A Modification of Internal Bone Transport Method for Reconstruction of Nonunion of Forearm

Abstract

Background: Defects of bone and soft tissue occur frequently after high-energy trauma, infections, and tumor resection. Treatment options are limited and outcomes are controversial in nonunion. Classical reconstruction methods are challenging. We describe a method of internal bone transport for treatment of complicated nonunion of the forearm. This method permits axial and internal bone transport without harming the distorted and complex neurovascular anatomy or soft-tissue envelope. **Materials and Methods:** Five patients (mean age, 27 years) with defect nonunion (3 ulna, 2 radius) were treated. Mean preoperative defect size was 36 mm, mean shortening was 14 (0–30) mm, and the extent of surgical resection was 24 (20–40) mm. Total bone loss due to defect, resection, or shortening was 74 mm. According to Paley classification, two of the patients had B1, and three had B3 defect nonunion. This study treats defect nonunion of the forearm using an internal bone-transport method. Our method involved cannulated screws, a cerclage wire, and a circular fixator being used in combination. When transportation was completed, internal fixation of the docking site with a plate and screws was done, with bone grafting after fixator removal. Bone healing and functional outcomes were assessed with radiographs and disabilities of the arm, shoulder, and hand (DASH) scores, respectively. **Results:** Mean followup was 67.6 months. Solid osseous union and functional improvement were achieved in all cases. Mean bone loss was 66 mm, mean fixator time was 131.8 days, the lengthening index was 1.3 days/mm, and the fixator index was 2.1 days/mm. DASH score was 82.2 before treatment and 15.36 after treatment. **Conclusions:** Using our method, internal bone transport and progressive axial docking of defects can be done with minimal effects on surrounding neurovascular arrangements and soft tissues. Size of fixators can be decreased and formation of painful scar tissue can be avoided.

Keywords: *Bone defects, modified internal bone transport, radius, ulna*

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Introduction

Defects of bone and soft tissue occur frequently after high-energy trauma, infections, and tumor resection. Appropriate initial attempts at treatment may fail and further reconstruction may be needed. Treatment options are limited and outcomes are controversial in nonunion, which are complicated by the resultant infection, soft-tissue contractures, and deformities in adjacent joints.[1-4]

In complicated nonunion of the forearm, classical reconstruction methods are challenging due to the distorted and complex neurovascular anatomy, bone structure, and soft tissue due to previous surgery, infection, and scar tissues. A possible alternative method of the treatment was to close the bone defect and acute limited size lengthening by various microsurgical reconstructive procedures as described by many authors.[5,6] However, with this procedures, complication rate is high, and there is a greater need for microsurgery skills. Nevertheless, very effective and successful methods can provide solutions to these problems, including bone transportation with external fixators.[7,8] Although it has disadvantages (e.g., long learning curve, severe complications, patient discomfort), a high prevalence of success has been reported.[7,9-11]

Here, we describe a method of internal bone transport for treatment of complicated nonunion of the forearm. The method involves cannulated screws and cerclage wires to construct an internal pulley system for transportation of osteotomized fragments. This method permits axial and internal bone transport without harming the distorted and complex neurovascular anatomy or soft-tissue envelope.

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Materials and Methods

The study cohort was 5 patients [4 males and 1 female; mean age, 27 years (range 16–35 years)] and involved 5 nonunions (3 ulna and 2 radius). Initial etiologic factors of defects were fracture due to a sport injury (*n* = 1), tumor resection (*n* = 1), and fractures due to a motor-vehicle accident (*n* = 3). Patients had undergone a mean 4 (range 3–9) surgical interventions before our treatment. These surgical procedures had involved, over a long period of time: tumor resection, debridement of open fractures, open reduction and internal fixation, debridement of infected bone, and bone grafting. Patients had severe loss of function due to contracture of the wrist and elbow [Table 1].

There were 2 type-B1 and 3 type-B3 nonunions based on the Paley classification.[12] These nonunions were termed "complicated" because of joint deformities, contractures, bone defects, and infection. Mean elapsed time from the injury to our treatment was 10.8 years (range 2–23 years). Defective area was 36 mm (range 20–50 mm), mean shortening was 14 mm (range 0–30 mm), and the extent of resection was 24 mm (range 20–40 mm). Resultant mean bone loss due to shortening, defects, or resection was 74 mm (range 60–90 mm). Anatomic integrity of radiocarpal and distal radioulnar joints was distorted in 2 cases. One patient had a failed vascularized fibular graft reconstruction after resection of an aneurysmal bone cyst localized at the distal radial metaphysis. The cause of this failure was deep infection, and the infection was unresolved at the time of surgery. The second patient experienced a physial injury and concomitant diaphysis defect that resulted in radial shortening of 17 mm. Deformity of the radial head (not round and larger than the other side) was noted in the other 2 patients[Table 2].

All patients (*n* = 5) provided their informed consent at enrollment for the use of patients' data for research. Outcomes at final followup were assessed using radiologic interventions and functional scoring systems. Evidence of union, infection, deformity, and length discrepancy were evaluated through anteroposterior and lateral radiographs of the forearm. Pain, range of motion, and disabilities of the arm, shoulder, and hand (DASH) scores for functional outcomes were recorded. For range of motion evaluation, an electronic digital goniometer was used.

Operative procedure

A bone transport pulley system (BTPS), which comprised cannulated screws (4.5 mm) and a cerclage wire (0.5 mm), was placed into the forearm by open surgery [Figure 1a-c].

Before insertion of the BTPS, meticulous debridement of the infected area and removal of necrotic tissues was undertaken. This step is of paramount importance, and

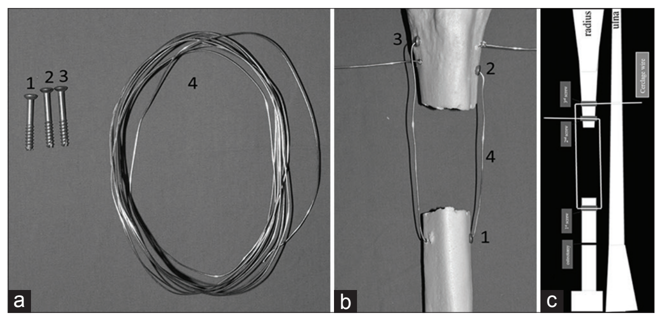

Figure 1: The bone transport pulley system is a combination of cannulated screws and a cerclage wire (a) was placed into the defect with open surgical technique (b). One cannulated screw is placed into the main fragment (labeled as number 1) and two cannulated screws are placed into the target bone (labeled as number 2 and 3), parallel to each other and perpendicular to the bone (c)

Table 1: Patient demographics

Patients	Age	Gender	Side	Localization	Dominant side	Etiology	Number of previous operations	Time elapsed from injury to the last treatment (years)
1	32	Male	Left	Ulna	Right	Traffic accident	3	5
2	16	Male	Left	Radius	Right	Tumor (aneurysmal bone cyst)	5	2
3	21	Male	Left	Radius	Right	Sport injury	5	8
4	35	Female	Left	Ulna	Right	Traffic accident	3	23
5	31	Male	Left	Ulna	Right	Traffic accident	9	16

Table 2: Preoperative clinical and radiological evaluations of the pseudarthroses

Patients	Infection	Defect size (mm)	Shortness (mm)	Resection size (mm)	Total defect size (mm)	Paley classification	Other pathologies	Wrist anatomy
1	+	40	0	20	60	B1	None	Normal
2	Active (*Pseudomonas aeruginosa*)	50	30	10	90	B3	Distal 1/3 radius resection	Radiocarpal joint resected
3	+	20	30	40	90	B3	TFCC-f + VISI	Radial shortness of 17 mm
4	+	40	0	20	60	B1	Rhd, radial bowing	Normal
5	+	30	10	30	70	B3	Rhd	Normal

TFCC-f=Triangular fibrocartilage complex failure, VISI=Volar intercalary segmental instability, Rhd=Radial head deformation (not round and bigger than other side) debridement should be repeated until the soft-tissue bed and punctuate bleeding from the bone is observed [Figures 2-4].

To construct the BTPS, one cannulated screw was inserted into the main fragment (fragment which was osteotomized for obtaining transporting fragment) and two cannulated screws were placed into the target bone (smaller fragment according to main fragment which transporting fragment go towards it), parallel to each other and perpendicular to the bone. A cerclage wire was inserted through the first screw (which was located in the target bone). Then, the cerclage wire was passed inside the screw in the main fragment and the remaining screw in the target bone. The two ends of the cerclage wire were removed from the skin [Figure 5]. The screws changed the direction of the traction force and made it parallel to the direction of bone transport, thereby enabling internal bone transport while reducing the risk of cutout of the screw. After skin closure, the forearm was stabilized in a circular fixator and a lengthening osteotomy carried out percutaneously. The fixator was used only for stabilization of fragments and carrying of motor units (which were used to move the osteotomized fragment toward the main fragment).

After a latency period, bone transport was initiated at 1 mm/day. To allow periosteal healing, the ends of the cerclage wire had to be loose during the latency period [Figures 6 and 7]. Transporting fragment was carried until the defect eliminated. After that, lengthening is done until length of bone was restored. What must be done at this point is to wait for minimum 3 weeks of pause when bone transport is completed. Minimum 3 weeks of waiting is essential for the maturation of regenerate bone. Following regenerate bone maturation seen in X-rays after this pause, fixator is removed, plate is placed over maturated regenerate bone, transported fragment, and distal target bone, spongious bone grafting of the docking-site and plate-screw osteosynthesis are performed.[Figure 8].

Results

Solid osseous union was achieved in all patients. Mean followup was 67.6 months (range 42–87 months). Mean bone loss was 66 mm (range 40–80 mm), mean time for fixator application was 131.8 days (range 82–180 days), the lengthening index was 1.3 days/mm (range 1.2-1.4 days/mm), and the fixator index was 2.1 days/mm (range 1.5–2.4 days/mm). The DASH score was 82.2 (range 68.4–97.3) before treatment and 15.36 (range 5.9–28.9) after treatment [Table 3].

One patient had active infection that necessitated wound drainage at treatment initiation. Surgical treatment for this patient comprised bone resection, debridement, and deep sampling of tissue for culture. The culture was positive for *Pseudomonas aeruginosa*, which was treated with 5 weeks of ceftriaxone (intravenous) and 6 weeks of cefuroxime.

Complications were seen while bone transport continued. Schanz pin and cerclage wire were broken in one patient. Although this complication was noticed, wire placement was revised without anesthesia in the outpatient setting

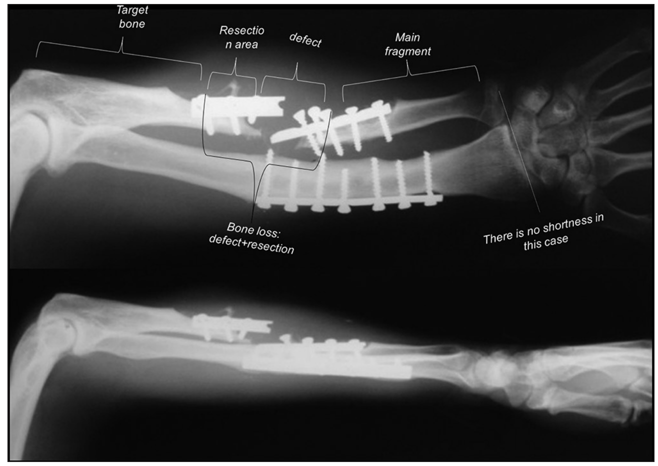

Figure 2: Anteroposterior and lateral radiographs of forearm revealed a large defective ulnar nonunion and a broken plate in a 32-year-old male patient

Figure 3: Skin condition and incision scar from previous surgeries of the forearm in Patient 1 before internal bone transport surgery

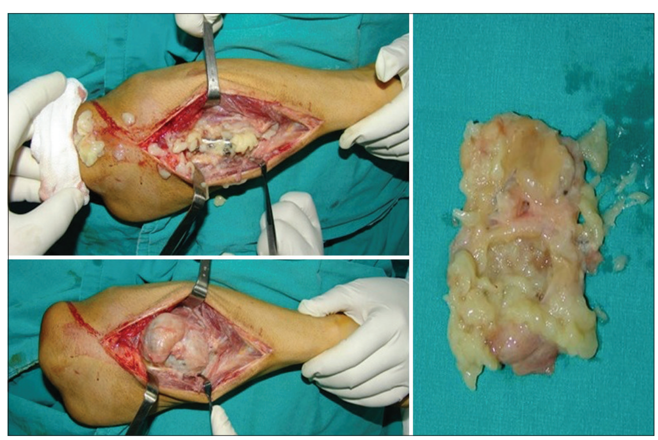

Figure 4: Intraoperative view of debridement from Patient 1's surgery. Before inserting the transport pulley system, meticulous debridement of the infected area and removal of the necrotic tissues is of paramount importance

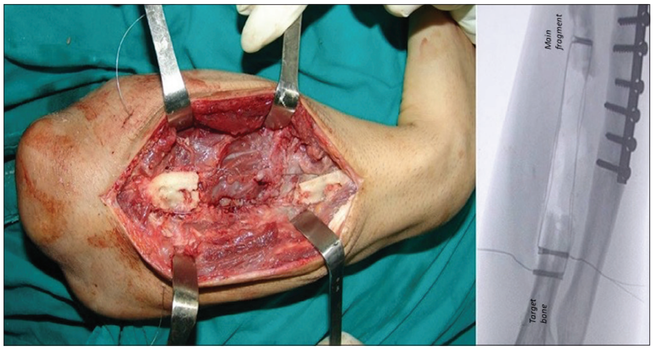

Figure 5: Intraoperative view and fluoroscopic image from Patient 1's surgery. The cerclage wire is inserted through the first cannulated screw which is located in the target bone, then passed inside the screw in the main fragment and the remaining screw in the target bone respectively. The two ends of the cerclage wire are taken out of the skin

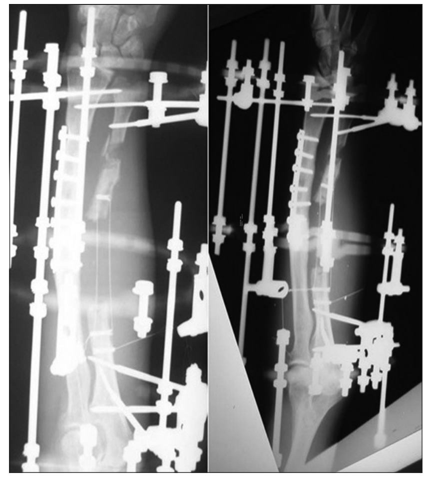

Figure 6: After closure of the wound, forearm was stabilized in a circular fixator and lengthening osteotomy was performed percutaneously. Early postoperative anteroposterior radiographs of forearm of Patient 1 revealed an effective bone transport following 5 days of latency period and 10 days of bone transport

Figure 7: Postoperative anteroposterior radiographs of forearm of Patient 1 after 2 months from surgery

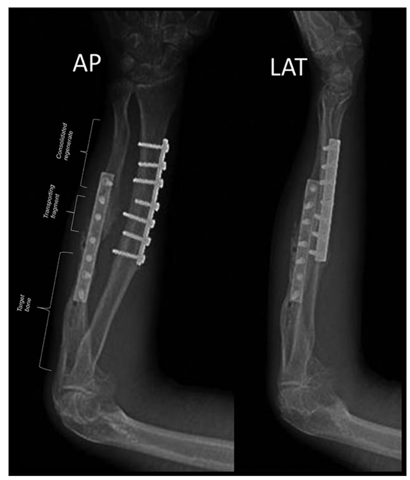

Figure 8: Following 138 days of fixator duration, fixator is removed from Patient 1's forearm after bone contact was achieved. Fixation of an internal plate with bone-grafting of the docking site was performed, ulnar defect was restored and solid osseous union was achieved, as seen in anteroposterior and lateral radiographs

and treatment was completed in this patient. Grade 1 pin-tract infection was observed in 2 patients but resolved with careful management at the pin site and use of a first generation cephalosporin for 5–7 days with clinical followup.

At final followup, mean flexion and extension at the elbow and wrist were improved. Two cases with 20° of elbow extension deficit in the preoperative period healed with full recovery and one case with 30° of elbow extension deficit improved to 10° of deficit. Elbow flexion range increased in two cases by 10° and 20°, decreased in one by 5° and did not change in two. Wrist flexion range improved in four cases with an average of 31° (range 10° to 75°) and did not change in one, compared to preoperative evaluations. Wrist extension range improved in three cases with an average of 10° (range 5°–20°) and did not change in two, compared to preoperative evaluations. Preoperative pronation range improved in all cases with an average of 22° (range 10°–45°), and forearm supination range improved in all cases with an average of 58° (range 10°–90°) [Table 4 and Figure 9].

Discussion

Several options have been described for the treatment of bone and soft-tissue defects of the radius and ulna caused by trauma, infection or tumor resection, and all have advantages and disadvantages.[2,13-16] For options not involving bone transport, treatment can be completed in a single session without the requirement of external hardware with relatively simple followup procedures for patients and the surgeon. However, these methods have disadvantages in patients with complicated bone defects: requirement of sophisticated microsurgical procedures, donor-site comorbidity, high level of surgical expertise, difficulty in acute restoration of shortening, and bone defects.[5,6]

Failure of sophisticated reconstruction methods can have devastating effects for patients and healthcare staff.

Table 3: Treatment of pseudarthroses technical data on bone transport and complications

Patients	Treatment	Complications	Other surgeries	Secondary surgical procedures	Lengthening size (mm)	Fixator duration (days)	Fixator index (day/mm)	Lengthening index (mm/day)
1	Nibtt	Cerclage wire failure, schanz pin failure	If + Dsg	None	60	138	2,3	1,3
2	Nibtt	G1 pin infection	If + Dsg + Rca	None	80	180	2,25	1,4
3	Nibtt + Rl	G1 pin infection	If + Dsg	None	80	121	1,5	1,3
4	Nibtt	None	If + Dsg	Radial head resection after 17 months	40	82	2,5	1,2
5	Nibtt	None	If + Dsg	Plate and screws removed after 60 months	70	168	2,4	1,3

Nibtt=Novel internal bone transport technique, Rl=Radial lengthening, G1=Grade 1, If=Internal fixation, Dsg=Docking side grafting, Rca=Radiocarpal arthrodesis

Figure 9: The primary goal of our treatment was restoring the functionality of the extremity. Despite of some restriction in supination (increased from 15° to 55°), a good functional outcome was obtained in Patient 1 at the end of 42 months of followup period

Multiple surgical procedures, infections, and resections undertaken in previous treatments altered the anatomic structures in our patients. In an altered anatomic environment, predisposition of additional trauma to neurovascular structures is increased and necessitates increased management and protection of these structures. From this viewpoint, despite all appropriate sophisticated microsurgical interventions, the risk of failure is not eliminated. Application of an external fixator is simple and possible at any time, but our treatment option is also very risky, and extreme care is needed.

Our patients had a mean number of 5 previous surgical procedures, and 10.8 years from the original trauma to our treatment. They had complex neurovascular structures in the forearm that had moved from their original anatomic location due to previous surgical procedures, and patients also had disuse osteoporosis.[8,10] Our new method can be used to transport bone in an axial direction and secure anatomic pathway.[17-19] All patients had anatomic and functional disabilities, so the primary goal of treatment was restoration of functionality of the extremities. DASH scores at final followup showed a significant improvement compared with preoperative DASH scores, revealing satisfactory treatment.

Bone transport with an external fixator has been used in the treatment of large defects in bone.[1,4,20,21] A high prevalence of success has been reported, but it is not first line treatment because the learning curve of the method is long and the fixator rings are uncomfortable for patients. Hence, this method is carried out in limited number of surgical centers.[8,22-26] With the modification of internal bone transport described here, the prevalence of complications for internal bone transport methods can be decreased and successful outcomes can be achieved. Less time is spent in the fixator, and therefore, the patient comfort is improved.

Defect size is not of paramount importance when deciding whether to use our internal bone-transport method. One of the most important advantages of our method is that bone can be transported in an axial direction, so progressive compression at the docking site is provided internally. The cerclage wire is placed parallel to neurovascular structures, so trauma to the soft-tissue envelope during transport is avoided. Tensioning and bone transport are carried out in the same direction, so the shearing forces that can result in screw cutouts in atrophic bone are decreased. In one of our patients, the cerclage wire broke because of the excessive force applied for transportation. However, the screws and internal part of the cerclage wire showed resistance to the same force, and screw cutout did not occur even though the bone was atrophic. After revision of wire placement without anesthesia in the outpatient setting, treatment was completed in this patient. Neurovascular complications were not observed in any of our patients.

Table 4: Clinical evaluations of the patients

Patients	Preoperative range of motion			Final followup postoperative range of motion						
	Forearm (pronation/ supination)	Elbow (extension/ flexion)	Wrist (extension/ flexion)	Forearm (pronation/ supination)	Elbow (extension/ flexion)	Wrist (extension/ flexion)	Followup (months)	Preoperative DASH	Postoperative DASH	Radiological outcome
1	20/15	0/120	25/20	65/55	0/120	30/30	42	80,9	9,8	Solid osseous union
2	10/−20	0/130	0/−30	30/0	0/125	0/0	56	97,3	28,9	Solid osseous union
3	10/−50	20/110	0/−35	30/90	0/120	20/40	87	78,2	7,2	Solid osseous union
4	40/45	20/90	20/25	50/55	0/110	20/25	77	68,4	25	Solid osseous union
5	15/−50	30/110	15/20	30/40	20/110	20/30	76	86,2	5,9	Solid osseous union

DASH=Disabilities of the arm shoulder and hand

In the literature, there are several articles that had described a modification of an internal bone transport technique, each having unique advantages and disadvantages.[26-28] However, all of these above-mentioned techniques had been described for the treatment of defects localized in the long bones of the lower limb, technically challenging to be performed in dimensionally smaller or comparatively weaker bones such as forearm bones. The technique that we are performing is different from the above-mentioned ones; the cannulated screws used in the technique are small in size, thus they can be easily applied to every small and weak bones. In addition, our method can be performed with a circular fixator in combination which helps an orthopedic surgeon to use circular fixator's supplemental ability to adapt into narrowest anatomical zones with technical ease, whenever needed. Another advantage of our technique is that cerclage wire passing in the screws has a capability to obtain docking-side compression if transport is continued after bone defect reconstruction is completed. For all these features, we believe that the axial internal bone transport technique that we use is more advantageous to perform compared to other methods.

The prevalence of complications of bone-transport methods can be more if the treatment period is long.[10,29] In addition, the time elapsed during the consolidation phase can increase the fixator index. To decrease the time of fixator application, internal fixation was done with grafting of the docking site after the defects had been closed, and fixators were removed. Mean segmental bone loss that necessitated treatment was high (74 mm), but the mean lengthening index was 1.3 days/mm, and the fixator index was 2.1 days/mm. In complicated defective nonunions, the biological responses of bones are affected negatively and the capacity for regeneration decreases.[4,8,14] All of our patients had complicated defective nonunions but solid osseous union was achieved in all cases.

We performed grafting at the docking site and plate screw fixation to reduce the duration of fixation because a longer duration of fixation can increase the prevalence of infection.[22,30] Infection or recurrence due to plate screw fixation was not observed in our cohort, probably due to meticulous debridement and removal of necrotic tissues.

Low number of patients in the cohort, heterogeneity in the etiological factors of the defects in patients and the lack of more objective functional assesment tools are the limitations of our study.

Technological advancements may allow the treatment of severe traumatic fractures with a low prevalence of complications. Nevertheless, orthopedic surgeons who deal with trauma and deformity must be familiar with conventional treatment options such as circular external fixators. Bone transport employing circular external fixators has become conventional treatment for large defects in bone. In our method, fixator application was simplified and a new internal transport device added and could be used for the treatment of chronic cases.

Conclusions

With this new treatment method, internal bone transport and progressive axial docking of defect can be performed with minimal influence of surrounding neurovascular tissues and soft tissues. The size of the fixators can be decreased and painful scar tissue formation can be avoided, resulting in better posttreatment DASH scores. We think that small sample size in the cohort is an important limitation for the study, thus the success in both clinical and radiological outcomes of the technique must be supported with further studies with larger group of patients.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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