Drilling percutaneously through the nonunion site: a more cost effective solution for long bone nonunions

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Research Article

Keywords: fracture, non-union, drilling hole percutaneously, minimally invasive surgery

Posted Date: November 8th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-2234636/v1

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Abstract

**Background:** Despite the development of improved fracture treatment, bone nonunion remains a challenge for orthopedic surgeons. Various therapies have been examined for the treatment of nonunions, including fixator exchange, bone grafting, application of growth factors, and even cell and gene therapy. However, all these methods have limitations, such as donor site complications, soft tissue problems, high cost and long hospitalization. This study aims to find a minimally invasive and cost-effective method for nonunion treatment.

**Methods:** Between October 2018 and October 2019, nineteen patients with long bone nonunions (11 tibia and 8 femur) were treated in our trauma center. There were 14 males and 5 females and the average age was 56.1 years. Treatment of the nonunion was performed by a novel technique consisting of a direct drilling procedure. Under C-arm guidance, a k-wire was used to percutaneously drill across the nonunion site. The k-wire was directed along the longitudinal axis of the bone. The necrotic cortex of the nonunion site was drilled and the medullary cavity was re-established. The implants were maintained, as the fixation was stable. Regular rehabilitation and follow-up was performed until the patient achieved bone union.

**Results:** 18 of the 19 cases achieved successful bony union with this technique. Sixteen achieved union after a single drilling procedure, while two patients required a second drilling procedure to achieve union. One failure occurred in a female patients with a tibial shaft nonunion which only achieved union after revision fixation and cancellous bone grafting. The average union time after drilling technique was 7.4 month (range: 4-14), and the average hospital stay was 5.3 days (range: 4-15).

**Conclusion:** This drilling technique provides a novel, minimally invasive, effective and low-cost method for the treatment of bone nonunion. It minimizes the iatrogenic damage and preserves the biological environment for fracture healing. The encouraging results of this technique warrants a larger study.

**Trial registration:** Chinese Clinical Trial Registry ChiCTR-PPC-14005360. Registered 17 October 2014

**Background**

Although the techniques for fractures treatment have been improving, approximately 5%-10% of fractures need additional intervention because of healing problems, such as delayed union, malunion or nonunion[1, 2]. Bone nonunion is considered one of the most serious complications and its treatment is usually associated with long hospitalization time, prolonged recovery, and a very low health-related quality of life [3-6]. There are multiple options for the treatment of bone nonunion. Autologous cancellous bone graft is considered the gold standard for the treatment of atrophic nonunions [7, 8]. Additional methods including the use of Bone Morphogenetic Proteins (BMPs), platelet-rich plasma (PRP), ultrasound stimulation and bone marrow graft have also been shown to be effective in nonunion management [1, 7-14]. While each of these treatments has their own advantages, cost is one common disadvantage of all of these nonunion treatment options. [5].
The aim of our study was to develop a minimally invasive, effective and low-cost technique for the treatment of bone nonunion. Nineteen long bone nonunions treated using this new technique were reviewed.

Methods

Patients

A total of 19 patients with long bone nonunions were treated in our trauma center from October 2018 to October 2019 (Table 1). There were 14 males and 5 females and their average age was 56.1 years (range: 38—74). There were 11 tibial shaft and 8 femoral shaft nonunions. The average time from initial injury to diagnosis of nonunion was 11.7 months (range: 8—22). Six cases were combined with other fractures. Patients underwent full preoperative photographic and clinical evaluation to identify the fixation stability, type of nonunion, absence of active infection, and the patient’s physical condition. Stable fixation was defined as no evidence of motion at the nonunion site. Preoperative examination included appropriate radiographic investigation to document the presence of a stiff nonunion. Often, stress radiographs or intraoperative fluoroscopic was necessary to demonstrate an absence of motion at the nonunion site. In this study, all cases presented with stable and atrophic nonunion. [11] There were no infected nonunions or hypertrophic nonunions. This study was approved by the Ethics Committee of the Third Hospital of Hebei Medical University and all participants gave signed informed consent.

Table 1 Demographic and result characteristics
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<th>Patients</th>
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<th>Age</th>
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<th>Initial Treatment</th>
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CRIF: close reduction intramedullary nail fixation; ORPF: open reduction plate fixation; MIPPO: Minimally Invasive Percutaneous Plate Osteosynthesis

* represents the patient underwent secondary drilling procedure

# represents the patient did not get union until accept open surgery and cancellous bone graft

Introduction of direct drilling technique

After the induction of anesthesia, the patients were placed supine on a radiolucent table. Under C-arm guidance of C-arm, a 4 mm diameter K-wire (Kirschner wire) driven by an electrical drill was used to percutaneously drill through the nonunion site. The K-wire was directed along the longitudinal axis of the bone. At nonunion sites fixed by intramedullary nails, the K-wire was drilled through the necrotic cortex around the nail using multiple passes in different planes. At nonunion sites fixed with plates, the K-wire was drilled through both cortices and longitudinally along the medullary canal. If the medullary canal was totally blocked, a larger diameter k-wire was used to open the medullary canal. In general, at least 6-10 drill passes through the cortex were performed at each nonunion site, including when possible passes along the anterior, posterior, medial and lateral side of the nonunion. Selecting the incision for this procedure requires careful consideration in order to minimize iatrogenic injury of vessels and nerves. Skin incisions were generally less than 1 cm, and often included the original incision. In addition incision were used over the safe-zones of the anterior and lateral thigh for femoral nonunions, and over the anteromedial and lateral sides of the lower leg for tibial nonunions.

Rehabilitation and follow up

Rehabilitation was started on the second postoperative day under professional supervision. Patients were recommended to begin partial weight-bearing 3 days after surgery. Full-weight bearing was permitted depending on the radiographic assessment of fracture healing, generally at three months postoperatively. Clinical follow-up was performed at 2 weeks, 1 months, 3 months, 6 months, 9 months and 12 months until union achieved. Criteria for clinical union was the absence of localized tenderness, pain or abnormal . Radiological union was assessed using anteroposterior, lateral and two oblique X-rays at each visit. Radiographic union was defined by at least three cortices showing bony continuity on the anteroposterior and lateral views[11, 15].

Results

18 of the 19 cases achieved succesful bony union with this technique (Fig. 1). Sixteen achieved union after a single drilling procedure, while two patients required a second drilling procedure to achieve union.
The overall union rate for this procedure was 94.7%. One failure occurred in a female patient with a tibial shaft nonunion which only achieved union after revision internal fixation and cancellous bone grafting. The average union time after drilling technique was 7.4 months (range: 4–14), the average hospital stay was 5.3 days (range: 4–15).

Patient B was treated with fixator replacement surgery (B1, B2) for the femoral non-union, and 12 months later, the fracture site remained unhealed. After the drilling process (B3, B4) was conducted, the bone got union in 9 months (B5, B6).

Discussion

Nonunion is associated with repeated surgical intervention, extended patient disability and a very low health-related quality of life, which is even worse than individuals with heart disease or a history of stroke [1, 3–6]. Various methods including autogenous bone grafts, bone substitutes, demineralized bone matrix, growth factors, cell therapy and gene therapy have been used for the treatment of nonunions[1, 7–11]. All nonunion treatment methods focus on providing stable fixation and an optimal biological environment to achieve union [16]. Autologous cancellous bone graft, which activates the biological healing environment, is regarded as the gold standard for the treatment of atrophic nonunions [7, 8, 17]. Although open graft harvesting and implantation is thought to be a relatively simple procedure, it is associated with many complications, including infection, bleeding, hematoma, chronic pain/painful scar formation, fracture, hernias, sensory loss, and occasional gait disturbances [7, 17–19]. BMPs have been shown to cause the differentiation and proliferation of mesenchymal stem cells to osteogenic cells which are capable of participating in bony repair and osseous regeneration[20, 21]. However, application of BMPs are considered to be prohibitively expensive[15] and will not always lead to expected outcomes[6]. The platelet-rich plasma (PRP) was recommended as a novel strategy in improve bone healing in recently studies. However, Low-level evidence adversely affects is the widely clinical application of PRP as a therapy for non-union fractures[14]. In general, each therapy has its benefits and limitations[1].

Ideally, treatment decisions should consider both the clinical outcomes and the socio-economic cost. For these reasons, the cost-effectiveness of nonunion treatment methods is always an important consideration [5]. In this study, drilling holes percutaneously through the nonunion site has offered a novel alternative in the treatment of long bone nonunion. This technique has provided biological stimulation to the nonunion through the drilling process, meanwhile minimizing the iatrogenic injury and maintained the soft tissue condition.

In the atrophic long bone nonunions, the medullary canal is usually blocked and filled with the fibrous tissue and necrotic bone that typically is resected in traditional open procedures[22]. In our study, the K-wire drilling across the nonunion site percutaneously broke through the medullary canal, eliminating the
potential complications associated with the traditional open procedure. Re-establishing the intramedullary canal may allow restoration of the intramedullary blood supply. The hematoma formed around the drilling sites may provide a stimulus for bone healing. The hematoma is gradually replaced by granulation tissue where osteoclasts remove the necrotic bone (anabolic stage) with the formation of the soft callus (cartilage) and subsequently hard callus[23]. Osteoblasts, osteoclasts and other growth factors are delivered to the nonunion site, accelerating the resorption of dead bones and formation of fresh bones and increasing the capability of fracture healing[11, 15].

Early rehabilitation and partial weight-bearing were encouraged in our treatment. The functional load can be considered as the mechanical stimulation, which increases the local blood flow during functional use and directly influences the bone biology on a cellular level [16, 24, 25].

The direct drilling technique, without additional bone grafting procedures or other adjuncts such as BMPs, significantly reduces the financial burden for the patient and society.

Limitations and Prospect

This technique is not suitable for infected nonunions and those with unstable fixation. Those conditions usually require additional procedures like revision fixation, anti-infective therapy and other methods. Additional potential applications of this procedure could include combining the direct drilling technique with the percutaneous delivery of BMPs, PRP or bone marrow within the drilled holes directly at the nonunion site.[26, 27].

Conclusion

The percutaneous direct drilling technique provides a minimally invasive, effective, and low-cost method for treatment of bone nonunion. This novel technique minimizes the iatrogenic damage and stimulates an optimal biological response for bone healing. The preliminary results of this study warrant a larger study and further research on possible combined application of percutaneous direct drilling with the delivery of bone growth factors.

Declarations

Ethics approval and consent to participate

The Ethics Committee of the Third Hospital of Hebei Medical University approved this study and all participants gave signed informed consent.

Consent for publication
The authors did obtain written permission from the patient to publish the manuscript and permission is extended to the publication of images in this study.

**Availability of data and materials**

The datasets generated and analysed during the current study are available from the corresponding author on reasonable request.

**Competing interests**

The authors declare that they have no competing interests.

**Funding**

There is no funding to be declared for this study.

**Authors’ contributions**

BY carried out the studies and did the operations, participated in the follow-up, drafted the manuscript and contributed equally to this article. BY and BL carried out the operations and revised the manuscript. BY and TW participated in the follow up. YZ and JG conceived of the study, and participated in its design and coordination, do the operation and helped to draft the manuscript. All authors read and approved the final manuscript.

**Acknowledgements**

Not applicable.

**References**


022-03216-z.


**Figures**
Patient A underwent an ORPF for the tibia fracture and developed non-union in 9 month (A1, A2). After drilling technique was performed (A3, A4), the bone got non-union in 5 month (A5, A6).

Patient B was treated with fixator replacement surgery (B1, B2) for the femoral non-union, and 12 month later, the fracture site remained unhealed. After the drilling process (B3, B4) was conducted, the bone got union in 9 month (B5, B6).