Technical Note
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Biologic Fixation through Bridge Plating for Comminuted Shaft Fracture of the Clavicle: Technical Aspects and Prospective Clinical Experience with a Minimum of 12-Month Follow-up

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For comminuted shaft fracture of clavicle, the operative goal, aside from sound bone healing without complications of direct reduction, is maintenance of the original length in order to maintain the normal biomechanics of adjacent joint. Our bridge plating technique utilizing distraction through a lumbar spreader was expected to be effective for restoring clavicular length with soft tissue preservation. However, there are two disadvantages. First, there is more exposure to radiation compared to conventional plating; and second, it is difficult to control the rotational alignment. Despite these disadvantages, our technique has important benefits, in particular, the ability to preserve clavicular length without soft tissue injury around the fracture site.
Keywords: *Clavicle, Shaft fracture, Communited fracture, Biologic fixation, Bridge plating*

Traditionally, midshaft clavicle fractures have been considered to be injuries that rarely require open reduction. The reported nonunion rates following surgical fixation of midshaft clavicle fracture were higher than those reported following nonoperative treatment.[1,2] Rowe has also reported nonunion in 0.8% of fractures treated by closed methods and in 3.7% treated by open reduction.[3] Recently, in a prospective, long-term follow-up study, Nowak et al.[4] found that as many as 46% of the patients did not consider themselves fully recovered (sequelae) after 9 to 10 years, while the nonunion rate 6 months after injury was 7%. More recent studies[2] have suggested the higher complication and nonunion rates of up to 15% following nonoperative treatment, in particular for patients with displaced midshaft clavicle fractures. Due to the increasing recognition of suboptimal outcomes following nonoperative treatment, there has been a uniform consensus in most surgeons that certain fractures, such as displaced or comminuted fractures, require operative intervention, although it is controversial.

For the treatment of displaced midshaft clavicle fractures, a variety of surgical techniques have been described including plating, superior or anteroinferior plating, Kirschner (K)-wire fixation and elastic intramedullary nailing. Nevertheless, the optimal treatment option for this fracture remains controversial. Recently, although there has been a high success rate of plate fixation of displaced midshaft clavicle fractures, some have resulted in postoperative complications including (deep) infection, implant-related problems (prominence, loosening, angulation, and breakage), poor cosmesis, nonunion and refracture due to implant removal.[2,5] Several studies which demonstrated the effectiveness of early operative reduction and fixation for displaced midshaft clavicle fractures have expanded the indications for surgical treatment. In addition, the operative intervention has gradually increased due to an increased incidence of complex fracture patterns following

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high-energy trauma.

Despite the popularity of plating for clavicle fractures, fixation optimization remains problematic. Recently, in lower limb fractures, to prevent surgical morbidities of direct reduction in a comminuted fracture, the biologic fixation through bridge plating has been used increasingly as it employs indirect reduction, which offers the advantage of minimal soft-tissue dissection and reduced additional injury to the fracture.[6] Although bridge plating techniques are widely used for treating metaphyseal and complex fractures of the lower limbs, there are few reports for upper limb fractures except those of the humeral shaft. Therefore, we present our novel technique for bridge plating, including distraction through a lumbar spreader to restore the length of clavicle without exposure of fracture site with successful outcome in consecutive patients with comminuted fractures of the clavicle.

TECHNIQUE

With experience of minimally invasive plate osteonsynthesis (MIPO) in lower limb fractures, the authors intended to perform biologic fixation through bridge plating in comminuted fractures of the clavicle. From January 2009 to December 2011, ten consecutive clavicular fractures of the shaft (eight patients) with comminution were enrolled by traditional indications for operative interventions and by follow-up of a minimum 12 months (Table 1). All patients with old fractures and nonunion of the shaft, distal clavicular fracture or floating injury of the shoulder joint were excluded from this study. In total, there were six women and two men aged between 21 and 69 years (mean, 45.1 years). Fractures were caused by a traffic accident in 5 patients, falling on outstretched hand in 2 patients and a sports-related injury (Judo) in one patient. According to Robinson classification of clavicle fracture,[7] eight fractures were 2B2 and two fractures were 2B1. As mentioned above, all fractures were stabilized using the bridge plating technique. The mean operation time for a patient was 138.8 minutes (range, 110 to 180 minutes), including a preparation time of 20 minutes. The mean image intensi-

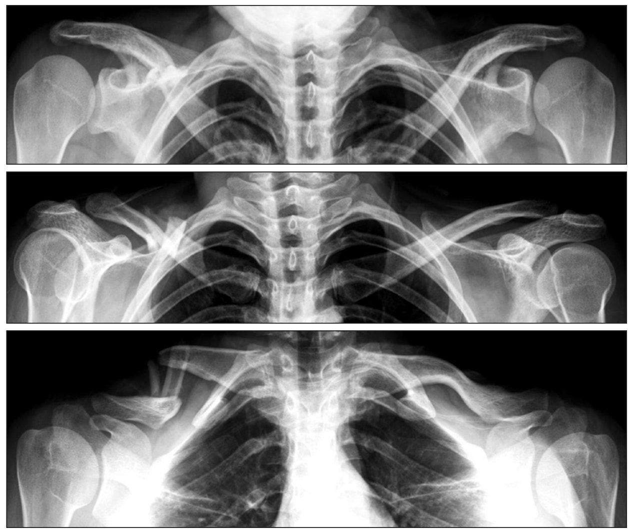

Fig. 1. A 20-year-old woman injured in a sports accident (Judo). Simple radiographs showed a comminuted segmental fracture of the clavicle (Robinson classification, 2B2).

Table 1. Summary of Cases

No.	Age/sex	Cause of injury	Both	Robinson classification	Operation time (min)	Radiation time (sec)	Radiation dose (kV)	Union (wk)	ASES score
1*	49/F	TA	+	2B2	180	90	75	10	94
2	55/F	SD	-	2B1 (wedge)	120	47	62	9	98
3	21/F	Sports	-	2B2	140	32	65	16	100
4	48/M	TA	-	2B1 (wedge)	140	43	55	9	99
5	69/F	SD	-	2B2	120	31	70	12	100
6	25/F	TA	-	2B2	145	30	65	8	100
7	43/M	TA	-	2B2	175	28	60	10	100
8	51/M	TA	+	2B2	180	54	67	10	98

Forward flexion range of motion of the shoulder: > 161°.
ASES: American Shoulder and Elbow Society, TA: traffic accident, SD: slip down, Sports: sport-related injury.
*Complication: decreased internal rotation.

fier radiation time for a patient was 44 seconds (range, 28 to 90 seconds). The mean image intensifier radiation dose for a patient was 64.9 kV (range, 60 to 75 kV). Bone union could be achieved without further procedure in all patients, and the average time to bone union was 10.6 weeks (range, 8 to 16 weeks). One patient whose fracture had postoperatively failed to make cortical contact finally achieved union at 16 weeks and was remodeled 9 months after surgery (Figs. 1–4). The time to bone union was not different as compared to fractures treated with open method. No operative complications such as implant failure, loss of reduction or infection were observed.

At the final interview, all patients were free of pain during rest and exercise and had returned to work with no changes in duties due to problems with the clavicle. De-

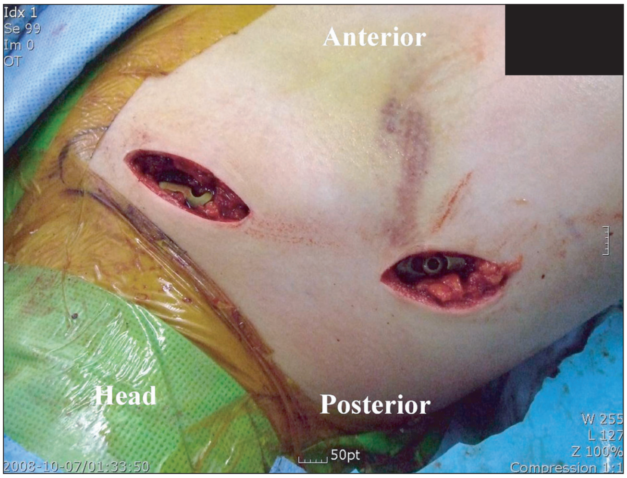

Fig. 2. The fracture was fixed by biologic fixation through bridge plating to preserve the soft tissue around the fracture site.

Fig. 4. The shoulder motion was fully recovered to the preinjury level.

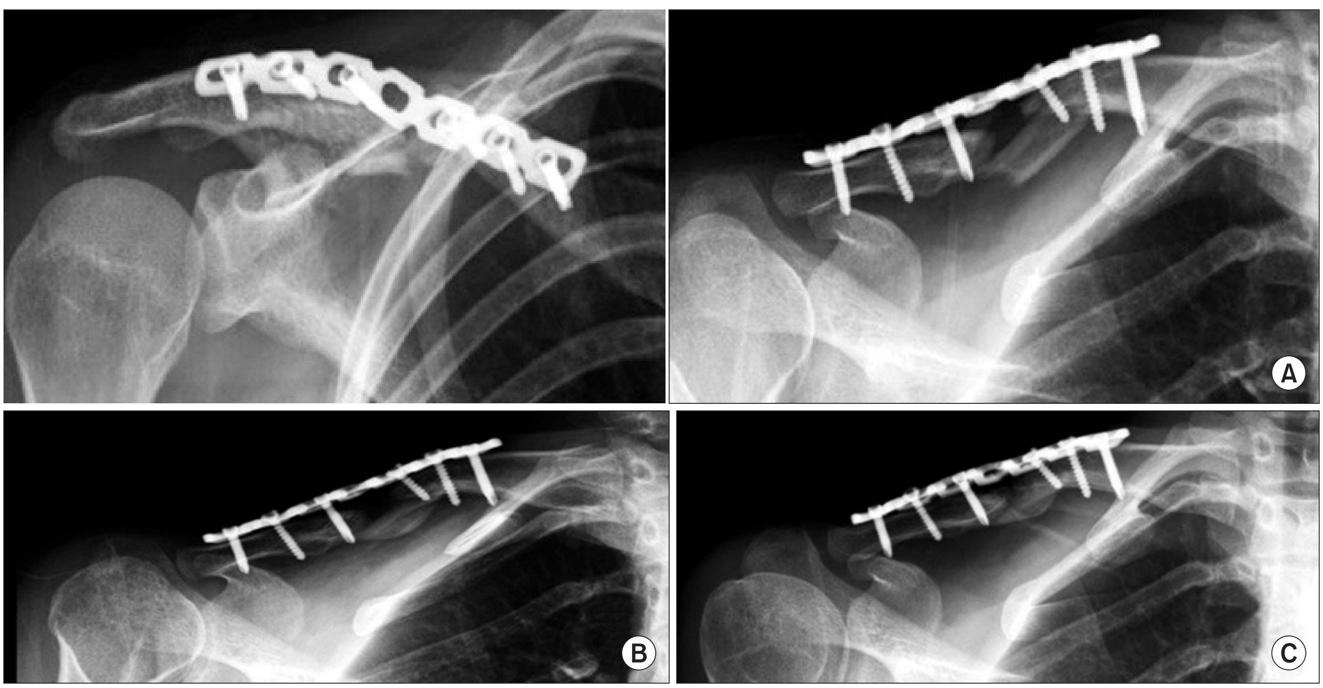

Fig. 3. (A) Postoperatively, the fractured clavicle failed to achieve cortical contact due to indirect reduction. (B) Callus bridging occurred 16 weeks after surgery. (C) The clavicle was remodeled at 9 months follow-up.

spite the lack of a subjective test of muscle strength, no patient experienced weakness of the involved shoulder joint. Shoulder motion was complete in all treated patients, except one patient who experienced mildly decreased internal rotation in one to two vertebral levels. The mean American Shoulder and Elbow Society (ASES) shoulder assessment score was 98.7 (range, 95 to 100). No patients underwent elective removal due to irritation after fracture healing, although one of eight patients (ten clavicles) showed even minimal tenderness or discomfort over the operative scar.

Surgical Technique

All procedures were performed under general anesthesia and with a prefabricated extremity drape, which included the whole limb and shoulder joint for manipulation. An illustration of the fractured clavicle was drawn on the

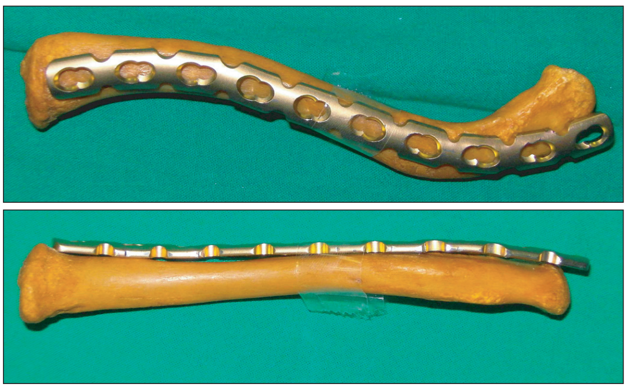

Fig. 5. A locking reconstruction plate (Synthes) was preoperatively bent to match the normal cadaveric clavicle.

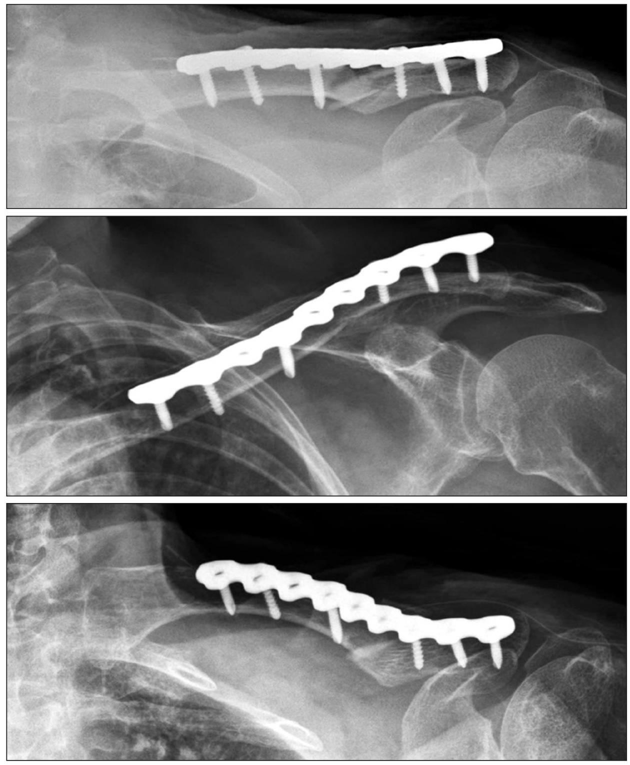

Fig. 7. Postoperative radiographs show the restoration of clavicular length and realignment of comminuted segments.

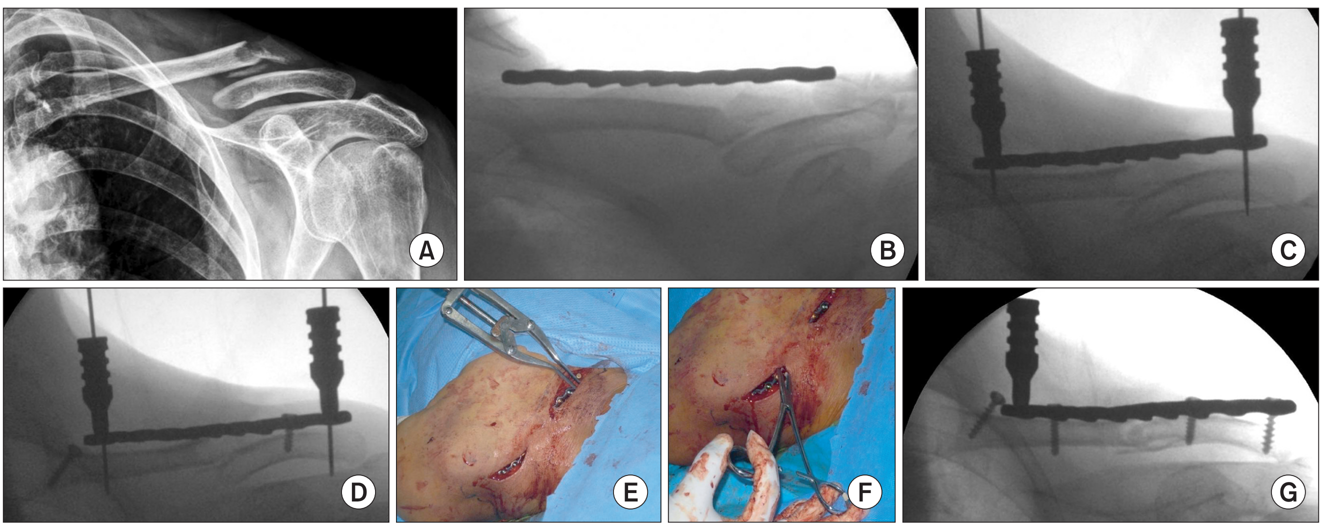

Fig. 6. Stepwise reduction and fixation. (A) Simple radiograph shows clavicular fracture with comminution and shortening, and the overlapping fragments. (B, C) The plate was passed through a submuscular tunnel and provisionally fixed with K-wires. (D) After fixation of the shorter fragment with a conventional screw, distractive force was applied through a lumbar spreader to achieve ligamentotaxis with the K-wire. (E and F) Simulated photos show how to use the lumbar spreader and Kelly clamp for indirect reduction. (G) The realignment of fracture sites was achieved by indirect reduction.

skin under an image intensifier (Varic, Siemens, Munich, Germany); and a locking reconstruction plate (Synthes, Oberdorf, Switzerland), which was preoperatively prebent to match a normal cadaveric clavicle, was placed along the drawing to determine the provisional position (Fig. 5). According to the provisional position of the clavicular plate, two separate 3 cm-sized incisions were performed along the anterior border of clavicular shaft.

The prebent plate was slid through a sub-muscular tunnel and temporarily fixed with K-wires through a locking hole; at least three screws were fixed at the center of shaft, and thus the positions were verified under an image intensifier using three views (anteroposterior [AP] view, cephalic tilt and caudal tilt view) (Fig. 6A–C). Of the fragments, the shorter was fixed in the optimal position using a conventional screw to reduce the gap between plate and clavicle, but was not completely tightened. After the fixation of one K-wire and one screw in the shorter fragment, the alignment condition of the comminuted fragment was verified using the image intensifier. For the re-alignment of fractures and restoration of clavicular length, a push-pull screw was placed at a distance of 1 cm from the end of plate on the longer fragment, and a distractive force for which the lumbar spreader was used was applied. After the restoration of clavicular length and realignment of the comminuted fragment, a K-wire through the locking sleeve was put to maintain the realignment (Fig. 6D and E). Then, a conventional screw passed through the plate-hole was fixed for reduction of the gap between the plate and clavicle. Afterward, the Kelly clamp was applied to optimize the plate axially on the clavicle (Fig. 6F). With the small-sized bone and relatively non-tightened screw, the axial alignment was achieved using this method (Fig. 6G). Once an acceptable realignment of the fracture was achieved, at least three screws were fixed on each side (Fig. 7). The two incisions were sutured in the standard fashion without a drain and were dressed. Postoperatively, the limb was maintained in an arm-sling for 4–6 weeks. Active movements of the shoulder joint were allowed, with the exception of overhead lifting and holding an object in hand during this period. In order to prevent the stiffness of shoulder joint, early passive motion exercise consisting of forward elevation and external rotation was conducted from one day after the operation during the sling-wearing period, in a supine position, three times a day.

DISCUSSION

Although surgery is recommended for middle-third fracture of the clavicle under certain circumstances, it has been recognized that surgical management is the most common cause of nonunion due to soft tissue stripping.[1,2] Some authors have suggested that the previously high rates of nonunion in surgically-treated clavicle fractures were due, at least in part, to inadequate internal fixation. Thus, new types of plates such as locking plate and precontoured plate have been developed to improve fixation stability. Anteroinferior placement of the plate was recently introduced in an effort to decrease implant irritation, reduce the need for plate removal and improve mechanical stability.[8] In a biomechanical study, Robertson et al.[8] noted that cantilever bending failure load was found to be significantly greater for superior plates compared to anterior-inferior plates, while anteroinferior plates were significantly stiffer than superior plates and locked plates significantly stiffer than non-locked plates in axial compression and axial torsion. For these reasons, the implant choice for optimal fixation and a meticulous technique should be regarded a sensitive issue. However, most surgeons still regard these types of fractures as simple due to easy accessibility and manipulation of a small-size bone, although problems with conventional fracture management are not uncommon in practice. Therefore, to prevent insufficient fixation and complications of direct reduction in displaced clavicle fractures, especially comminuted fracture, we present our novel technique which includes biologic fixation using the bridge plating technique with its associated experiences.

After achieving a refined understanding of the role of soft tissue vascularity around a fracture site and the development of locking plate technology, to reduce the problems with direct reduction including infection and nonunion, the concept of bridge plating, the so-called MIPO was developed and widely used to treat complex fractures of the lower limbs, especially comminuted fracture. In this, the amount of soft tissue dissection at the fracture site could be reduced by indirect reduction despite technical difficulties. However, for clavicular fractures, the bridge plating technique is not yet reported in the English literature to our knowledge. Why this concept has developed more slowly for the clavicular shaft is unclear. It is perhaps the easy accessibility and manipulation that have dissuaded surgeons from indirect reduction. A previous report noted that it is difficult to perform plate fixation in middle-third clavicular fractures with minimally invasive plating, because the anatomic features need to be tightly contoured to fit the complex morphology. This tight contouring inevitably results in a larger skin incision and extensive soft tissue stripping, both of which lead to potential complications.[9] The results of our technique in this study show the possibility of biologic fixation through bridge plating for middle-third clavicular fractures, as in lower limb fractures. In addition, this technique has advantages in that it does not require a special instrument and ease of performance. It has some limitations in the increased amount of radiation exposure and the expected level of experience for MIPO, as fundamentally included. However, because we could not demonstrate the superiority of biologic fixation for clavicular shaft compared with conventional fracture management, the following two questions are raised. First, is biologic fixation really needed for clavicular fractures? Second, if so, when is it beneficial?

In radiologic assessment of a clavicular fracture, most surgeons generally perform conventional radiographs on the basis of a single AP view or a cephalic and caudal tilt posteroanterior radiograph to assess the degrees of shortening and comminution. Although spiral computed tomography with three-dimensional reformatted views allow the best assessment of displacement, it is controversial, especially in fractures involving the midshaft of clavicle. Therefore, most surgeons encounter unexpected comminuted fragments when using the open method, requiring the use of wiring and lag screws with increased dissection and insufficient plate length due to the size of the incision. In our bridge plating technique using separate incisions, the plate length was not limited, leading to longer plates than are used in conventional management. From this, we were able to prevent insufficient fixation and used the comminuted fragments as a autogenous bone graft, rendering secondary bone grafting unnecessary.[6] Indeed, we did not perform bone grafting, wiring or lag screw fixation in all cases. Therefore, we would expect that biologic fixation is useful in fractures with comminution.

Regarding the concerns for minimally invasive fixation in clavicular shaft fractures, intramedullary fixation has been frequently used for the preservation of the soft tissue envelope around a fracture site, although there is a serious risk of pin migration and weak fixation strength to resist fracture site motion and length of the comminuted fracture during healing.[7]

However, intramedullary stabilization is in practice difficult by closed method for two reasons. First, the clavicle morphology shows not only anatomic variations, but is also characterized by complex anatomy with S-shaped curvature and a cephalad-to-caudad bow.[10,11] Second, in fractures, the prominence of displaced fragments is not uncommon, especially in severely angulated or comminuted fractures.[5] Therefore, when inserting an intramedullary implant, surgeons inevitably encounter difficulties unlike plate fixation due to the anatomy of the fractured clavicle.

Other anatomic features of the clavicle, such as easy accessibility and a small-sized bone, are advantages of our technique. These features enabled us to easily apply the distraction using the lumbar spreader and optimization of plate position on the clavicle using a Kelly clamp. To overcome the complexity of the clavicular anatomy, the 3.5-mm locking reconstruction plate was preoperatively bent along the cadaveric clavicle, with the caution taken against stripping the lock-hole. For definite gender- and individual-related anatomical variations, additional intraoperative fitting should be performed through compression, using a conventional compression screw. As mentioned above, our technique was easily executed without special instrumentation, and no conversion to the open method was required. Despite these advantages, our technique has some disadvantages. First, radiation exposure will be inevitably increased for the surgeon and operating room personnel compared to that of the conventional method. Second, this technique could be regarded as more harmful than conventional methods, as the size of the two incisions may be larger than those in the conventional technique. Third, we could not check the rotational alignment due to indirect reduction.

In conclusion, although the number of cases is small and the superiority of biologic fixation over conventional fracture management could not be demonstrated, biologic fixation through bridge plating of a clavicular shaft fracture is an effective technique for fractures which require preservation of the soft tissue around the fracture site, such as lower limb fractures. Its anatomic features also enable us to easily apply indirect reduction without special instruments. In the future, we expect that further studies will be conducted to compare the outcomes of conventional management in comminuted fractures of the clavicular shaft.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

REFERENCES

1. Canale ST, Beaty JH. Campbell's operative orthopaedics. 11th ed. Philadelphia: Mosby; 2007. 3371-6.
2. Wijdicks FJ, Van der Meijden OA, Millett PJ, Verleisdonk EJ, Houwert RM. Systematic review of the complications

of plate fixation of clavicle fractures. Arch Orthop Trauma Surg. 2012;132(5):617-25.

3. Martinez AA, Cuenca J, Herrera A. Philos plate fixation for proximal humeral fractures. J Orthop Surg (Hong Kong). 2009;17(1):10-4.

4. Nowak J, Holgersson M, Larsson S. Can we predict long-term sequelae after fractures of the clavicle based on initial findings? A prospective study with nine to ten years of follow-up. J Shoulder Elbow Surg. 2004;13(5):479-86.

5. Khan LA, Bradnock TJ, Scott C, Robinson CM. Fractures of the clavicle. J Bone Joint Surg Am. 2009;91(2):447-60.

6. Krettek C, Muller M, Miclau T. Evolution of minimally invasive plate osteosynthesis (MIPO) in the femur. Injury. 2001;32 Suppl 3:SC14-23.

7. Smekal V, Oberladstaetter J, Struve P, Krappinger D. Shaft fractures of the clavicle: current concepts. Arch Orthop Trauma Surg. 2009;129(6):807-15.

8. Robertson C, Celestre P, Mahar A, Schwartz A. Reconstruction plates for stabilization of mid-shaft clavicle fractures: differences between nonlocked and locked plates in two different positions. J Shoulder Elbow Surg. 2009;18(2):204-9.

9. Liu PC, Chien SH, Chen JC, Hsieh CH, Chou PH, Lu CC. Minimally invasive fixation of displaced midclavicular fractures with titanium elastic nails. J Orthop Trauma. 2010;24(4):217-23.

10. Huang JI, Toogood P, Chen MR, Wilber JH, Cooperman DR. Clavicular anatomy and the applicability of precontoured plates. J Bone Joint Surg Am. 2007;89(10):2260-5.

11. Andermahr J, Jubel A, Elsner A, et al. Anatomy of the clavicle and the intramedullary nailing of midclavicular fractures. Clin Anat. 2007;20(1):48-56.