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Percutaneous cerclage wiring, does it disrupt femoral blood supply? A cadaveric injection study

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ABSTRACT

Background: A percutaneous cerclage wiring technique has been developed to reduce iatrogenic soft tissue and vascular disruption associated with classic cerclage fixation.
Objectives: The purpose of this study was to evaluate the extent of femoral vascular disruption resulting iatrogenically from the application of two percutaneous cerclage wire loops.
Methods: Pairs of cerlage wire loops were percutaneously inserted on 18 fresh cadaveric femurs. The position of the wire loops varied. The wire loops were either inserted 10 and 15 cm, 10 and 20 cm, or 15 and 20 cm distal to the tip of the greater trochanter. Each study group had 6 cadavers. Contralateral femurs without cerclage wiring were used as controls. Liquid contrast–gelatin was injected into the common femoral artery. Using axial and 3D CT scan images the superficial femoral artery (SFA), deep femoral artery (DFA), perforating arteries and their anastomotic patterns as well as endosteal perfusion were identified and their patency was graded.
Results: Percutaneous cerclage wiring did not disrupt femoral endosteal blood supply and maintained the integrity of all of the superficial femoral arteries. Four specimens demonstrated maintenance of all 4 perforators, 11 showed disruption of 1 perforator, and 3 showed disruption of 2 perforators. One deep femoral artery was disrupted after its first perforator branched off; however, perfusion was maintained by fill from an alternative anastamosis. There was no significant difference between disruption of deep femoral arteries and perforating arteries ($P = 1.000$), location of wiring ($P = 0.905$) or spacing between wire loops ($P = 1.000$).
Conclusion: Percutaneous cerclage wiring resulted in minimal disruption of the femoral blood supply. When partial disruption occurred the SFA, DFA, and their associated perforators compensated to maintain femoral perfusion through their anastomoses. The location of the cerclage wire and the distance between the wire loops in the proximal femur showed no significant difference in the rate of iatrogenic perforator injury.

Introduction

Recent developments in modern surgical techniques for fracture treatment have aimed to reduce the surgical insult to surrounding soft tissues and fracture zone vascularity. Conventional open reductions performed through extensive surgical approaches afford great fracture visualization at a cost, potentially increasing the risk of bone necrosis, delayed union and/or infection. Minimizing ones surgical insult, accomplished using indirect reduction techniques, allows for faster bone healing because bone vascularity is maintained or can be restored early.[1,2]

Cerclage wiring is a well-known procedure in the treatment of periprosthetic femoral fractures.[3] Its centripetal mode of action is well suited for obtaining and maintaining the reduction of oblique, spiral or spiral wedge fractures. Cerclage wiring is classically done using an open technique, which requires soft tissue stripping. For this reason many have the opinion that cerclage wiring can resulting in "Strangulation of blood supply". A cerclage itself is not strong enough to withstand forces occurring during functional fracture aftercare and requires some form of augmentation. The disrepute that cerclage technology has suffered for decades is related to these disadvantages, and some disappointing early results.[4]

It is possible that applying some of the principles of minimally invasive fracture surgery to cerclage application may improve the technologies clinical utility. Apivatthakakul et al.[5,6] described a percutaneous cerclage technique to treat femoral shaft fractures using a cerclage passer. The cerclage passing instrument (Synthes®) facilitates minimally invasive direct fracture reduction while leaving a small footprint on bone (Fig. 1). The newly

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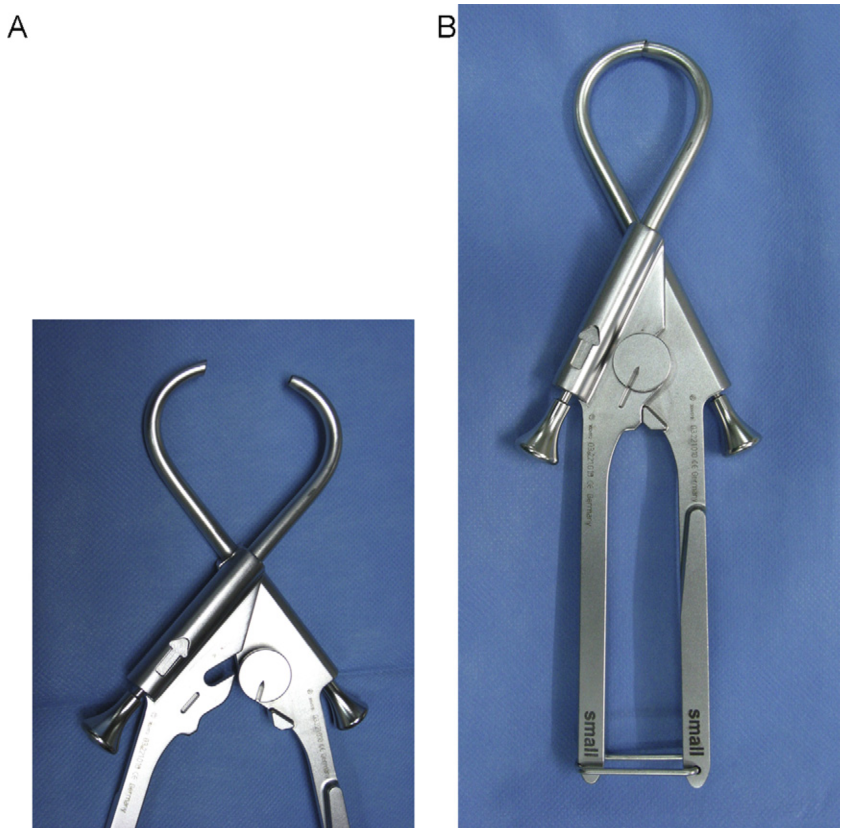

Fig. 1. The percutaneous cerclage passer consists of 2 dividable forceps which are connected in the middle flat part. When closing the forceps, the tube tips will meet together.

developed instrument allows wire passage through a 2–3 cm small incision. It permits the ability to obtain and maintain fracture reduction without obstructing definitive plate or intramedullary nail fixation. Small incisions preserve the soft tissue envelope around the fracture zone, theoretically resulting in less iatrogenic blood flow disruption than an open wiring technique.

The purpose of this study was to evaluate the extent of iatrogenic femoral vascular disruption that resulted from the application of two cerclage wire loops placed in different positions. This information will help define the clinical application of percutaneous cerclage wiring.

Materials and methods

Eighteen fresh human cadavers (10 males and 8 females), age range from 22 to 72 years old, were obtained for this study. The donors were free of conditions affecting lower limb vascularity. We obtained Institutional Ethical Committee Board approval for the study protocol. The torso was supine during lower limb preparation. The common femoral vessels were exposed bilaterally at the femoral triangle using 8 cm longitudinal incisions. The common femoral artery (CFA) was catheterized and secured with two non-exclusive silk ties. The proximal part of the CFA was ligated to prevent the liquid contrast gelatin from tracking proximally. The clotted blood was flushed from the artery with 300 ml of warm normal saline until the saline flowed through the common femoral vein.

A pair of cerclage wire loops was inserted percutaneously at 3 different intervals depending on the assigned group. In the first group of femurs the wire loops were inserted 10 and 15 cm distal to the tip of the greater trochanter. In the second and third groups, the wire loops were placed 10 and 20 cm, and 15 and 20 cm distal to the tip of the greater trochanter, respectively. Each study group consisted of 6 cadavers. In each cadaver the non-cerclaged contralateral femur represented normal vascular anatomy and allowed for a comparison.

The percutaneous cerclage technique consisted of making a 2–3 cm longitudinal incision through skin, subcutaneous tissue and fascia at the designated level. Deep dissection was performed

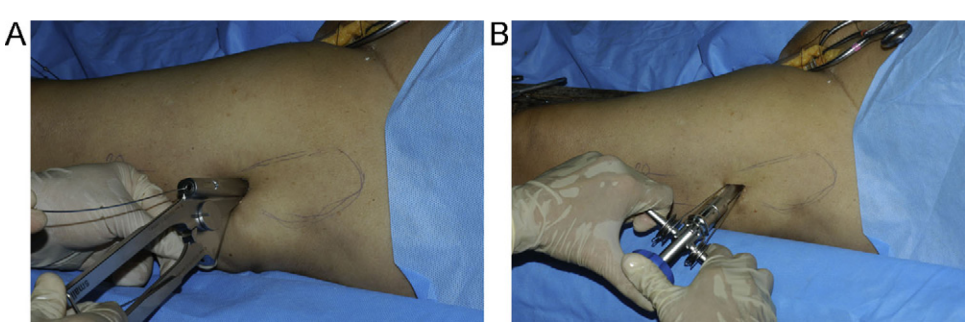

Fig. 2. (a) The cerclage passer inserted through a small incision, the wire was passed into the cerclage tube. (b) The wire tensioner was used to twist the wire around the femur.

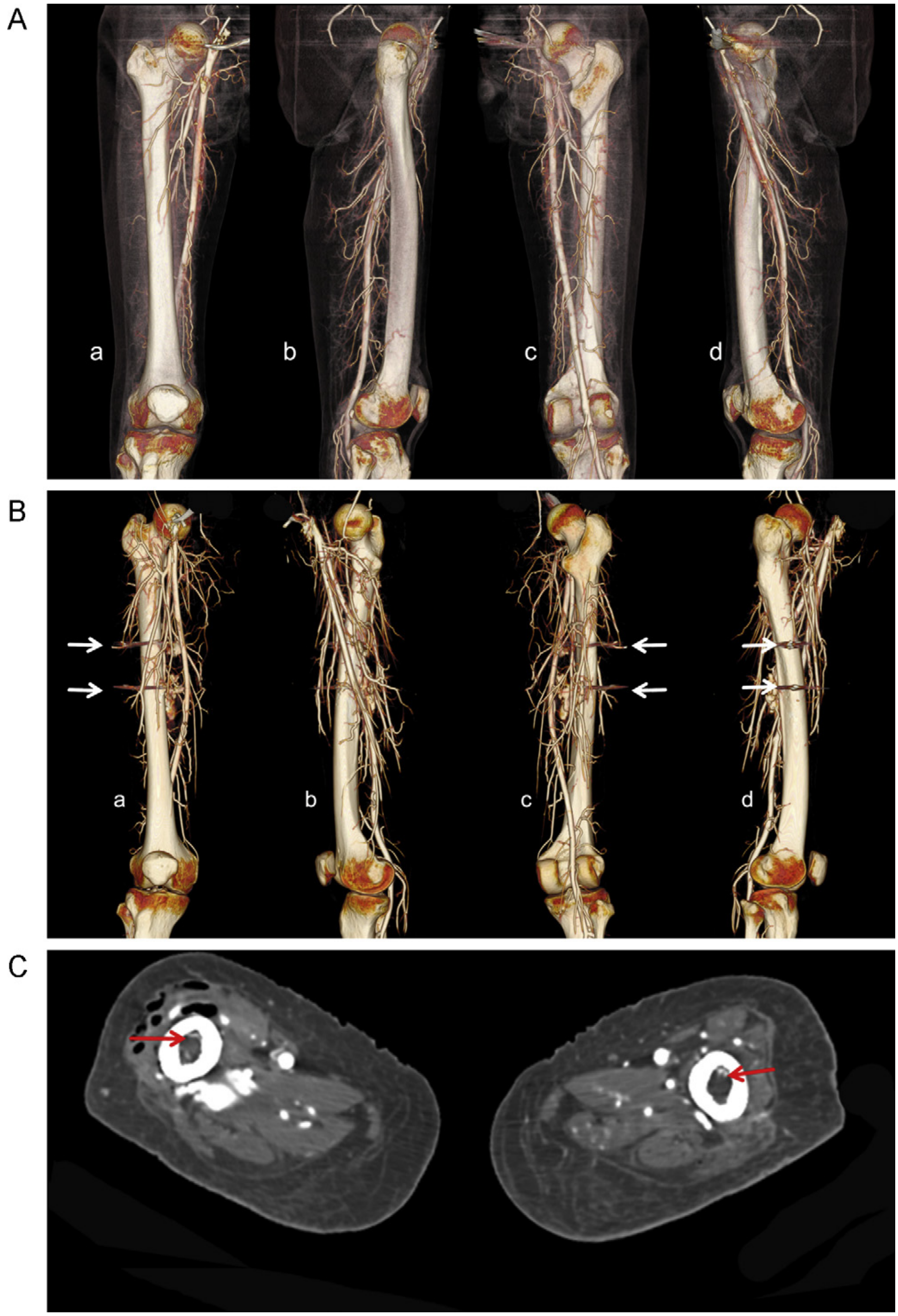

Fig. 3. (a) Three dimensional reconstructed CT of the blood supply of the femur. (a) Anterior view, (b) lateral view, (c) posterior view and (d) medial view. (b) Three dimensional reconstructed CT of the blood supply of the femur after 2 cerclage wire loops (white arrows) were applied. (a) anterior view, (b) medial view, (c) posterior view and (d) lateral view. In this specimen the second perforator was interrupted, however, all the blood vessels were filled by the anatomosis. (c) The axial CT used to determine the nutrient artery (red arrow) and follow through the artery. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

directly to the lateral aspect of the femur. A cerclage tunnelling device was used to facilitate the insertion of the cerclage passer through the intermusucular septum. A trocar was placed in each tube of the cerclage passer to prevent the soft tissue from entering the cannulated tubes. One half of the cerclage passer was inserted gently into the prepared tunnel dorsally. The other half of the forcep was inserted ventrally. The flat middle parts of the forceps were connected and the forcep handles were then brought together and secured by locking the bracket on the end of the device. The trocar was removed from both sides of the forcep and a cerclage wire was passed through the cerclage passer until the wire passed through the opposite side (Fig. 2a). The forcep was unlocked and the two halves of the forcep were disconnected and removed. The wire tensioner was used for tightening each cerclage with equal tension (Fig. 2b). The second wire loop was passed and tightened using the same technique.

Liquid contrast (Omnipaque 0.35%) mixed with gelatin and dye 50–80 ml was injected through the catheterized CFA until the dye

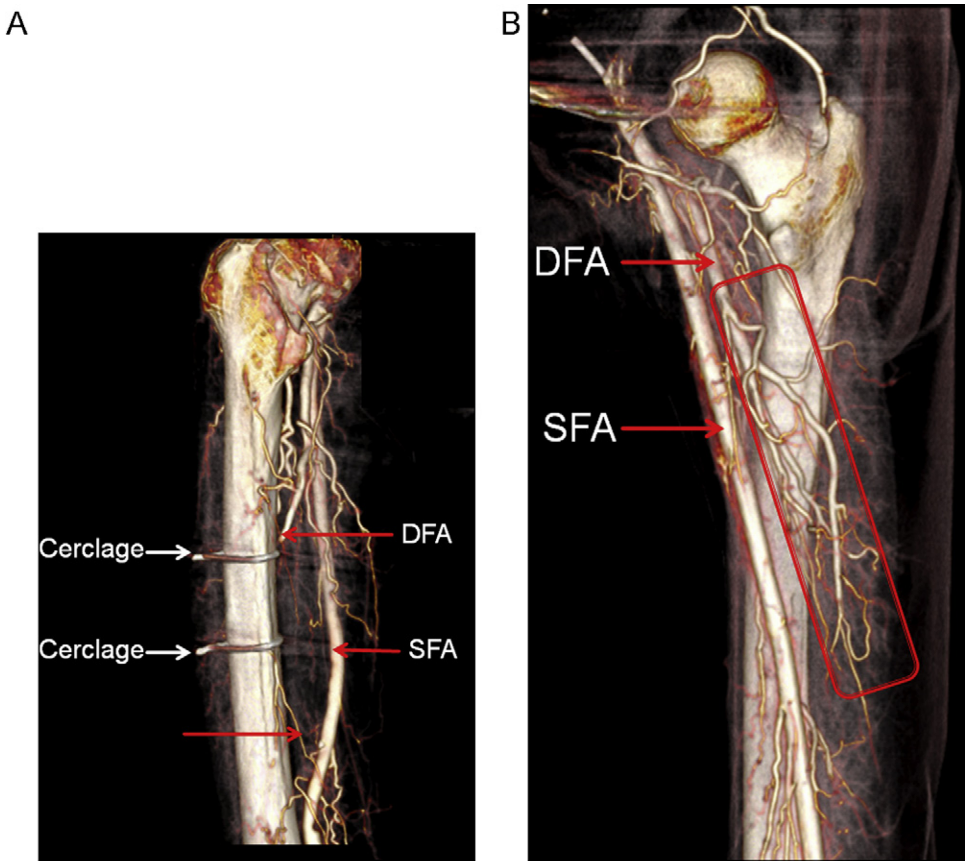

Fig. 4. (a) The DFA was interrupted by the upper wire loop resulted in decrease the blood supply to the posterior and medial part of the femur. However, the distal part of the perforator was demonstrated by the anastomosis from perforating anastomosis or SFA (lower red arrow). (b) The perforating anastomosis system from first to fourth perforators and the distal part of DFA (red rectangular area). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

was seen at the subcutaneous incision on the medial side of the proximal tibia. The torso was left at room temperature for 20 min to allow the gelatin to harden. An axial CT scan with a 3D reconstruction (Siemen®, Somatom definition) of both femurs was performed to identify the superficial artery (SFA), deep femoral artery (DFA), perforating arteries and their anastomosis patterns, descending branch of the lateral femoral circumflex artery and the endosteal perfusion.

The 3D reconstruction data was used to identify the configuration of the global femoral arterial anatomy along its entire length and allowed comparison to the normal non-cerclaged femur (Fig. 3a and b). The axial CT was used to identify the nutrient artery and the endosteal blood supply as well as the perforating arteries and their anastomosis. Axial imaging was especially useful in cases of contrast gelatin leakage, where some of the blood vessels on the 3D rendered images were obscured (Fig. 3c). Two of the authors separately analysed the femoral arterial anatomy and graded the vessels as intact or interrupted. The following arteries were graded: SFA, DFA, perforating arteries and their anastomosis, descending branch of the lateral femoral circumflex artery and the endosteal blood supply. In situations where opinions conflicted, the vessels were graded as interrupted to represent the worst-case scenario.

The data was analysed with STATA version 10.0 software (Stata Corp., LP, College Station, TX, USA). The iatrogenic femoral arterial disruption between different cerclage wire groups was compared using a Fisher's exact test. P-values less than 0.05 were considered statistically significant.

Results

There was no notable variation in the vascular anatomy between the left and the right side. The SFAs were intact in all of the specimens in both groups. The DFAs were intact in 17 of 18 limbs (94.4%) (Fig. 4a). The pattern of interruption for the perforating arteries was variable. The perforating arteries were intact in 76.4% and interrupted in 23.6% (Table 1). All of the perforating arteries had an anastomosis from the first perforator to the fourth perforating artery and the distal part of SFA (Fig. 4b). All of the specimens exhibited intact endosteal blood flow.

We found placing the cerclage fixation 10 cm distal to the greater trochanter resulted in 6 injuries to the perforators. At 15 cm from the greater trochanter there were also 6 injuries.

Table 1
Incidence of perforating artery interruption after wiring.

	Wiring		Control	
Artery condition	Intact	Interrupted	Intact	Interrupted
1st perforator	13	5	18	0
2nd perforator	14	4	18	0
3rd perforator	12	6	18	0
4th perforator	16	2	18	0
Total	55	17	72	0
Percentage	76.4	23.6	100	0

Table 2
Level of wiring and interrupt of the perforators.

Distant from GT (cm)	*n*	Interrupt	1st perforator	2nd perforator	3rd perforator	4th perforator
10	12	6	5	1	0	0
15	12	6	0	3	3	0
20	12	5	0	0	3	2

GT = Greater trochanter; *n* = number of wiring specimens.

Table 3
Distance between the wire loops and interrupt of the perforators.

Distance (cm)	*n*	Interrupt	1st perforator	2nd perforator	3rd perforator	4th perforator
5	12	12	3	3	5	1
10	6	5	2	1	1	1

At 20 cm there were 5 injured perforators. There was no statistically significant difference in disruption of perforating arteries as different wire loop positions (*P*-value = 0.91) (Table 2).

When a pair of wire loops was placed with a 5 cm space between them at least 1 perforator was injured in all 12 cases. When the spacing was increased to 10 cm at least 1 perforator was injured in 5 of 6 cases. There was no statistically significant difference between different wire loop spacing positions (*P*-value = 0.99) (Table 3).

Discussion

Internal fixation techniques have evolved over the past decade resulting in improved fracture healing and less complications.[1,2] Cerclage wires or cables provide satisfactory clinical results when used for provisional or definitive fixation of periprosthetic femoral fractures with an added advantage of not interfering with definitive fixation and not obstructing the intramedullary canal.[3,6,7] Cerclage fixation can also be used as a reduction tools in some difficult femoral fractures.[5,8] However, the argument put forward against classic cerclage technology has revolved around a foregoing concept or belief that wires could strangulate the bone and result in bone necrosis risking nonunion.[4]

Percutaneous cerclage technology has been developed to facilitate improved percutaneous cerclage application through small 2–3 cm incisions. With this new minimally invasive cerclage technology, the disruption of the femoral blood supply should be less than conventional classical open cerclage fixation. This percutanous method has been shown to be effective clinically, with small incisions, little blood loss and excellent healing.[6] However, this current investigation demonstrates for the first time that a percutaneous technique does not strangulate the femoral blood supply.

Our study design used an intact femur to avoid the variability in femoral arterial anatomy introduced with a fracture model. The blood supply was studied using a liquid contrast gelatin injected into the arterial system and subsequently analysed using axial and 3D rendered CT scan images. Proximal femoral cerclage fixation was designed to simulated periprosthetic femoral fracture treatment. Spacing the pair of wire loops 5 cm apart was designed to represent the commonly used position for periprosthetic fracture fixation. Furthermore, a previous biomechanical study of periprosthetic femoral fractures managed with cerclage fixation further substantiates this selected spacing distance.[9] The distance of 10 cm represented the longest distance between the wire loops that would continue to hold both ends of the long spiral or oblique fractures.

According to Rhinelander,[10] the blood supply to the long bone arises from three sources: the periosteal, metaphyseal, and nutrient arteries. The nutrient artery of the femur usually arises

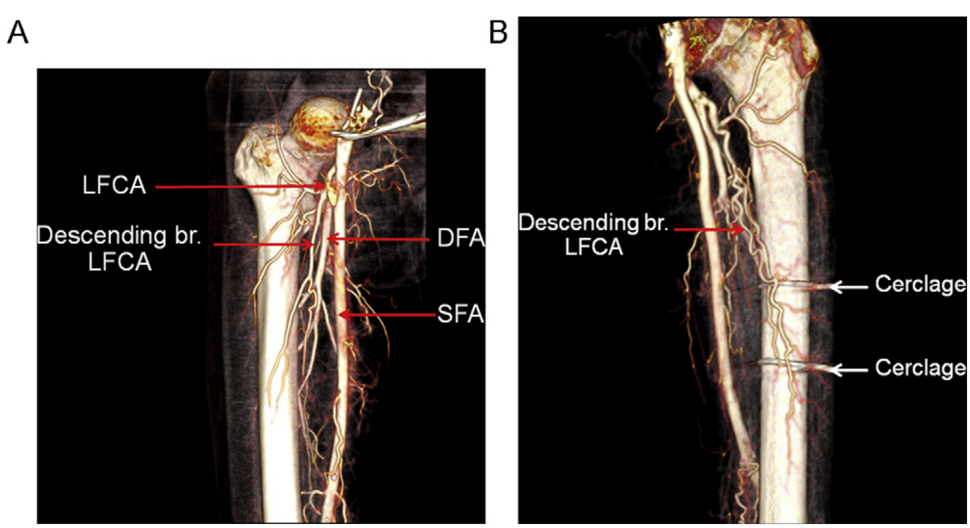

Fig. 5. (a) The anterior view of the proximal femur demonstrated the descending branch of the lateral femoral circumflex artery (LFCA) supplied the anterior and lateral part of the thigh. It lies between rectus femoris and vastus lateralis, which means it is unlikely to be injured by the cerclage. (b) The anterior view of the proximal femur demonstrated the descending branch of the lateral femoral circumflex artery (LCFA) (red arrow) usually be preserved beneath the two wire loops (white arrows). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

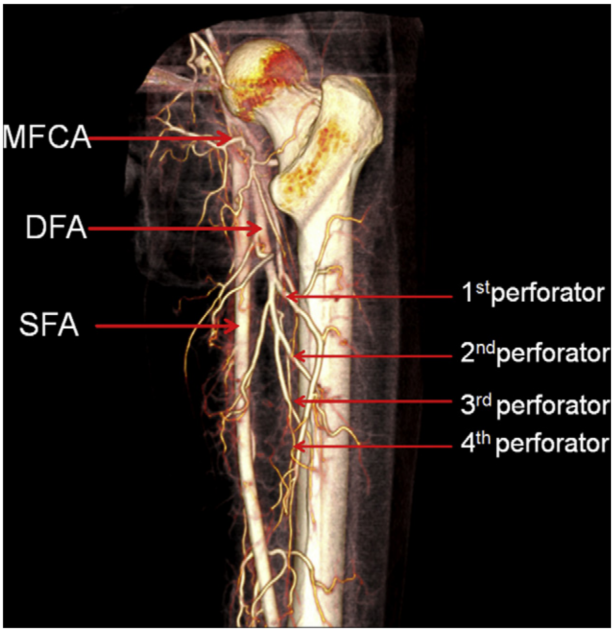

Fig. 6. The posterior view of the proximal femur demonstrated the medial femoral circumflex artery (MFCA), the deep femoral artery and the perforating branches includes first, second, third and fourth perforators.

from the second perforator.[11] It represents the main source of blood supply to the inner two-third of the cortex. The periosteal vessels supply the outer third of the cortex. During the healing of nondisplaced fractures, the endosteal circulation remains intact and provides a majority of the blood supply around the fracture zone. With displaced fracture, an enhanced periosteal circulation, derived from the surrounding muscle becomes the primary source of the blood supply to the fracture site. Brooks described that blood vessels reach the bone mainly in a centripetal direction and are therefore less sensitive to strangulation by a cerclage loop around the bone.[12] Many authors have further substantiated this concept. Rhinelander and Stewart showed that bone necrosis was minimal when rabbit osteotomies were fixed with nylon straps.[13] Perren et al.[4] did a pilot experiment of percutaneous cerclage fixation in a sheep model and used fluorescent dyes to visualize the vascular perfusion area on the periosteum. They found the effect of cerclage was minimal. In their study a solid cerclage wire only limited periosteal perfusion for a length of 0.36 mms and a cerclage cable limited perfusion for $<$0.3 mm. From a biological internal fixation concept, the disrepute of cerclage wiring is a result of the complications resulting from the extensive surgical dissection and soft tissue stripping required for fracture reduction. Nevertheless, this is a problem occurring with classic cerclage application and not a problem with cerclage fixation itself.

Femoral shaft blood supply is derived from three parallel arterial pathways including the superficial femoral artery (SFA), the deep femoral artery (DFA) or profunda femoris artery, and the collateral pathway via the perforators.[14] This relationship was demonstrated well in our study as shown in Fig. 3a. An additional path is also available by way of the descending branch of the lateral femoral circumflex artery (LFCA) (Fig. 5a and b).

The perforating branch of the DFA typically includes three separate numbered branches and the terminal branch, which is referred to as the fourth perforating artery. The perforating arteries sequentially anastomose with adjacent perforators along the linea aspera, posterior to the femur.[11] These branches provide the primary arterial supply to numerous muscles of the thigh, especially in the medial and posterior compartments, and a large nutrient artery to the femoral shaft (Fig. 6). The first perforator has a rich anastomotic relationship with the inferior gluteal artery, the medial femoral circumflex artery, and the second perforator. It is through these important relationships that the first perforator participates in the anastomotic network in the posterior aspect of the thigh. The second perforator gives off ascending and descending branches that anastomose with the first and third perforators. Typically, the second perforator supplies the nutrient artery to the femur. The third and forth perforators anastomose with adjacent perforators, muscular branch of the popliteal artery, and the distal part of SFA. The perforating arteries sequentially anastomose with adjacent perforators along the linea aspera posterior to the femur (Fig. 4b). The anatomoses continue distally with muscular branches of SFA and genicular braches of the popliteal artery. These anastomotic relationships were demonstrated in our study. In the one specimen where the DFA was interrupted by a cerclage wire, after giving off its first perforator, the forth perforator was still patent because of an anastomosis from the distal pathway (Fig. 4a).

The perforating vessels have distinct pathways relative to the surface of the femur. In contrast to the first and fourth perforating vessels, the second and third perforating vessels pass near the lateral surface of the femur.[11] These findings support that there is a particular risk to the second and third perforators with a conventional lateral approach to the femur, performed during classic open cerclage fixation. The clinical effectiveness of minimally invasive percutaneously plate fixation may be related to the fact that the plate is slide submuscularly and avoids injury to femoral perforators.[6,15,16] In our study a minimally invasive percutaneous cerclage technique caused minimal iatrogenic injury to the perforators. In the case of an injured perforator the remaining perforators and the anastomoses from the SFA played a compensatory role to maintain adequate vascular supply around the femur (Fig. 3b).

The descending branch of the LFCA is a significant distal vascular pathway that supplies the muscle on the anterior and lateral aspect of the thigh (Fig. 5a). It passes inferiorly deep to the rectus femoris in the groove between the vastus lateralis and the vastus intermedius and give numerous branches to supply the surrounding musculature. It terminates at the lateral aspect of the knee by forming an anastomosis with superior lateral genicular branch of the popliteal artery. The muscular branches in the vastus lateralis form an anastomosis with the system of perforators at the linea aspera. The collective anastomoses in the thigh form important collateral pathways in the situation that one of the arterial systems or branches are obstructed.[14] The LFCA was intact in all study specimens since it lies in between muscles, and is a significant blood supply if the DFA is disrupted (Fig. 5b).

Regarding medullary perfusion, Laing[17] studied the anatomy of the femoral nutrient artery. He found that lateral and posterolateral femoral exposures with vastus lateralis elevation and ligation of the perforating arteries endangered the nutrient artery. These concepts are support by Farouk et al.[18] who compared the maintainance of the nutrient artery in minimally invasive plate osteosynthesis (MIPO) and conventional plate osteosynthesis (CPO). The nutrient artery was intact in all MIPO specimens, but was intact only 40% of the time in the CPO group. In each of the latter specimens, the dissection revealed that the perforating arteries were ligated near the nutrient artery adjacent to the linea aspera. The endosteal blood supply in our study was intact in all study specimens even in cases of injury to the DFA or second perforator (Fig. 3c). In such cases, we were not able to identify the nutrient artery on the surface of the femur but the patency of the endosteal circulation was confirmed. Preserving the vastus lateralis muscle, the perforating anastomoses along the linea aspera, the periosteal arterial system and/or the medullary canal could account for this finding.[12]

As a result of their histologic and anatomical study of femoral vascularity Nather et al.[19] and Pazzaglia et al.[20] suggested that the periosteal vascular supply is circumferential, rather than longitudinal, with multiple musculo-periosteal vessels nourishing the periosteal layer. Nather et al.[19] concluded, "The old taboo that applying a cerclage wire strangulates the periosteal blood supply to a bone no longer holds true". Kennedy et al.[8] provided evidence to support the statement made by Nather et al.[19] They reported on a series of 17 subtrochanteric fractures provisionally fixed with an average of two cerclage cables and subsequently definitively treated with long cephalomedullary nails. All except one of the patients healed within 6 months and everyone returned to independent living. Therefore, two well-spaced cerclage loops should have little deleterious effect on periosteal vascularity. Our study supports this conclusion. We demonstrated that using a pair of percutaneous cerclage wires did not strangulate the femoral blood supply and preserved the macroscopic vascular supply around the femur. Some branches of the perforators were interrupted but the integrity of the blood supply was maintained by an anastomotic system around the femur (Fig. 3b).

Major devastating complications of femoral cerclage wire application have been reported. Mehta and Finn[21] reported a superficial femoral artery and vein ligation by a femoral mid-shaft cerclage during revision total hip arthroplasty. Aleto et al.[22] described the same injury in the proximal femur occurring during revision total hip arthroplasty. In our study, there were no interruptions of the SFA. The SFA is further away from the bone in the proximal femur and it is more mobile. The SFA moves closer to the femur in the distal shaft and has a fixation point in the adductor canal limiting its mobility. As a result the distal SFA is more vulnerable to injury from cerclage. Injury to the DFA is not common and less devastating than the injury to the SFA, but such an injury can still disrupted some of the blood supply to the posterior and medial musculature of the thigh. In our study, in 1 of the 18 specimens (5.6%) an iatrogenic DFA injury occurred. It occurred 15 cm distal to the greater trochanter. The CT demonstrated decreased blood flow to the posterior thigh musculature (Fig. 4a). However, the anastomosis in the posterior part of proximal femur provided collateral circulation from the medial femoral circumflex artery, inferior gluteal artery, and first perforator. In the midshaft and the distal shaft region, the collateral circulation was derived from the anastomosis of the third and fourth perforators as well as the SFA. To avoid such serious complications, the percutaneous cerclage technique must be done carefully by guiding the tip of the wire passer as closed to the femur as possible.

The limitations of this study include that an intact femur model was used but the technique will be used in vivo in fracture situations. In real clinical situation, the fracture itself may already damaged some perforating vessels, in this situation, the risk of vascular disruption by cerclage wiring may increase. Different surgical techniques of fixation may lead to different result of blood supply damage. A comparative study with the open cerclage wiring was not possible due to the fact that leakage of the liquid contrast gelatin through the injured vessels would occur during the surgical exposure. The study demonstrated only static perfusion of the arterial system as the capillary and venous system was not evaluated. The model also cannot account for revascularization. The density, the numbers and the location of the cerclage wires which is different from this study may have the different results. Percutaneous cerclage fixation of fractures still has no in vivo experimental evidence to show the effect of cerclage wires on cortical vascularity and the surrounding muscle. Further study including animal experimentation are needed.

In conclusion, percutaneous cerclage fixation showed minimal disruption of femoral blood supply. The location of the cerclage wire and the distance between the wire loops in the proximal femur showed no significant difference in the rate of iatrogenic perforator injury.

Conflict of interest

The authors receive financial support from Faculty of Medicine, Chiang Mai University and AO Technical Commission for preparation of this manuscript. They did not receive payments or other benefits or commitments or agreement to provide such benefits from commercial entity.

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