# Bone transport versus acute shortening for the management of infected tibial bone defects: a meta-analysis

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# Abstract

Background The treatment for infected tibial bone defects can be a great challenge for the orthopaedic surgeon. This meta-analysis was conducted to compare the efficacy and safety between bone transport (BT) and acute shortening technique (AST) in the treatment of infected tibial bone defects.

Materials and Methods A literature survey was conducted by searching the PubMed, Web of Science, Cochrane Library, Embase together with China National Knowledge Infrastructure (CNKI), and Wanfang database for articles published as of August 9, 2019. NOS (Newcastle-Ottawa scale) and Cochrane's risk of bias tool were adapted to evaluated the bias and risk of each eligible study. The data of external fixation index (EFI), bone grafting, bone and functional results, complications, bone union time and characteristics of participants were extracted. RevMan V.5.3 was used to perform relevant statistical analyses. Relative risk (RR) were used for the binary variables and standard mean difference (SMD) for continuous variable. Each variable included its 95% confidence interval (CI).

Results 5 studies, including a total of 199 patients, were included in the meta-analysis. Statistical significance was observed in EFI (SMD = 0.63,95% CI:0.25,1.01,P=0.001) and Bone grafting (RR = 0.26,95%CI:0.15,0.46,P<0.00001), however, no significance was observed in bone union time (SMD = -0.02, 95% CI: -0.39, 0.35, P=0.92), bone results (RR = 0.97,95%CI:0.91,1.04,P=0.41),functional results (RR = 0.96,95%CI:0.86,1.08,P=0.50) and complication (RR = 0.76,95%CI:0.41,1.39,P=0.37).

Conclusions AST is preferred on the aspect of minimizing treatment period, while BT is superior to AST for reducing bone grafting. Due to the limited number of trials, The meaning of this conclusion should be taken with caution for infected tibial bone defects.


# Background

The treatment for infected tibial bone defects can be a great challenge for the orthopaedic surgeon,The occurrence and progression of infectious bone defects of tibia is often associated with severe wound infection, soft tissue defects, vascular and nerve injuries, and joint dysfunction, so its treatment full of difficulty.[1–6] Most research [1, 2, 7–9] recommend Ilizarov technique reconstruction to repair tibial bone defects because it has several advantages. First, infection can be strictly controlled. Second, this technique can tackle varying degrees of bone defects and restore limbs discrepancy to a satisfactory length; Thirdly, bone defects and soft tissue defects can be repair at the same time. Fourthly, it eliminate the necessity of bone grafts and donor sites sacrifice. The main treatment methods include BT and AST, and both methods have their advantages and disadvantages.[6, 10–14] It is still unclear which choice is better.

At present, there are numerous comparative studies on these two techniques, but no meta-analysis on this topic has been published. The present meta-analysis perform a comparison between BT and AST for the treatment of infected tibial bone defects published before August 8, 2019. The aim of the present study was to help with decision making about choice of AST or BT.

## Methods

### Meta-analyses principles

We performed all the analyses based on previously published studies, thus no ethical approval was required.The metaanalysis followed the principles of ‘Preferred Reporting Items for Systematic Reviews and MetaAnalyses(PRISMA)’ statement(S1 Checklist). [15] It was prospectively registered in the PROSPERO registry (CRD42019133659).

### Search strategy

Two individual investigators (WHJ, and ZSY) searched the selective databases according to the principles of the Cochrane collaboration. The following databases were searched: The PubMed, Cochrane Library, EMBASE, Web of Science and Chinese databases included WanFang Data, CNKI. All the databases were searched up to August 8, 2019, with language being restricted by English and Chinese. We performed the literature search by using the keywords of ‘bone transport’, ‘bone transportation’, ‘Distraction Osteogenesis’, ‘ilizarov techniques’, ‘acute compression and distraction’, ‘acute shortening’, ‘bone defects’, ‘non-unions’, ‘tibial’. Detailed search terms were provided in document S2. Any differences are resolved through consensus and discussion.

### Study selection

The inclusion criteria were as follows: i) open tibial fractures with tibial bone and soft-tissue defects;ii) RCT, prospective or retrospective trails; ) age ≧ 16 yeas old; ) treatment protocols were either bone transport or acute shortening/lengthening with Ilizarov circular external fixator, and the patient's clinical datas was complete. Exclusion criteria were as follows: i) Reviews, metaanalyses, case reports, letters and editorial articles; ii) duplicates of previous published papers; and iii) studies which children included (< 16-years-old).

### Data extraction

In order to extract the data, a standardized selective protocol was designed. The outcome parameters were as follows: external fixation index, bone grafting, heal time, functional results, bone results, number of complications. In one study the external fixation index was reported in days/cm, which was converted to months/cm. The following characteristics of each eligible study were recorded: the first author, publication year, country, case number, average age, gender, bone defects, and journal reference.

### Quality assessment

NOS (Newcastle-Ottawa scale) (S3) and Cochrane's risk of bias tool were adapted to evaluated the bias and risk of each eligible study.[16] All the investigators evaluate each included trial, and the NOS scores was illustrated in table 1. In addition, the risk of bias graph and summary were make up (Fig. 2).

### Statistical analysis

The Review Manager software (version 5.3; The Nordic Cochrane Centre, Copenhagen, Denmark) was adapted to perform statistical analysis and get forest plots. Relative risk(RR) were used for the binary variables and standard mean difference (SMD) for continuous variable. Each variable included its 95% confidence interval (CI). Meta analysis was performed on the data included in the study, and the studies with clinical heterogeneity were divided into subgroups, and then statistical heterogeneity was analyzed ($I^2 < 50\%$, $P > 0.01$ is the test standard of heterogeneity). When the heterogeneity between subgroups was low ($I^2 < 50\%$, $P > 0.05$), the fixed effect model was used; otherwise, the random effect model was applied. When the $I^2$ value is inconsistent with the P value, the P value is used as the standard to select the processing model. when $P < 0.05$, the difference was considered statistically significant.

# Results

# Included literature

Study characteristics. The search procedure is shown in Fig. 1. Initially, 252 related studies were searched, and 154 trials were excluded according to the title and abstract. Then, according to the inclusion criteria, 78 studies were excluded from the 83 studies which might be relevant. Finally, 5 studies [6, 10, 12–14] were included in the meta-analysis, including a total of 199 patients. To avoid heterogeneity, studies which only applying bone transport or acute shortening were excluded. In this paper, intervention of bone transport was set as the study group, and in contrary, acute shortening as the control group. Baseline characteristics of the studied and patients are shown in table 1 and 2.

Of the 5 included studies, only 3 [10, 13, 14] had a score of 8(the highest was 10). All studies did not use any methods of blinding, which may lead to observation bias; In addition, one article [6] did not report the loss of follow-up. The main problem in the included trials lies in the implementation of randomization and the improper use of the methods of blinding, which may lead to a moderate degree of bias. The specific quality evaluation of the 5 studies is shown in Fig. 2.

# Results of the meta-analysis

# Bone union time

Overall, 3 studies [6, 10, 12] reported bone union time, and no significant heterogeneity was found ($P = 0.18$, $I^2 = 42\%$). fixed-effect model was used and the results showed that there was no significant difference between the two groups (SMD = -0.02, 95% CI: -0.39, 0.35, $P = 0.92$), indicating no difference in bone union time between the study group and the control group (Fig. 3).

# EFI

A total of 3 studies [6, 10, 12] reported EFI, and no significant heterogeneity was found ($P = 0.65$,$I^2 = 0\%$). fixed-effect model was used and the results showed that there was significant difference between the two groups (SMD = 0.63,95% CI: 0.25,1.01,P = 0.001), indicating there was difference in EFI between the study group and the control group (Fig. 4).

# Bone grafting

In total, 4 studies [6, 10, 12, 14] compared the bone grafting rate, and no significant heterogeneity was found ($P = 0.76, I^2 = 0\%$). fixed-effect model was used and the results showed that there was significant difference between the two groups (RR = 0.26,95%CI: 0.15,0.46,P < 0.00001), indicating there was difference in bone grafting between the study group and the control group (Fig. 5).

# Bone results

In total, 5 studies [6, 10, 12–14] compared the bone results, and no significant heterogeneity was found ($P = 0.91, I^2 = 0\%$). fixed-effect model was applied and the results showed that there was no significant difference between the two groups (RR = 0.97,95%CI: 0.91,1.04,P = 0.41), indicating no difference in bone union rate between the study group and the control group (Fig. 6).

# Functional results

Overall, 5 studies [6, 10, 12–14] described the functional results, and no significant heterogeneity was found ($P = 0.89, I^2 = 0\%$). fixed-effect model was applied and the results showed that there was no significant difference between the two groups (RR = 0.96,95%CI: 0.86,1.08,P = 0.50), indicating no difference in functional results between the study group and the control group (Fig. 8).

# Complication

Complication were mentioned in 3 studies[12–14], which had significant heterogeneity ($P = 0.004, I^2 = 82\%$). random-effect model was applied and the results showed that there was no significant difference between the two groups (RR = 0.76,95%CI: 0.41,1.39,P = 0.37), indicating no difference in functional results between the study group and the control group (Fig. 9).

# Publication bias

A funnel plot of bone results was used to analyze whether there was publication bias. As can be seen from the funnel plot, the two sides of the funnel plot are symmetrical (Fig. 7). However, the number of included trials was less than 10, so the conclusion may not be completely accurate.

## Discussion

At present, Ilizarov reconstructions, Masquelet technique, vascularised and non-vascularised bone grafts and bone substitutes are the main methods for tibia defects.[2, 8, 9, 17–22] However, bone transfer is the preferred technique for the treatment of infected tibial bone defects.[1, 4, 23, 24] Ilizarov reconstructions techniques includes two main clinical treatment protocols: bone transport (BT) and acute shortening gradual lengthening (ASD).[11, 25] Bone transport is a safe and reliable approach of tackling segmental tibia bone defect. It can repair the bone defect while treating the soft tissue defect. It has the advantages of quick wound healing, shortening course of treatment, less bone grafting and definite curative effect.[26, 27]

However, postoperative complications are common, such as bone exposure and bone nonunion is usually along with axis deviation of long segmental bone transport, consolidation of newly formed bone is poor, delayed union or nonunion at docking site, pin track infection and screw loosening, stiffness of knee and ankle joints foot drop.[5] For acute shortening and lengthening technique, many studies have shown that it has obvious advantages and can significantly shorten the time of union.[24, 28–30] It reduces or closes the wound, effectively reduces the soft tissue tension, and reduces the incidence of postoperative bone infection, bone exposure, osteonecrosis and soft tissue necrosis, and especially suitable for patients with large wound.[31–37]

However, according to studies,[38, 39] it may cause vascular and nerve injury, and require more bone grafts and a limited shortening distance. At present, there are many comparative studies on bone transport and acute shortening technique in the treatment of infected tibial bone defects, but no conclusion has been reached. As far as the author knows, the present study is the first meta-analysis about the issue.

The present meta-analysis showed that, compared with the acute shortening, bone transport was significantly different from EFI, bone grafting, but no significant difference in bone union time, bone results, complications and functional results.

EFI is an effective index to evaluate the treatment of bone defect and nonunion with ilizarov technique, which is closely related to age, pathological characteristics, osteotomy position, elongation speed and bone defects length.[40, 41] Many studies reported that the EFI of bone transport group ranged from 0.87–2.8 months/cm[4, 5, 23, 42] compared to 1.2–2.5 months/cm in acute shortening group.[24, 30, 32, 33, 35, 36, 39, 43] In the present study, significant difference had been detected in the two groups in terms of EFI ($P < 0.05$)( Fig. 4), which mean the EFI of bone transport group was high than acute shortening group. This result highlights the advantage of acute shortening group in the treatment cycle, which is consistent with the current mainstream literature.

Bone defect was quickly filled by connective tissue just because bone defect end can not reach the docking site in time. Consequently, it may affect the bone union. Acute shortening technique can bring forward and solve the problem of nonunion because it shortening the time of bone defect end contact and earlier bone grafting.[12] Kemal et al. reported on patients of 24 with mean defects of 7.01 cm. They reported average bone union time of 275.5 ± 70.6 days.[5] In a study of 31 cases reported mean time to union was 40.1 weeks (12.6–80.7 weeks).[32] Mean healing index in another study was 30 days/cm.[33] MP Magadum et al. described the mean lengthening achieved was 10 cm, and mean union time was 6.3 month in a study of 27 patients with infected nonunion and large bone defects in the tibia.[30] In the meta-analysis, no difference had been detected in the two groups according bone union time ($P > 0.01$) (Fig. 3). Some studies show that multiple-level bone transport can significantly decrease bone union time.[44] Results may also be affected by the different bone transport modality used in the included studies. Some studies believe that docking site union is the key factor to affect the whole therapeutic time, and acute shortening is more advantageous in shortening docking site union time.[24, 28–30] Therefore, the bone union time of AS group may be shorter. However, bone union may be affected by many factors, such as the severity of original injury and infection, the length of bone defect and other factors. In addition, the number of studies included was small, so the results should be critically considered.

At present, most of the research claims to perform bone grafting at docking site to reduce bone union time.[25] According to literature reports, the bone grafting rate of bone transport groups ranged from 14.3–40% [1, 23, 45] compared to 20–43% in acute shortening groups.[2, 11, 36] 4 studies included in this study reported the bone grafting data, and the results showed that the difference between the two groups was statistically significant ($P < 0.05$)(Fig. 5), which mean the acute shortening groups need more bone grafting.

All the eligible trials applied the Association for the Study and Application of the Method of Ilizarov (ASAMI) criteria to assess bone and functional results.[30] It is documented that, excellent rate range from 64–83% in bone transport groups [4, 19] compared to 53–100% in acute shortening groups.[30, 34–36] Kemal et al. reported bone union of 95.8% and 12 (50%) cases had excellent radiological results.[5] No difference had been detected in the two groups according bone results ($P > 0.01$)( Fig. 6). This suggested that both groups were at same risk for delayed union, malunion and nonunion. Due to the limited number of references, there may be some bias in the results, so it is necessary to include more high quality literatures for further analysis and evaluation to draw more accurate conclusion.

All the 5 eligible studies described the detail of functional results, and the result showed that on significant difference had been found in the two groups according functional results ($P > 0.01$)( Fig. 8). Studies illustrated that excellent functional results range from (38%-58% )[4, 5, 19] in bone transport groups compared to 60–86%[30, 35, 36] in acute shortening groups. The functional results mainly depends on effective guidance of functional exercise, prevention of needle penetration too close to the joint, and adoption of methods to correct the existing ankle deformity, etc. Although AS is inclined to close the wound earlier and avoid the need of flap repair, the shortened tendon becomes relaxed and prone to foot drop.[12]

Complication Pin track infection and screw loosening are the most common complications in external fixation, and usually the final results will not affect by these complications. In terms of reports, limb length discrepancy, permanent nerve and vascular damage, vascular crisis, re-fracture and newly formed bone infection are rare, and thorough debridement is the key step to control bone infection.[4] Studies reported complications of bone transport groups ranged from 8.3–100%,[1, 4, 23, 42] and 9-100% in acute shortening groups [32, 33, 36, 37, 43]. Sarah et al. recommended the use of Doppler ultrasonography to assess distal pulses is necessary, and choose appropriate shortening method according soft tissue and wound condition.[38] 3 studies publish the data of complications, and on significant difference had been found in the two groups according complications (P > 0.01)(Fig. 9). Since the included studies did not describe the types and detailed statistical data of complications, this study could not carry out subgroup analysis, so there may be some bias in the results.

# Strengths and limitations

To the best of our knowledge, this is the first meta-analysis to compare the treatment effect between bone transport and acute shortening technique for the treatment of infected tibial bone defects. Moreover, Heterogeneity analysis of this study found little and no publication deviation in heterogeneity. There were certain limitations in the present study: first, all of the eligible studies were retrospective study, as well as the sample size is small and most studies were performed in single center, which may lead to a certain degree of bias. Therefore, part of the conclusions should be treated with caution. Second, due to the different inclusion and exclusion criteria and measurement indicators of each study, the results may be affected. Thirdly, the included literatures lacked standardized and unified standards for the record of observation indicators, especially the external fixation index and bone healing time, so many indicators could not be combined for analysis. It is suggested to adopt unified evaluation indicators in subsequent studies, so as to draw more stable and reliable conclusions. Fourth, in the 5 studies, the further fixation after remove of external fixation were different, including nail, plate and plaster. The shortening ways were also disunity, immediate shortening or gradual shortening were applied in different studies. And the external fixation types included monolateral fixator and ring fixator. All of these may induce heterogeneity and impair the reliability of the conclusion.

We suggest that it is still necessary to perform further large-size, multi-center clinical RCTs in the future, and obtain higher-level evidence for clinical treatment by using unified and correct scoring system, evaluation indicators, random and methods of blinding.

# Conclusions

AST is preferred on the aspect of minimizing treatment period, while BT is superior to AST for reducing bone grafting. Due to the limited number of trials, The meaning of this conclusion should be taken with caution for infected tibial bone defects.

# Declarations

### Ethics approval and consent to participate

Not applicable.

### Availability of data and materials

All data generated or analyzed during this study are included in this published article.

### Competing interests

The authors declare that they have no competing interests.

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### Authors' contributions

HJW participated in conception and design of this study. HJW, SYZ and CZL performed the acquisition of data. SYZ and CZL performed the statistical analyses. SYZ was involved in the interpretation of data. HJW drafted the manuscript. YQX revised the manuscript for important intellectual content. All authors have read and approved the manuscript

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Not applicable.

### Abbreviations

95% CI: 95% confidence interval; CNKI: China National Knowledge Infrastructure; BT: bone transport; AST: acute shortening technique; RR: Relative risk; SMD: standard mean difference; EFI: external fixation index; NOS: Newcastle-Ottawa scale.

### Consent for publication

We obtained written informed consent from the patient for publication of this case report and any accompanying images and data. A copy of the written consent is available for review by the editor of this journal.

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# Tables

Due to technical limitations, the tables could not be displayed here. Please see the supplementary files section to access the tables.

# Figures

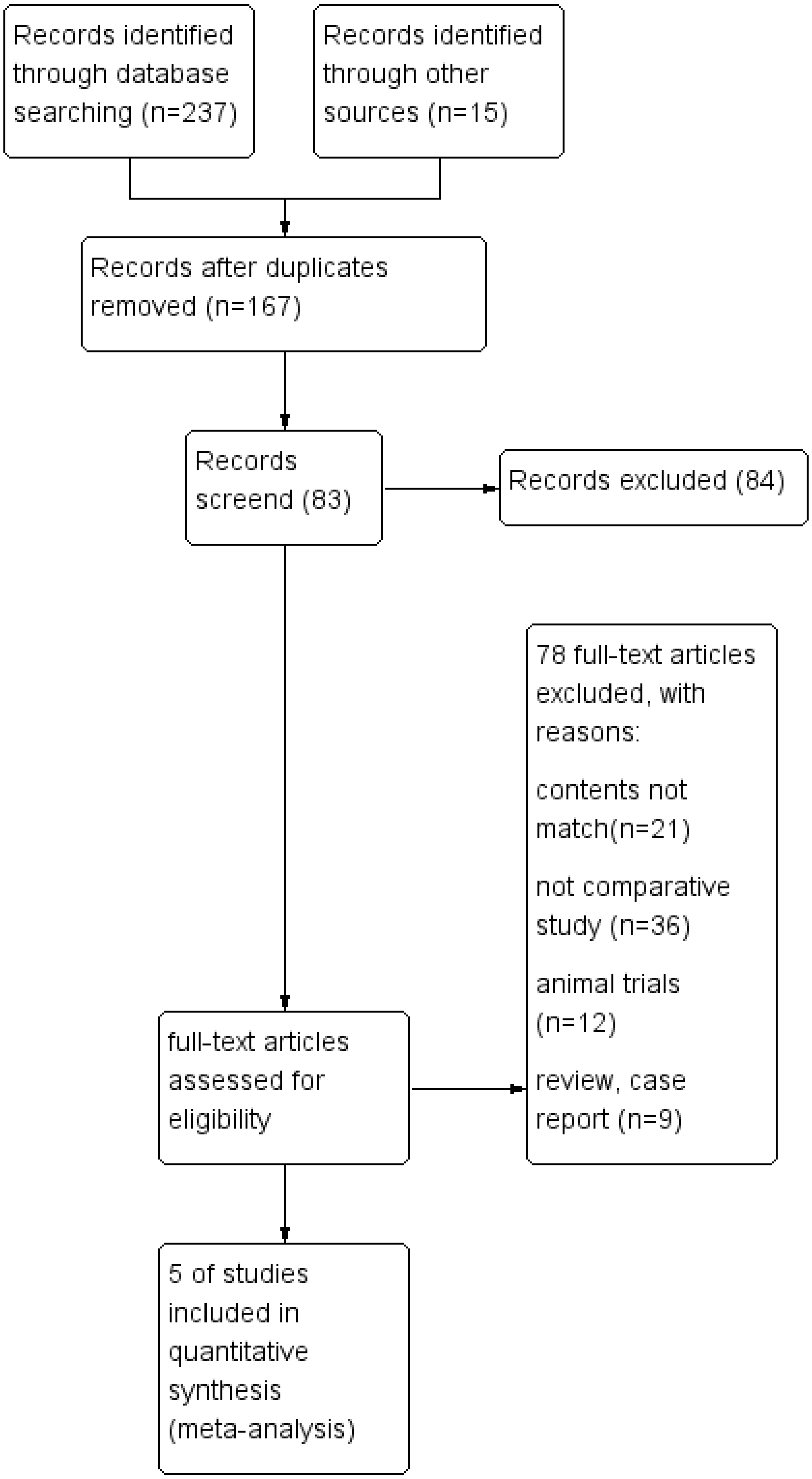


**Figure 1**

Flowchart diagram of the study selection.

**Figure 2**

Assessment of the study quality. Risk of bias (A) graph and (B) sum¬mary. The green circle represents the low risk of bias, the yellow circle represents unclear risk of bias, and the red circle represents a high risk of bias.

**Figure 3**

Comparison of bone union time between the bone transport and acute shortening groups.

**Figure 4**

Comparison of external fixation index between the bone transport and acute shortening groups.

**Figure 5**

Comparison of bone grafting between the bone transport and acute shortening groups.

**Figure 6**

Comparison of bone results between the bone transport and acute shortening groups.

**Figure 7**

Funnel plot of the bone results of bone transport and acute shortening groups. SE, standard error; RR, relative risk.

**Figure 8**

Comparison of functional results between the bone transport and acute shortening groups.

**Figure 9**

Comparison of complication between the bone transport and acute shortening groups.

# Supplementary Files

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- TableI.xls
- NewcastleOttawascale.pdf
- PRISMAChecklist.doc
- searchterm.pdf
- TableII.xls