Reconstructive options of the chest wall after trauma: a narrative review

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Background and Objective: Trauma remains the third leading cause of death in the world and the involvement of the chest with multiple rib fractures is an aggravating factor in the patient's outcomes. We perform a review of the literature, examining the current surgical options, in order to evaluate the most effective method of restoring quickly the excellent general conditions.

Methods: We carried out research of the papers in literature by performing a search on the MEDLINE database through PubMed including works from the past 10 years using the following criteria: "chest trauma AND chest wall". A total of 1,385 results were obtained and 1,108 articles were identified after the duplicates were removed. Only 214 were rated relevant after reading the full text.

Key Content and Findings: There are different but still valid approaches to reconstructions. Techniques often motivated by the adaptive abilities of the operator with the instruments available and according to the different clinical needs. The surgical stabilization with titanium plates and Judet's struts allows a faster recovery of respiratory function and a lower risk of lung infections. This leads to shorter intubation times, shorter stays in intensive care and a shorter overall hospitalization.

Conclusions: The main goal is the rapid recovery of the patient, respecting the anatomy and avoiding complications. Whenever possible, surgical stabilization is the preferred option. Non-rigid materials offer greater safety but titanium remains the best choice due to the possibility of customization, resistance and compatibility with parietal tissues.

Keywords: Thoracic trauma; chest wall; reconstruction; prosthetic materials

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Introduction

Background

Despite the development of many methods for safety in the workplace, home and on roads, chest trauma retains a 60% rate in polytrauma with a mortality of about 20–25% (1,2). Moreover, chest trauma accounts for 15% of injuries affecting the emergency room and luckily only 10% of the total, requires a surgical approach (3). The patient's general conditions should be stabilized early using orotracheal intubation and mechanical ventilation if necessary, associated with pain control and systematic toilet of airway. Although it is possible to achieve medium-/long-term recovery of respiratory function (4), prolonged conservative

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Table 1 The search strategy summary

Items	Specification
Date of search	October, 2022
Databases and other sources searched	PubMed
Search terms used	Chest trauma AND chest wall
Timeframe	2010–2022
Inclusion and exclusion criteria	Inclusion: all types of studies that included stabilization techniques, in English
Selection process	Research conducted by two independent reviewers, discussion of results and elimination of duplicates and irrelevant work

treatment exposes the patient to the risk of pneumonia, fibrosis and chest deformity as well as the inability to wean from ventilator (5).

Rationale and knowledge gap

If on the one hand there is unanimous consensus in the surgical approach of the flail chest, on the other hand there are doubts about fixation of isolated chest fractures (ICF). Untreated displaced ICF not only increase the risk of pneumothorax, hemothorax and pulmonary hernias (6) but can lead to chronic disunion/disruption of the stumps up to pseudarthrosis (7,8) with pain, reduced respiratory dynamics and dyspnea. A further point of discussion is the correct time for surgical fixation. The early osteosynthesis appears to be ideal in order to avoid inflammatory processes and exuberant bony callus (9) although extended pulmonary contusions and lung or brain injury may contraindicate this approach. In the literature, the first information about chest wall reconstruction dates back to the early 1900s and focused on the technique of myoplasty using the latissimus dorsi (10). Titanium is the alloy of choice of plates, bars and screws, offering malleability, strength and easy applicability. Today, the discovery of prosthetic and biocompatible materials allowed the development of different surgical techniques for rib fractures stabilization, also managing particularly clinical conditions (11). Biocompatible synthetic materials are used also in association with rigid molded or titanium supports, muscle, musculocutaneous and omentum flaps, allowing the minimal adverse reactions.

Objective

The aim of this work is to report the state of the art on the reconstruction of the chest wall. We present this article in accordance with the Narrative Review reporting checklist (available at https://asj.amegroups.com/article/view/10.21037/asj-22-19/rc).

Methods

We carried out a review of the literature focusing the chest wall stabilization methods. The search has carried out using a combination of words, relevant MeSH terms and appropriate filters. As shown in *Table 1*, the strategy has developed in MEDLINE (via PubMed) between January 2010 and January 2022 and the following criteria are used: "chest trauma AND chest wall". This research has allowed us to verify the most used techniques in the last period based on the possibility of the new materials available. A total of 1,385 results were obtained and 1,108 articles were identified after the duplicates and non-English were removed. Of these, 356 were relevant after reading the title and abstract. Subsequently only 214 were rated relevant after reading the full text (*Figure 1*). This step was performed independently by two investigators (surgeons experienced in the chest wall stabilization after trauma). In case of doubt, a third independent researcher (both senior surgeon and scientific researcher) intervened from the precedents. However, not being a systematic review but a wide review of the literature, we chosen to cite some older works as the indications provided are valid even today and support the most modern studies. After reading these articles we were able to evaluate the advantages and disadvantages of the various techniques. We evaluated exclusively the articles concerning the reconstruction of the chest wall after trauma (inclusion criterion), not considering the stabilization after resection of primary or secondary tumor (exclusion criterion).

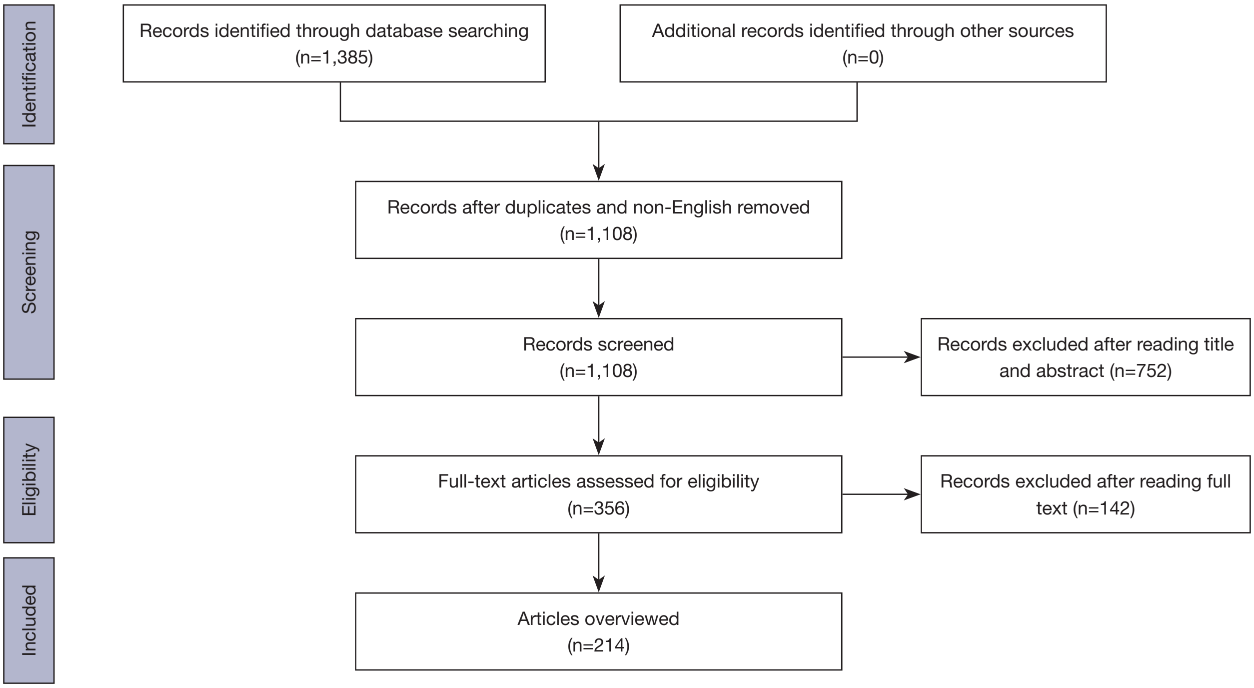

Figure 1 Flow chart of selected articles.

Key content and finding

Titanium plates and screws

Titanium screws and plates have been a recognized method in thoracic surgery for about twenty years and mainly used for flail chest osteosynthesis (*Figure 2*). Titanium is an excellent prosthetic material: it is inert, resistant to corrosion and traction and compatible with all types of radiological and instrumental examinations. There are many different application systems whose use is often linked to the anatomical characteristics of lesions and manual skills of the surgeon (12-14). The needs must lead the shaping of plates, in order to adapt to the individual patient according to the ribs involved. There are two fundamental features of these devices: (I) corrosion resistance and elasticity, with coefficient of friction minimization and not interference with the physiological movement of the ribs, once the stiffness of the rib cage obtained; (II) quick and easy application method that allows a drastic reduction in surgical time (15,16). Some authors (17-19) compared outcomes between surgical stabilization with titanium plates and conservative management of trauma. The first group showed better results in terms of: (I) postoperative use of mechanical ventilation (4.5 *vs.* 16.0 days); (II) ICU stay (7 *vs.* 9 days); (III) total hospital length (12 *vs.* 19 days); (IV) percentage of complications such as pneumonia (4.55% *vs.* 25%); (V) need for reintubation (4.55% *vs.* 17.86%); (VI) home oxygen requirements (4.55% *vs.* 17.86%). The fast restoration of a good quality of life and of daily and working habits has an extremely positive economic and social impact (20). The plate breakage is rare but still described and probably linked to the different composition to the base titanium plate (21), the presence of pre-existing microfracture for an incorrect shaping of the device and the hyperactive delirium of the patient who carries out uncontrolled movements in the early postoperative time (22).

Judet's struts and other types

Judet's struts, used for a single rib fracture stabilization, are characterized by a linear base variable in length and width (from 12 to 24 mm) and by two or three pairs of hooks at the ends. The branches of the hooks show different angles in order to better adapt to the different anatomy of the upper and lower costal margins. After wide subperiosteal exposure of the fracture foci and the preventive correction of lesion, the strut application proceeds by tightening the hooks with special forceps. The advantages of this technique described in the seventies consist in the safety, ease and speed rib fixation (23). The disadvantages are as follows: (I)

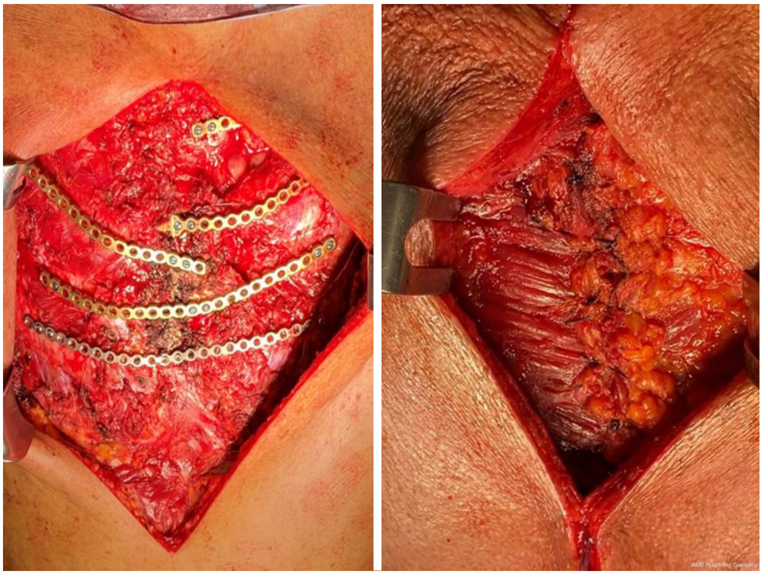

Figure 2 Anterior flail chest stabilized by different types of titanium plates and myoplasty with pectoralis major muscle.

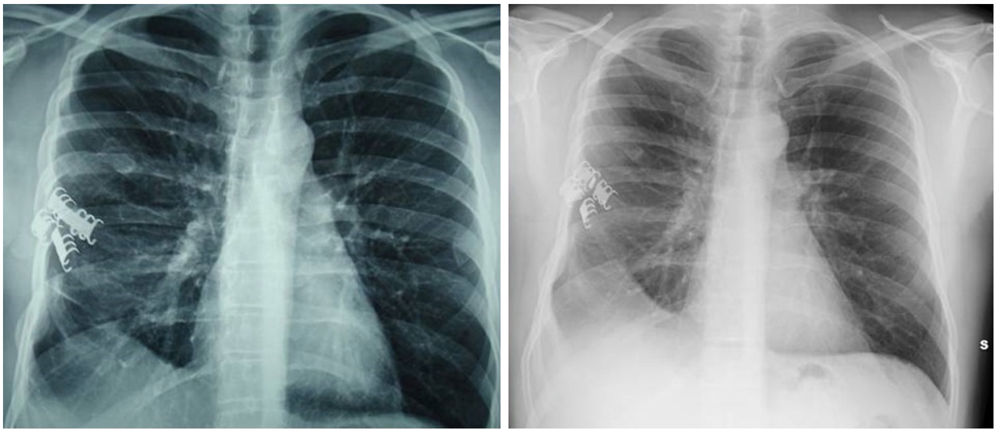

Figure 3 Spontaneous breaking of steel Judet's struts.

the need for a large thoracotomy to expose the injured chest wall; (II) longer operating times in case of multiple fracture foci; (III) chronic pain due to the crushing or entrapment of the neurovascular bundle; (IV) spontaneous rupture of the device if in steel (*Figure 3*), requiring the immediately removal to avoid vascular damage. The Sanchez-Lloret struts display straight and non-angled branches, equidistant along the plate; they meet the surgical indication for stabilization of several comminuted rib fractures (24). In addition to these classic devices, there are the plates made of 99% "pure" titanium which allow, compared to the various alloy steels, a greater thermal, mechanical and corrosive resistance and as well as greater lightness due to low density. Unfortunately, the plates with the hooks along their entire length are poorly adaptable to the morphology of the ribs. In fact, there is an overlap of the branches and a lifting of the extremities after modeling the horizontal component of the device and tightened the branches. This results in the non-adherence of the plate to the rib, with the possibility of seroma and displacement of the fracture stumps.

New struts in titanium

Device characterized by a straight support plate from

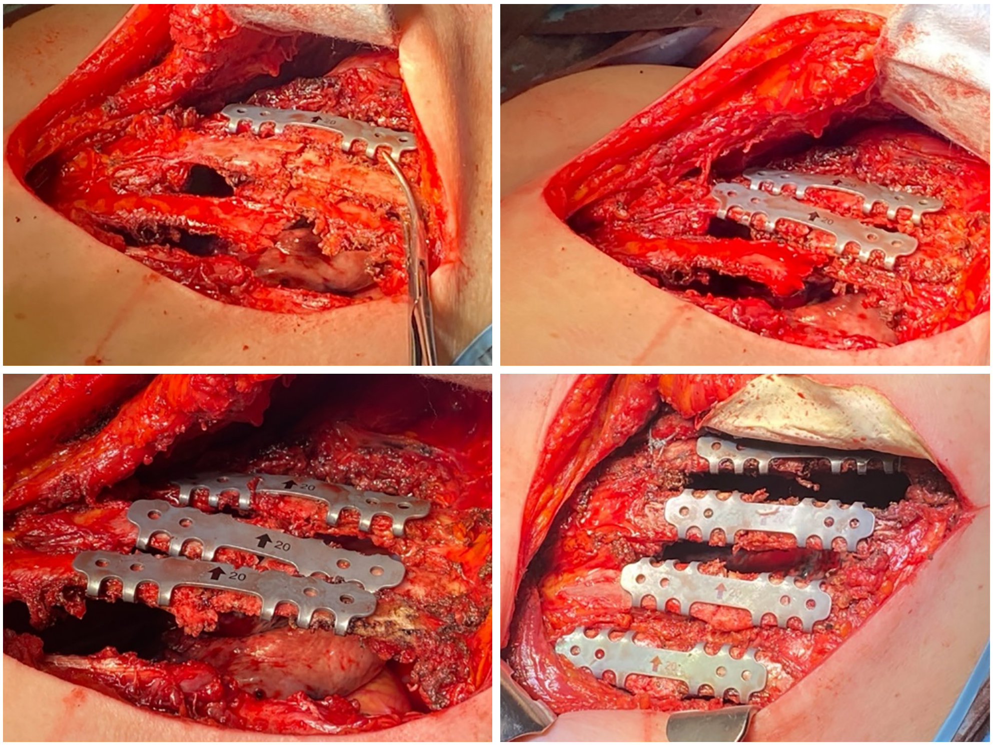

Figure 4 The new titanium devices, which combine the advantages of the linear plate and the precontoured and shaped vertical branches of the old struts.

which two or three pairs of hooks extend laterally, starting from each end (*Figures 4,5*). This plate is easily to shape in two dimensions (anteroposterior and superoinferior) according to the orientation and morphology of ribs, through the flexibility and deformability of all components. This involves the non-overlapping of the hooks after modeling due to the shape of plate that allows maintenance of the correct dimensional relationships. Consequently, the plate anchoring to the fractured ribs is easy, obtaining the quickly chest wall stabilization. The different angle of the vertical branches, according to the different anatomical characteristics of the rib edges (upper and lower), enhanced the sealing effect. In addition, there are two holes at the ends to simplify the fixation of several consecutive plates with screws in the case of comminuted fractures (16,22).

Bioresorbable materials

Unsintered hydroxyapatite (u-HA) particles/poly-L-Lactide (PLLA) (u-HA/PLLA) is a latest generation biocompatible and bioactive device already used in cranial, oral and maxillofacial surgery. There are sets of mini-plates and specific screws for the repair of flail chest and ribs. Mayberry *et al.* (25) showed the good clinical results, emphasizing the need to fix the rib with screws and cerclage. After 13 years, Oyamatsu *et al.* (26) proposed a U-shaped bioresorbable plate (SuperFIXSORB MX40) with ethibond 0/0 non-absorbable fixing points for the treatment of flail chest. Recently, Waseda *et al.* (27) described the same procedure in a severe osteoporotic octogenarian with serious flail chest due to a traffic accident, using resorbable Vicryl threads for fixation. The device would be partially reabsorbed at the 4-year follow-up and theoretically completely reabsorbed with another 2 years. This technique, applied in selected patients, requires more studies because the surgical stability failure leads to dislocation through the forces acting during the respiratory cycle (28).

Intramedullary components

The intramedullary stabilization method requires less surgical dissection; Kirschner wires, Adkins posts, steel wires and the Rehbein plate are the most frequently

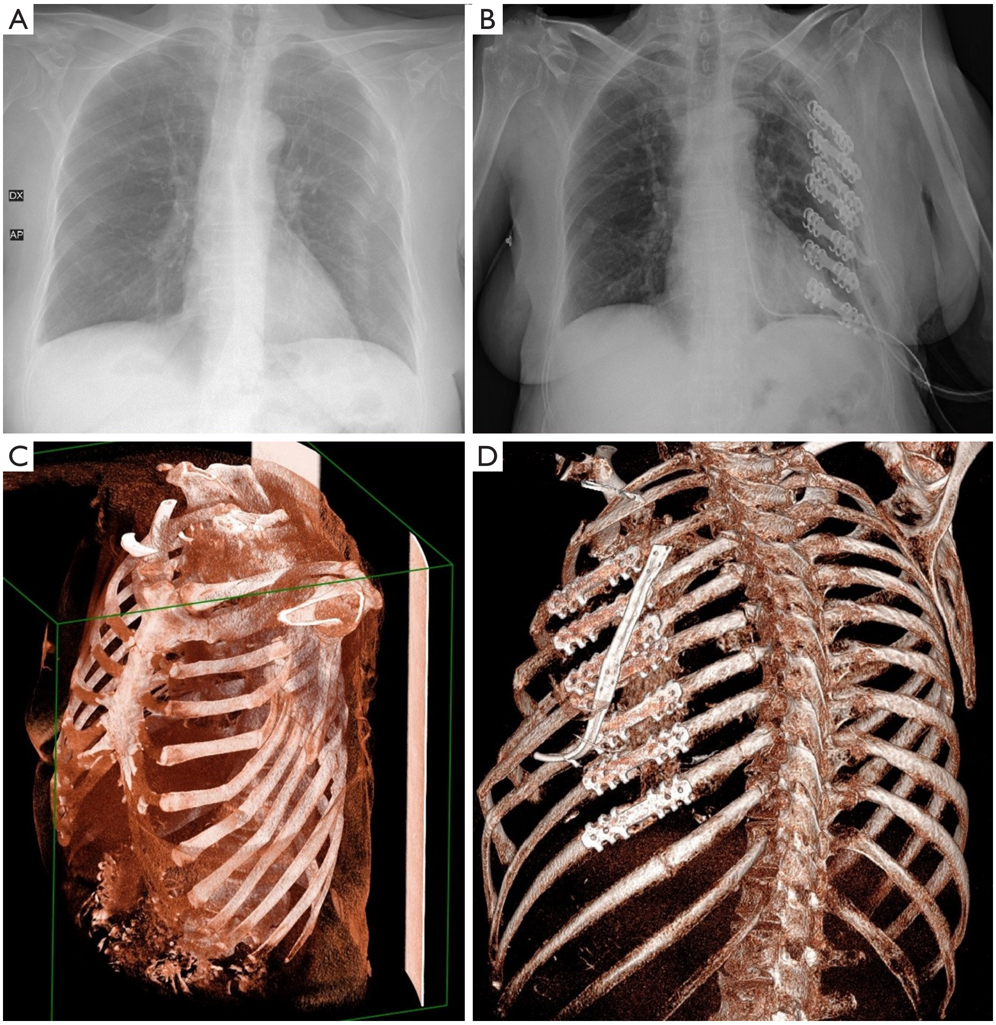

Figure 5 Preoperative and postoperative X-ray (A,B) and 3D-CT (C,D) of the thorax reconstruction. CT, computed tomography; 3D, three-dimensional.

used. Although Kirschner wires displayed good results, the rotational instability or migration of the wires with local complications are still described (29). The Rehbein plate and the MatrixRIB plate with the rectangular intramedullary portion exploit a direct anchorage on the rib strut to prevent rotational instability (30,31). According to Botlang *et al.* (32) these systems are 48% stronger than Kirschner wires with reduced complications. These devices are clearly useful in the repair of ribs with limited access, such as the posterior ones. In the last period, the rib fractures stabilization has achieved with bioabsorbable intramedullary implants (33). Liovic *et al.* (34) described a novel technique with an intramedullary telescopic splint fixed by bone cement.

Mesh

Chest wall reconstruction with non-rigid materials is widely used. This technique involves the use of different devices, each with specific characteristics; the choice is evaluated case by case. Generally, the meshes adapt perfectly to any type of parietal defect reducing respiratory complications but involving to a risk of infections ranging from 10% to 25%; in these situations, removal may be required (35,36). Polypropylene, polyester and polytetrafluoroethylene (PTFE) are the most common non-absorbable materials. Easily extensible and applicable on the bone defect, these patches displayed good rigidity, protection and tolerance acting as a support for myoplasty. In particular, the DualMesh with bimaterial interface (one for the biocompatibility and the other for the tissue regeneration) seems to have excellent findings, reducing the risk of infection (37) ranged between 10% and 25% using Methyl Methacrylate (38). The collagen matrices collected from human or animal sources and processed for medical use that promote remodeling, neovascularization and exchange of the extracellular matrix with the tissues have proposed, with the biocompatibility advantages. D'Amico *et al.* (39) described parietal reconstructions associating biological implant and muscle flap, without major complications and patch infections. A polyglactin mesh has also used to avoid friction between the plate and the overlying skin after reconstruction (40). The titanium meshes are about 5 mm thick, perforated and with variable design. Tamburini *et al.* (41), in 26 chest wall tumors patients, used titanium mesh alone or associated with plates, with satisfactory short- and medium-term outcomes. Divisi *et al.* (42) applied the same device after wide sternal resection, with rapid recovery function of anterior chest wall. A further indication to the mesh is the thoracoabdominal injuries in which it is not possible to use the diaphragm for direct suturing (43). Gonfiotti *et al.* (44), in 10 trauma patients with a diameter of chest wall defects >5 cm, used a porcine-derived acellular dermal matrix associated with titanium plates for reconstruction. Overall survival was 100% after 30 days.

Discussion

The main objectives of the chest wall reconstruction are the respiratory function restoration, organ protection and pain reduction. In a multicenter study (45) we found that plates, screws or struts showed the same excellent results in the surgical stabilization of flail chest. The ideal timing for intervention is within 72 hours from trauma (16,45,46), if patients showed the hemodynamic and respiratory stabilization. In a previous study, we have already demonstrated the economic viability of titanium plate fixation in the sternal fracture and manubriosternal joint dislocation (46). Apaydin *et al.* (47) in a traumatic flail chest involving 7–8 costochondral joints in the right and 8 in left side and lower 1/3 of the sternum used: (I) 2 flat plates and 8 screws for the sternum; (II) 4 flat plates and 30 overall titanium screws for the ribs. Patient was extubated and mobilized on the first day. Evman *et al.* (48), in a patient who could not be weaned from mechanical ventilation after 14 days, carried out the surgical stabilization with titanium plates and screws allowing the extubation on third day and discharge on eighth day. The reconstruction of the chest wall with titanium plates and screws seems to have received unanimous consent from the literature (49,50). The patient's clinical conditions, the morphology of the parietal defect and the experience of surgeon lead the choice of device (16). Dantis *et al.* (51) described a simple figure-eight suture with non-resorbable thread of rib fractures and apposition of polypropylene mesh. Patient needed the postoperative bronchoscopic cleaning of tracheobronchial tree and he was discharged from hospital after three weeks. In one month patient returned to work and one year follow-up shows no problem of respiratory dynamic. Tarng *et al.* (52) revealed chest wall repair with intramedullary titanium elastic nails (TENs) by video-assisted thoracoscopic surgery (VATS) and minimal thoracic incisions. All patients were successfully weaned from ventilators after an average of 3 days, with a shorter hospitalization than non-surgical patients, quickly returning to normal daily activities and work. Waseda *et al.* (27) stabilized the flail chest in a severe osteoporotic octogenarian using a biological resorbable plate and screw system in u-HA/PLLA with reinforcement by vicryl sutures. The 4-year check-up displayed the partial reabsorption of the fixing system, the completion of which will take an additional two years. Vacuum-assisted closure (VAC) therapy is a relatively new method of protecting sutures; the indications of which consist of infection or high infectious risk. Feng *et al.* (53), in a severe open trauma of the chest with multiple fractures, used the VAC therapy on the external site of the trauma after repair with titanium plates and screws. Lodin *et al.* (54) in 71 patients undergoing surgical chest stabilization with precontoured plates, systematically applied a local system of vacuum therapy (ciNPT: closed-incision negative pressure therapy). The study showed a reduction in both infection to 3% over a range of 2–20% (55) and in costs as also described by Hyldig *et al.* (56). In the reconstruction of the thoracic wall with large tissue defects needing greater stability, the use of prosthetic or biologic mesh associated with titanium plates and soft tissue flaps is described (57-59). Khan *et al.* (60), in a firearm chest injury with parietal defect measuring 10 cm × 15 cm, noticed excellent outcomes in term of stability and recovery function by rotation of the latissimus dorsi. However, there are many experiences on the use of the pectoralis major muscle (61), rectus abdominis (62) and omentum (63). Regarding the costs related to the surgical treatment, an interesting meta-analysis was carried out by Swart *et al.* (64). It is obvious that the cost of intervention is greater than conservative therapy ($23,682 *vs.* $8,629).

However, the quality-adjusted life year (QALY) was equal to 32.60 *vs.* 30.84 respectively with a final ratio of $8,577/QALY. This finding, mainly due to the lower incidence of complications and shorter hospital stays, suggests that surgical treatment is to be preferred (65).

Conclusions

In the trauma chest wall reconstruction, the use of rigid devices is the quickest and safest way to achieve stability. Titanium is the preferred material due to inertia, chemical and physical properties and resistance to corrosion, evolving into lighter and more malleable alloys. Bioabsorbable implants are increasingly used although display limits of costs. Nonrigid mesh allows an excellent protection of the thoracic organs. Myoplasty is always advisable in order to re-establish the rigidity and functionality of the chest wall. VAC therapy is essential to avoid the risk of infection on the site of trauma. The best timing for intervention must be decided jointly between anesthesiologist and surgeon.

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Footnote

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