Surgical fixation of sternal fractures: locked plate fixation by low-profile titanium plates—surgical safety through depth limited drilling

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Received: 27 July 2013 / Accepted: 13 September 2013 / Published online: 12 October 2013
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Abstract

Purpose Operative treatment of sternal fractures has become a matter of increasing interest. Anterior plating seems to be the most appropriate method for fixing sternal fractures. However, there are several concerns in relation to the operative procedure such as severe injuries to mediastinal organs, patient comfort and proper stabilisation, for example. This paper describes a safe method of anterior sternal plating using locked plate fixation with limited depth drilling.

Methods Ten patients with sternal fractures were included in this cohort study and were treated by anterior plating using one or two plates in parallel through a median approach to the sternum. Follow up was performed after six weeks, 12 weeks and six months.

Results Follow up revealed no serious complications. One patient suffered from postoperative wound seroma. No problems were caused by the plates.

Conclusions Sternal plating using low profile locked titanium plates seems to be a safe and stable method with a high level of patient comfort.

Keywords Sternal fracture · Locked plate · Low profile plate · Mediastinal injury · MatrixRib®

Introduction

Sternal fractures are described as a rare entity with a total frequency of 3–8 % out of the total number of trauma cases in the current literature [1]. Usually sternal fractures are caused by a high impact force to the chest, as in a car accident [2]. However, it can also occur with low impact trauma, especially in osteoporotic bone [3].

Several mechanisms of trauma have been held responsible for sternal fractures. The direct impact on the anterior chest wall is described, as well as the combination of direct impact and a strong forward trunk flexion or a hyperextension injury of the chest tearing the sternum apart [4–6]. Sternal fractures can either occur as an isolated injury or with concomitant injuries to the soft tissues, thoracic organs and/or the surrounding bony structures [5, 7].

On the one hand the vast majority of sternal fractures consolidate with conservative treatment in almost anatomical position, on the other hand, insufficient consolidation can lead to a pseudarthrosis [8]. Numerous cases are described, but they are mostly case reports or small cohort studies [9, 10]. Those with symptomatic pseudarthrosis were revised and stabilised by osteosynthesis.

The primary sternal fixation of traumatic fractures has become a matter of increasing interest as Harston systematically reviewed in 2011 discussing indications and possible methods of sternal stabilisation [11]. Indications were severe or persistent pain, respiratory failure or dependency on mechanical ventilation, shifted, overlapping or impacted fractures, as well as deformity or instability of the sternum, non-union or hunched posture and restricted movement of the trunk. The majority of authors have stabilised sternal fractures either by cerclage wiring or plate fixation. The plate fixation from a biomechanical point of view is the more stable option. This has already been demonstrated in sternum closure after median sternotomy [12].

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Another aspect is the positioning of an osteosynthesis plate on the anterior sternum wall, without a soft tissue dissection the mediastinum.

Analogous to median sternotomy closure, plate fixation of sternal fractures seem to provide the most stable method with the best alignment of the fragments [12]. However, in order to fix the plate to the bone, drill holes and screws are required. Drilling too deep can lead to injuries of retrosternal structures, such as the major vessels and the heart. This can have catastrophic consequences and therefore must be strictly avoided [5, 11].

Mayberry et al. discussed this issue in 2009 in association with the competency of the various surgical disciplines [13]. An orthopedic surgeon would have a high confidence in dealing with plate fixation, however, would be reluctant to operate on the chest. Whilst general surgeons and thoracic surgeons would have less inhibitions with regard to the anatomical structures on the chest wall, they would be more familiar with the wire osteosynthesis.

The aim of this paper was therefore to describe a method of internal fixation, which on the one hand allows less invasion but provides adequate stabilisation of the sternal fractures, and on the other hand reduces the risk of injury to the thoracic organs by the use of a special dissection technique and limited depth drilling. Additionally, good patient acceptance should be achieved by the use of low-profile osteosynthesis plates.

Methods

In the year 2012, ten patients with transverse sternal fractures were included in this study; the mean age of the patients was 51.5 years (range 18.6–82.6 years, SD = 20.56). The cohort included six men and four women (Table 1). All patients were victims of high-speed crashes and admitted through the emergency room. The setting was a Level 1 trauma centre. Eight out of ten patients had severe associated injuries, including multiple trauma. All patients were examined by whole body multi-slice computed tomography (trauma scan). The only patients which were included in the follow-up, were the ones that had received the sternum plate osteosynthesis. The indications for this were an unstable anterior chest wall, fracture displacement, and a persistent, painful instability of more than seven days. Plate fixation was performed through a median approach over the fracture region under general anaesthesia. For adequate exposure of the fracture, haematoma was removed first and then pectoralis muscles cautiously were taken from the anterior wall of the sternum to the margin of the sternum bilaterally whilst respecting the anatomical layers.

An important step was the exposure of the intercostal margin of the sternum. Along the front edge of the sternum, the sternal periosteum was incised longitudinally. An elevator was then used subperiostally to dissect from the sternal margin

to the posterior wall of the sternum (Fig. 1a). Thereby, retrosternal structures were not disturbed in any way or even injured. Also spared by this technique were the internal thoracic vessels which run laterally to the sternum. This manoeuvre was performed bilaterally. A pointed ball reduction forceps was then pinned along the posterior wall of the sternum through the intercostal space proximally and distally to the fracture site (Fig. 1c).

With these two clamps, one or two low-profile titanium plates were temporarily attached in a longitudinal direction next to sternal margin. An anatomical reduction of the fracture was thus ensured. Plates were fixed with 2.9-mm locking screws. A prior measurement of the sternal thickness determined the drilling depth of any screw holes to be used (Fig. 2a and b). In all cases, a stable osteosynthesis with anatomical reduction was achieved by using one or two plates.

Afterwards the wound area was lavaged, the retrosternal haematoma was removed, followed by the insertion of a drain, and a sufficient coverage of the osteosynthesis with soft tissue was performed by anatomical replacement and reattachment of the pectoral muscles. Each anatomical layer was then closed anatomically by a row of stitches in the pectoralis fascia, subcutaneous layer and on the surface of the skin itself.

Those patients who preoperatively had depended upon ventilation due to respiratory failure, were brought to the ICU after surgery and quickly weaned from artificial ventilation within less than two days in all cases included in this study. All other patients were immediately extubated postoperatively in the operating room and transferred to the normal ward. All patients were checked with a chest X-ray in two axes postoperatively. Mobilisation out of bed occurred on the first postoperative day, providing the concomitant injuries would allow it. Follow-up examinations were performed on day seven and after six weeks, 12 weeks and six months postoperatively.

Results

A stable osteosynthesis was achieved in all cases using one or two parallel plates. On average, 1.8 plates (range 1–2, SD = 0.42; Table 2) were needed for the sternal plate fixation. Three patients had, in addition to the sternal fracture, another sternocostal, cartilaginous, dislocated rib fracture, which was also stabilised (patients 2, 5, 10). An average of 34.5 minutes (range 22–48 minutes, SD = 8.37) were needed for the operative stabilisation of the sternal fracture. In all cases, the fracture was reached through a limited median access and anatomically reduced (Fig. 3). It was not necessary to extend the incision or even perform a median sternotomy as Irani et al. advised for repairing traumatic sternal deformity [14].

Complications did not occur during the operation. Because the dissection was strictly subperiosteal and extrapleural there

Table 1 Status of patients

Case number	Age (years)	Gender	Localisation of fracture	Dislocation (mm)	Concomitant injuries
1	54.8	Male	Body	5	Multiple rib fractures, lumbar spine (fracture L2), clavicle fracture
2	64.4	Female	Manubrium and body	13	Serial rib fracture right, lumbar spine (fracture L2), extensive lower leg fractures both sides
3	49.9	Male	Body	14	None
4	18.6	Male	Body	3	Clavicle fracture
5	74.3	Female	Body	4	Thoracic spine (fracture th 4, th 5, th 6), midface
6	52.4	Female	Body	10	None
7	19.2	Male	Angle	13	Thoracic spine (fracture th 3, th 4), lung contusion, scapula fracture, rib fracture, cerebral contusion
8	49.4	Male	Manubrium	4	Serial rib fracture, femur fracture
9	82.6	Female	Body	11	Cardiac contusion
10	49.1	Male	Angle	18	Pneumothorax bilateral, cerebral contusion, lumbar spine (fracture L2)
Average	51.5	6 male/4 female		9.5	

were no patients who needed an additional chest tube. Because of their concomitant injuries three of the patients had already received a chest tube in the emergency room. There was no injury of the substernal or mediastinal structures, nor was there major bleeding into the surgical area. In all cases, the drain was removed at the latest after the fifth postoperative day.

The wounds healed primarily without any complications and no wound healing problems were observed in the follow ups. The follow-up also showed a good bony healing of all sternal fractures. After six weeks a sufficient callus formation was already seen in the X-ray and after 12 weeks a full consolidation in all cases (Fig. 4)

There was no case of dislocation or loosening of the plates, nor a material failure. The plates were well accepted by all

patients. The level of patient satisfaction was measured in school grades (range: 1 very good to 6 insufficient). The grade achieved was 1.4 (range 1-2, SD = 0.52). The follow-up examination at six months also showed no other general complications of the patients included in this study.

Discussion

Even today, the operative stabilisation of sternal fractures is rarely performed [11]. To our knowledge, the first surgical fixation was described by MCKIM in 1943 using a Kirschner wire [15]. In the following years, several methods such as intramedullary fixation, external fixator and conventional methods with wire cerclage and plate osteosynthesis have

Fig. 1 Performing anterior sternal plating. **a** Subperiosteal preparation. **b** Elevation of the depressed segment and fixation of the first plate to this segment. **c** Fixation of plate with pointed ball forceps. **d** Completed osteosynthesis

Fig. 2 **a** Measuring of sternal thickness. **b** Limited depth drilling

been described [16–18]. Currently published trials mostly describe sternal plating with locked implants such as LCP plates, special devices for sternal fractures such as the “TiFix” and the use of any other plate usually employed for internal fixation of long bones [8, 19]. For example, use of plates for distal radius fractures was described by Ergene et al. in 2012 [20]. All previous studies describe adequate consolidation rates, rarely material failure or other complications from the surgery. However, some authors highlight the risk of injury of the mediastinal structures and the thoracic vessels [5, 11, 20]. That is why in 2009 Mayberry et al. discussed the issue of different surgical disciplines involved in the performance of chest surgery. There lies the reluctance of various surgical, and in particular, orthopaedic disciplines, to make any fixation of the chest [13]. Another aspect of the implants is sometimes

their poor patient acceptance and/or soft tissue irritation [19]. Plates can be removed in a later operation if they were bothering patients in everyday life or patients ask for their removal.

We have included in this study points which elucidate a meaningful, easy-to-use and low risk osteosynthesis of sternal fractures with high patient comfort by the use of low profile 1.5-mm titanium plates (Matrix Rib®, Synthes, Switzerland), which were developed for stabilisation of the unstable chest wall [21] (Figs. 1, 3 and 4). The original use, particularly for stabilisation of rib fractures, led to the development of low profile plates with low implant cross-section of 1.5 mm, whilst maintaining very high stability and providing enough elasticity for continuous respiratory chest wall movements [22].

In a biomechanical study that compared these plates with LCP plates and pelvic plates, after biomechanical considerations, each plate showed a load average of several hundred Newtons, which was fully sufficient for stabilisation of the chest wall, especially for the sternum [22]. The titanium-aluminum alloy used leads to a very small implant weight, only a few grams. Thus, the implants have no disturbing dimensions, either in weight or in length, which resulted in a high level of patient comfort in our experience. During the observation period of six months, no patient requested removal of the MatrixRib® plates. The plates were always introduced paramedianly longitudinally on the anterior sternum so as not to hinder any subsequent median sternotomy if required (Fig. 1b, c and d).

From the perspective of the authors, this could be required in the worst case perioperatively immediately because of injuries to the internal organs such as cardiac tamponade, for example. Median sternotomy may also become necessary in due course, in the years after surgery, for example, in interventions of the heart such as coronary artery disease or

Table 2 Operation

Case number	Number of plates	Length of procedure (minutes)
1	2	22
2	2	33
3	1	48
4	2	38
5	2	29
6	2	42
7	2	35
8	1	23
9	2	33
10	2	42
Average	1.8	34.5

Fig. 3 **a** Manubrio-sternal dislocation. CT scan performed after primary survey in emergency department. **b** Lateral chest X-ray after reduction and anterior plating of the sternum with two plates

valvular disease. Plates can be left in situ in these cases and would not interfere with median sternotomy in any way.

In our follow-up of the included cohort, no problems with wound healing were seen. All patients developed non-irritable scars with a length of five to max. ten centimetres. In all patients, a subcutaneous drain was inserted for safety, which could be removed timely on average after 2.6 days. Only one patient developed seroma within 14 days and needed another drainage (Patient 8). The preparation technique described

reduced the risk of mediastinal injury. In all cases reduction of the fracture was achieved performing a strictly subperiosteal dissection along the sternum (Fig. 1a). Through this technique, no injuries to vessels of the chest wall, mediastinal organs such as the large vessels or the very thin-walled brachiocephalic vein, the aortic arch or the heart itself were seen. All sternal fractures were adequately reduced through the described approach and a wide exposure of the fracture or soft tissue dissection was not required in any case. The preparation of the sternal

Fig. 4 Lateral chest X-ray during follow up. **a** Postoperative (patient no. 6). **b** After 6 weeks, callus formation at posterior sternal cortex (patient no. 1). **c** After 1 year, restitution ad integrum (patient no. 1)

edge further allowed a direct thickness measurement (Fig. 2a). This way one does not have to rely on CT values [20]. The surgeon himself determines the thickness of the area to be drilled. With limited depth drilling, the risk of injuries caused by the hole was completely avoided because the drill does not penetrate deeper than the back of the sternum (Fig. 2b).

Practical experience shows that firstly the posteriorly dislocated fragments of the sternum should be raised by an elevator and then the plate should be attached to this fragment with a pointed ball forceps (Fig. 1b and c). In this way the plate is supported on the opposite fragment and secures anatomically the alignment in the sagittal plane (Fig. 1c). After fixation of the plate by screws to the dorsally displaced fragment, the fragments may be reattached to each other and the screws are placed in the opposite fragment (Fig. 1d). Reduction of dehiscence transverse fractures can be done using pointed ball forceps, compression wires or other reduction clamps. In most cases, compression is not necessary because oblique fractures are present in the frontal or sagittal level with a large contact surface. Anatomical reduction is achieved sufficiently by raising the dehiscence posterior fragment and securing adequately with plate fixation (Fig. 3). Therefore other risky manoeuvres can be dropped which could provoke further injuries. Indications for surgical plate fixation were strictly observed in the described cohort. The condition was either a detectable instability of the sternum at least for seven days or a high sternal instability associated with the instability of the anterior chest wall, leading to respiratory failure. Secondary treatment of fractures such as longer-term instability or non-union were not included in this observation.

The study of the available literature shows a lack of standardised treatment algorithms for sternal fractures. It has already been concluded by Harston and Roberts in 2011 that prospective studies of incidence and long-term courses of non-surgically treated sternal fractures would be necessary [11]. The aim of this work was to demonstrate a secure internal fixation for existing indications. By sufficient fixation, chronic pain, which is mostly associated with respiratory movement, can be minimised, avoiding early pulmonary complications caused by shallow breathing. In the described cases, the quality of life of patients could be improved significantly. The present literature on cohort studies has already shown the benefit of a fixed-angle plate fixation of the sternum [23].

Conclusions

Osteosynthesis of sternal fractures using low-profile titanium plates in a fixed angle technique can be performed with a secure preparation technique. Injuries of thoracic organs and vessels are safely reduced with limited depth drilling and subperiosteal preparation. In the observed cohort, the plates

used guaranteed sufficient stability to the sternum and resulted without exception to a complete consolidation of the fracture in its anatomical position. Patient acceptance was good to very good in all cases. There were no severe complications seen six months after operation.

Acknowledgments We thank the Radiological Institute of the Erlangen University Hospital (Director: Prof. Dr. Michael Uder) for providing the X-rays and CT scans.

We also wish to thank Mr. Dominic Taylor, Erlangen, for support in preparing the English manuscript.

Conflict of interest The first author has a consultant agreement with Synthes CMF. No funds were received in connection to the presented study. The coauthors are not involved in any conflict of interest.

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