Role of open cerclage wires used in patients with comminuted fractures of femoral shaft treated with intramedullary nails

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Research article

Keywords: comminuted, cerclage

Posted Date: January 29th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-49503/v2>

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Version of Record: A version of this preprint was published at Journal of Orthopaedic Surgery and Research on August 7th, 2021. See the published version at <https://doi.org/10.1186/s13018-021-02633-w>.

Abstract

Introduction

The role of open cerclage wiring in comminuted femoral shaft fracture treatment with intramedullary nails remains unclear. Here, we analyzed the effect of open cerclage wiring and the risk factors for nonunion after interlocking nailing in comminuted femoral shaft fracture treatment. We hypothesize that open cerclage wiring is applicable to patients with severe comminuted femoral shaft fractures without affecting bone healing.

Patients and Methods

This retrospective cohort study used data of consecutive patients who underwent interlocking nail fixation of a comminuted femoral shaft fracture between January 1, 2009, and December 31, 2016. First, eligible patients were divided into wire and no wire groups according to the surgical technique used and their union rate was recorded. The patients were then divided into union and nonunion groups and their perioperative data were analyzed.

Results

In total, 71 comminuted femoral shaft fractures treated with interlocking nail fixation were included: 38 fractures (53.5%) augmented with the open wiring technique and 33 reduced with closed or mini-open wound without wiring. The wire group demonstrated significant improvements in fracture reduction compared with the no wire group, whereas no significant difference was observed in the union rate between the wire and no wire groups ($p = 0.180$). Moreover, 46 (65%) of 71 fractures united smoothly, and no significant difference was observed in any perioperative data between union and nonunion groups.

Discussion

Augmented open cerclage wiring is indicated for comminuted femoral shaft fractures treated with intramedullary nails, even when the fragments are large or far displaced. Thus, open cerclage wiring can be used for fracture treatment, without decreasing the union rate.

Introduction

Although interlocking nailing is a preferred procedure for femoral shaft fractures and has a high union rate [1], fracture comminution lead to challenges. Anatomically restoring multiple displaced fragments is difficult [2]. Thus, to facilitate reduction and increase stability, cerclage wires are widely used. In 1987, Fitzgerald documented excellent results of using cerclage wires in comminuted fractures of the femur [3]. Subsequently, successful procedures for comminuted fractures of the femur have been reported [4-9], and percutaneous wiring techniques are being continually improved [10-11].

However, fractures reported in the literature are mainly of the peri-trochanteric area [4-8], not of the shaft. Unlike peri-trochanteric fractures, femoral shaft fractures are usually caused by high-energy trauma. The far displaced fragments [12-13] usually make percutaneous wiring impossible. Surgeons have to perform open reduction and internal fixation using one or more cerclage wires combined with an intramedullary nail for stability in the comminuted fracture of the femoral shaft. However, open cerclage wiring has some drawbacks. To achieve anatomic reduction, some soft tissues have to be detached from the fragment, which may disturb blood supply and result in nonunion, increasing the infection rate [14-15]. Moreover, the passing cerclage wire may strangulate large blood vessels [16-17] and periosteal blood vessels [18], which may affect bone healing.

Surgeons may, however, attempt to reduce the fragment number by using the all-closed or mini-open method to preserve the soft tissue coverage. However, performing these techniques is difficult, and a residual gap may occur after reduction, increasing the nonunion risk [12]. Moreover, “bridging” interlocking nails through the comminuted region of the femoral shaft does not provide sufficient stability. Therefore, this study analyzed the timing and effect of open cerclage wire use and identified factors affecting bone union when treating comminuted femoral shaft fractures. We hypothesized that open cerclage wiring is applicable to patients with severe comminuted fractures of the femoral shaft without affecting bone healing.

Materials And Methods

Participants

This retrospective cohort study was approved by the institutional review board, and patients who underwent surgical fixation of a broken femur at National Cheng Kung University Hospital and its Douliu branch between January 1, 2009, and December 31, 2016, were recruited. All fractures were identified using the coding system of the National Health Insurance database in Taiwan. The inclusion criteria were a comminuted femoral shaft fracture, namely Arbeitsgemeinschaft für Osteosynthesefragen or Orthopaedic Trauma Association (AO/OTA) classifications 32-B and 32-C. The femur shaft fracture was defined as being between 5 cm distal to the lesser tuberosity and 9 cm proximal to the knee joint line[19]; fractures that extended beyond this range were excluded. The exclusion criteria were simple fractures (AO/OTA classification 32-A), fractures in skeletally immature patients, revision procedures, peri-implant fractures, open fractures classified as Gustilo III, pathological fractures, fractures fixed using other implants, and insufficient follow-up (less than 24 months). Each extremity undergoing a surgical procedure was evaluated independently. Thus, patients with bilateral femoral shaft fractures were regarded as two independent participants.

The primary aim of the study is to determine the effect of open cerclage wire use. Eligible patients were categorized according to the surgical technique used. The Wire group was defined as fractures fixed using interlocking nails and augmented with the open wiring technique. The No wire group was defined as fractures fixed using only interlocking nails through closed or mini-open reduction. After grouping, the

medical records of each patient and fractures were reviewed to obtain patient demographic characteristics, including age, sex, fracture classification (AO/OTA), largest fragment size, fragment number, and displacement of proximal and distal fragments. Only fragments measuring more than 10 mm were counted. Images of patients included in this study were displayed and measured using digital imaging and communication in medicine image-viewing software (π ViewTM, INFINITT Co., Ltd., Seoul, Korea).

Surgical method and postoperative rehabilitation

The study focused on the effect of open cerclage wiring, and therefore, the intra-operative details of patient position and the nail insertion technique were not considered. The patient may be treated on a fracture table or in a lateral decubitus position. The interlocking nails could be inserted antegradely from piriformis fossa or greater trochanter or inserted retrogradely. In the No wire group, the fracture was reduced through traction, manipulation, or use of the bone hook and joystick technique in mini-open wounds (Figure 1). By contrast, in the Wire group, the fracture was reduced using a bone holder or reduction clamp directly, and the simple stainless cerclage wires were passed through a cannulated semicircular wire passer (Figure 2).

Postoperative rehabilitation programs were similar for all individuals. Partial weight bearing under crutch protection was allowed immediately after surgery except if the concomitant fracture was over contralateral lower limb or pelvis. The timing of full weight bearing depended on the callus formation, which was usually 6 to 8 weeks after the surgery, when some callus formation was noted on the plain film.

Data collection

After the surgery, the displacement of proximal and distal fragments was measured to evaluate reduction quality, and the modified radiograph union score for tibias (mRUST) [20-21] was used to assess bone healing. The mRUST was evaluated at 1, 3, 6, 9, and 12 months after surgery. To avoid observation bias, two authors evaluated the outcomes independently. Disagreements were resolved through discussion with a third author.

The outcomes of the study include the rate of fracture union and nail broken. Considering the inclusive fractures were comminuted, the "Union" was defined as an mRUST equal to or more than 13 within 24 months postoperatively [20-21]. By contrast, "Nonunion" was defined as an mRUST of less than 13, or the fracture received any revisional procedures including nail exchange, plate augmentation, or bone grafting within 24 months postoperatively.

Regarding the second aim of the study, the patients were then assigned to union and nonunion groups, and factors that may affect bone healing, including age, smoking, body mass index (BMI), brain injury, degree of preoperative and postoperative fracture comminution, and open cerclage wire use, were

analyzed. Brain injury is defined as decreased initial Glasgow Coma Scale and any evidence of intracranial hemorrhage or brain edema in the computed tomography scan.

Statistical Analysis

The results were analyzed using SPSS statistical software (SPSS Inc., USA). The chi-square test was conducted for evaluating categorical variables such as the number of bony unions. Continuous variables, including the size and displacement of fragments, were evaluated using the unpaired Student *t* test. A *p* value of less than 0.05 was considered statistically significant.

Result

Using the coding system of the National Health Insurance database in Taiwan, 71 fractures treated with interlocking nail fixation were included in this study, namely 38 fractures (53.5%) augmented with the open wiring technique and the remaining 33 fractures reduced with closed or mini-open wound without wiring. The patient flowchart is listed in Figure 3.

Of the 71 fractures, 45 were in men (63.4%) and 26 in women (36.6%); the mean age of the patients ($\pm$ standard deviation) was 28.5 ± 13.4 years, and no significant differences were observed in age and gender distribution between the Wire and No wire groups. In total, 43 fractures were at the right side (60.6%) and the other 28 were at the left side (39.4%), which was similar between the two groups (Table 1).

Table 1
Demographics of patients with a comminuted femoral shaft fracture treated using an interlocking nail with and without an open cerclage wire

Characteristic	Wire (n = 38)	Non wire (n = 33)	<i>p</i> -value
Age	27.74 $\pm$ 14.77	29.30 $\pm$ 12.09	0.635
Sex			
Male	25	20	0.651
Female	13	13	
Side			0.847
Right	23	20	
Left	15	13	

Considering the preoperative severity of the fractures, the Wire group showed significantly more severity than the No wire group in fragment number (*p* = 0.043), largest fragment size (*p* = 0.004), proximal fragment displacement (*p* = 0.006), distal fragment displacement (*p* = 0.009), and Winquist and Hansen

Classification ($p < 0.001$). By contrast, the Wire group showed significantly less displacement ($p < 0.001$) proximally and distally compared with the No wire group postoperatively (Table 2).

Table 2
Fracture pattern and union rate in patients with a comminuted femoral shaft fracture treated using an interlocking nail with and without an open cerclage wire

Characteristic	Wire (n = 38)	Non wire (n = 33)	<i>p</i> -value
Classification			0.06
32B	31	32	
32C	7	1	
Fragment number	1.53 ± 0.79	1.24 ± 0.49	0.043
Fragment size (mm)	87.66 ± 30.40	66.09 ± 29.03	0.004
Proximal displaced (mm)			
Pre-operative	21.64 ± 16.94	12.80 ± 7.50	0.006
Post-operative	2.96 ± 1.88	7.51 ± 3.32	< 0.001
Distal displaced (mm)			
Pre-operative	20.08 ± 13.52	13.05 ± 7.50	0.009
Post-operative	3.57 ± 2.91	7.11 ± 3.26	< 0.001
Union with 24 months	22	24	0.180
Nail broken	6	4	0.558

Considering postoperative results, 46 of 71 fractures united smoothly, and the union rate was 65%. No significant difference existed in the union rate between the Wire and No wire groups ($p = 0.180$) (Table 2). Among the united fractures, the average union time was 11.77 months in the Wire group and 10.29 months in the No wire group, which were similar ($p = 0.206$). The nail broke in 10 fractures, and the average duration from surgery to nail break was 11.4 months (Table 2).

Regarding the factors affecting the fracture union, no significant difference was observed between union and nonunion groups regarding age, smoking, BMI, brain injury, degree of preoperative and postoperative fracture comminution, and open cerclage wire use (Table 3).

Table 3
Patient demographics and fracture pattern and union rate in patients with a comminuted femoral shaft fracture treated using an interlocking nail with and without bone union

Characteristic	Union (n = 47)	Nonunion (n = 24)	p-value
Age	27.85 ± 13.69	29.67 ± 12.81	0.596
Gender			0.352
Male	28	17	
Female	19	7	
Smoking	11	6	0.882
BMI	23.00 ± 4.65	24.73 ± 4.14	0.140
Open fracture	8	4	0.970
Brain injury	5	6	0.113
Bilateral femur involvement	5	1	0.354
Classification			0.576
32B	41	6	
32C	6	2	
Fragment number	1.47 ± 0.74	1.25 ± 0.52	0.207
Biggest fragment size (mm)	76.05 ± 32.60	75.85 ± 29.46	0.560
Proximal displaced (mm)			
Pre-operative	16.52 ± 12.20	19.51 ± 17.07	0.404
Post-operative	5.05 ± 3.11	5.23 ± 4.08	0.841
Distal displaced (mm)			
Pre-operative	15.80 ± 9.47	18.78 ± 14.89	0.316
Post-operative	5.56 ± 3.15	4.55 ± 4.09	0.259
Nail size	11.13 ± 1.06	11.48 ± 1.02	0.202
Table Legend			

Discussion

Application of an interlocking nail in comminuted fractures of the femoral shaft is challenging for orthopedic surgeons. The far displaced fragments make closed reduction impossible, even if a

percutaneous wire passer or bone hook is used through a mini-open incision. Thus, open cerclage wiring is the preferred method for achieving and maintaining the reduction for further reaming and nail application. However, open cerclage wires involve the risk of disruption of soft tissue and periosteal blood flow. This study aimed to identify the roles of augmented cerclage wires used in patients with comminuted fractures of the femoral shaft treated with intramedullary nails, especially the timing, effect, and drawbacks.

The first result of the study is that augmented open cerclage wires are usually used in severe comminuted fractures and they effectively reduce the fractures. Thus, cerclage wires could be used not only for reducing long spiral and torsional fractures [22-23] but also for effectively treating severe comminuted fractures with far displaced fragments (Figure 2). Moreover, Scharf et al. [24] proved that fixation stability was superior with a combination of cerclage wiring and interlocking nailing in a femur model. Therefore, cerclage wiring could both simplify the surgery and improve the stability of fixation.

The second result is that the open cerclage wiring technique would not decrease the union rate and union time in comminuted femoral shaft fractures. In the past, open cerclage wiring was criticized for extensively dissecting the soft tissue while approaching the fracture site; thus, it is a dilemma whether to preserve the soft tissue or to obtain improved reduction. However, the literature [25-27] has failed to document the significant difference between open and closed nailing for femoral shaft fractures. Furthermore, by using the directly open approach, surgeons could see the fracture line directly to bring the fragments together and to achieve anatomic reduction with less fluoroscopy exposure [26]. The presented results suggest that open nailing to comminuted femoral shaft fractures would not disturb callus formation and bone healing.

The other concern with using the open cerclage wire technique is the risk of blood supply disruption by cerclage wires. Blood supply may be disrupted through the strangulation of blood vessels [28-29] and the contact between cerclage and the bone surface. The risk of vascular injury due to the cerclage passer was 1.59% in proximal femur shaft fractures and 7.14% in distal femur shaft fractures[28]. However, previously reported cases of vascular injury mostly occurred due to the percutaneous cerclage wiring technique. With the percutaneous technique, it is difficult to ensure that the cerclage passer is passed extremely subperiosteally and the vessel is outside the cerclage loop. However, by using the open wiring technique, surgeons were able to ensure the wire is placed subperiosteally and thus prevent the strangulation of the vessel.

Furthermore, the contact between the cerclage wire and bone surface impedes blood supply, especially when the endosteal blood supply might have been disrupted by reaming and application of interlocking nails. However, the histologic and anatomical study of femoral vascularity by Pazzaglia et al.[30] suggested that the periosteal vascular supply is circumferential, rather than longitudinal, with multiple musculo-periosteal vessels nourishing the periosteal layer. Moreover, Apivatthakakul et al.[17] and Kennedy et al.[9] proved that cerclage wiring resulted in minimal disruption of the femoral blood supply despite the location of the cerclage wire and the distance between the wire loops.

Moreover, our results implied that the cerclage wire is beneficial in severe comminuted fractures of the femoral shaft. Lin et al.[12] and Lee et al.[13] observed that the large fragment size and great distance of fragment displacement in comminuted femoral shaft fractures were associated with nonunion. In our study, the Wire group had significantly larger fragment sizes and greater distance of fragment displacement than the No wire group; thus, it theoretically had an inferior union rate. However, these two groups showed a similar union rate. The benefit of anatomic reduction and augmented fixation seems to overcome the extensive soft tissue and periosteal blood disruption. Although this is not a reasonable statistical analysis, it suggests that the cerclage wire is safe and might be beneficial.

Regarding the final result of the study, we failed to identify risk factors for nonunion, including smoking, BMI, and preoperative and postoperative fragment number and displacement. The risk factor for nonunion in femoral shaft fracture treatment with interlocking nail remains controversial. Taitsman et al. [31] found that open fracture, tobacco use, and delayed weight bearing are risk factors for femoral nonunion. By contrast, Metsemakers et al. [14], Lin et al. [12], and Lee et al. [13] documented that the severity of the fracture comminution, including AO/OTA classification and preoperative displacement of the fragment, is the only risk factor for nonunion. Therefore, the eligible fractures in our study were all comminuted (AO/OTA 32B/32C) and theoretically had more displacement of the fragment. This can explain the reason that the union rate (65%) in our study was lower than that reported previously [1]. Moreover, no significant difference was observed between union rate and preoperative size and displacement of the fragment. This might be explained by the decreasing fracture gaps after cerclage wiring, and thus improving fracture healing.

This study had some limitations. First, we attempted to obtain samples with similar fracture patterns in the two groups by excluding simple fractures, but we failed. Thus, we were unable to obtain an objective conclusion from the presented results. Second, data were collected retrospectively, where surgeries were performed by different surgeons. Individual surgeons may follow different indications for the use of interlocking nailing or plating, mini-open reduction or closed reduction, and lateral decubitus position or supine position on fractures when in the operating room. The postoperative rehabilitation programs of different surgeons were slightly different, which may have affected the study outcomes, particularly for fixation failure. We identified some possible confounding variables, such as fracture classification. However, some related factors that could not be controlled for, such as bone quality or patient compliance, may have had an influence. Third, this study primarily focused on radiologic results and a simple review of medical records. Further investigation is required, and precise measurements of functional results, such as range of motion, knee score, or an injury-specific questionnaire, should be used in future research.

Conclusion

Augmented open cerclage wiring is indicated in comminuted fractures of the femoral shaft treated with intramedullary nails even when the fragments are large or far displaced. By using the open cerclage wiring technique, fractures could be reduced better without decreasing the union rate. We advocate that

augmented open cerclage wiring is safe in treating comminuted femoral shaft fractures with interlocking nails.

Abbreviations

AO/OTA: Arbeitsgemeinschaft für Osteosynthesefragen or Orthopaedic Trauma Association

mRUST: Modified radiograph union score for tibias

BMI: Body mass index

Declarations

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Disclosure of interest

The authors declare that they have no competing interest.

Acknowledgement

1. This manuscript was edited by Wallace Academic Editing
2. We thank Medical Device R & D Core Laboratory, National Cheng Kung University Hospital, Tainan, Taiwan, and Ms. Shing-Yun Chang BS, MSc (Department of Orthopedic Surgery, National Cheng Kung University Hospital, College of Medicine, National Cheng Kung University, Tainan, Taiwan) for assistance with this project.
3. We thank Prof. Miin-Jye Wen (Department of Statistics, National Cheng Kung University, Tainan, Taiwan) for helpful advice and suggestions in statistics.

Funding

No funding was received by any of the authors for this study.

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Contributions

TH Wang: Study conception and design, acquisition of data.

HC Chuang, FC Kuan, CK Hong: Analysis and interpretation of data.

WR Su, ML Yeh: Critical revision.

KL Hsu: Drafting of manuscript.

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Figures

Figure 1

(A) Preoperative, (B) postoperative, and (C) 15 months postoperative images of a 19-year-old man who met with a motorcycle accident and developed a comminuted fracture over his right femur. The reduction and fixation were achieved via mini-open wounds, and the fracture healed 15 months after the surgery.

Figure 2

(A) Preoperative, (B) postoperative, and (C) 14 months postoperative images of a 24-year-old man who met with a road accident and developed a comminuted fracture over his right femur. The reduction was successfully achieved using open cerclage wiring, and the fracture healed 14 months after the surgery.

Figure 3

Patient recruitment flowchart.