Surgical management of traumatic isolated sternal fracture and manubriosternal dislocation

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Submitted: May 7, 2013, Revised: June 23, 2013, Accepted: June 25, 2013.
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DOI: 10.1097/TA.0b013e3182a686a5

BACKGROUND: The aim of this study was to evaluate the surgical procedures of osteosynthesis and the respective costs in isolated sternal fractures and manubriosternal dislocations.

METHODS: Between January 2006 and July 2011, we treated 47 patients with an isolated fracture and 18 patients with a dislocation of the sternum surgically. In case of sternal fracture, the titanium plate was used in 30 (64%), steel plate in 12 (25%), and steel wire in 5 patients (11%). The stabilization after traumatic luxation was obtained with steel wire in 4 patients (22%) and titanium plate associated with demineralized bone matrix in 14 patients (78%). The quality adjusted life years (QALYs) was analyzed, as well as the incremental cost-effectiveness ratio based on QALYs.

RESULTS: In the sternal fractures, titanium plate showed a decreased time of intervention (30 [2] minutes), length of stay (3 [1] days), and total cost (€2,277.10) compared with steel plate (€2,667.70) and steel wire (€2,801.60) procedures, displaying an excellent difference in QALYs (0.825 and 1.615, respectively). In the sternal dislocation, steel wire technique highlighted a poor QALYs, although this approach was less expensive than titanium plate with demineralized bone matrix (€3,553.60 vs. €6,047.80). Incremental cost-effectiveness ratio revealed that the titanium plate costs were €623.55 more than the steel wire per QALYs gained.

CONCLUSION: The rigid titanium plate application ensured a safe and easy management of traumatic sternal lesions with a good prognosis of patients, justified by the improved QALYs compared with other methods. (*J Trauma Acute Care Surg*. 2013;75: 824–829.

LEVEL OF EVIDENCE: Therapeutic study, level IV; economic analysis, level IV.

KEY WORDS: Chest trauma; sternal fracture; manubriosternal dislocation; osteosynthesis; costs.

Isolated sternal fractures and manubriosternal dislocations are rare pathologies caused by deceleration injuries, blunt chest trauma, hyperextension of the cervical and thoracic spine, or hyperflexion of the head on the chest. Knobloch et al.,[1] studying 42,055 traumatized patients, revealed that 0.64% had sternal fractures as well as the correlation between Injury Severity Score (ISS) ($r^2 = 0.92$) and maximal Abbreviated Injury Scale (AIS) score ($r^2 = 0.81$) and the deceleration velocity. The increased frequency of these lesion could be explained by the common use of seat belts.[2] In fact, being mainly on the anterior chest wall, kinetic energy is exhausted on the sternum, causing the fracture, the dislocation, or an anterior flail chest. The treatment of sternal lesions, without cardiac or lung injuries, is still controversial. Harston and Roberts,[3] in a review of the literature during a period of 20 years, highlighted only 76 patients surgically treated (52 with plates and 24 with wires) for sternal fracture, supporting the need for a shared management. The reduction of pain with analgesics and the limitation of movements, ensuring an effective cough and respiration, is in most cases the main approach. However, this choice is inefficacious if the broken bone, the overlap deformity, or the luxation and the instability of the sternal body in the posterior (Type I, direct trauma) or anterior (Type II, indirect trauma) direction to the manubrium interfere with breathing.[4] In the fracture of the sternum, the early plate stabilization[5,6] seems to reduce pulmonary morbidity to prevent chronic pain and chest deformity, allowing no restriction in physical activity and no psychological impairment. The lack of fibrosis and bone callus can facilitate the correction of the overlapping stumps, reducing intraoperative complications and time of intervention. Currently, the optimal surgical procedure in traumatic sternal lesions has yet to be established and standardized in relation to the quality adjusted life years (QALYs) and the incremental cost-effectiveness ratio (ICER). The purpose of the study was to evaluate the indications and the best method of operative fixation, in relation to costs.

PATIENTS AND METHODS

From January 2006 to July 2011, we observed 624 chest trauma patients, 47 of whom showed a fracture (7.5%) and 18 showed a dislocation (2.9%) of the sternum necessitating surgical repair. There were 46 males (71%) and 19 females (29%), with an mean (SD) age of 43 [4] years (range, 19–56 years). Patients with sternal injury who underwent fixation were hemodynamically stable and conscious, and the computed tomography of the brain-thorax-abdomen displayed (*a*) in isolated fracture, one pneumothorax caused by blunt trauma (2%) and two nondisplaced fractures of one and three ribs (4%); and (*b*) in traumatic dislocation, three retrosternal hematomas (16.6%). Road accidents in 31 patients (47.6%), trauma at work in 22 patients (34%), and accidental falls in 12 patients (18.4%) were the etiology of anterior chest wall lesions. Direct trauma was the prevalent mechanism of injury, involving 53 of 65 patients. Blood gas analysis highlighted no hypoxia and/or hypercapnia despite shallow breathing caused by chest pain. The indications for treatment were (1) oblique stumps and unstable nonunion of the sternum in case of fracture and (2) respiratory distress and kyphosis of cervicothoracic rachis (the mean [SD] distance between the chin and sternum was 3 [1] cm) in case of luxation. In both pathologic conditions, the aesthetic damage with pain were considered for surgical repair. Isolated fracture was repaired using titanium plate in 30 patients (64%), steel plate in 12 patients (25%), and steel wire in 5 patients (11%). The sternal stabilization after traumatic dislocation was performed with steel wire in 4 patients (22%) and titanium plate with demineralized bone matrix in 14 patients (78%). The mean (SD) time between trauma and intervention was 3 (2) days.

Osteosynthesis With Steel Wires

Phases of osteosynthesis were (1) the dissection of the pectoralis major muscle sternal beams on the midline, (2) the subperiosteal exposure of the fracture or dislocation site, and (3) the wide dissection of the retrosternal space and the corresponding intercostal spaces bilaterally. The sternum was stabilized by one or two U-shaped or X monofilament stitches (Ethicon, Somerville, NJ) to full bone thickness.

Osteosynthesis With Steel Plates

Enforcement required subperiosteal exposure of the fracture, after dissection of sternal beams of the pectoralis major muscle. The plate (presently not available in Italy) was fixed to the sternum by means of five threaded screws anchored between the anterior and posterior cortex without crossing it, so as to lift and stabilize the stumps.

Osteosynthesis With Titanium Plates

We used titanium plate (thickness, 2.4 mm; length, 248.5 mm with 30 threaded holes) that can be divided into two parts with 15 holes and threaded screws (diameter, 3 mm; length, 8–18 mm) (SynthesTM, Switzerland). In the case of fracture, technique was similar to that described in the T steel plate application (difference was in the use of four and not five threaded screws), whereas it was more complex in the manubriosternal dislocation. After longitudinal incision of the skin and subcutaneous tissue, the insertions of the pectoralis major were dissected starting from the midline and extending horizontally for 3 cm to 4 cm along the ribs (from second to fifth). We performed the subperiosteal dissection of the sternum, the excision of the ligament between the manubrium and the sternal body, as well as the cuneiform resection of the third and fourth costal cartilage bilaterally preserving the internal mammary artery. Four to six screws allowed articulation of the plate, modeled on the basis of the morphologic characteristics of the lesion. The screws, whose length was precisely established by means of a depth gauge, were fixed to the posterior cortical bone after drilling a hole in the anterior cortex. The demineralized bone matrix shaped strips (DBX Putty, Musculoskeletal Transplant Foundation, Edison NJ; imported into Italy by the Bone Bank "Gaetano Pini," Milan) were positioned between the manubrium and the body of the sternum while, in the form of paste, covering and supporting the titanium implantation. Two Redon drains 14 mm were placed above the second-to-fifth intercostal spaces. The intervention was completed with the suture of the pectoralis major in the midline by polyfilament 2 and two continuous sutures by polyfilament 0 and monofilament 3-0 absorbable in the subcutaneous and skin, respectively.

Statistical Analysis

Analysis was performed using SPSS 10.0 (SPSS Inc., Chicago, IL). Data were entered into a database using SPSS Data Entry II and were expressed as mean (SD) (range, 95%). We analyzed by two-way analysis of variance test the time of intervention, the duration of drainage, and the length of hospitalization for each surgical method in isolated sternal fractures and manubriosternal dislocations. All p values less than 0.05 were considered to indicate significance and confidence interval at 95%.

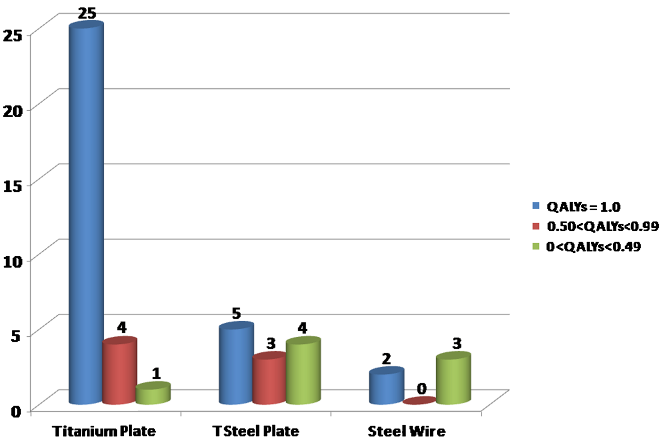

Figure 1. QALYs in isolated sternal fractures. Titanium plates showed the excellent results compared with steel plates and steel wires.

QALYs

Effectiveness evaluation for each technique was performed based on the QALYs. The QALYs was established through the EuroQol questionnaire[7,8] administered to all patients at the 12th, 24th, 36th, and 48th month after surgery. The dimensions of health status taken into consideration were the following: (1) ability to move, (2) care for themselves, (3) usual activity, (4) pain/discomfort, and (5) anxiety/depression. Three levels of severity were evaluated through specific scores for single dimension: (1) none, (2) moderate, and (3) severe. The synthetic value of quality of life at the time of the interview (time tradeoff method) was obtained by the specific algorithm. The result of the algorithm was multiplied by the follow-up, obtaining the QALYs.

ICER

ICER determines whether the costs incurred for treatment do or do not give rise to a return to proportionate health.[9] The calculation of ICER was superfluous if the costs and

TABLE 1. Cost Analysis per Patient of Different Surgical Approach in Isolated Sternal Fracture

Parameters	Titanium Plate	T Steel Plate	Steel Wire
Operating room time (€167.00/h)	€201.60	€235.20	€266.00
Length of hospitalization (€350.00/d)	€1,050.00	€1,750.00	€2,450.00
Devices	Plate, €591.00	Plate, €400.00	€21.60
	Screws, €392.00	Screws, €230.00	
Drainage	€0.50	€0.50	€1.00
Operating room charges	€42.00	€52.00	€63.00
Total	€2,277.10	€2,667.70	€2,801.60

TABLE 2. Cost-Benefit Relationship in Isolated Sternal Fracture Between the Different Techniques

Methods	Costs	QALYS	DC	DQ
Titanium plate	€2,277.10	3.625*	-	-
T steel plate	€2,667.70	2.80*	-	-
Values	-	-	€390.60	0.825*
Titanium plate	€2,277.10	3.625*	-	-
Steel wire	€2,801.60	2.01*	-	-
Values	-	-	€524.50	1.615*
T steel plate	€2,667.70	2.80*	-	-
Steel wire	€2,801.60	2.01*	-	-
Values	-	-	€133.90	0.79*

*Average value of QALYs per year of life gained.
DC, differences in costs; DQ, differences in QALYs.

TABLE 3. Cost Analysis per Patient for Different Surgical Approach in Manubriosternal Dislocation

Parameters	Titanium Plate	Steel Wire
Operating room time (€167.00/h)	€226.80	€308. 00
Length of hospitalization (€350.00/d)	€2,100.00	€3,150.00
Devices	Plate, €1,182.00	€21.60
	Screws, €784.00	
	DBX paste, €506.00	
	DBX strip, €1,200.00	
Drainage	€1.00	€1.00
Operating room charges	€48.00	€73.00
Total	€6,047.80	€3,553.60

results of treatment were clearly advantageous (lowest cost and greater effectiveness) than the other method under consideration. In case of uncertainty (higher spending and greater effectiveness), it was necessary to evaluate the ICER, which was expressed in units of cost per QALYs gained. ICER corresponded to the increase in the total cost needed to get one additional positive outcome. When ICER remains within the threshold value, there was an appropriate use of NHS money well spent.

RESULTS

No operative iatrogenic complication was noticed. The work loss after hospital discharge was 11 (2) days. All patients are alive at 54 (1) months from intervention and were reassessed.

Costs

The cost of operating room use was €167.00 per hour (equivalent to €2.8 per minute), while that for the single day of hospitalization was €350.00. The operating room charges also included the drug, the antalgic (morphine and similar), and the tracheal tube.

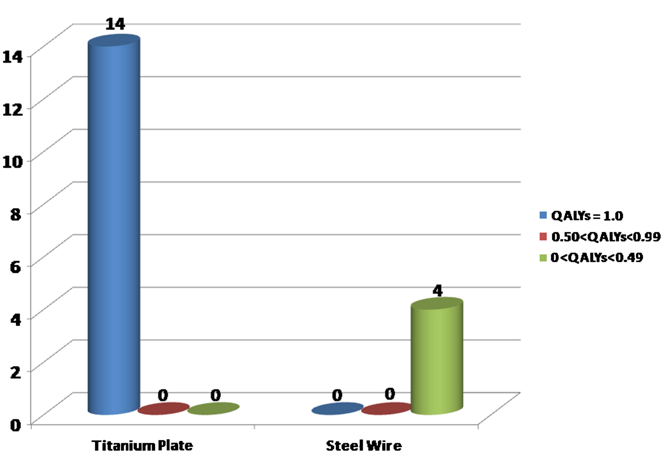

Figure 2. QALYs in manubriosternal dislocations. The best outcomes of titanium plates compared with steel wires can easily be assessed.

TABLE 4. Cost-Benefit Relationship in Manubriosternal Dislocation Between Titanium Plate and Steel Wire

Methods	Costs	QALYs	DC	DQ	ICER
Titanium plate	€6,047.80	5.0*	-	-	-
Steel wire	€3,553.60	1.0*	-	-	-
Values	-	-	€2,494.20	4.0*	€623.55

*Average value of QALYs per year of life gained.
DC, differences in costs; DQ, differences in QALYs.

Isolated Sternal Fractures' General Costs

The surgical costs per procedure were as follows: (1) titanium plate, €40.00; T steel plate, €50.00; steel wire, €60.00 for the drugs; (2) titanium plate, €1.00; T steel plate, €1.00; steel wire, €2.00 for the antalgics; and (3) tracheal tube, €1.00. We used an average of four screws (one screw, €98.00) to fix the titanium plate and five screws (one screw, €46.00) for anchoring the T steel plate. We placed one Redon (one drainage, €0.50) in the plates and two Redon in the wire methods.

Manubriosternal Dislocation General Costs

The costs for each method were (1) titanium plate, €45.00; steel wire, €70.00 for the drugs; (2) titanium plate, €2.00; steel wire, €2.00 for the antalgics; and (3) tracheal tube, €1.00. We used an average of two titanium plate segments (€591.00 × 2 = €1,182.00) with four screws for each segment (€392.00 × 2 = €784.00). We placed two Redon (one drainage, €0.50) for each technique.

Clinical and Economic Outcomes in Isolated Sternal Fractures

The devices were removed in eight patients (17%): (1) titanium plate in one patient (4%) owing to seroma between the plate and the sternum associated with fever; (2) T steel plate in four patients (33%) to 30, 45, 51, and 57 days after surgery because of the displacement of the plate and screws between the bundles of the pectoralis major muscle; (3) steel wire in three patients (60%) to 68, 73, and 82 days after surgery, following the granuloma (two cases) and nearthrosis (one case) at the fracture site. The titanium plate compared with T steel plate and steel wire approach showed (1) an inferior time of intervention (30 [2] minutes vs. 40 [5] minutes vs. 51 [2] minutes; p = 0.0001), with a total time use of operating room rate of 72 minutes versus 84 minutes versus 95 minutes, respectively; (2) a reduction of drainage duration (2 [1] days vs. 3 [1] days vs. 4 [2] days; p = 0.0002); (3) a short hospitalization (3 [1] days vs. 5 [1] days vs. 7 [1] days; p = 0.0001), with the average time of stay of 2 days to 10 days versus 3 days to 12 days versus 4 days to 14 days, respectively. Furthermore, the application of titanium plate was less expensive than the other procedures (Table 1). The effectiveness analysis of treatments (Fig. 1) displayed (1) an excellent QALYs (EuroQol equal to 1) in 25 titanium plate patients (83%), 5 T steel plate patients (42%), and 2 steel wire (40%) patients; (2) a good QALYs in 4 titanium plate (EuroQol equal to 0.85) patients (13%) because of moderate pain and 3 T steel plate (EuroQol equal to 0.73) patients (25%) because of moderate anxiety; (3) a poor QALYs in 1 titanium plate (EuroQol equal to 0.23) seroma patient

(4%), 4 T steel plate (EuroQol equal to 0.01) patients (33%), and 3 steel wire (EuroQol equal to 0.03) patients (60%), owing to the removal of the device. Table 2 summarizes the economic and QALYs benefits in the use of titanium plate over the other two methods.

Clinical and Economic Outcomes in Manubriosternal Dislocations

All patients undergoing stabilization with steel wire showed the deformity of anterior chest wall and pain after 37 (2) moths of intervention associated with a moderate restrictive respiratory insufficiency and refused reintervention. The titanium plate and demineralized bone matrix method highlighted a decreased time of intervention (45 [1] minutes, with 81 minutes of operating room use), duration of drainage (3 [1] days), and length of hospitalization (6 [1] days, with an average time of stay of 3–15 days) compared with the steel wire technique (68 [3] minutes, with 110 minutes of operating room use; 6 [1] days; 9 [2] days, with an average time of stay of 5–18 days) with statistical significance ($p = 0.0001$). The first approach was more expensive compared with the second (Table 3) but did not display the QALYs reduction (Fig. 2) that was 96% (EuroQol equal to 0.04) in four patients treated with steel wire. ICER revealed that the cost of titanium plate associated with bone matrix was €623.55 more than the steel wire per QALYs gained (Table 4). This amount falls within the threshold of acceptability of budget (referring to Diagnosis-Related Group 839.71 and the fees for outpatient rate for medical checkup).

DISCUSSION

Our study showed that the use of titanium plate was the main method of treatment in traumatic sternal lesions. Intervention on 10.4% of patients can be traced to two reasons as follows: (1) the mandatory use of seat belts, which has been generally accepted and respected by people in the last 5 years to 6 years; and (2) the analgesic and aesthetic needs that may be within the indications for surgery, considering the ease of sternal stabilization technique.

Isolated Sternal Fractures

Randomized trials concerning the indications and techniques for sternal stabilization were frequently incomplete. Mayberry et al.[10] identified three key points for intervention: (1) the presence of a sternal deformity, (2) the loss of sternal continuity for a period exceeding 6 weeks, and (3) the persistence of chest pain, between 2 weeks and 8 weeks for most surgeons surveyed. We think that the overlap and mobility of stumps or the obliquity of the fracture site with possible injury to the underlying vascular structures must also be considered. The steel wire application showed a wide clinical use, although the results were somewhat questionable. The dissection of the surgical site and the adjacent structures should be broad to avoid an incomplete or abnormal positioning of the wire, verifiable only in the immediate postoperative period. Consequently, the patient may be exposed to a high risk of vascular lesions in the face of poor stability of the sternum. To provide for a greater stiffness in the stabilization of the sternal fracture, Molina[11] proposed in 12 patients the use of wires associated with two threaded pins inserted in the thickness of the bone up to crossing the line of the fracture. Although the results were satisfactory, this approach did not seem to be easy, being characterized by the wide exposure of sternal fragments and the difficult positioning of the intramedullary pins. In our clinical practice, we applied both T steel and titanium plates, characterized by fast and easy fixation. In the steel plate, we noticed the following problems: (1) difficulty of modeling the device, particularly rigid; (2) screws selected on the basis of the experience of the surgeon and not through an unequivocal assessment of the required length; and (3) tendency of displacement of the plate and screws. These aspects were overcome with the linear titanium plates, easily modeled according to the extension and morphology of the sternal fracture. The threading holes allowed the simultaneous anchoring of threaded screws to the bone and plate, avoiding dislocation. Chou et al.[12] successfully repaired two traumatic sternal fractures with the SternaLock plating system. We have some perplexities about the method proposed by the authors. In our experience, the objective measure of distance existing between the anterior and the posterior cortex was obtained with the depth gauge that optimized exposure of the fracture site, without dissection of the intercostal spaces. In fact, the use of bone reduction forceps placed around the sternum was not necessary, and patients were not exposed to the risk of iatrogenic complications (intercostal and internal mammary artery lesions). Moreover, the X-plate must be fixed near the sternal segments, with possible worsening of the extent of the fracture and sternal stability. The linear plate prevented the movement of the sternal stumps as it allowed a rigid support to the sternum, to which the screws were anchored on an intact bone above and below the fracture at the required distance. We experienced excellent results with titanium plates. In fact, this method showed a high QALYs in 25 (84%) of 30 patients and a good QALYs in 4 patients (13%). Good QALYs were highlighted only in 5 (42%) of 12 patients using steel plates and in 2 (40%) of 5 patients with steel wires. As the clinical benefits were added to the economic advantages, the priority choice of titanium plates was justified.

Manubriosternal Dislocations

The few cases of this rare pathology reported in the literature determined that the best surgical approach and its indications are still under debate. Conservative treatment is linked to ankylosis and chest deformity, with impaired mechanical and respiratory functions. El Ibrahimi et al.[13] recommended surgery only for unstable injuries associated with mediastinal lesion. We think that the respiratory distress caused by morphologic alteration of the thorax, kyphosis of rachis with stiff neck, persistence of pain despite pharmacologic therapy, and aesthetic damage lead to open reduction and fixation. Nijs and Broos[14] in one patient, Kälicke et al.[15] in two patients, and Gloyer et al.[16] in three patients used an angular stable implant, an eight-hole one-third tubular plate, and a 3.5/4.0-mm fixed-angle plate, respectively, with positive results. We believe that any proposed method must respond to a proportionality between expenditures incurred and health produced, especially in this period of health service budget reductions in Italy. In our study, we noted the progressive loss in tension of steel wires with normal breathing that have not ensured an acceptable rigidity of the sternum resulting in chest wall deformity. Moreover, the increase in costs of titanium plates with respect to steel wires was mainly caused by the use of demineralized bone matrix. Allograft facilitated bone callus development, based on its osteoinductive activity and compatibility with the surrounding blood cells. This heterologous substance contributed to the stability of the implant, maintaining a normal motility of the thorax. Comparative analysis of effectiveness showed that titanium plate gained four QALYs more than steel wires, making it economically favorable. ICER supported these findings, noting that it is justified to spend more if the return to health is correspondingly high. The limit of our experience was the inability to calculate the indirect costs. In fact, the work loss (up to 3 weeks) and the effect of surgery on worker productivity fell within €2,631.45 (flat rate), which is the budget for this type of pathology, intervention, and medical checkup.

CONCLUSION

In traumatic sternal fractures and dislocations, surgery should address the need for ease, speed, and safety of approach, followed by the minimization of complications or recurrences. Moreover, the economic sustainability of intervention must be considered in view of the escalation in health care costs. The use of titanium rigid plates and screws, with or without demineralized bone matrix, satisfied these criteria and may represent currently the method of choice to successfully treat these lesions.

AUTHORSHIP

D.D. contributed to the study design, development of methodology, collection of data, interpretation of data, writing of the manuscript, and supervision. G.D.L. performed the statistical analysis. R.C. contributed to the study design.

DISCLOSURE

The authors declare no conflicts of interest.

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