CLINICAL ARTICLE

Minimally Invasive Treatment of Clavicular Fractures with Cannulated Screw

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Objective: To evaluate minimally invasive treatment of clavicular fractures with cannulated screw.

Methods: Data of 65 patients who had undergone minimally invasive treatment with cannulated screws for clavicular fractures from April 2009 to October 2010 were retrospectively analyzed and compared with those of 65 patients with clavicular fractures who had been treated by the same surgeons with plates. In the study group, there were 41 males and 24 females, aged from 19–67 years (mean, 35.8 years). According to Craig's classification, there were 29 group 1 and 36 of group 2-II. Neer scores were used to evaluate shoulder function and radiographs to assess fracture union.

Results: The incision length was 4–5 cm in the cannulated screw group (CSG) and 10–11 cm in the reconstructive plate group (RPG). Radiographs showed bone union was achieved in both groups, the bone healing time being 13.2 ± 6.9 weeks in the CSG and 16.3 ± 8.7 weeks in the RPG. All patients were followed up for 6 to 20 months (average, 10.6 months). The average Neer score was 96.6 ± 3.4 in the CSG and 94.2 ± 5.8 in the RPG. In the CSG, screw loosening occurred in five, and fracture displacement in three. There was a significant difference in fracture healing time between two groups but not in Neer score.

Conclusion: Minimally invasive treatment of clavicular fractures with cannulated screws has the advantages of minimal invasion, short bone healing time, good clinical outcomes, and being relatively inexpensive.

Key words: Bone; Bone screws; Clavicle; Fractures; Intramedullary

Introduction

Currently, the two main procedures for surgical treatment of clavicular fractures are internal fixation with a plate or with Kirschner wire. Plates provide reliable and secure fixation, but require a long incision and have to be removed in a second operation; possible complications include implant failure and clavicular re-fracture after removal of the plate. Kirschner wires were once widely applied because of the procedure is simple and costs little. However, because it provides poor stability and has multiple complications, Kirschner wires are gradually being abandoned¹. Wang *et al.* used closed reduction with elastic threaded screws to treat clavicular fractures and achieved good results². However, this procedure requires X-ray imaging guidance and has the risks of puncturing the apex of the lung, vessels and nerves. Meanwhile, threaded screws are

too thin (1.5–2.5 mm in diameter) to achieve firm fixation and have the complications of screw failure (1/56), subcutaneous bursitis (24/56), and pressure ulcers (19/56)².

In light of the above considerations, we assessed minimally invasive intramedullary fixation with cannulated screws to treat clavicular fractures. This study retrospectively analyzed data of patients with clavicular fractures treated by minimally invasive intramedullary fixation with cannulated screws and compared them with patients who had undergone internal fixation with reconstructive plates. Its objective were: (i) to evaluate the effectiveness of minimally invasive intramedullary fixation with a cannulated screw, which is an easy, inexpensive, and reliable technique for achieving intramedullary fixation of clavicular fractures; and (ii) to compare its effectiveness with that of reconstructive plate fixation.

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Materials and Methods

Patient Characteristics and Fracture Assessment Procedures

Sixty-five patients with clavicular fractures treated by retrograde transfixation with 6.5 mm-diameter cannulated screws from April 2009 to October 2010 were studied. They comprised 41 males and 24 females aged 19–67 years, with a mean of 35.8 years. The cause of fracture was traffic accidents in 45 cases, sports trauma in 11, falling from heights in 6, and heavy object injury in 3. According to Craig typing³, 29 cases (44.6%) were type 1 and 36 cases (55.4%) type 2-II. Eleven were simple fractures, 31 with one butterfly bone slice and 23 splintered fractures.

Because of the “S” shape of the clavicle and the fact that it is not parallel with the coronal section, measuring the inner and outer diameter of the medullary cavity only on orthophoric X-ray films can be extremely inaccurate. Thus, in this study CT multiplanar reformation was used to rebuild the shape of the clavicle, after which one CT image showing the narrowest medullary cavity section on PACS platform was chosen and its inner and outer diameters measured (Figs 1,2). On average, cannulated screws can be used when the outer diameter is >8.5 mm.

Another 65 cases of clavicular fracture treated by reconstructive plates by the same doctors from February 2008 to March 2009 were used as a control group. This group comprised 44 males and 21 females aged 18–57 years, with a mean of 32.6 years. Thirty-nine cases of these fractures were caused by traffic accidents, 15 sport trauma, 9 falling from heights and 2 by heavy objects. According to Craig typing, 25 cases (38.5%) were type 1, 32 cases (49.2%) type 2-II and 8 cases (12.3%) type 2-V.

This study had approved by the Ethics Committee of the 105th Hospital of the People's Liberation Army.

Surgical Procedures

Minimally Invasive Intramedullary Fixation with Cannulated Screw

After brachial plexus anesthesia, the patient was placed in a supine position and the shoulder blade on the affected side elevated by placing a pad beneath it to form a 30° angle with the bed. The shoulder on the affected side was stretched into the abducent position to rectify the shortened clavicle. The upper limb of the affected side was secured beside the trunk with the shoulder of the affected side protruding slightly beyond the side of the operating table to allow the guide pin to be pushed out posterior to the acromion. Standard disinfection was performed, sterile towels draped and the operative area covered with iodine operation film.

Taking a point 1 cm from the fracture end towards the lateral side as the center, a transverse incision 4–5 cm long was made along the anterior edge of the clavicle. The proportion of exposure of distal and proximal fracture ends was 2:3. The fracture ends were exposed and blood clot removed to make

Fig. 1 Craig 1 type fracture, the inner and outer diameters of the medullary cavity of the clavicle were measured with CT in a horizontal position; because the diameter of the proximal end was smaller, it was chosen to be the reference standard. Len, length.

(a) Measurement of the inner and outer diameters of the medullary cavity of the proximal end of the fracture. Len, length.

(b) Measurement of the inner and outer diameters of the medullary cavity of the distal end of the fracture. Len, length.

the fracture surface clearly visible without over-stripping the surrounding soft tissue or disassociating the bone fragments.

The distal end of the fracture was lifted with globular-shaped bone-holding forceps and the small protective sleeve of the guide pin inserted as far as possible (0.5–1 cm) into the medullary cavity of the distal fractured end, adjusting the angle to ensure it was located in the center line of the medullary cavity and in alignment with the axle wire of the acromial protuberance posteriorly, the objective being to keep the greatest length of the guide pin possible in the medullary cavity of

Fig. 2 Craig 2-II type fracture, the inner and outer diameters of the medullary cavity of the clavicle were measured with CT in a horizontal position; because the diameter of the proximal end was smaller, it was chosen to be the reference standard. Len, length.

(a) Measurement of the inner and outer diameters of the medullary cavity of the proximal end of the fracture. Len, length.

(b) Measurement of the inner and outer diameters of the medullary cavity of the distal end of the fracture. Len, length.

the distal fractured end and to ensure it emerged at the central point of the acromion. With the aid of this sleeve positioning, a 2.3 mm-diameter threaded guide pin was inserted along the center line of the clavicular cavity from the distal end of the fracture towards the lateral side and through the clavicular cortex to the subcutaneous tissue adjacent to the S-shaped protuberance posterior to the acromion at the distal end of the clavicle. A 1 cm-long skin incision was made to allow the guide pin to protrude (Fig. 3a). Using a 5 mm-diameter cannulated drill, the medullary cavity was enlarged from the acromion outlet by drilling retrogradely and a 6.5 mm-diameter cannulated screw tapped in along the guide pin. The proximal end of the fracture was prepared in the same way, ensuring that the

Fig. 3 Schematic diagram of intramedullary fixation of a clavicular fracture with a cannulated screw.

(a) The guiding device has been pushed into the medullary cavity of the distal fractured end, then the guide pin inserted and pushed out posterior to the acromion.

(b) The fractured bone has been set, then the guide pin pushed back into medullary cavity of the proximal fractured end and the cannulated screw screwed in along the guide pin after tapping.

(c) The clavicular fracture is fixed.

guide pin did not go through the anterior cortex of the clavicle at its proximal end. Drilling with the cannulated drill was stopped when resistance was felt from the bone cortex.

Reduction forceps were used to clamp and reset both fractured ends in an orthophoric position, the guide pin brought back through the fractured ends and its length measured. Next, a 85–100 mm long, 6.5 mm-diameter cannulated screw was screwed in along the guide pin through the posterior skin incision (Fig. 3b). In most cases, a 100 mm-long cannulated screw fit. Care was taken to ensure the cannulated screw did not go through the inner bone cortex of the proximal fractured end, thus preventing its tip from protruding under the skin and causing skin ulceration. The main aim was to keep the whole length of the thread on the tip of the cannulated screw in the inner cortex of the cavity of the proximal fractured end. When the cannulated screw had been screwed in, both ends of the fracture were secured in a satisfactory position with reduction forceps and rotation resisted. The cannulated screw was placed under pressure after getting it through the fractured ends in an orthophoric position. Meanwhile, the bone fragments were aligned, keeping pressure on them to secure them (Fig. 3c). With splintered fractures and poor stability, absorbable surgical sutures were used to attach the bone fragments to the soft tissue.

No drainage tube was inserted after fracture reduction. Absorbable surgical sutures were used to perform intradermic suturing of the skin incision. The head of the cannulated screw was inset into the bone cortex of the acromion as far as possible to reduce the subcutaneous space occupied and enhance stability. The affected-side forearm was supported with a sling postoperatively (Video S1).

Clavicle Reconstructive by Plate Fixation

The standard procedure of clavicle reconstructive plate fixation was performed and the affected-side forearm supported with a sling postoperatively.

Postoperative Management

Both groups of patients received standard antibiotics for 3–5 days. Graduated exercises for the shoulder joint with pendular movements in a range of 15°–20° with the protection of a forearm sling were commenced from the postoperative second day. The sling was removed when X-ray films showed growth of callus or an indistinct fracture line.

Follow-up and Observation Index

The patients were followed up in the outpatient department in the first, third, sixth and twelfth postoperative weeks, after which regular examination were performed at 4–6 week intervals according to the degree of healing of the fracture. Orthophoric X-ray films of the clavicle were taken to assess fracture union. The criteria for fracture union were standard: (i) no local tenderness; (ii) no abnormal activity; and (iii) clavicle orthophoric X-ray films showing continuity across the bone cortex. Shoulder function was assessed according to Neer criteria⁵ after fracture union had been achieved.

Observation indexes included operation duration, blood loss during surgery, time to fracture union, Neer shoulder function score and complications (including infection, non-union, delayed union, cannulated screw rupture or displacement and plate loosening or rupture).

Evaluation of Effectiveness

The Neer shoulder function score was used to evaluate the effect of treatment; this includes pain, function, motion range and anatomical restoration, 100 points being a perfect score⁴.

Statistical Analysis

Statistical analysis was carried out with the SPSS 13.0 package. The duration of surgery, blood loss during surgery, time to fracture union and Neer shoulder function scores were compared between the cannulated screw group (CSG) and clavicle reconstructive plate group (RPG) with Student's two independent sample *t*-test. The α value for significance was set at 0.05 in the two-sided tests.

Results

Patient Characteristics

There were no significant differences in age ($t = 1.71$, $P = 0.19$), sex ($\chi^2 = 4.26$, $P = 0.74$) and Craig typing ($\chi^2 = 24.87$, $P = 0.82$) between the two groups.

Operative Variables

All 65 cannulated screw fixation procedures ran smoothly with no clavicle cleavage and an operation duration ranging from 20 to 45 min, with a mean of 32.0 min. Intraoperative blood loss ranged from 5 to 40 mL, with a mean of 22.0 mL. The length of the incision ranged from 4 to 5 cm. All 65 clavicular reconstruction and plate fixation procedures also all ran smoothly with an operation duration ranging from 35 to 70 min, with a mean of 52.0 min. Intraoperative blood loss ranged from 20 to 70 mL, with an average of 46.0 mL. The length of the incision ranged from 10 to 11 cm. There were statistically significant differences between the two groups in operation duration and blood loss ($P < 0.05$, Table 1).

Clinical Assessment

All patients in both groups were followed up for from 6 to 20 months, with a mean of 10.6 months.

Bony union was achieved in all cases. Time to fracture union in the CSG ranged from 7 to 20 weeks, with a mean of 13.2 ± 6.9 weeks (Fig. 4), whereas in the RPG it ranged from 7 to 25 weeks, with a mean of 16.3 ± 8.7 weeks; this difference was statistically significant ($P = 0.018$, Table 1). After fracture union had occurred, the cannulated screws were removed under local anesthesia in the outpatient department, whereas the reconstructive plates were removed under brachial plexus anesthesia after admission of the patients to hospital.

During the most recent follow-up, shoulder activity was assessed according to Neer's system. The CSG gained from 87 to 100 points, the mean being 96.6 ± 3.4 points, whereas the

RPG gained from 83 to 100 points, the mean being 94.2 ± 5.8 points; this difference is not statistically significant ($P = 0.062$, Table 1).

Complications

No postoperative infection, local skin necrosis, or non-union occurred in the CSG. Within 3 weeks of surgery, five patients had slight screw withdrawal towards the distal end, the screw having rotated and cocked a little against the skin: none of these patients required further treatment. Three of the patients with splintered fractures were noted to have slight rotating changes in the fracture area during examination in the third to sixth postoperative weeks. These were caused by over-activity of the affected-side limb and the fractures healed uneventfully with 3–4 weeks' clavicle strap protection and reduced activity.

Four patients in the RPG had poor skin healing; however, their incisions healed with regular removal of stitches and dressing changes.

Discussion

The Feasibility of Minimally Invasive Treatment with Cannulated Screw for Clavicular Fractures

Because the entire clavicle is about 15 cm long and its central straight section is about 12 cm long⁵, it is long enough for intramedullary fixation. In addition, the average vertical height of the clavicle is 1.1 cm in men and 0.9 cm in women and its average anteroposterior diameter is 1.2 cm in men and 1.1 cm in women. The thickness of the acromion, from which the screw protrudes and is later removed, is about 0.9–1 cm, whereas the diameter at the hilt of a 6.5 mm diameter cannulated screw is 4.5 mm, these dimensions provide the anatomical basis for choosing a 6.5 mm-diameter, 85–100 mm-long cannulated screw³. In addition, the threads of screws with larger diameters cut into the clavicular cortex more firmly and their anti-rotation and anti-withdrawal forces are greater than those of securing pins. These screws' blunt tails do not irritate the skin under the thick muscular tissue of the shoulder and back. Removal of these implants can be carried out in clinics under local anesthesia and there is no need for admission to hospital. Also, cannulated screws cost only 1/4–1/3 of the cost of reconstructive plates from the same company, therefore the cost of the former treatment is significantly less. Finally, removal of screws does not injure the clavicle, therefore there is

no stress concentration point after they have been removed; thus, the risk of re-fracture is basically eliminated.

Plates used to secure clavicular fracture may rupture because of metal fatigue⁶, and drilling during the procedure has an associated risk of injuring nerves, vessels, and the apex of the lung beneath the clavicle; the complication rate is reportedly 20.2%⁷. Osteoporosis or short plate ending at the point between the distal and middle 1/3 where the mechanical structure of the clavicle is weakest may cause screw loosening and stress fractures in the junctional zone⁸. Although there is virtually no medullary cavity in the distal and middle sections of the clavicle, it is still a type of tubular bone and the advantages of intramedullary fixation in tubular bone fractures is universally accepted⁹. Experiments have shown that securing the clavicle with 3.5–4.5 mm-diameter cannulated screws achieves three-point bending strength and bending rigidity similar to that of a normal clavicle¹⁰. Increasing the diameter of the intramedullary screw by more than 2 mm remarkably increases the structural stability and rigidity¹¹. Using 6.5 mm-diameter cannulated screws avoids the risk of screw bending or breaking and confers strong anti-angle forming, anti-rupture qualities. In addition, insertion of screws avoids the risk to surrounding vessels, nerves, and lung injury associated with plate drilling. Because cannulated screws are placed inside the medullary cavity, they occupy no extra space; thus, blood supply to the incision margin is secure. In five of the patients in the study group, the screw bulged under the skin at the back of shoulder after fracture union, however, the skin was not punctured and the patients experienced no discomfort. Compared with closed reduction transfixation, there is less radiation exposure, and the risk of injury of vessels, nerves and the apex of lung is negligible.

Comparison between Cannulated Screw and Conventional Plate Fixation

The cannulated screw procedure took a much shorter time and caused much less blood loss than the reconstructive plate procedure, the time saving being nearly 50%. There was no subsequent significant difference between the two groups in Neer shoulder activity scores. We did not compare the lengths of the incisions in these two operations; however, the average length in the CSG was 4–5 cm, just covering the length of the fracture surface is enough. In comparison, in the RPG the incision needed to be 3 cm longer towards both the distal and proximal

TABLE 1 Comparison between the cannulated screw group and the reconstructive plate group in operation duration, blood loss in operation, fracture union duration, Neer shoulder function assessment (mean $\pm$ s.d.)

Group	Cases	Operation duration (min)	Blood loss (mL)	Time to fracture union (weeks)	Neer score
Cannulated screw group	65	32.0 $\pm$ 12.5	22.0 $\pm$ 17.5	13.2 $\pm$ 6.9	96.6 $\pm$ 3.4
Plate group	65	52.0 $\pm$ 17.5	46.0 $\pm$ 21.6	16.3 $\pm$ 8.7	94.2 $\pm$ 5.8
t value	—	2.347	2.804	2.476	1.890
P value	—	0.021	0.006	0.018	0.062

ends to ensure that 2–3 screws could be fixed at each end (the pitch of holes in a reconstructive plate is about 1 cm). Therefore, we contend that, for the same outcome, the surgical injury in the CSG is less than that in the RPG.

The time to fracture union in the CSG was 13.2 ± 6.9 weeks and in the RPG 16.3 ± 8.7 weeks. Although this difference is statistically significant, we question whether it is clinically significant. First, the patients were not randomly allocated to the groups; rather, the procedure they underwent was determined by time, reconstructive plates being used from February

2008 to March 2009 and cannulated screws from April 2009 to October 2010. The basic operative steps remained the same; thus, doctors performing the cannulated screw procedure became increasingly more skillful, with improved ability to protect the surrounding soft tissues. Theoretically, this may have affected the time to fracture union. The second factor is the accuracy with which we identified Craig 2-II fractures. Craig 2-II fractures are on the medial side of the coracoclavicular ligament, with conoid ligament laceration and uninjured trapezoid ligaments. When the trapezoid ligament is also

Fig. 4 Man, 25 years old, left-side clavicle Craig 2-II fracture.

(a) Preoperative orthophoric X-ray film showed splintered fracture medial to coracoclavicular ligament (Craig 2-II).

(b) The diameter of the medullary cavity of the proximal fractured end was measured preoperatively with CT in horizontal section. Len, length.

(c) Postoperatively, an X-ray film shows good alignment of the clavicle after reduction.

(d) Postoperatively, CT in horizontal section showed satisfactory reduction and good position of the screw in the medullary cavity.

torn, along with horizontal avulsion of the coracoclavicular ligament, the fracture is classified as Craig 2-V. Because the surgical incision in the CSG was as short as 4–5 cm and the surrounding soft tissue was stripped as little as possible, there may have been a blind area in regard to assessing injury of the coracoclavicular ligament. This would have resulted in inaccurate fracture typing, which would certainly affect the time to fracture union. Thirdly, there is the factor of timing of follow-up. Follow-up occurred in the first, third, sixth and twelfth weeks, after which it occurred at 4–6 week intervals. Thus, apparent time to union was determined by time of follow-up. Because of its position in the body, standard orthophoric X-ray films show only the upper and lower layers of the clavicle's cortex; in the RPG, only the lower layer of cortex can be observed because of shading by the plate. In addition, the accuracy of time to union time can be influenced by those who interpret the X-ray films. In addition to the statistical findings, we have also observed clinically that patients treated with cannulated screws recover faster.

Surgical Tips

Particular attention should be paid to the following matters when treating clavicular fracture by intramedullary fixation with cannulated screws:

1. Try to use long screws; a 100 mm long screw is suitable on average. The correct specific length can be ascertained by measuring the guide pin during the procedure.
2. Because a 6.5 mm-diameter cannulated screw is rather thick, the screw threaded path has to be made in advance to avoid causing a vertical crack, which would affect the firmness of fixation.

3. When screwing in the cannulated screw, clamp the clavicle to neutralize the torsion released by the process of screwing, thus preventing linkage rotation of clavicle, which could injure the acromioclavicular (or sternoclavicular) ligament and articular capsule, and maintaining the position of the fracture ends.
4. After the screw has been inserted through the fracture ends, check the fracture gap. When the effects of the resultant pressure begin to appear, bone fragments can be reduced and clamped to secure them. Trapping of the bone fragments between the two fracture ends under pressure after they have been reduced preserves the normal length of clavicle. If the fracture ends cannot be secured by steady squeezing (as in long oblique fractures), fix the bone with an absorbable surgical suture by running it close to the bone and sewing and securing the soft tissues to the bone.
5. Plate fixation equipment should be prepared before the procedure in case the fracture is severely splintered over a large area.
6. It is important to note that the clavicles of women with slight figures may be too thin to use 6.5 mm-diameter cannulated screws; in such cases, 6.00 mm-diameter or even thinner ones can be tried.
7. Patients with severely splintered fractures should engage in limited shoulder activity with the protection of a clavicle belt for 3–4 weeks.
8. If less than 1 cm of the medullary cavity can be fully fixed at the proximal end of the clavicle, which means the thread on the tip of the cannulated screw cannot be included, intramedullary cannulated screw fixation should be abandoned.

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