Original Article
Minimally invasive surgery for complex scapular fractures through small incisions combined with titanium miniplate fixation

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Abstract: This study aimed to investigate the efficacy of surgery through small incisions combined with titanium miniplate fixation for complex fractures of the scapula. Fifty-two cases of scapular fractures treated with different surgical methods at our hospital between October 2008 and October 2013 were included in the study. Of these, 27 patients were randomly selected to undergo traditional surgical treatments (control group), and 25 patients were selected to undergo surgery through small incisions combined with titanium miniplate fixation (experimental group). The Hardegger evaluation method was used for rating the functional outcomes. Statistical analysis was performed with SPSS 17.0 software. The differences in the wound infection rates and favorable Hardegger functional assessment scores between the two groups were compared by using $\chi^2$ tests. Comparisons of the operative time, blood loss, hospital stay, and fracture healing time were performed by using t tests. $P < 0.05$ was considered statistically significant. Significantly different treatment results were observed for wound infection, Hardegger function score ($\chi^2 = 4.086, P = 0.043$), and bleeding amount ($t = 5.454, P < 0.001$). Conversely, the differences in operative time ($t = 0.128, P = 0.9$), fracture healing time ($t = 1.732, P = 0.096$), and length of hospital stay ($t = 0.339, P = 0.737$) were not statistically significant. Surgery through small incisions combined with titanium miniplate fixation was significantly superior to the traditional surgical methods for complex fractures of the scapula in terms of wound infection, Hardegger function score, and bleeding amount.

Keywords: Scapula, minimally invasive, titanium mini-plate, combined with small incision

Introduction

According to a previous report, scapular fractures account for 3-5% of all shoulder girdle injuries and 0.4-1% of all bone fractures [1]. High-energy direct traumas on the side and top of the scapula are the most common mechanisms of injury, and these injuries most frequently occur in middle-aged men. Approximately 90% of patients reportedly also have injuries in other parts of the body, which are commonly severe and may be life threatening. In the immediate management, the diagnosis and treatment of scapular fractures are often overlooked because medical professionals only aimed to rescue patients, resulting in a high rate of initially missed diagnosis [2-5]. Most scapular fractures do not require surgery; moreover, nonunion rarely occurs. However, shoulder joint dysfunction, back pain, and other symptoms often occur simultaneously. Fractures with a significant shift, those involving articular fractures, and those causing shoulder instability require surgery [6, 7], commonly by using the anterior, posterior, outer edge, before-and-after combined, or improved posterior approach [8-10]. The traditional surgical approaches fully reveal the surgical field through a large incision, consequently resulting in a high risk of soft-tissue injury. Early surgery may aggravate soft-tissue injuries or damage the blood supply around the fracture, resulting in skin flap necrosis, delayed healing, or nonunion. Thereby, adverse soft-tissue conditions commonly lead to delayed surgical intervention, owing to the time required for soft-tissue recovery. Furthermore, the optimal timing of surgery is therefore often missed. At our hospital, the use of small incisions combined with titanium miniplate fixation in the minimally invasive sur-
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The surgical treatment of complex fractures of the scapula has shown good healing outcomes. Between October 2008 and October 2013, 52 patients with scapular fractures underwent different surgical treatments by random assignment, and the effects of these treatments on the postoperative recovery were analyzed.

Materials and methods

Surgical groups and internal fixation

Fifty-two patients with scapular fractures admitted to the orthopedic department of People’s Hospital of Dongying between October 2008 and October 2013 were included in the present study. The inclusion criteria were age of 18-60 years and presence of complex scapular fractures (more than two fractures). The experimental surgery involved the use of mini-incisions and placement of a microtitanium internal fixation plate. According to the Hardegger classification, 26, 15, 5, 10, 16, 3, and 2 patients had fractures in the scapular caudomedial part, circumferential cartilage, glenoid fossa, surgical neck, mesoscapula, acromion, and coracoid, respectively. The patients were randomly divided into the control and experimental groups. All cases were from one institution, and all the surgeries were completed by the same surgeon. This study was conducted in accordance with the declaration of Helsinki. This study was conducted with approval from the Ethics Committee of People’s Hospital of Dongying and the ethics approval No. was 201501. Written informed consent was obtained from all participants.

Surgical approaches

Management of life-threatening injuries, braking and debridement (open fractures), and other treatments were provided on admission. For the experimental group, surgery through combined small incisions was performed (Figure 1), and a miniature titanium plate and screws were used for fixation. For the control group, a range of traditional surgical approaches were used, including the deltopectoral-gap, Judet, outer edge, before-and-after combined, and improved shoulder posterior approaches [8-10].

Internal fixation materials

The instruments used in this study included reconstruction locking plates (thickness, 2 ± 1 mm), screws (diameter, 2.0/2.5 mm and 3.5 mm), and miniature titanium plates (1.0 ± 0.5-1.2 ± 0.5 mm). All instruments were purchased from Aosi Mai Medical Devices Co., Ltd. (Changzhou, Jiangsu, China).

Postoperative treatment

Conventional drainage strips were placed after surgery and removed after 48-72 h; antibiotics
were administered for 24 h postsurgery to prevent infection. Isometric contraction exercises were performed on the limb muscles 3 days after surgery. Shoulder shrug, elbow bending, and shoulder movements within 90° could be carried out after postoperative days 4-7. The range of activities was gradually increased 1 week after surgery, and shoulder pendulum exercises could be carried out at this time. Movement activities, such as elbow rotation, neck holding, and finger climbing could be freely performed 3 weeks after surgery. Active functional exercise was the main exercise performed. Functional exercises involving holding of 1-kg weights could be performed 4 weeks after surgery.

### Statistical analysis

SPSS version 17.0 (SPSS Inc., Chicago, IL, USA) was used for all statistical analyses. The differences in the wound infection rates and favorable Hardegger functional scores between the two groups were compared by using the \( \chi^2 \) test. The differences in operative time, blood loss, length of hospital stay, and fracture healing times were analyzed by using the t test. \( P < 0.05 \) was considered statistically significant.

### Results

Twenty-seven patients undergoing traditional surgical treatments were classified as the control group, and 25 patients undergoing surgery through small incisions combined with titanium miniplate fixation were classified as the experimental group. The sex, age, and cause of injury of the patients before treatment did not differ significantly between the two groups (\( P > 0.05 \); Table 1).

In the experimental group, the wound infection rate was 0% and the rate of favorable Hardegger functional assessment scores was 94.7%. The mean operative time, bleeding amount, length of hospital stay, and fracture healing times were \( 96.4 \pm 24.8 \) min, \( 208 \pm 109.6 \) mL, \( 15.2 \pm 3.0 \) days, and \( 8.9 \pm 1.9 \) months, respectively. In the control group, the wound infection rate was 14.8% and the rate of favorable Hardegger functional assessment scores was 69.2%. The mean operative time, bleeding amount, length of hospital stay, and fracture healing times were \( 96.8 \pm 18.4 \) min, \( 273.2 \pm 78.7 \) mL, \( 15.4 \pm 3.4 \) days, and \( 11.6 \pm 1.7 \) months, respectively. Significant differences between the two groups were observed for wound infection, Hardegger function score (\( \chi^2 = 4.086, \ P = 0.043 \)), and bleeding amount (\( t = 5.454, \ P < 0.001 \)), whereas the differences in operative time (\( t = 0.128, \ P = 0.9 \)), fracture healing time (\( t = 1.732, \ P = 0.096 \)), and length of hospital stay (\( t = 0.339, \ P = 0.737 \)) were not statistically significant (Table 2; Figure 2).

### Discussion

The scapula plays a key role in upper-limb function and stability. It is an irregular, triangular, flat cancellous bone that connects to the trunk bones and upper limbs through the clavicle, acromioclavicular joint, sternoclavicular joint, and glenohumeral joint. It is affixed to the outside of the thorax and includes the scapular caudomedial part, acromion, coracoid, and glenoid, which play roles in protecting the chest and fixing the upper limb. The outer segment of the clavicle, acromioclavicular joint, acromioclavicular ligament, acromion, upper glenoid, coracoid process, and coracoclavicular ligament comprise the superior shoulder suspensory complex. The sources of blood supply of the scapula include the suprascapular artery, circumflex scapular artery, and dorsal scapular artery, which form a vascular network; hence, the healing ability of the scapula is generally strong. Therefore, as the scapular caudomedial part is covered by muscles with a rich blood supply, which protects the scapula and reduces the risk of fracture displacement, nonunion is rare. Most scapular fractures are treated with nonsurgical therapy; however, some conserva-

### Table 1. Fracture type and number of cases (case)

<table>
<thead>
<tr>
<th>Fracture Type</th>
<th>Caudomedial part</th>
<th>Circumferential cartilage</th>
<th>Glenoid fossa</th>
<th>Surgical neck</th>
<th>Mesoscapula</th>
<th>Acromion</th>
<th>Coracoid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental group</td>
<td>13</td>
<td>7</td>
<td>2</td>
<td>4</td>
<td>9</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Control group</td>
<td>13</td>
<td>8</td>
<td>3</td>
<td>6</td>
<td>7</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total case</td>
<td>26</td>
<td>15</td>
<td>5</td>
<td>10</td>
<td>16</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>
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Table 2. Hardegger function evaluation

<table>
<thead>
<tr>
<th>Grade</th>
<th>Hardegger function evaluation standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellence</td>
<td>Shoulder activities were not limited, no shoulder circumferential pain, abductor was grade 5.</td>
</tr>
<tr>
<td>Good</td>
<td>Slightly limited shoulder mobility, mild shoulder circumferential pain, abductor was grade 4.</td>
</tr>
<tr>
<td>Middle</td>
<td>Moderate limited shoulder mobility, moderate shoulder circumferential pain, abductor was grade 3.</td>
</tr>
<tr>
<td>Poor</td>
<td>Moderate limited shoulder mobility, outreach missing was more than 40°, severe shoulder circumferential pain, abductor was grade 2.</td>
</tr>
</tbody>
</table>

Surgery to treat scapular fractures is still somewhat controversial. Most foreign studies have concluded that the absolute indications for surgery include scapular glenoid fractures involving the articular surface with displacement, displaced scapular neck fractures, and mesoscapular comminuted fractures [15-20]. Moreover, the recognized indications for surgery are as follows [21]: patients with downward shift exceeding 5 mm in acromion fractures, affecting the subacromial structures; patients with upper and lower shift of mesoscapular fractures exceeding 5 mm, affecting the sliding of the upper and lower muscles; patients with associated or isolated scapular neck fractures with displacement of >1 cm, and a tilted (back and forth) glenoid of 40° or up-and-down over inclination exceeding 40° on computed tomography; patients with a lateral margin scapular body fracture displaced >1 cm with capsular rupture; patients with combined ipsilateral clavicle or humeral surgical neck fracture with the appearance of floating shoulder; patients with circumferential cartilage dislocation causing the humeral head; patients with obvious coracoid fracture displacement accompanied by neurovascular compression;
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patients with multiple fractures; and patients with mixed shift signs, as mentioned above.

The most commonly used surgical approaches in the clinical setting are as follows [8-10, 22]: (i) Anterior approach (deltoplastical-gap approach): starting from the coracoid process, an incision is made along the ditch between the deltoid and pectoralis and specific attention is paid to protecting the head vein. The musculus biceps brachii and coracobrachialis are pulled inside to expose the subscapulatus muscle, which is subsequently cut just 1 cm vertical to the muscle and flipped inside to expose the fracture site. (ii) Posterior approach (Judet approach): the skin incision is started from the back edge of the acromion, entered along the inner edge of the mesoscapula and the scapula, and curved to the bottom corner of the mesoscapula. The rear deltoid muscle is separated from the mesoscapula, and the infraspinatus and musculi teres minor are exposed and separated to expose the gap, thereby revealing the lower part of the glenoid fossa and the outer edge of the scapula. If clearer visualization of the scapular glenoid and neck is desired, the infraspinatus muscle can be cut and turned to the outside; however, close attention should be paid to protect the scapular nerve, axillary nerve, and circumflex humeral artery. (iii) Outer edge approach: straight cuts are made along the outer edge of the scapula, and the deltoid attached to the lower part of the mesoscapula is cut and pulled outside to expose the infraspinatus and musculi teres minor located below. Subsequently, the infraspinatus and musculi teres minor are separated to expose the outside of the scapula body and neck, and the periosteum is stripped close to the scapula, allowing clear visualization of the scapular neck, mesoscapula, and scapular caudomedial part. (iv) Before-and-after combined approach: this approach is appropriate for combined injuries of the acromion, collarbone, and scapular neck. (v) Improved shoulder posterior approach (modified Judet approach): the incision is started from the bottom of the acromion and behind the shoulder joints, slightly tilted into the arc, extended along the outer edge of the scapula, and introverted to the point where it is partially inside. The deltoideus triangularis is pulled to the outer upper scapula or a small part of the deltoid muscle fibers is cut, depending on the type of fracture. Next, the fascia in the gap between the infraspinatus and teres minor muscles is cut, blunt dissection is carried out, and the infraspinatus muscle is pulled upward, while the teres minor is pulled downward.

All of these common surgical approaches have their own advantages and disadvantages. Scapular fractures are often associated with soft-tissue contusion on the shoulder and back, and, compared with minimally invasive surgery, the risk of soft-tissue injury with the above-mentioned traditional surgical approaches is high because the larger incision fully reveals the surgical field. Early surgery easily aggravates the potential soft-tissue injury and may damage the blood supply around the fracture, thereby resulting in necrosis of the skin edge and delayed healing or even nonunion of the bone; however, delaying the surgery to allow soft-tissue recovery often leads to missing the optimal timing of surgery. Studies have shown that scapular fractures left untreated for >3 weeks commonly become aggravated and associated with increased surgical difficulty, owing to the formation of calluses and increased intraoperative blood loss, potentially leading to surgical failure. Hence, it has been suggested that surgical treatment should carried out within 3 weeks of an injury.

The combined small incisions used in the present study can effectively reduce the damage to local soft tissue, and are associated with improved flexibility. However, this technique requires detailed preoperative examination and evaluation. Three-dimensional computed tomography plays an important role in deciding the appropriate treatment for any scapular fracture [9]. Orthopedic surgeons can simulate surgery by using three-dimensional image reconstruction, which can help them choose the surgical approach, simulate the reset procedure, and determine the treatment plan, thereby shortening the operation time, improving the surgical safety and success rate, and reducing the risk of complications [10].

In this study, the treatment for multiple scapular fractures involved using combined small incisions (~5 cm) and marking of fracture fragments on the skin, determined through physical examination and imaging studies, with the fracture fragments as the center. In addition, the side prone position was used for coracoid
fractures. For scapular fractures on the outer edge of the upper body, the skin, subcutaneous tissue, superficial fascia, and deep fascia to the muscle layer were cut, and part of the infraspinatus muscle was disconnected before blunt dissection was performed along the teres minor and infraspinatus muscles. Subsequently, the fracture site was first palpated by hand, and the fracture fragments along the gap were explored. In this position, special attention should be paid to the scapular artery and nerve. The suprascapular artery runs around the base of the mesoscapula, whereas the scapular nerve runs from the fossa supraspinatus into the fossa infraspinata, and is distributed along the muscle branches to support the supraspinatus and infraspinatus muscles, accompanied by the scapular artery. To avoid damage to the scapular nerve and the accompanying artery, the infraspinatus should not be excessively pulled outside while the fracture site is revealed. Because the circumflex nerve protrudes from the quadrilateral hole from the lower edges of the musculi teres minor, where it divides into branches to innervate the muscles, it is essential to distinguish the infraspinatus muscle and musculi teres minor, as well as to prevent excessive downward stretching in order to avoid damage to the circumflex nerve and its concomitant humeral circumflex artery, which would lead to difficult-to-control bleeding. Therefore, we kept the gap separating the infraspinatus and musculi teres minor, and avoided operating outside of the area, which reduced the risk of injury to the circumflex nerve and arteria circumflexa humeri posterior. If the patient had a fracture involving the outside edge portions, this incision can be used to probe the fracture fragments to help locate the skin incision. For fractures of the lower portion for the outer edge, it is particularly important to note the arteria circumflexa scapulae in the space with the three rims, composed of the musculi teres minor, musculi teres major, and circumflex scapular artery, and the long head of the brachial triceps. The artery could be explored first and protected by avoiding excessive stretching, as this may cause the artery to retract into the thoracic side of the scapula, resulting in uncontrollable bleeding. For fractures on the medial edge of the body, part of the infraspinatus muscle can be cut to fully reveal the fracture site; however, it should be noted that the scapular dorsal artery runs along the medial border of the scapula, and separation from the inside edge of the scapula bone should hence be avoided during surgical procedures to avoid damage to the dorsal scapular artery. The surgical field is generally safe as long as operation to the inside of the medial margin of the scapula is avoided.

The focus of attention during operations for fractures of the glenoid rim, glenoid fossa, and anatomical neck are the same as those for operations for fractures of the upper edge of the scapular body. In addition, attention should also be paid to minimize damage to the rotator cuff in order to reduce postoperative shoulder joint dysfunction. For mesoscapular fractures, 1-cm incisions above the scapula are often chosen, during which the skin, subcutaneous tissues, superficial fascia, and deep fascia to the muscle layer are cut, and the supraspinatus is stripped and oriented down the mesoscapula. Subsequently, the fracture site is explored. In most cases, the fracture is superficial and the reset is relatively simple; however, particular attention should be paid to the adjacent artery and nerve. The suprascapular nerve runs around the bottom of the scapula, entering from the fossa supraspinatus into the fossa infraspinatus, and is distributed along the muscular branches to support the musculi supraspinatus and musculi infraspinatus, accompanied by the scapular artery, such as the cumulative fracture line at the bottom of the scapula. Importantly, it should be noted that the reset process may damage the scapular artery and nerve. The steel plate can be fixed to the side of the mesoscapula; however, fixation on the scapular backside should be avoided, as this may cause plate exposure and discomfort due to friction. In this study, in the approach for acromion and coracoid process fractures, the incision was frequently entered along the ditch between the deltoid and ectopectoralis, during which special care to protect the cephalic vein was taken. Subsequently, the muscle gap was bluntly dissected and the fracture site was explored along the bone surfaces. In many cases, the fracture fragments are small, and screws may be needed for these cases. Attention should be paid to the speed and depth of drilling to avoid causing damage to the pleura and lungs. Moreover, the screws must not be too long, as such screws cannot enter into the joint surface, which may, in turn, affect
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the postoperative functional exercise outcomes. Moreover, the layers of tissues should be tightly sutured to avoid iatrogenic shoulder abduction dysfunction. This requires the surgeon to be highly familiar with the important nerves and blood vessels surrounding the scapula. Furthermore, detailed preoperative preparation is needed.

Concerning the internal fixation materials, Kirschner wires or screws, including absorbable screws for internal fixation, are available for small pieces of glenoid rim, acromion, glenoid fossa, and coracoid fractures. Reconstruction plates can be chosen for caudomedial part and neck fractures, as they offer strong and reliable fixation. Cancellous bone screws can be used for fractures along the scapula, to extend and fix the bone. Alternatively, a reconstruction plate fixed below the mesoscapula and along the inner edge of the body may be used. Additionally, Kirschner wire tension bands may also be used for fixation. In previous clinical studies, reconstruction plates were most commonly used as internal fixation materials for body and neck fractures [23, 24]; however, because of the special anatomical characteristics of the scapula, the shaping process of reconstruction plates is complicated. To achieve improved shaping of the reconstruction plates, a longer procedure would be required, resulting in reduced elastic modulus after shaping. Owing to the low thickness of the scapula, the holding power of the screws tends to be decreased, or the nail may be stripped upon tightening of the screws, which often results in a relatively poor anatomical reset. Again, this is largely owing to the special anatomical structure of the scapula. Studies have shown that the average thickness of the scapular fossa is 25 mm, whereas the average thicknesses of the outer edge of the scapula and the mesoscapula are 9.7 and 8.3 mm, respectively. Hence, good results are often difficult to achieve with general reconstruction plate fixation.

The use of miniature titanium plates can effectively solve this problem. The miniature titanium plate is thin and relatively small, and can be placed close to the surface of the scapula. Therefore, it can better adapt to the irregular shape of the bone and fit better to the bone surface. Moreover, the screw spacing is narrow, allowing effective fracture fixation from different angles. Meanwhile, the proportions of the nail length and thickness are also more appropriate, which ensures sufficient gripping force. The scapula is a non-weight-bearing bone, and titanium plates are hard and associated with good flexibility. Moreover, these plates not only provide adequate biomechanical strength but also show good biocompatibility; hence, titanium is an ideal material for scapular fracture fixation.

Concerning hospitalization expenses, the miniature titanium plate is much cheaper than reconstruction bone plates and locking bone plates. Therefore, this material is more easily acceptable to patients and can reduce the financial burden to the patients’ families and the society. Because the microtitanium plate has a small volume, a large surgical window is not required to complete the fixation; instead, only several small incisions are needed to complete the fixation of complex fractures of the scapula.

In this study, to achieve the greatest degree of recovery of shoulder function, early postoperative functional exercise was applied to significantly reduce the loss of function and the decline of the quality of life of the patients. Preoperatively, many patients refuse functional exercises because of pain; hence, active functional exercises should be performed after the internal fixation to prevent muscle adhesions. The miniature titanium plates sufficiently tolerated the dispersed stress and shear force of the fracture fragments. Isometric muscle activities for the shoulder, elbow, and wrist, and the muscles surrounding the finger joints should be performed 3 days after the surgery to promote blood circulation and help reduce swelling. Proactive shrug and elbow bending, and active motion of the shoulder joints within 90° can be carried out at 4-7 days after the operation. The range of activities can be gradually increased 1 week after surgery. At this time, shoulder pendulum exercises can be performed to loosen shoulder joint adhesions and to increase shoulder mobility and strength. Approximately 3 weeks after surgery, movement activities such as arm rotation, neck holding, and finger climbing can be freely performed to effectively prevent joint adhesions, traumatic arthritis, and periarthritis of the shoulder. Four weeks after
surgery, functional exercises with 1-kg weights can be performed. Importantly, while slight motion can promote fracture healing, holding of heavy objects and performing strenuous activities should be avoided.

In summary, combined small incisions can be used to fully expose most types of scapular fractures, especially scapular body, scapular neck, mesoscapula, and multisite complex fractures without coracoid process and glenoid fractures. Combined small incisions can effectively reduce soft-tissue damage, thereby providing maximum protection to the soft tissue, especially for patients with soft-tissue shoulder contusion and serious pollution. The microtitanium plate has moderate proportions and a good fit, and can effectively fix various types of scapular fractures, as well as provide a sufficient holding force. Furthermore, it is cheaper than reconstruction bone plates and locking plates, making surgery more easily acceptable to patients and resulting in reduced financial burden to the patients’ families and the society. Thus, surgery through small incisions with titanium miniplate internal fixation is a safe and effective treatment strategy for scapular fractures, and should be considered for clinical application. Future biomechanical studies are needed to further validate the feasibility of internal fixation with microtitanium plates.

Disclosure of conflict of interest

None.

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