (IBM, New York, USA). Firstly, bivariate correlation was used to analyze relationships between retraction distance and ten variables including age, gender, disease course, length of bone defect, times of pre-operation, size of TBS, transport distance, cause, timing and time interval of removal of TBS fixator. Risk factors with significant level were further identified using multivariate linear regression. $P < 0.05$ was considered significant.

Results

Bivariate correlation analysis showed the timing of removal was negatively correlated with the retraction distance ($r=-0.861$, $P=0.000$), while the time interval, cause, transport distance and size of TBS were positively correlated with the transport distance ($r=0.363$, $P=0.027$, $r=0.522$, $P=0.001$, $r=0.448$, $P=0.005$ and $r=0.408$, $P=0.012$, respectively), however the age, gender, disease course, bone defect length and times of pre-operation were not correlated with the transport distance ($r=-0.121$, $P=0.475$, $r=0.020$, $P=0.907$, $r=-0.247$, $P=0.140$, $r=0.006$, $p=0.974$, $r=0.312$, $p=0.060$, respectively), seen table 1. Multivariate linear regression analysis of the 5 risk factors showed the timing of removal, transport distance and size of TBS were significant risk factors for the retraction of TBS (table 2), of which, the timing of removal had the greatest impact ($t=-8.751$, $p=0.000$), followed by the transport distance and size of TBS ($t=2.287$, $p=0.029$, $t=2.204$, $p=0.035$, respectively), however the cause of removal and time interval were not significant for the retraction ($t=1.752$, $p=0.090$, $t=1.704$, $p=0.098$, respectively). Scatter diagram of regression model of standardized predicted value of retraction distance seen Fig. 1. Typical cases are shown in Fig. 2-3.

Table 2. Result of multivariate linear regression analysis

Variables	Unstandardized Coefficients		Standardized Coefficients	P-value
	B	Std. Error	B	
Timing of removal	-2.583	.295	-.685	.000
Transport distance	1.154	.504	.186	.029
Size of TBS	.534	.242	.164	.035
Cause of removal	2.616	1.493	.134	.090
Time interval	.260	.152	.145	.098

Discussion

The whole distraction osteogenesis process is divided into three phases: 1-2 weeks of latency period, then about 3-4 months of distraction period, and at last another 3-4 months of consolidation period [12-15]. The traction force of the TBS suffered at distraction and consolidation periods comes from two aspects:

one is generated from the distraction of the adherent soft tissue of TBS, and the other is generated from the distraction callus at the lengthening site. They come from different sites or directions and have different properties and functions. The former is elastic and make at retraction of TBS, while the latter isn't elastic and has anti-retraction properties [10-14].

Although the periosteal connection was cut off after osteotomy, there were still adherent structure of the TBS such as fascia, tendon or muscle, nerve, vessels, skin, tendons, ligaments and the connections among them. The traction force from soft tissue begins with transporting of TBS at latency period, gradually become greater at distraction period and reach its peak at the end of distraction period. The magnitude of the traction force from soft tissues is mainly related to the transport distance, site and size of TBS [10-13], i.e The thicker the skeleton, the longer of the transport distance, or the greater the size of TBS, the greater the traction force[10-13]. Horas *et al.* [11] conducted a experiment using eight cadaveric thigh specimens with 60 mm bone defect at the middle femur to assess the traction force required for 40-mm and 60-mm long of TBS using a novel type of intramedullary distraction system, conclusion found that the traction force generated by soft tissue was linearly correlated with the transport distance; after a period of sharply increased in force at 0-10 mm transport distance, a relatively slow increased in force at 10-50 mm distance, whereas it again increased rapidly up to a maximum of 444.5 N at 50-60 mm transport distance; the traction force required for 60-mm long of TBS was higher than that for 40-mm long of TBS. The study indicated the TBS size and transport distance were closely related to the magnitude of the traction force generated by its adjacent soft tissues.

The distraction callus appears at the early stage of distraction period, then gradually become dense and maturing of mineralization at consolidation period. The distraction force from the distraction callus appears with the appearance of the distraction callus, and gradually increases with the maturity of the distraction callus, i.e it has to do with time[15,16].

Therefore, the two kinds of retraction force of the TBS suffered change dynamically during bone transport. In the early stage (within 3 months after bone transport), the retraction force from the soft tissues is great than that from the distraction callus and becomes an important role[12]; in the middle stage (3-6 months after bone transport), the former reaches a peak and the latter gradually increases; in the late stage (>6 months after bone transport), the former become small, the latter gradually increases and becomes an important role[11].

The retraction distance is mainly affected by the distraction force from soft tissue and timing of removal. The greater the retraction force and earlier the timing of removal, the greater the retraction distance. Our study showed that the timing of removal, transport distance and size of TBS were significant risk factors for the retraction distance, especially the timing of removal had the greatest impact. In the typical case 1 of this study, mainly because the timing of TBS removal was earlier (3.5 months), meanwhile the TBS size was larger (15.2 cm) and the transport distance was longer (10.5 cm), which resulted in greater retraction (3cm). Juzheng H *et al.* [7] reported on patients with large tibia bone defect treated by modified Ilizarov bone transport using external distraction system, slight retraction after

bone transport in 8 months still observed in their study. In this study, we also observed a slight retraction in patients with delayed mineralization after removal of TBS fixator in 10 months postoperatively; all patients with retraction of TBS in whom the distraction callus were immature of mineralization. After statistical analysis combined with the actual situation of the research object, we concluded that the timing of removal is an independent risk factor. Theoretically, the time interval may affect the retraction distance. However, it was not a significant risk factor in the study.

In order to avoid the adverse effect on the healing of the docking site caused by retraction of TBS, temporary external fixation should be considered, especially when removal is performed at early stage. This study explored the retraction and force of TBS during Ilizarov bone transport. The findings of this study are helpful to understand the related factors of retraction of TBS, improve prognosis and reduce complications of bone transport in the treatment of bone defect. However, the present study had certain limitations. Firstly, the number of cases is small. Secondly, there is sampling error or bias. Therefore, more clinical data and multicenter studies or experimental research are needed to investigate the relevant factors of retraction of TBS.

In conclusion, when the fixator of TBS is removed before mature of mineralization of the distraction callus or union of the docking site during Ilizarov bone transport, the distraction force from the adherent soft tissue, not from the distraction callus, is elastic and can make a retraction of TBS. The retraction distance is related to the size of TBS, transport distance and timing of removal of TBS fixator, especially the timing of removal is an independent risk factor.

Abbreviations

TBS: transporting bone segment.

Declarations

Conflict of interest

The authors declare that they have no conflict of interest.

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Not applicable.

Authors' contributions

YH M , QD Y and XF H put forward the concept of this study and designed this experiment. YW W and ZN W revised this manuscript. ZZ S, SJ G, and RY R collected data and performed the statistical analysis. All authors read and approved the final manuscript.

Ethics approval and consent to participate

All procedures performed in studies involving human participants were in

accordance with the ethical standards of the institutional standards. Informed consent was obtained from all individual participants included in the study.

Consent for publication

Informed consent was obtained from all individual participants included in the study.

Availability of data and material

Not applicable.

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Figures

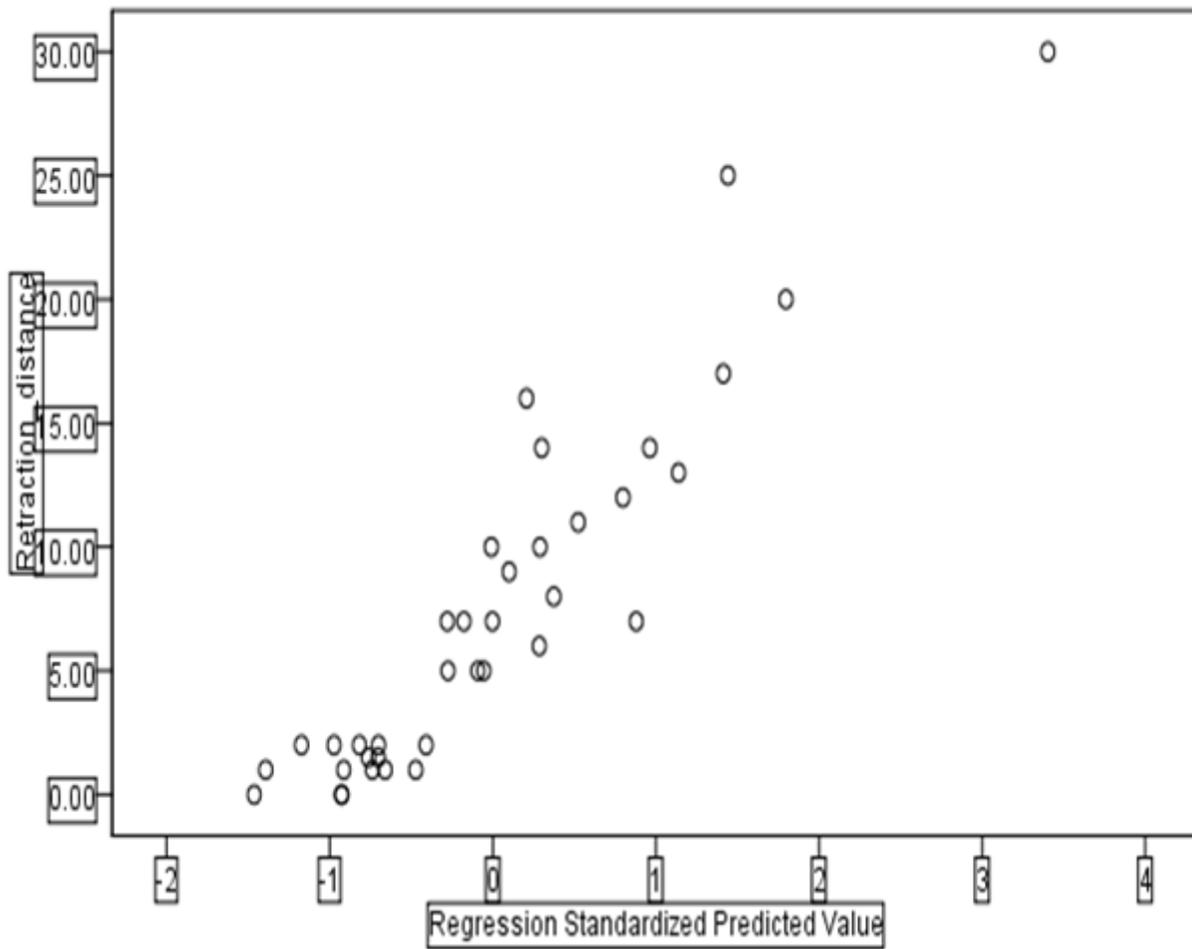


Figure 1

Scatter diagram of the regression model standardized predicted value of retraction distance

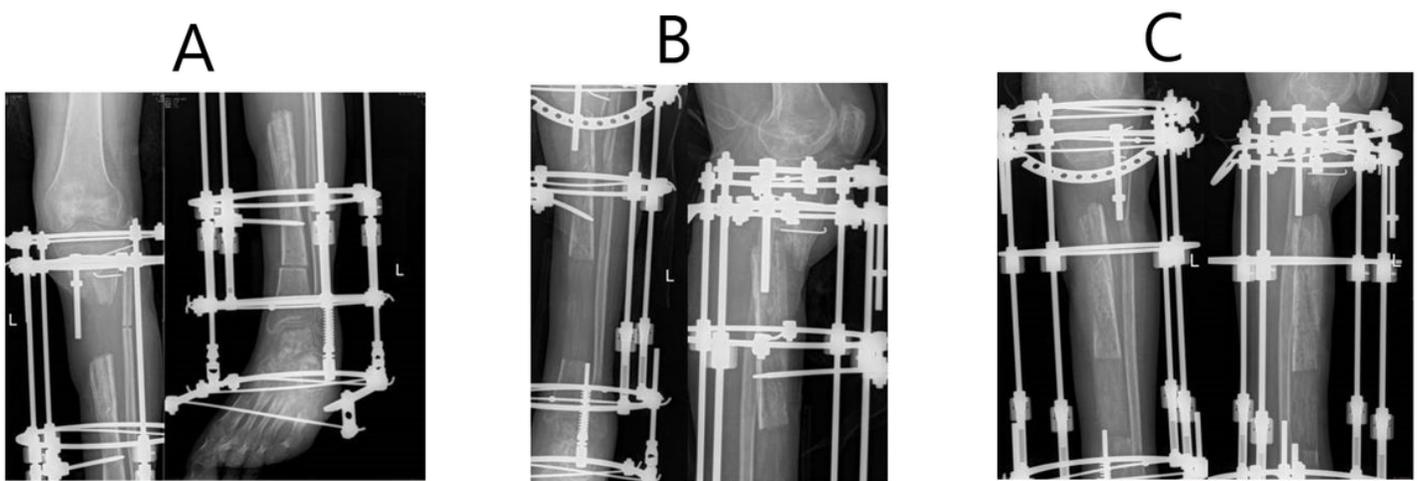


Figure 2

Fracture and defect of tibia and fibula treated by bone transport. (A) After osteotomy. (B) The docking site is closing. (C) The TBS retracted 3.0 cm after removal of TBS fixator in 3.5 months postoperatively in an time interval of 25 days.

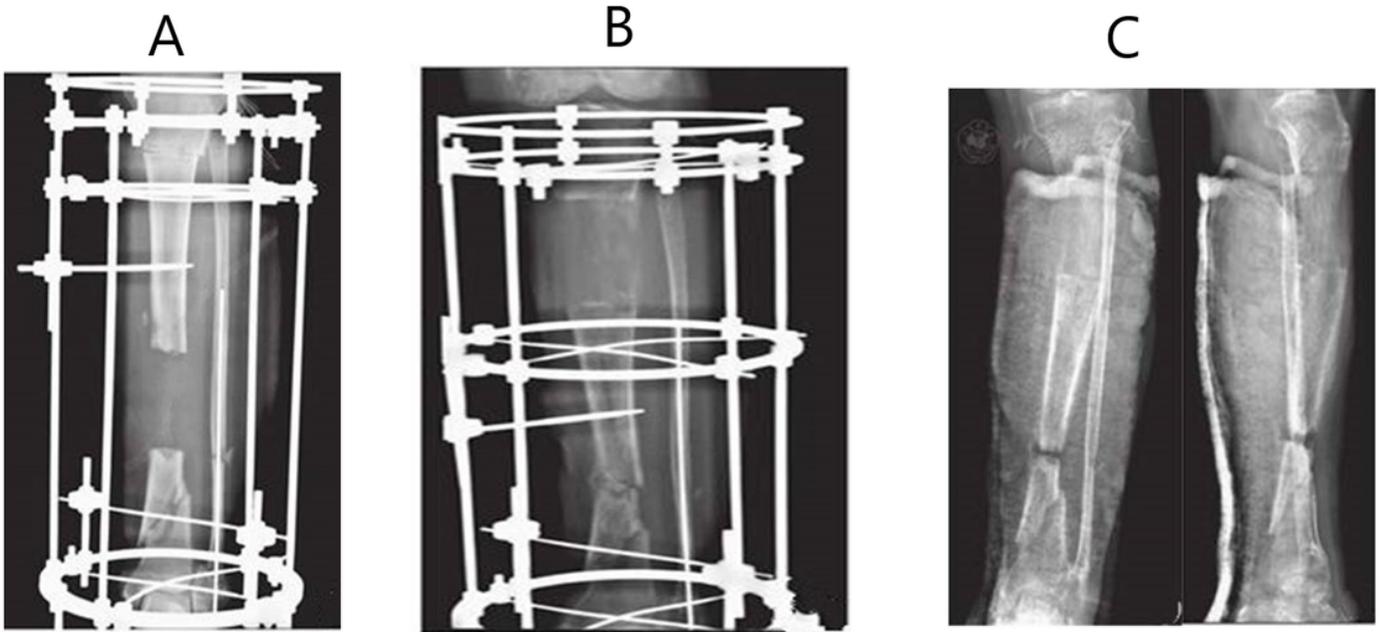


Figure 3

Fracture and defect of tibia and fibula treated with bone transport. (A) After osteotomy. (B) The docking site is closing. (C)The TBS retracted 4.0 mm after removal of total external fixator in 7 months postoperatively in an tome interval of 10 days.