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Outcome Assessment of Z-shaped Osteotomy in the Management of Humeral Shaft Nonunion Secondary to Failed Plate Osteosynthesis

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Summary: Restoration of fracture alignment by osteotomy is crucial for the management of humeral nonunion. In the present study, we introduced a new way of osteotomy (Z-shaped) in treating humeral shaft nonunion secondary to failed plate osteosynthesis. Clinical data of 24 patients with humeral shaft nonunion following implant failure (from 2010 to 2014) were retrospectively evaluated. These patients underwent Z-shaped osteotomy in revision surgery after the initial surgery, plate osteosynthesis, was failed. Outcomes were evaluated using visual analogue scale (VAS) and Constant and Murley score. Repeated analysis of variance (ANOVA) was used for statistical analysis. Patients were followed up for a minimum of 24 months (26.83±4.33 months). The operative time was 102.33±10.16 min, and hospital stay averaged 9.75±2.13 days. All patients achieved clinical union at the latest follow-up. Complications included radial palsy (n=1) and superficial wound infection (n=1). The postoperative VAS scores decreased significantly compared to preoperative score (F=257.99, P<0.01). Constant and Murley score increased and reached 81.33±0.95 at 24 months' follow-up (F=247.35, P<0.01). Among all the cases, 15 cases were graded as "excellent", and 9 as "good". In conclusion, Z-shaped osteotomy was easy to perform, and it provided additional medial support with more bone contact areas. Revision surgery using locking plate and Z-shaped osteotomy achieved high union rate and improved functional outcome. It was a reasonable and safe option for treating humeral nonunion following implant failure.
Key words: Z-shaped osteotomy; humeral shaft nonunion; implant failure

Humeral shaft nonunion poses a challenge to orthopedic surgeons. The incidence of this condition ranges from 8% to 12% postoperatively[1]. Fracture classification, infection, initial treatment, selection of implants, age, injury mechanism are common factors involved in humeral nonunion[2]. Bone loss is the main issue following failed plate osteosynthesis and makes stable fixation more difficult since less bone surface is available for screw insertion. Surgical treatment of humeral nonunion using dynamic compression plate (DCP), intramedullary nail (IMN), Ilizarov fixator, locking compression plate (LCP) and shape memory connector has been previously examined and reported[3]. Despite a few favorable results gained, there still exist numerous unsolved problems, and even today the ideal surgical method for humeral shaft nonunion remains undetermined[4–6]. After implant failure, loss of stability in fracture ends and closed medullary cavity make bone union more difficult. In atrophic nonunions, osteotomy is usually performed to achieve a better reduction. Different patterns of osteotomy (oblique osteotomy, "cup and cone" osteotomy) have been reported recently[7], with different merits and demerits.

In this study, we introduced a new way of osteotomy (Z-shaped) that can increase bone contact areas and is easy to perform. Moreover, we evaluated the outcome of Z-shaped osteotomy and LCP osteosynthesis in the management of humeral shaft nonunion secondary to failed plate fixation.

1 MATERIALS AND METHODS

1.1 Ethical Approval and Inclusion and Exclusion Criteria

This study retrospectively analyzed the clinical efficacy of Z-shaped osteotomy and LCP. The inclusion criteria were as follows: humeral nonunion following implant failure; age between 20–80 years; atrophic nonunion; nonunion duration more than eight months; revision surgery performed between 2010 and 2014. Patients with the following conditions were excluded from the study: nonunion following conservative treatment; open fractures; multiple

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fractures; hypertrophic nonunion; follow-up time less than one year.

This research was approved by the Ethics Committee of the authors' affiliated institution. The patients and/or their families were informed that their data would be published, and gave their consent.

1.2 General Data of Patients and Surgical Procedures

A total of 24 patients were included in this study, including 10 males and 14 females with their average age of 52.21±11.56 years. Seven patients had smoking history and 3 patients were diagnosed with diabetes. All cases were closed fractures. There were no bilateral fractures in this study. Fractures were classified on the basis of the primary X rays and CT scans. Seventeen cases were classified as type A, 5 cases as type B and 2 as type C, according to the Association for the Study of Internal Fixation (AO/ASIF) classification. Nonunion was defined as failure to unite within eight months or strong evidence of therapy failure without any signs of improvement[8]. All the patients were diagnosed with atrophy nonunions except one as having infectious nonunion. The infectious nonunion was confirmed to be atrophy nonunion after infection control. DCP (n=5) or LCP (n=19) was used for initial plate osteosynthesis. Implant failure (breakage or bending of plates, loosen screws) was confirmed by X rays in all patients.

Selection of surgical approaches depended on the location of the nonunion. Henry's anterolateral approach was sufficient for nonunions located at the proximal and middle-third humeral shaft, while distal nonunions might require posterior approach. After the exposure of nonunion site, avascular tissue was thoroughly removed, and the cortical bone was freshened until a bleeding surface was found. The intramedullary canal was then reconstructed with a curette. The radial nerve was explored and protected if indicated.

The Z-shaped osteotomy procedure is shown in fig. 1. Briefly, after debridement, the medical saw was used to smooth out the rough end of the nonunion site (perpendicular to vertical axis of the humerus), then the humerus less than 2 cm (parallel to vertical axis of the humerus) was sawed, and finally, the contralateral cortex bone was removed. The same process also took place with the other end of the nonunion. To avoid rotating movement of the humerus, some marks were made on the cortex before sawing. Once completed, the two ends of the nonunion were temporarily fixed with K wires, and a "Z" shape was then created on the bony surface. Lastly, LCP 4.5/3.5 Narrow (DePuy Synthes) or PHILOS or PHILOS LONG™ (DePuy Synthes, USA) was used for final internal fixation. Auto iliac bone graft was added in all cases. All fractures were reduced as anatomically as possible, and a minimum of 8 cortices were achieved on either side of the fracture. Antibiotics were intravenously given for 3 days and arm slings were used for immobilization after surgery. Patients were recommended to practice functional exercise of shoulder joint 1 week after surgery and arm slings were removed 1 week later, and then active exercises were initiated.

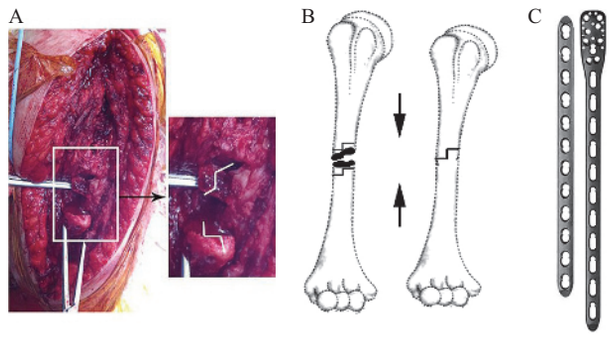

Fig. 1 Description of Z-shaped osteotomy
A: The scar and ossified tissues were excised, and Z-shaped osteotomy was performed at both fracture ends. The Z-shaped bones are shown in the white rectangle, which is magnified on the right panel as indicated by the white markings. B: the diagram of Z-shaped osteotomy. As indicated by black arrows, fractures are reduced by shortening the length of the humerus at both fracture ends to obtain Z-shaped bones. C: LCP 4.5 (DePuy Synthes) or PHILOS LONG™ (DePuy Synthes) was used in revision surgery.

Preoperative and postoperative visual analogue scale [VAS, range from 0 (no pain) to 10 (agonizing)] was recorded for further analysis. Outcome was evaluated using Constant and Murley score, which was recorded at four time points (preoperation, 3 months postoperation, 12 months' and 24 months' follow-up). A score between 80 and 100 was graded as "excellent", between 60 and 79 as "good", between 40 and 59 as "fair", and less than 39 as "poor".

1.3 Statistical Analysis

Statistical analysis was performed using SPSS 19.0. Repeated analysis of variance (ANOVA) was used for statistical analysis. A P value <0.05 was considered significant.

2 RESULTS

All patients achieved clinical union following revision surgery. Representative cases are shown in fig. 2–4. Patients were followed up for a minimum of 24 months (26.83±4.33 months). The operative time was 102.33±10.16 min and hospital stay averaged 9.75±2.13 days. Radial palsy occurred postoperatively in one patient and was completely recovered in 4–6 months without any treatment, and superficial wound infection was healed in one patient after postoperative debridement and antibiotic therapy, and no deep infections occurred. All cases were atrophy nonunions except one being initially

diagnosed with infectious nonunion but eventually confirmed to be atrophy nonunion after infection control. In this case, the infection was cured by two-time debridement and external fixation, following which vancomycin bone cement bead chain was filled into the medullary cavity. One bead was pulled out per day. The external fixation was removed when infection was completely controlled. The remaining procedure was the same as the treatment of atrophy nonunion. The postoperative VAS score at 24 months' follow-up averaged 0.63±0.07, which decreased significantly as compared with preoperative score (5.76±0.20) (F=257.99, P<0.01). Moreover, Constant and Murley score tended to increase over time (fig. 5), and the score reached 81.33±0.95 at 24 months' follow-up (F=247.35, P<0.01). It was significantly higher than the preoperative score (45.75±1.33). Among all the cases, 15 cases were graded as "excellent", and 9 cases as "good".

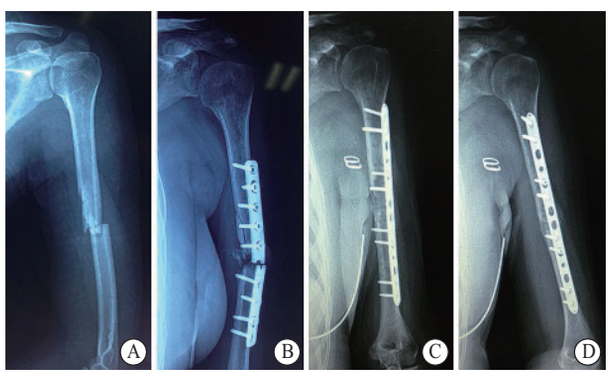

Fig. 2 Representative case of plate breakage
A: a 32-year-old female with type 12-A3 transverse humeral fracture; B: The initial surgical treatment using LCP was failed 5 months later. C and D: anterioposterior (C) and lateral (D) X-rays of the humerus of patients who underwent Z-shaped osteotomy and fixation with 3.5 mm LCP.

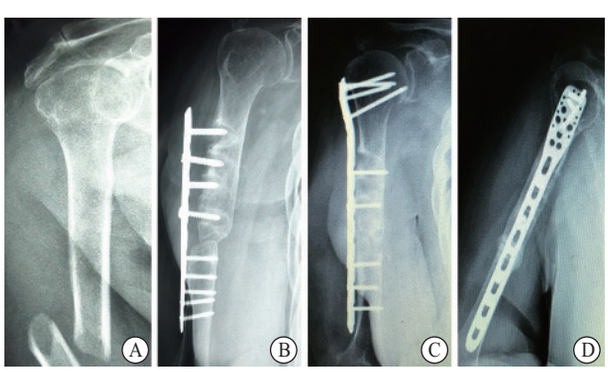

Fig. 3 Representative case of internal fixation failure
A: a 65-year-old female with type 12-A1 spiral humeral shaft fracture; B: 18 months after initial fixation, the screws were "backing out". C and D: anterioposterior (C) and lateral (D) X-rays of the humerus of patients who underwent osteosynthesis using PHILOS LONG™ combined with auto-iliac bone grafting and Z-shaped osteotomy.

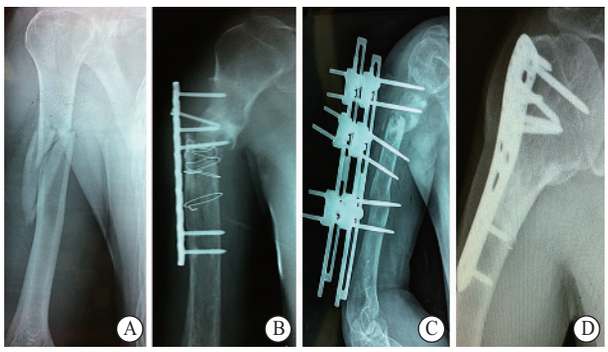

Fig. 4 Representative case of infectious nonunion
A: a 28-year-old male with type 12-B1 comminuted proximal humeral fracture; B: 6 months later, initial implant was failed. C: The patient then received external fixation to control infection. D: The intramedullary canal was reconstructed using Z-shaped osteotomy and osteosynthesis with PHILOS and auto-iliac bone graft.

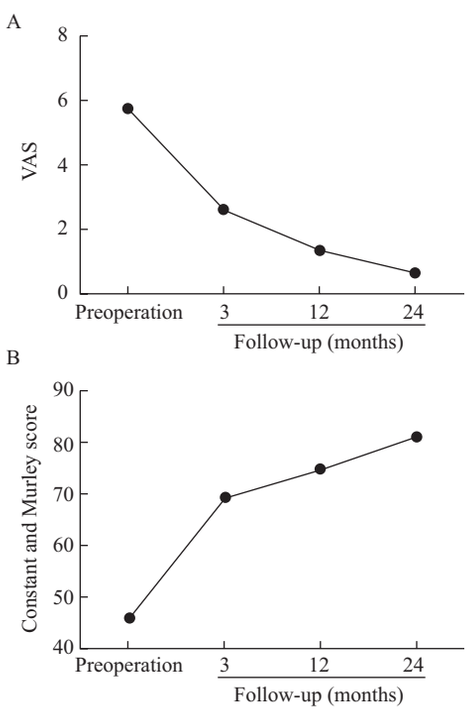

Fig. 5 The changes of VAS (A) and Constant and Murley score (B) during follow-up

3 DISCUSSION

Many factors including fracture classification, the choice of implant, gender, age, smoking, osteoporosis, obesity, alcoholism, infection, the quality of the rehabilitation program, the location and type of nonunion, lead to humeral fracture nonunion following operative or non-operative treatment[9]. Some research has proposed that open fractures, type B and C fracture are associated with delayed union and negatively influence the function of elbow and shoulder[10].

The incidence of nonunion following failed plate osteosynthesis is increasing, probably because of an obvious shift from IMN to plate fixation from 2004 (42.9%) to 2013 (21.2%) in treating closed humeral fractures[11]. DCP fixation with cancellous bone graft for revision surgery of nonunion after surgical treatment of humeral shaft fracture achieves high union rate[12, 13]. Interlocking IMN is another optimal choice, and good functional outcomes following retrograde nailing were reported[14]. It was found that there was no significant difference in the occurrence of complications between the two techniques[15, 16]. Ilizarov external fixation is also used in the management of non-infected humeral nonunion[17, 18]. Besides, there are reports stating vascularized fibula graft for treating sustained nonunion[19–21], a technique that is only recommended for large bone defect or nonunion secondary to 3 or 4 failed revision surgery, since disastrous consequences would happen if the indication is not taken seriously. In our cases, we selected LCP for final fixation, as screw holes of initial plate caused bone loss, and revision surgery inevitably led to excessive periosteum stripping. LCP, based on the design, could solve these problems to the large extent.

As for osteotomy, Nickel *et al* proposed a novel technique, more like a model of cup and cone. One end of nonunion is shaped into a "cup" while the other end is shaped into a "cone" to create concentric surfaces[7]. This technique can easily correct the deformity in any plane besides increasing bone-to-bone contact. In addition, Su *et al* demonstrated the effectiveness of their patented "Ni-Ti shape memory alloy swan-like memory pressure connector" for the management of humeral shaft nonunion[3]. This technique allows balanced axial and compression forces, but the plate is circumferentially placed, which is more likely to cause damage to radial nerve and vascularity[22]. Notably, all the osteotomy techniques may cause humeral shortening to varying degrees. A two or more centimeters osteotomy would lead to loss of triceps muscle tensioning. Therefore, shortening humerus as minimal as possible is recommended. In this study, we introduced a new way of osteotomy (Z-shaped). Compared to oblique osteotomy, Z-shaped osteotomy provided additional medial support and more bone contact areas. Besides, the two ends of the fracture were mutually supportive, ensuring maximal stability. Compared to the "cup and cone" osteotomy, Z-shaped osteotomy was easy to perform and the length of humeral shortening during operation was easy to handle. In addition, it provided more resistance to torque force.

There was no consensus on bone graft in treating nonunions. Some studies suggest that bone graft is unnecessary when the fracture ends are well aligned after debridement[23]. Moreover, there is no significant difference in medullary blood supply at the nonunion sites between hypertrophic or atrophic nonunions[24]. In our practice, bone graft is applicable to hypertrophic nonunions, which are treated only using plate fixation for providing additional stability. In cases of atrophic nonunions, autologous iliac graft, more like an osteogenic stimulus, strongly stimulates bone healing by enhancing the biological response at the nonunion sites.

Conflict of Interest Statement

The authors declare that there is no conflict of interest with any financial organization or corporation or individual that can inappropriately influence this work.

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