Retraction of transporting bone segment during Ilizarov bone transport

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Research article

Keywords: Callus distraction, Bone transport, Retraction of transporting bone segment, Traction force, Retraction distance

Posted Date: February 5th, 2020

DOI: https://doi.org/10.21203/rs.2.22706/v1

Version of Record: A version of this preprint was published at BMC Musculoskeletal Disorders on October 26th, 2020. See the published version at https://doi.org/10.1186/s12891-020-03702-7.

Abstract

Objective

To investigate the cause and relevant factors of retraction of transporting bone segment (TBS) after removal of its fixator during Ilizarov bone transport.

Methods

The clinical data of 37 cases with tibial bone defect treated by Ilizarov bone transport, in whom the TBSs were removed before mature of mineralization of the distraction callus and 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 that the timing of removal was negatively correlated with the retraction distance, the time interval, cause of removal, transport distance and size of TBS were positively correlated with the transport distance(all $p<0.05$), whereas 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 of the 5 risk factors showed that the timing of removal, transport distance and cause of removal were independent 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 cause of removal. The transport distance and time interval were not significant for the retraction ($p>0.05$).

Conclusion

The TBS is subjected to distraction force from all the adherent soft tissues during Ilizarov bone transport, which has elastic properties and can make a retraction of TBS if its fixator is removed before mature of mineralization of the distraction callus and union of the docking site. The retraction distance is related to the TBS size, transport distance, timing and time interval of removal of TBS fixator. Importantly, the timing of removal and transport distance are the main factors for the retraction, especially the timing of removal had the greatest impact.

1. Introduction

Callus distraction (distraction osteogenesis) by Ilizarov's method has been an effective technique to reconstruct large bone defect and correct discrepancies of limbs[1–3]. 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, 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. Therefore, how to reduce complications and defects has become a clinical research topic. Recently, some scholars [7–9] reported improved Ilizarov bone transport with less complications, in which external fixator was removed when the docking site are closing or showing difficulty in healing and then plate or intramedullary nail was used as a relay internal fixation. Sometimes, the TBS fixator or total external fixator must be removed in advance in cases with pin-track problem (pin-track infection or associated with loosening) which is not effective for conservative treatment, and then internal fixation is used. In these cases, 1–2 weeks or more is need for the heal of the pin-track before implantation of relay internal fixation. During the period between removal of total external or TBS fixator and 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 union and complications in distraction osteogenesis, rarely reported the cause and relevant factors of retraction of TBS; whether the predominant part of the force generated by the soft tissues or by the distraction callus is uncertain [10–12]. Therefore, 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 retrospectively analyzed to identify the cause and risk factors of the retraction of TBS.

2. Materials And Methods

2.1 Inclusion and exclusion criteria

Inclusion criteria: 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 and union of the docking site. Exclusion criteria: Patients with incomplete radiographic data were excluded. 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.

2.2 Patients

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 with an average age of 39.95 years.

2.3 Observation indexes

Retraction distance: the retraction length examined by radiographic evaluation before and after removal of TBS fixator. The course: the days from traumatic bone defect to bone transport. Times of pre-operation: patients had other operations before bone transport. Cause of removal (P/H): pin-track or external fixator related problem or healing difficulty of the docking site. Timing of removal of TBS fixator: from the beginning of bone transport to the removal of TBS fixator. Size of TBS: length of the TBS. Time interval: days before and after removal of TBS fixator. Retraction distance and ten risk factors seen Table 1.

Table 1
Descriptive statistics of variables

Retraction distance(mm)	**7.46 ± 7.30**
Age(yrs)	39.95 ± 14.83
Gender(m/f)	22/15
Disease course(day)	40.54 ± 25.65
Cause of removal(p/h)	8/29
Size of TBS(mm)	9.68 ± 2.24
Length of defect(mm)	6.41 ± 1.16
Time interval(day)	10.54 ± 4.07
Timing of removal(day)	7.47 ± 1.94
Times of preoperation(No.)	1.65 ± 0.82
Transport distance(mm)	6.82 ± 1.17

2.4 Statistical analysis

Data analysis was performed using SPSS 20.0 statistical software (IBM, New York, USA). Firstly, scatter diagram and bivariate correlation were 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.

3. Results

Correlation between the retraction distance and ten variables using scatter diagram showing variables for access analysis were timing of removal, time interval, causes, transport distance and size of TBS, Fig. 1–5. Bivariate correlation analysis showed that the timing of removal was negatively correlated with the retraction distance (r=-0.861, P = 0.000), whereas 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).

Multivariate linear regression analysis of the 5 risk factors showed that the timing of removal, transport distance and cause of removal were independent risk factors for the retraction of TBS(table 2–5), of which, the timing of removal had the greatest impact ($t=-9.425$, $p = 0.000$), followed by the transport distance and cause of removal ($t = 3.287$，$p = 0.002$, $t = 2.227$，$p = 0.033$, respectively), and the transport distance 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. 6. Typical cases are shown in Fig. 7–8.

Table 2. Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Timing of removal	.	Stepwise (Criteria: Probability-of-F-to-enter < = .050, Probability-of-F-to-remove > = .100).
2	Transport distance	.	Stepwise (Criteria: Probability-of-F-to-enter < = .050, Probability-of-F-to-remove > = .100).
3	Cause of removal	.	Stepwise (Criteria: Probability-of-F-to-enter < = .050, Probability-of-F-to-remove > = .100).
a. Dependent Variable: retraction distance			

Table 3. Model Summary[d]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.861[a]	.741	.734	3.76857	
2	.899[b]	.809	.798	3.28410	
3	.913[c]	.834	.819	3.10804	1.707
a. Predictors: (Constant), timing of removal					
b. Predictors: (Constant), timing of removal, transport distance					
c. Predictors: (Constant), timing of removal, transport distance, causes of removal					
d. Dependent Variable: retraction distance					

Table 4. ANOVA[d]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1421.614	1	1421.614	100.099	.000[a]
	Residual	497.075	35	14.202		
	Total	1918.689	36			
2	Regression	1551.989	2	775.995	71.949	.000[b]
	Residual	366.700	34	10.785		
	Total	1918.689	36			
3	Regression	1599.912	3	533.304	55.208	.000[c]
	Residual	318.777	33	9.660		
	Total	1918.689	36			

a. Predictors: (Constant), timing of removal

b. Predictors: (Constant), timing of removal, transport distance

c. Predictors: (Constant), timing of removal, transport distance, cause of removal

d. Dependent Variable: retraction distance

Table 5. Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	31.712	2.502		12.675	.000
	Timing of removal	-3.245	.324	− .861	-10.005	.000
2	(Constant)	18.678	4.337		4.307	.000
	Timing of removal	-3.018	.290	− .801	-10.404	.000
	Transport distance	1.663	.478	.268	3.477	.001

Table 4. ANOVA[d]

3	(Constant)	14.004	4.610		3.038	.005
	Timing of removal	-2.779	.295	− .737	-9.425	.000
	Transport distance	1.506	.458	.242	3.287	.002
	Cause of removal	3.404	1.528	.174	2.227	.033

a. Dependent Variable: retraction distance

4. Discussion

Distraction osteogenesis is to perform slow bone transport or lengthening using external distraction system or intramedullary distraction system after osteotomy. The resistance force of the TBS suffered (equal to the traction force) comes from two aspects during bone transport: one is generated from the distraction of the soft tissues of TBS, and the other is generated from callus distraction at the lengthening site, which come from different sites or directions, and have different properties.

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 magnitude of the traction force from soft tissues reported differs by different authors [10–13], which is mainly related to the transport distance, site and size of TBS. The thicker the skeleton, or the longer the TBS and transport distance, the greater the force[10–13]. Horas et al. [11] used eight cadaveric thigh specimens to make a 60 mm bone defect at the middle femur, and then assessed the traction force required for 40-mm and 60-mm long of TBS using a novel type of intramedullary distraction system. The results showed that the traction force generated by soft tissue was linearly correlated with the transport distance; after a period of sharply increase in force at 0–10 mm transport distance, a relatively slow increase 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 that the TBS size and transport distance were closely related to the magnitude of traction force generated by its adjacent soft tissues.

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 callus distraction gradual appears at distraction period, then gradual become dense and mature of mineralization at consolidation period. Mature of mineralization (complete consolidation) of the callus distraction can prevent the retraction of TBS.

There were still different opinions on the main traction force of the TBS endured during bone transport [10–12]. Aronson et al. [11] concluded that with the increase of transport length, the traction force generated by callus distraction gradually increases, which is greater than the traction force generated by soft tissues. However, Wolfson et al. [12] considered that the soft tissues play a decisive role in traction force generation. We believe that two kinds of traction forces of the TBS change dynamically during bone transport. In the early stage (within 3 months after bone transport), the traction force from the soft tissues is great than that from the callus distraction and becomes an important role; 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. The former has elastic properties, whereas the latter does not have elastic properties and has anti-retraction properties, which can prevent the retraction of TBS [10–14]. Therefore, the retraction of TBS is induced by soft tissue, rather than callus distraction. Juzheng H et al. [7] reported on patients with large tibia bone defect treated by bone transport using external distraction system and relay plate internal fixation, slight retraction after bone transport in 8 months still observed in their study. In this study, we observed that in patients with delayed mineralization, there was still a slight retraction after the removal of TBS fixator in 10 months postoperatively. All patients with retraction of TBS in whom the callus distraction were immature of mineralization.

The retraction distance is mainly affected by the magnitude of distraction force and time interval of TBS removal. Theoretically, the longer the time interval, the more the retraction. However, the data of time interval in this study is concentrated and not normal distribution, so it is not correlated with the transport distance. Our study showed that the transport distance and the size of TBS, especially the timing had the greatest impact; the cause of removal is another important factor affecting the retraction because it reflects the timing of removal as refractory pin-track problem was usually at early phase whereas healing difficult of the docking site was usually at late phase. In the typical case 1 of this study, the time interval was longer (because of pin-track infection and loosening, internal fixation and bone grafting were not performed until 4 weeks after removal of TBS fixator), the timing of TBS removal was earlier (3.5 months), the TBS size was larger (15.2 cm), the transport distance was longer (10.5 cm), which resulted in great retraction (3 cm), showing that the retraction distance of TBS is mainly related with the timing of removal, TBS size, transport distance and time interval of removal.

Conclusion

In conclusion, before mature of mineralization of the callus distraction and union of the docking site, the TBS is always endured two aspects of distraction forces- generated by the distraction of the soft tissues of TBS and callus distraction at the lengthening site. The force generated by soft tissues has elastic properties and can induce a retraction of TBS when the TBS fixator or total external fixator is removed in advance. In order to reduce the gap caused by retraction of TBS, the time interval should not be long or use another external fixation to avoid the adverse effect of retraction of the TBS on the healing of the docking site.

This study explored the cause and relevant factors of the retraction of TBS during Ilizarov bone transport. The findings of this study are useful for understand of the retraction of TBS, improving prognosis and reducing complications of bone transport in the treatment of bone defect.

Declarations

Conflict of interest

The authors declare that they have no conflict of interest.

Funding

None.

Acknowledgments

Not applicable.

Authors' contributions

YH M and XF H put forward the concept of this study and designed this experiment, YW W and SJ G revised this manuscript. QD Y, ZN W, YJ R and ZZ S 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

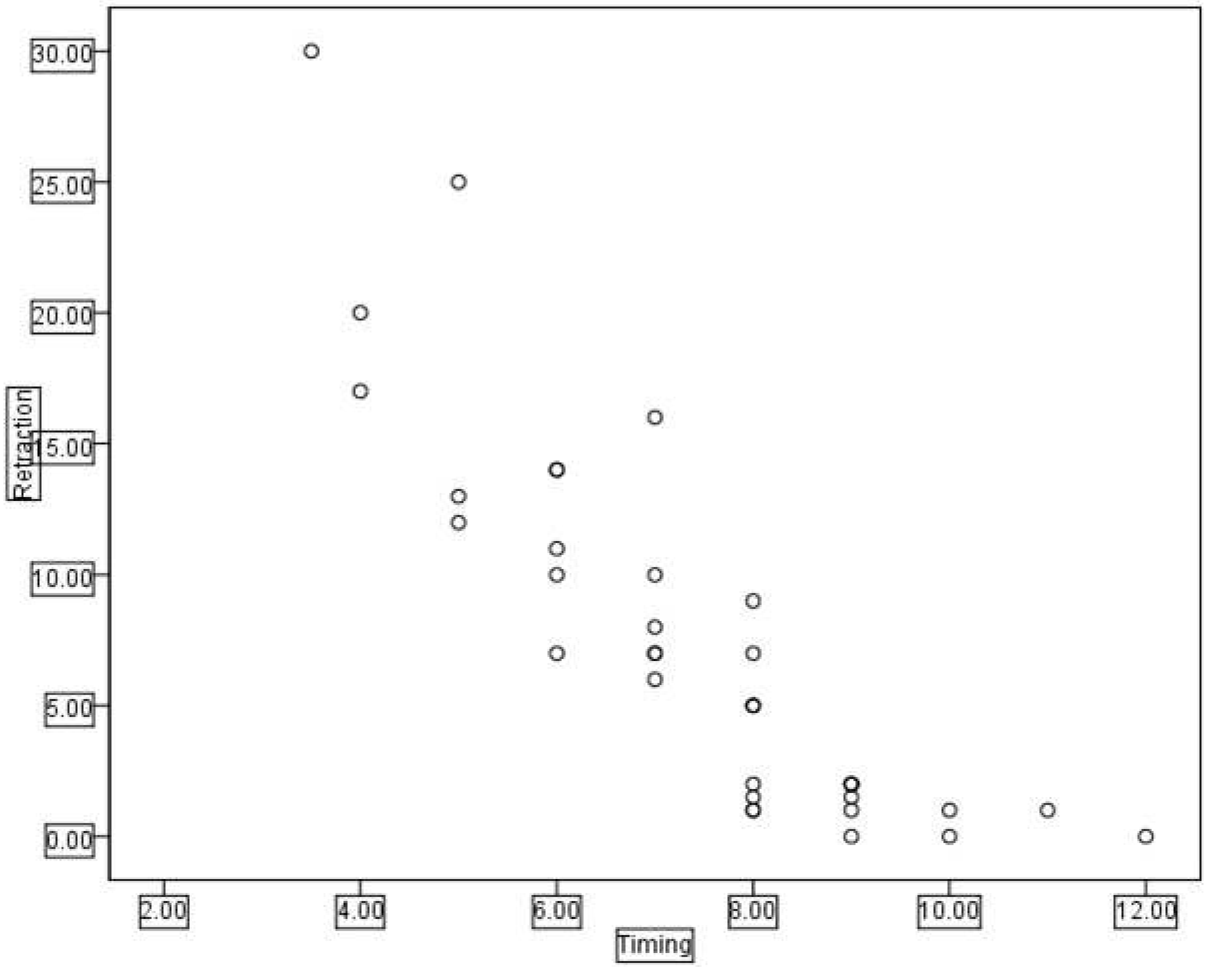

Figure 1

Scatter diagram of the timing of removal

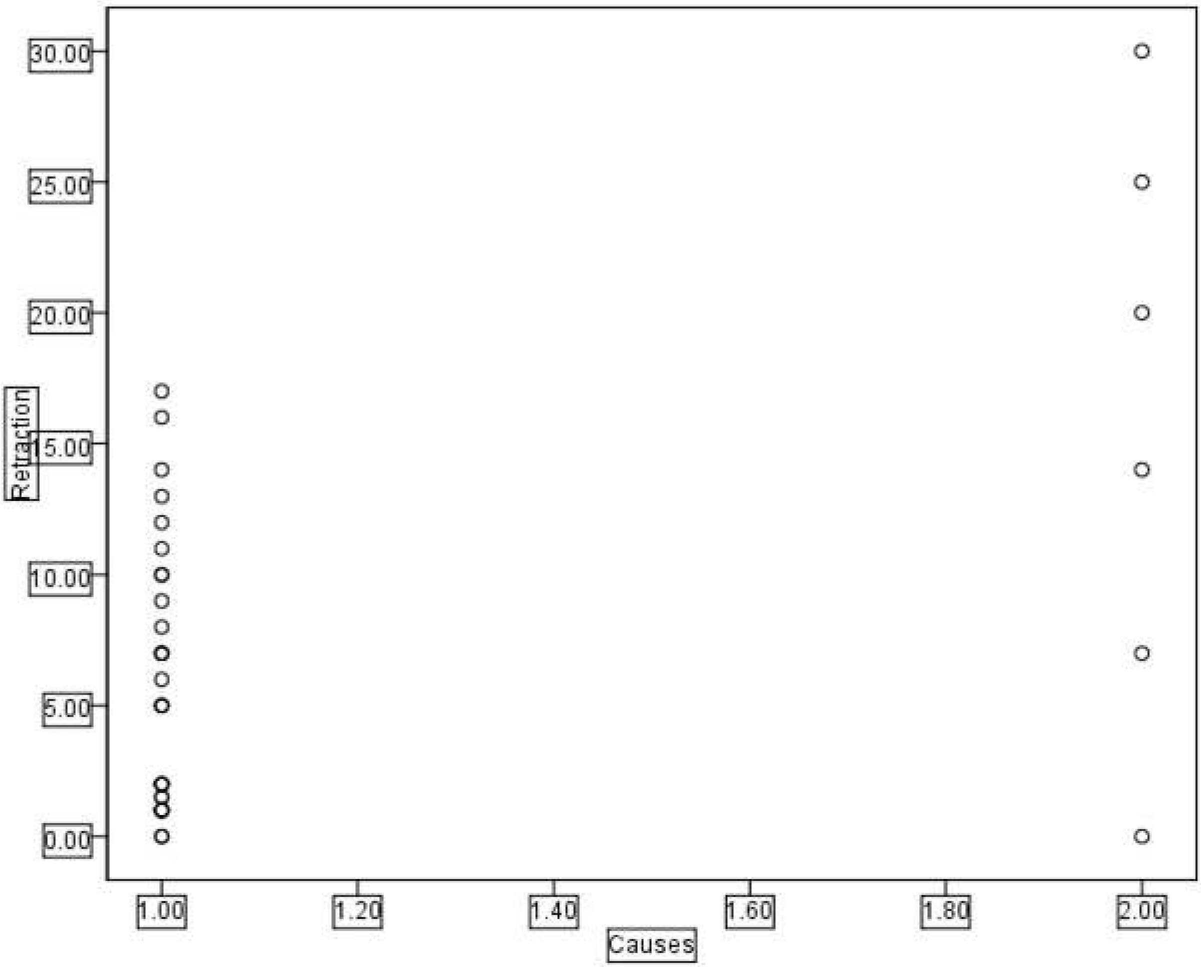

Figure 2

Scatter diagram of the cause of removal

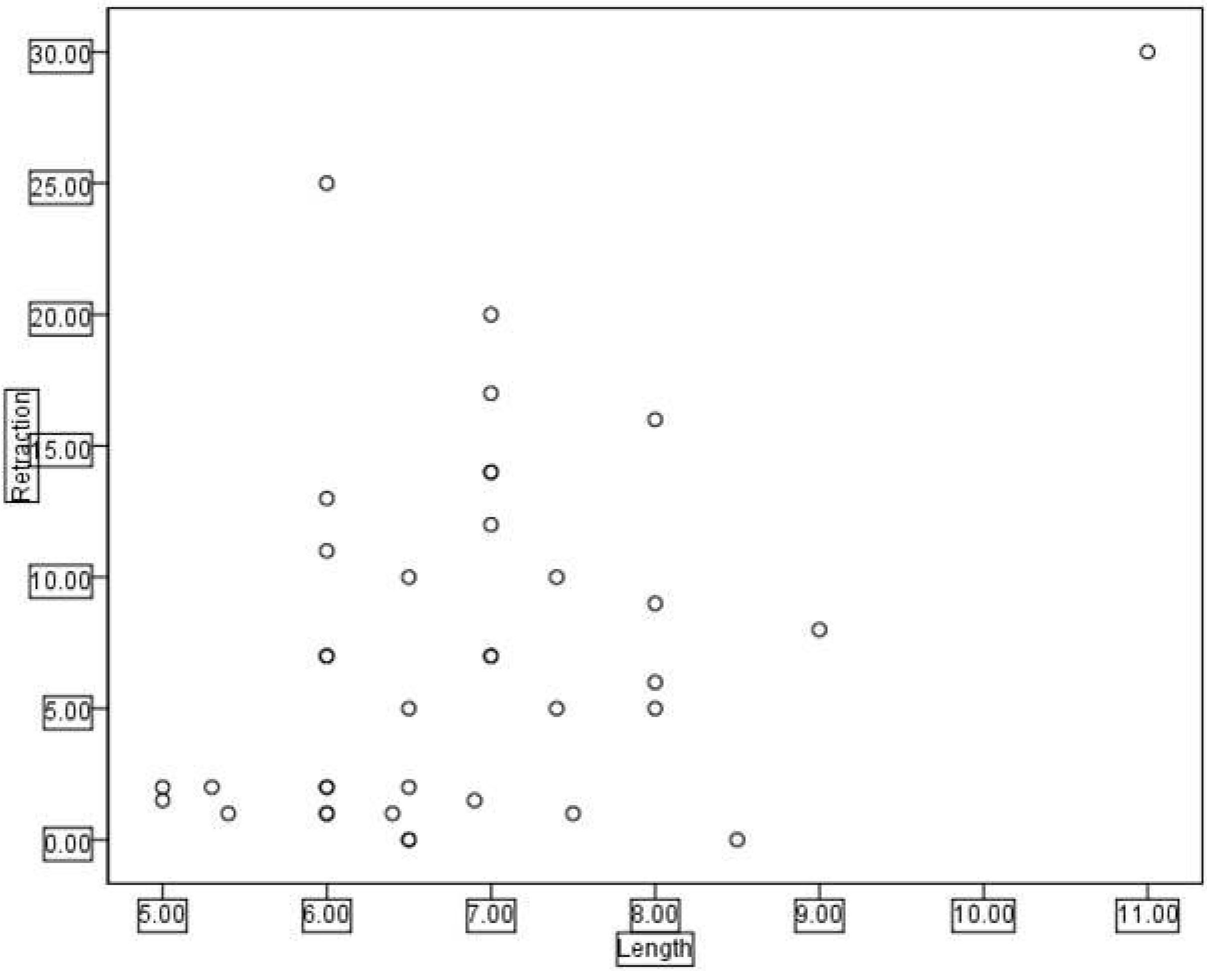

Figure 3

Scatter diagram of the transport distance

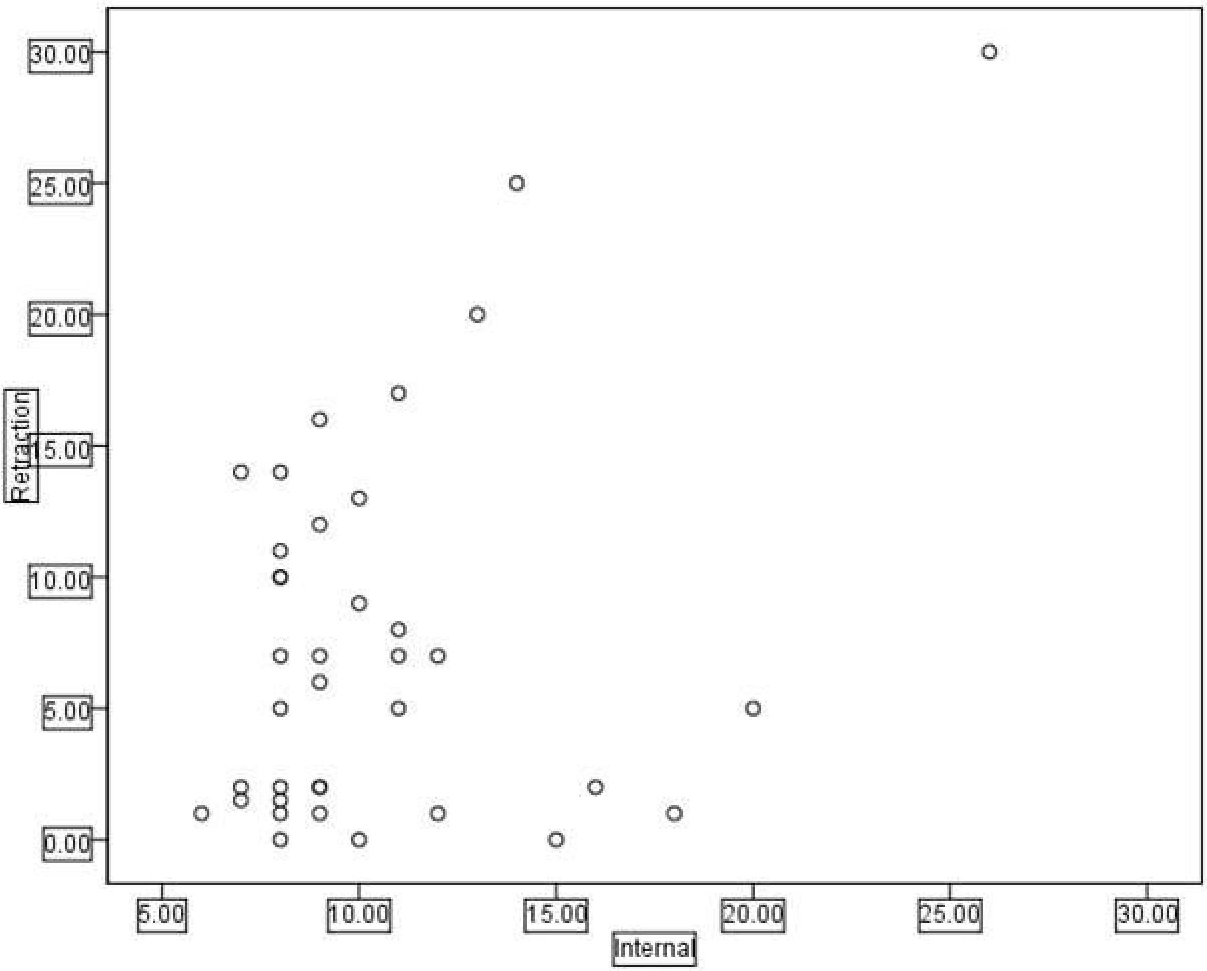

Figure 4

Scatter diagram of the time internal of removal

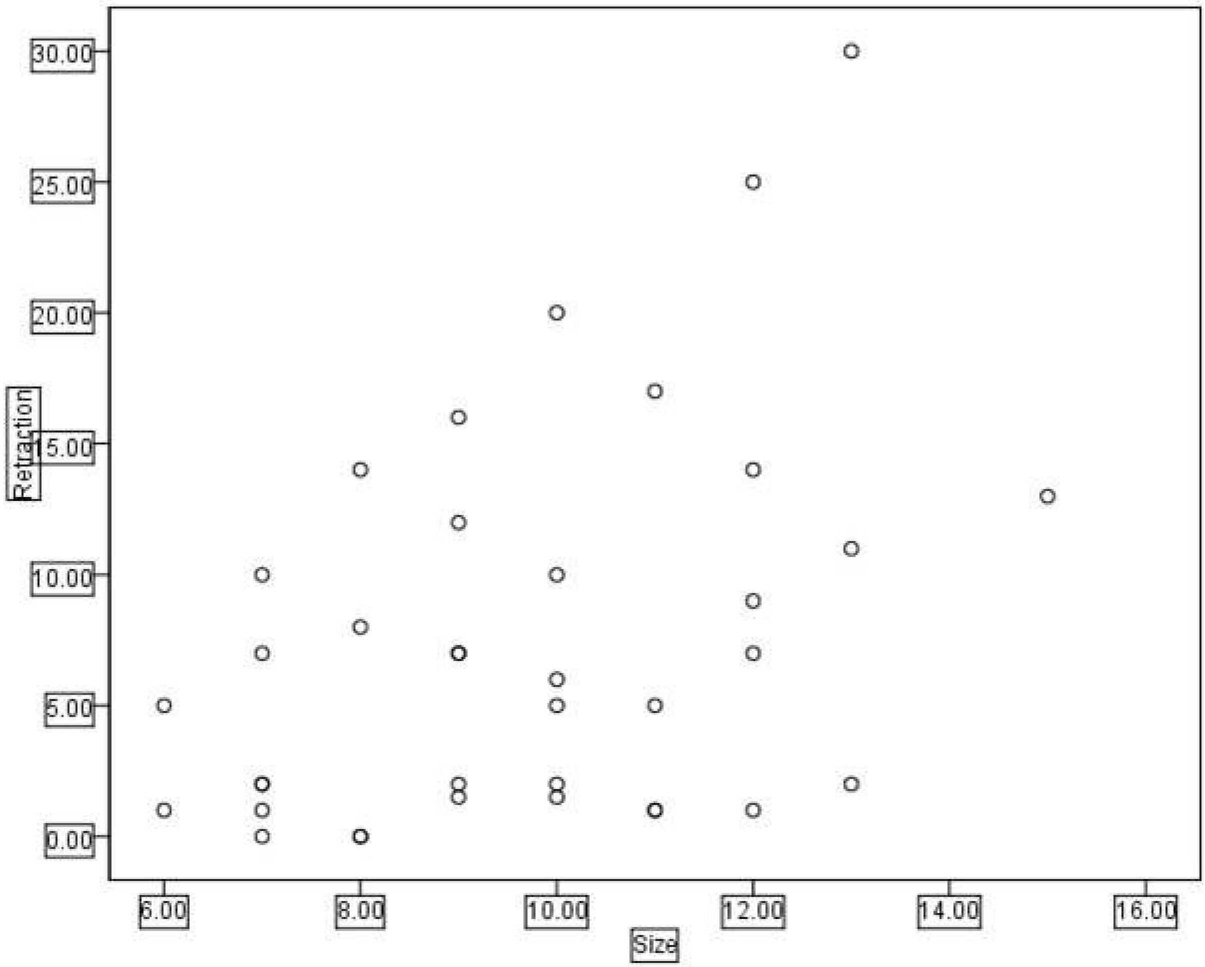

Figure 5

Scatter diagram of the size of TBS

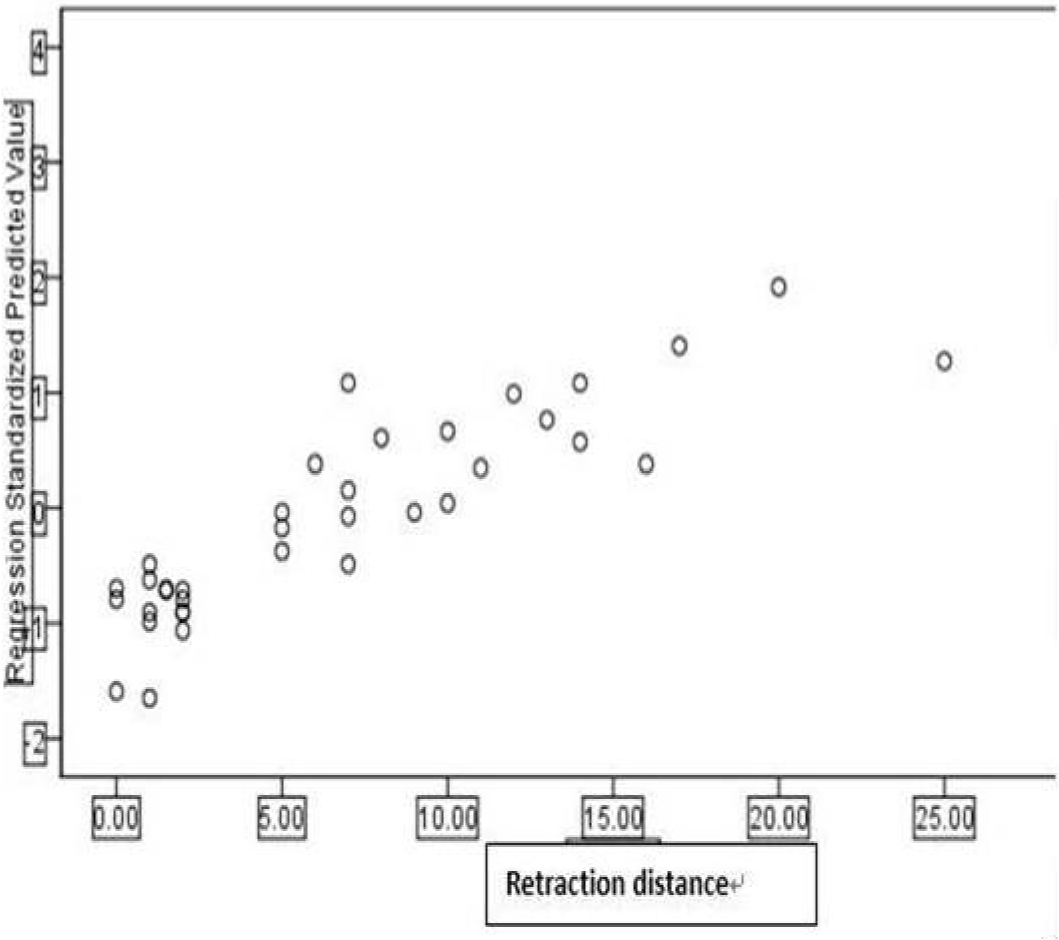

Figure 6

Scatter diagram of the regression model

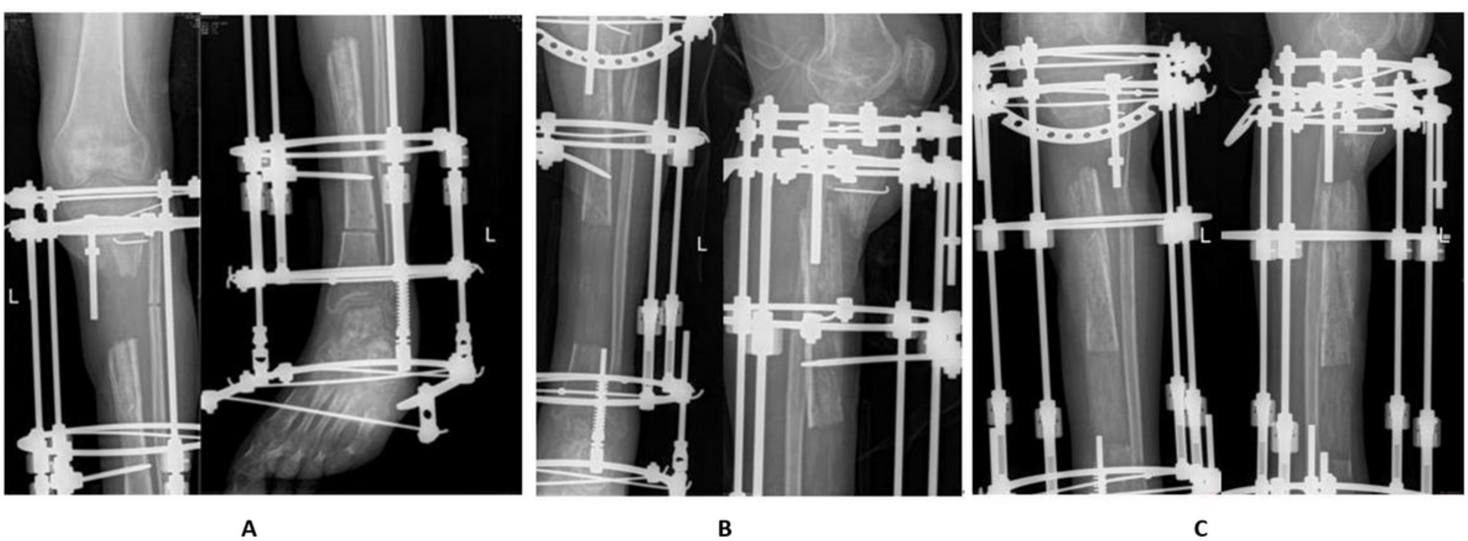

Figure 7

Fracture and defect of tibia and fibula treated by bone transport (a,b), the TBS retracted 3.0 cm after removal of TBS fixtor in 3.5 months postoperatively in an time interval of 25 days(c).

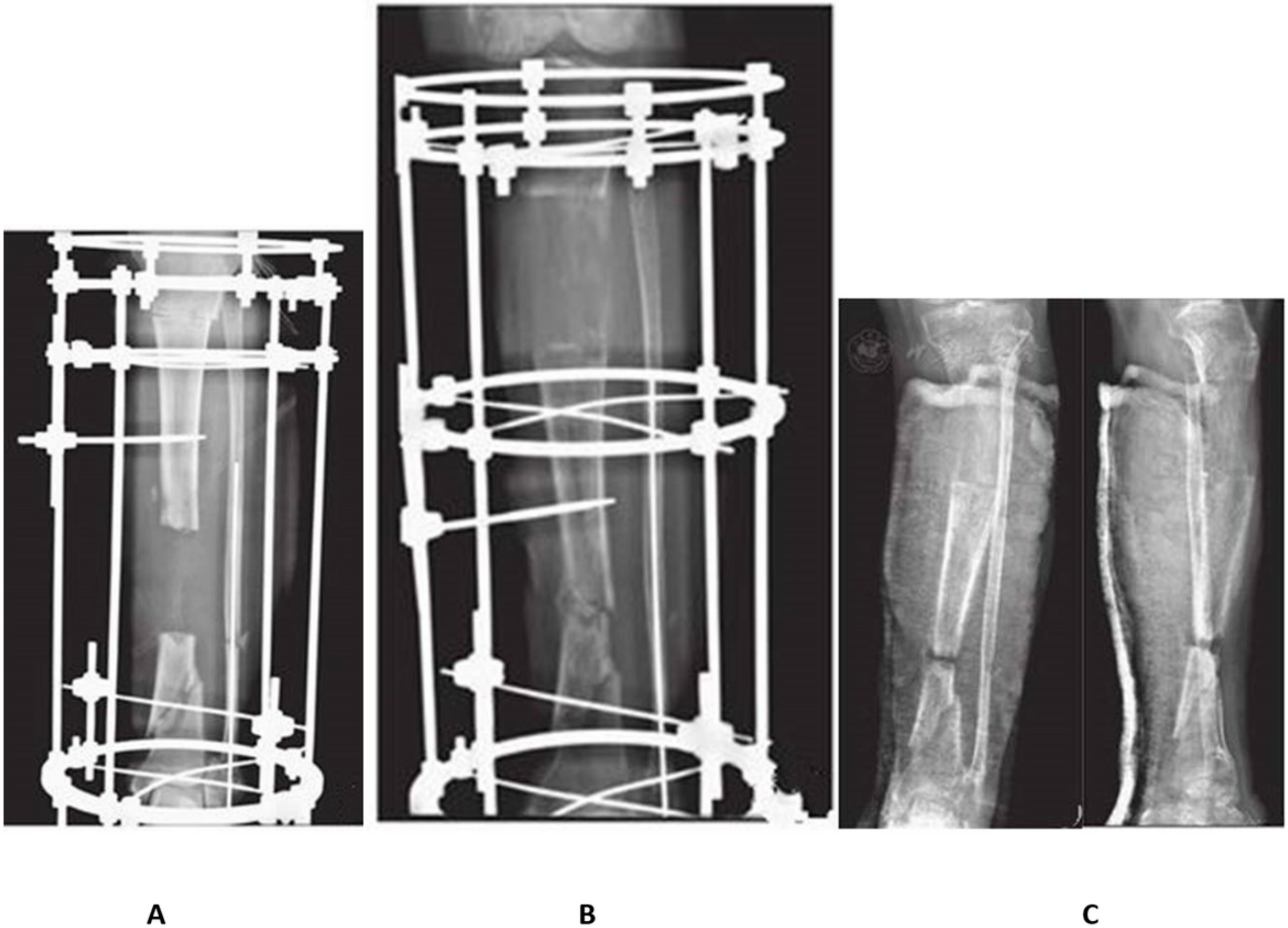

Figure 8

Fracture and defect of tibia and fibula treated with bone transport (a,b), the TBS retracted 4.0 mm after removal of total external fixator in 7 months postoperatively in an tome interval of 10 days(c).