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Cerclage wiring: Innovations and applications☆

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ABSTRACT

Immediate full weight-bearing of osteosynthesis constructs is gaining increasing importance in modern trauma surgery. Many geriatric patients cannot reliably adhere to partial weight-bearing instructions, and younger patients may benefit from accelerated rehabilitation enabled by early full weight-bearing. In this context, an older technique of minimally invasive cerclage fixation of the tibia is receiving renewed attention. The surgical technique has been adapted to contemporary cerclage systems and biomechanically evaluated for the first time. Several studies using synthetic and cadaveric bone models have demonstrated that modern cable cerclages, particularly in spiral fractures, are capable of significantly increasing the stiffness of both locking plate and intramedullary nail osteosyntheses, provided that anatomical reduction is achieved through the cerclage. From a biomechanical standpoint, the additive cerclage thus enables immediate postoperative full weight-bearing. Early clinical studies suggest, that minimally invasive tibial cerclage can be applied without an increased complication rate and is associated with faster rehabilitation and higher patient satisfaction in the early postoperative phase. Although evidence is limited, the principle of additive cerclage appears to be transferable to humeral shaft spiral fractures.

Introduction

It is now widely accepted and supported by studies, that many geriatric patients are unable to comply with partial weight-bearing after fracture fixation [1,2]. It is therefore the responsibility of surgeons to provide immediate full weight-bearing stability, particularly for fractures of the lower extremity in geriatric patients. Moreover, younger patients may also benefit from such treatment through faster rehabilitation.

In femoral neck fractures, primary full weight-bearing is routinely achieved through arthroplasty. This approach is also gaining increasing importance in perigenicular fractures [3].

However, endoprosthetic treatment is not feasible for every fracture entity, and even modern osteosynthesis implants do not always provide sufficient stability as stand-alone procedures to allow immediate full weight-bearing.

In such cases, modern trauma surgery is required to augment existing osteosynthesis techniques with additive procedures. One possible tool in this context is the use of additive cerclage wiring. Its application in subtrochanteric femur fractures is widely accepted, and its advantages have been demonstrated in severeal studies [4–6].

In contrast, the use of additional cerclage wiring in tibial shaft fractures remains uncommon. This anatomical region is characterized by particularly vulnerable soft tissue conditions, which in geriatric patients may be further aggravated by long-term corticosteroid use or chronic venous insufficiency. These circumstances must be carefully considered when planning the use of additional cerclage wiring in this region.

Surgical technique of minimally invasive cerclages at the tibia

As early as 1933, Götze [7] described a minimally invasive technique for the placement of steel cerclage wires on the tibia. This technique has now been modified for the use of modern cable cerclage systems: Through small incisions at the ventrolateral and dorsomedial aspects of the tibia, blunt dissection is carried out strictly along the bone using a curette and a drill sleeve. During these steps, particular attention must be paid to the anterior and dorsal neurovascular bundles of the calf, to

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avoid entrapement. In the next step, a plastic drain is then carefully passed circumferentially around the tibia in close contact with the bone. In the next step, this drain is replaced with a cable cerclage. For a detailed description of the surgical technique, reference is made to Fig. 1 and the article by Förch et al. [8].

The feasibility and safety of this technique were further demonstrated in an anatomical study [9]: Cerclages were placed at four defined levels in ten cadaveric tibiae using the described minimally invasive technique. Axial sections were subsequently prepared at the level of the cerclages, and the spatial relationship between relevant neurovascular structures and the inserted cerclage was assessed. Vessels, nerves, or tendons were never entrapped. However, a very close proximity was observed regularly, with distances of only a few millimeters. At the proximal tibia, the posterior tibial artery and vein as well as the tibial nerve are in close anatomical relation; at the distal tibia, the anterior tibial artery and vein, the deep fibular nerve, and the tibialis posterior muscle lie in immediate proximity to the tibia.

Biomechanical results of additive cerclages

Biomechanical studies investigated the mechanical properties of additive cerclages.

Initially [10], using a synthetic bone model of a spiral fracture of the distal tibial shaft, osteosynthesis with a locking plate alone was compared to a locking plate combined with additive cerclage. It was shown, that axial stiffness of the construct was nearly tripled. Shear movements were also significantly reduced. With additive cerclage under simulated full weight-bearing, these movements were even lower than with plate osteosynthesis alone under simulated partial weight-bearing. From a biomechanical perspective, treatment with additive cerclage therefore permits immediate full weight-bearing (see Fig. 2). Furthermore, the measured stiffness values were within the range considered optimal for fracture healing [11]. This stabilizing effect of cerclage as augmentation to plate osteosynthesis has since been demonstrated biomechanically not only in synthetic bone models but also in cadaveric bone [12].

In a further study [13], intramedullary nailing was tested using the identical fracture model. Four different configurations were investigated:

In the first group, the fracture was reduced anatomically and osteosynthesis was done by intramedullary nailing. In the second group, the fracture was also anatomically reduced, but the osteosynthesis was performed by intramedullary nailing and additive cerclage. In the two remaining groups, a non-anatomical reduction with a residual fracture gap was performed and the stabilisation carried by nail osteosynthesis alone (group 3) or nail ostesosynthesis and additive cerclage (Group 4)

The results demonstrated that, in cases of non-anatomical reduction, additive cerclages did not provide a significant increase in stability. In anatomically reduced fractures, cerclages had no influence on axial stability; however, under full weight-bearing conditions, shear and rotational movements were significantly reduced.

In the synthetic bone model of distal tibial shaft fractures, not only different primary osteosynthesis techniques but also various cerclage configurations were evaluated [14]. In addition to locking plate osteosynthesis, the following additive cerclage options were applied:

In a first group, only one single cable cerclage was placed in addition to the plate. Two cable cerclages were applied in group 2. Group 3 used a double-looped steel cerclage, group 4 a double-looped polyethylenepolyesther cerclage as augmentation of the plate osteosynthesis

In this setup, cable cerclages provided the greatest increase in stability, followed by steel cerclage and polyethylene/polyester cerclage (see Fig. 3).

Clinical results of additive cerclages in tibial spiral fractures

Minimally invasive cerclage for tibial spiral fractures has already been implemented in clinical practice. In an initial study [8], the use of 113 cerclages in 96 tibial fractures was documented. Fig. 1 describes one

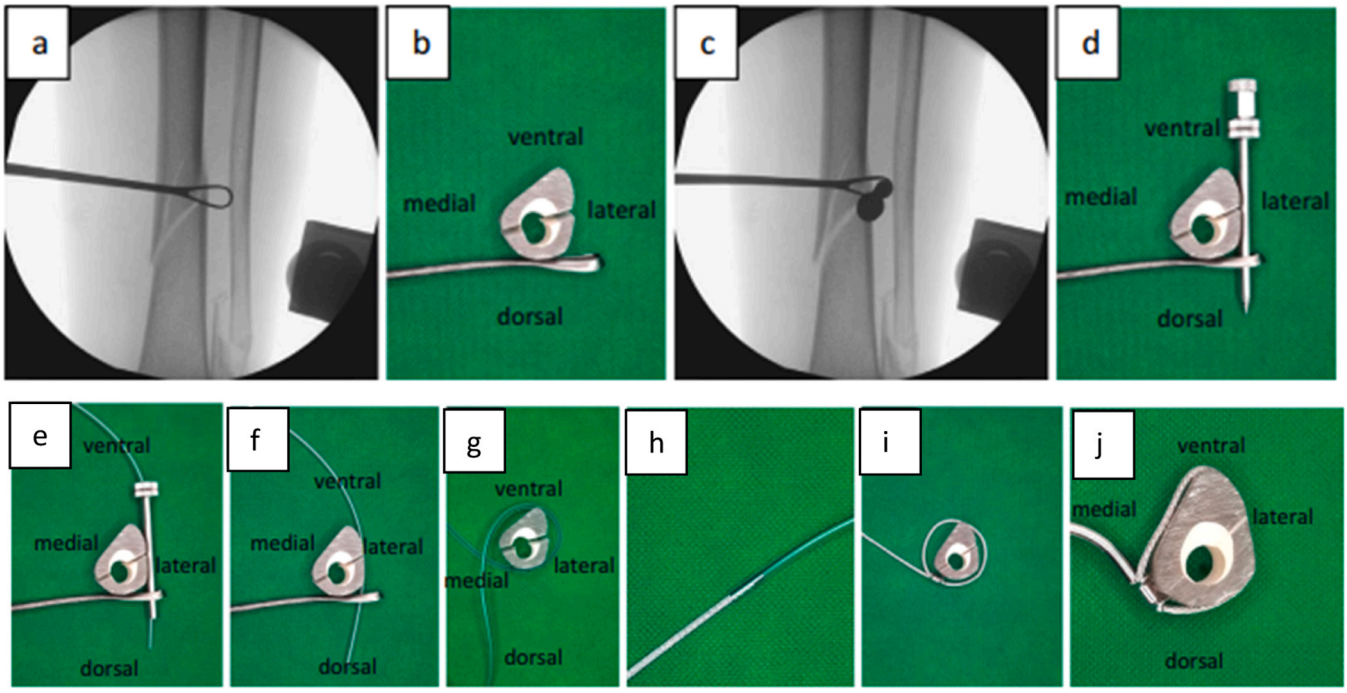


Fig. 1. Minimally invasive cerclage of the Tibia. a/b: A curette is introduced under constant contact to the bone via a dorsomedial step incision. X ray in ap view and schematic in axial view. c/d: Via an anterolateral incision, a drill sleeve is inserted and slided along the lateral aspect of the tibia. X ray in ap view and schematic in axial view. e/f: after insertion of a redon drainage, the drill sleeve is removed. g: the drainage is pulled out through the dorsomedial incision via the curette. The other free end of the drainage can be guided along the anteromedial aspect of the tibia using a clamp. The drainage ist now looped around the tibia. h: a cable cerclage is connected to the free end of the drainage. i/j: using the drainage as a guide the cable cerclage can now be inserted and tightened around the tibia.

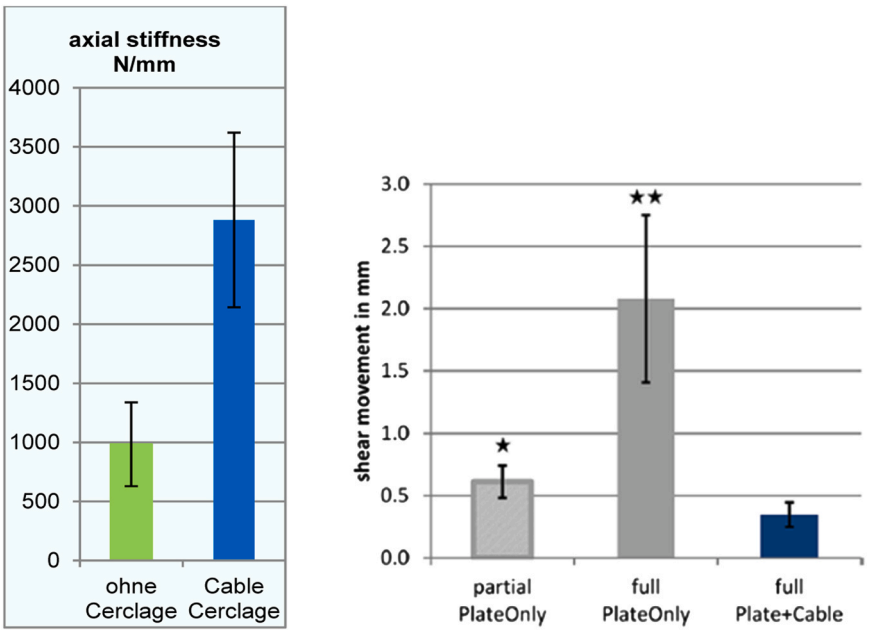


Fig. 2. Biomechanic testing of ancle stable plate osteosynthesis of tibia spiral fractures with and without additive cerclage. a: Due to the additive cerclage the axial stiffnes is nearly trippled. b: Through the additve cerclage the shear movements are reduced significantly, even under simulated full weight bearing conditions.

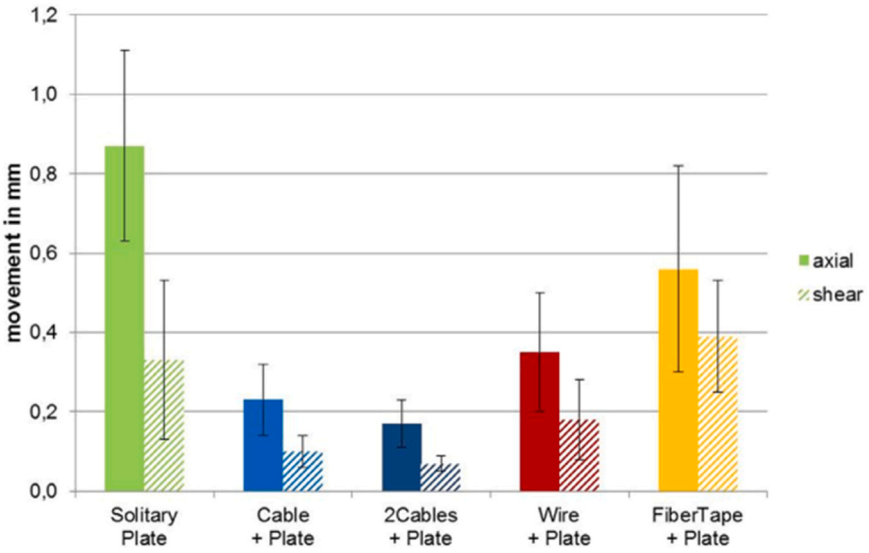


Fig. 3. Biomechanic testing of different cerclage types. Compared to a solitary plate, axial and shear movement are significantly reduced by the additive cerclages. The biggest effect is produced by 2 Cable cerclages followed by a single cable cerclage, a double looped steel cerclage and a double looped polyethylene/polyester cerclage.

of these cases. Wound healing complications occurred in 10 cases, 7 of which were unrelated to the cerclage. In one case, irritation of the deep fibular nerve (n. fibularis profundus) was observed. Compared with complication rates reported in the literature for plate osteosynthesis alone in tibial shaft fractures, the use of cerclage did not result in an increased complication rate. Fig. 4 shows one clinical case as example.

A multicenter study [15] demonstrated that the treatment of tibial shaft spiral fractures with cerclage and permission for full weight-bearing led to significantly faster and improved mobilization compared to treatment without cerclage and with postoperative partial weight-bearing. In addition, quality-of-life scores in the early post-operative phase were significantly higher. There was no significant difference between the two groups regarding complications.

In summary, additive cerclages significantly increase the stability of locking plate and intramedullary nail osteosyntheses in spiral fractures in synthetic bone models. However, anatomical reduction is required to achieve this effect. Cable cerclages appear to provide the greatest stabilizing effect, followed by steel and polyethylene/polyester cerclages. From a biomechanical perspective, the additional stability achieved with cable cerclages would allow immediate full weight-bearing. In clinical application, no increased complication rates have been observed, and patients appear to benefit from the possibility of early full weight-bearing.

Clinical results of additive cerclages in humeral shaft fractures

In biomechanical investigations of spiral fractures in synthetic tibial bone models, cerclages were shown to be effective in neutralizing

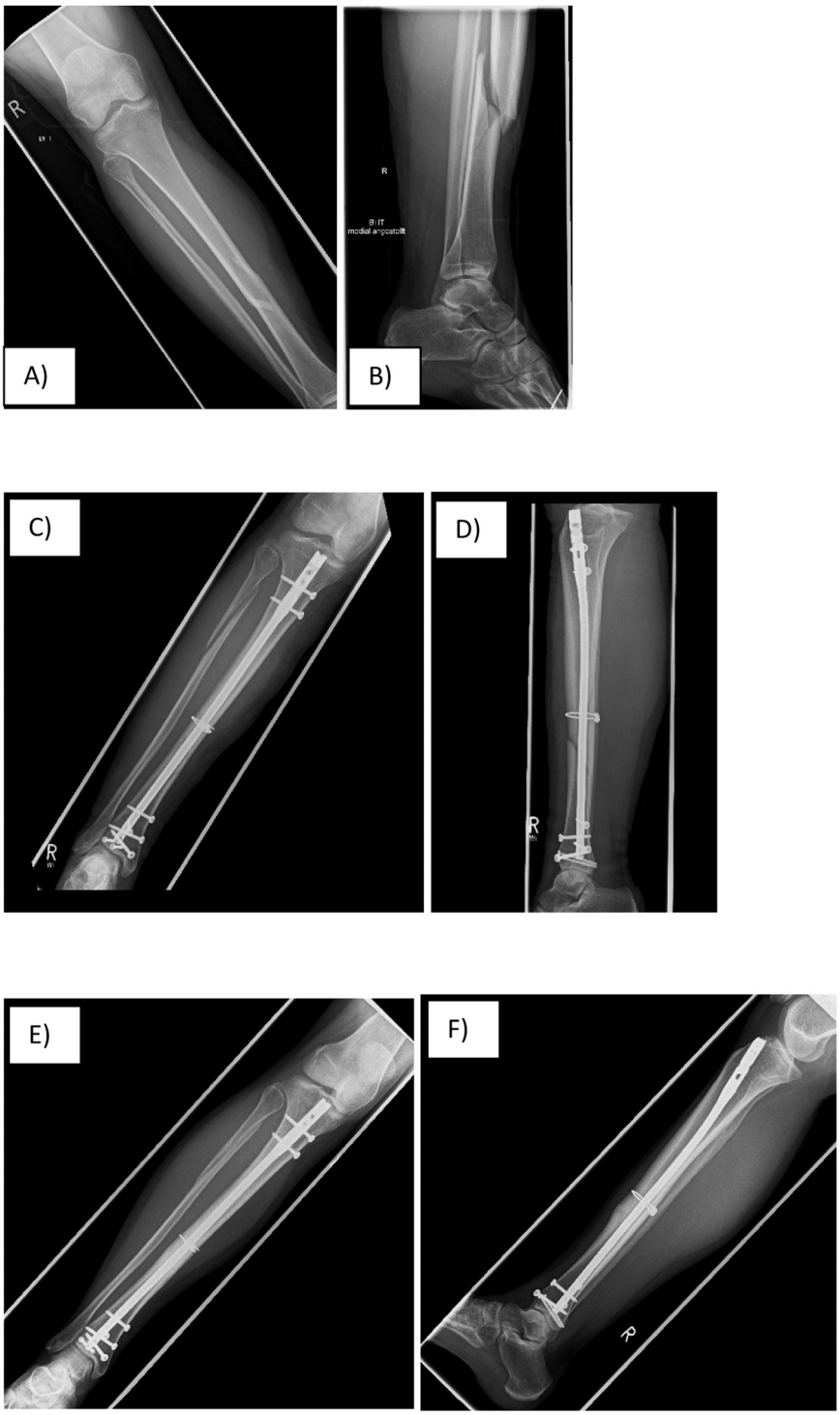


Fig. 4. A 30-year-old female patient sustained a right tibial shaft fracture (AO 42-B2) with an additional nondisplaced distal tibial fracture (Volkmann fracture) after falling from a height of approximately 4 m while bouldering. A) and B) show the conventional anteroposterior and lateral radiographs of the fracture. Surgical treatment was performed on the day of admission using minimally invasive cerclage wiring, intramedullary nailing and screw fixation of the distal tibia. C) and D) show the postoperative anteroposterior and lateral radiographs. Postoperative management allowed immediate full weight-bearing. Follow-up radiographs E) and F), obtained one year postoperatively, demonstrate complete bony consolidation.

rotational forces. This finding makes their use particularly interesting for humeral shaft fractures, which frequently occur as spiral fractures. Unlike the lower extremity, the humerus—due to the forearm acting as a long lever arm—is subjected primarily to rotational rather than axial loads. Nevertheless, geriatric patients who rely on walking aids may require load-stable fixation of a humeral shaft fracture in order to maintain mobility.

From a biomechanical standpoint, the use of cerclage in humeral shaft spiral fractures therefore appears reasonable and is already performed clinically. A retrospective study of 109 patients with humeral shaft spiral fractures [16] demonstrated that cerclage placement at the humeral shaft via a limited surgical approach is feasible. Notably, there was no increased rate of nerve lesions, wound healing disorders, or delayed fracture healing.

Although the available data on cerclage use in the humerus are less extensive than for tibial shaft fractures, the technique appears promising from both biomechanical and clinical perspectives and is already being applied in clinical practice.

Discussion

Primary full weight-bearing fracture treatment is becoming increasingly important in modern trauma surgery. It is now well established that geriatric patients are unable to reliably adhere to partial weight-bearing restrictions, and younger patients likewise benefit from faster rehabilitation when full weight-bearing is permitted.

One option to achieve immediate postoperative full weight-bearing is the augmentation of conventional plate or intramedullary nail osteosynthesis, for example through the use of cerclage. For tibial shaft spiral fractures, a minimally invasive technique is available.

This technique was first described almost a century ago [7] but has now been adapted to modern cable cerclage systems and investigated scientifically for the first time. An anatomical study demonstrated that minimally invasive, tissue-preserving insertion of cable cerclages at the distal tibia is feasible using an appropriate technique, without entrapping relevant anatomical structures such as vessels, nerves, or tendons, even when these structures are located in close proximity [9].

In recent years, biomechanical investigations of cerclage augmentation in tibial spiral fractures have also been performed for the first time [10,13,14]. All of these studies were conducted using synthetic bone models. In addition to evaluating different cerclage materials, various configurations were tested, including combinations with angular stable plates or intramedullary nail fixation, as well as fracture models with either anatomical reduction or simulated bone defects. Whenever anatomical reduction was achieved, all studies demonstrated a substantial, and in most cases statistically significant, increase in osteosynthesis stability, particularly when cable cerclages were used. Shear forces, which are known to negatively influence fracture healing, were markedly reduced. In some synthetic bone models, under simulated full weight-bearing conditions, the use of cerclage augmentation reduced shear forces to values below those observed during simulated partial weight-bearing without cerclage augmentation.

The available biomechanical studies therefore demonstrate clear advantages of additive cerclage augmentation. These findings suggest that, from a biomechanical perspective, immediate postoperative full weight-bearing may be achievable through the use of an additional cerclage, potentially providing trauma surgeons with a valuable treatment option. However, it must be emphasized that all investigations to date have been performed using synthetic bone models of healthy, isolated tibiae. Studies involving osteoporotic bone models or complete human lower-leg specimens are currently lacking, which may limit the direct translation of these findings into routine clinical practice.

Nevertheless, current clinical studies are also available [8,15]. First, these studies demonstrate that minimally invasive cerclage insertion can be performed without an increased complication rate. This finding is consistent with previous experience from studies investigating minimally invasive cerclage based on the original technique published in 1933 [17–19]. Furthermore, a prospective randomized study demonstrated that permitted postoperative full weight-bearing was indeed implemented rapidly and resulted in improved functional outcomes and favorable fracture healing, without increasing complication rates [15]. These observations suggest that the existing and well-established biomechanical findings can be successfully translated into clinical application for tibial fractures.

In addition, clinical studies investigating the use of additive cerclages in humeral shaft fractures have been published [16,20], although corresponding biomechanical studies are currently lacking. The clinical results are also promising, demonstrating no increased complication rates, particularly with regard to potential nerve injuries, and showing rapid fracture healing. Although the evidence base is less robust, the technique of additive cerclage appears to be transferable to spiral fractures of the humeral shaft as well.

Conclusion

Minimally invasive cerclage augmentation in tibial shaft fractures was described many decades ago but has recently been adapted to modern implant systems and systematically evaluated using biomechanical methods. These investigations have demonstrated that additive cerclages can significantly increase the stability of both intramedullary nail and plate osteosynthesis constructs in synthetic bone models. Clinical studies suggest that these biomechanical findings may be transferable to clinical practice in tibial and also in humeral shaft fractures.

CRediT authorship contribution statement

S Förch: Writing – review & editing, Writing – original draft, Visualization, Supervision, Methodology, Conceptualization. **S Sandriesser**: Writing – original draft, Visualization. **A. Fenwick**: Writing – review & editing. **P. Augat**: Writing – review & editing, Validation, Methodology, Formal analysis, Conceptualization. **E. Mayr:** Writing – review & editing, Conceptualization.

Declaration of Competing Interest

All authors declare, that there is no conflict of interest concerning this article.

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