Review

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Surgical Methods of Chest Stabilization in Multiple Rib Fractures

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ABSTRACT Closed chest injury occupies one of the leading places among all injuries. Rib fractures can lead to the formation of floating fragments of the chest wall, the "costal valve". With multiple rib fractures, surgical methods of chest stabilization have been used since the beginning of the 20th century, which have become more popular in recent decades.

Surgical treatment can significantly reduce pain, accelerate the recovery of respiratory function. In turn, a decrease in pain reduces the incidence of pneumonia, the need for mechanical ventilation and tracheostomy, and the period of hospitalization. There are four main surgical methods of treatment: 1) chest traction methods; 2) external fixation devices; 3) methods of permanent internal fixation; 4) plate osteosynthesis. We also separated the group of techniques performed via thoracoscopic access and the technique using biodegradable materials. Surgical options in the treatment of patients with multiple rib fractures have not been exhausted and are likely to improve with advances in technology.

Keywords: rib osteosynthesis, closed chest injury, rib fractures

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CCT - closed chest trauma
CPAP - non-invasive continuous positive airway pressure ventilation
ICU - intensive care unit
FEV1 - forced expiratory volume in 1 second
MV - mechanical ventilation
PEEP - positive end-expiratory pressure
VAS - visual analogue scale

RELEVANCE

In 25% of cases, chest trauma is the cause of mortality among all patients who died from trauma [1]. More than half of the injuries are due to closed chest trauma (CCT) [2]. Rib fractures occur in 39% of injuries [3]. According to Martin T.J. et al. (2019), in the United States in 2018, 249 000 patients with rib fractures were identified with a tendency to increase the number of victims requiring hospitalization [4]. In China, this figure approaches 2 million [5]. In Russia, there is no general database on rib fractures, however, given the high level of injuries due to road traffic accidents, this issue is also relevant [6].

Most patients with rib fractures receive conservative therapy with good results. In the case of multiple fractures of the ribs and (or) a floating chest, mortality can reach 22%, and this figure increases with each additional broken rib [7]. In this case, patients need to stabilize the rib cage for adequate breathing. Since the 1950s, a method of pneumatic stabilization has become widely used, mechanical ventilation (MV) using positive end-expiratory pressure (PEEP) [3]. In parallel, since the beginning of the 20th century, surgical methods of chest stabilization have been developed [8], which have become more popular in recent decades. This article provides a literature review of various techniques for fixing ribs in patients with multiple fractures.

PATHOPHYSIOLOGICAL ASPECTS OF RIB FRACTURES AND UNSTABLE CHEST

In a closed injury, kinetic energy mainly affects the bone frame of the chest, which one of the main roles is protection of internal organs. With the number of broken ribs, the likelihood of an unfavorable outcome increases. Thus, in the presence of fractures from 1 to 5 ribs, the mortality rate reaches 5.8–10%, and with 6 or more, it grows up to 15% [9]. The reason is multifactorial. The development of respiratory dysfunction occurs due to pain syndrome, paradoxical breathing, secondary damage to internal organs by fragments of ribs, and pulmonary contusion. The first factor provoking the development of the pathophysiological cascade of respiratory dysfunction in patients with rib fractures is the pain syndrome, which is associated with the activation of the nociceptive system. Under the influence of a traumatic factor on the peripheral endings of nociceptors located in the impact zone and in places of rib fractures, a pain impulse is formed, which is transmitted along myelinated A-delta fibers and unmyelinated C-afferents to the dorsal horns of the spinal cord. Nociceptive neurons of the dorsal horns of the spinal cord form ascending tracts that carry out nociceptive signals to various subcortical regions of the brain and to the nuclei of the thalamus. There is a feeling of pain [10].

In response to pain, the body "isolates" the area of damage by contracting the muscles of the chest wall and restricting movement in the fracture zone, which leads to impaired chest excursion and, as a result, to impaired ventilation in the adjacent lung parenchyma [11]. In the absence of an adequate cough and a violation of mucociliary transport, the formation of mucous plugs, atelectasis, and the development of pneumonia during bacterial colonization are possible [12].

In addition to the pain syndrome, rib fractures can lead to the formation of floating fragments of the chest wall, the "costal valve". With an isolated injury, such a complication can develop in up to 20% of cases, with a combined injury, up to 70% [13]. This creates conditions under which the free section of the chest wall moves in the opposite direction to the movement of the chest wall, which reduces the efficiency of breathing and can lead to gas exchange disorders [14]. The instability of the chest in almost 50% leads to respiratory failure and the need for pneumatic stabilization, artificial ventilation with positive airway pressure on exhalation [15]. In a pathoanatomical study of those who died from CCT, in more than 50% of cases, a floating chest with hemo- and pneumothorax was detected [16], while the vast majority of the dead had lamellar atelectasis, projectively coinciding with the zones of flotation [17].

Instability of the chest wall is inextricably linked with pulmonary contusion, as one of the factors in the development of respiratory failure. The mechanism of pulmonary contusion is not fully understood. Based on physical laws, it is assumed that the acceleration and deceleration of the human body can cause damage to the lung tissue even without a significant collision, like a strong compression [18]. The whole process can be divided into three parts. Inertial effect — the alveolar tissue is damaged as a result of the shear force of the structures of the lung root, since tissues of different density are accelerated and slowed down in different ways [19]. The delamination effect is small discontinuities in places where the shock wave meets various adjacent surfaces [20]. Implosion effect is a shock wave compresses the gas in the tissues of the lung. Following this, the gas expands and leads to microexplosions of the air part of the lung [21]. With such displacements of the lungs, deformation and damage of the alveoli occurs with their separation from the bronchioles, thereby reducing the respiratory surface [22].

In the impact zone, blood and interstitial fluid accumulate in the alveoli [23]. Almost immediately, in response to injury, inflammatory proteins are concentrated in the area of injury, which further impairs ventilation [24]. There is a decrease in the amount of surfactant, and the alveoli eventually collapse, and the lung tissue loses its elasticity due to the accumulation of pathological fluid in it [25]. Pulmonary contusions in blunt trauma occur in the range of 17–75%. Given the above mechanisms, bacterial pneumonia can join, the frequency of which in pulmonary contusions reaches 20% [18]. Acute respiratory distress syndrome can also be a complication of pulmonary contusion in 17% of cases, and if more than 20% of lung tissue is damaged, it reaches 82% [26].

Rib fragments can damage various structures of the chest with the formation of hemo- or pneumothorax. Pneumothorax is observed in almost half of cases of chest injury [27], and hemothorax — in 1/3 [28]. With multiple and floating fractures, such interpleural complications are determined in 80–90% of cases [14]. Pneumothorax occurs due to damage to the lung tissue or airways. The presence of air in the pleural cavity leads to compression of the lung both on the side of damage and the contralateral lung due to the displacement of the mediastinum to the healthy side, which disrupts adequate gas exchange.

The ingress of blood into the pleural cavity can be associated with both damage to the lung and damage to the vessels of the chest wall (most often intercostal) and mediastinal vessels. Functional respiratory disorders in hemothorax practically do not differ from those in pneumothorax, with the exception of hemorrhagic anemia [29]. In addition, hemothorax can develop when the diaphragm is damaged, which occurs in 3% of CCT cases [30]. In addition to hemothorax, diaphragmatic rupture can lead to the development of diaphragmatic hernia [31] with infringement and necrosis of various abdominal organs [32].

Thus, an important direction in the treatment of a patient with a severe chest injury is the restoration of adequate chest excursion, prevention of lung damage by rib fragments, and relief of the consequences of pulmonary contusion.

BASIC TREATMENTS

In the treatment of rib fractures complicated by a floating chest, there are two fundamentally different approaches: conservative and surgical [33]. A conservative method is to stabilize the rib fragments by creating increased intrathoracic pressure due to PEEP. Respiratory support in this case can be performed using invasive mechanical ventilation or non-invasive constant positive airway pressure (CPAP) [34]. According to the results of studies, CPAP can reduce the time spent by patients in the intensive care unit (ICU), the total duration of hospitalization, and also helps reduce the likelihood of a nosocomial infection and reduces the need for patient intubation [35]. Also in the 1970s, the study demonstrated the technique of mechanical ventilation with intermittent ventilation and PEEP, which made it possible to reduce the duration of mechanical ventilation and stay in the intensive care unit [36].

Despite the positive results of conservative treatment using "positive pneumatization", patients had to be on a ventilator for a long time. This led to the development of a number of ventilator-associated complications. The desire to minimize the likelihood of complications, to reduce the duration of hospitalization has led to the search for more advanced and effective methods of treatment. Including surgical.

When compared with surgical techniques, conservative treatment is associated with prolonged mechanical ventilation, the risk of developing pneumonia, and prolonged stay in the intensive care unit [37]. Surgical treatment can significantly reduce pain, accelerate the recovery of respiratory function. Which, in turn, reduces the incidence of pneumonia, reduces the need for mechanical ventilation and tracheostomy, reduces the period of stay in the ICU and in the hospital as a whole [38].

The decision to choose one or another method of treatment is based on two indicators: the effectiveness and safety of the method. The effectiveness of the treatment method can be assessed by reducing or increasing the duration of hospitalization, the duration of mechanical ventilation. Safety is assessed by the number of complications and deaths.

There are four main surgical methods of treatment: 1) the use of chest traction methods; 2) use of external fixation devices; 3) use of methods of permanent internal fixation; 4) the use of plate osteosynthesis with plates [39]. Also, a group of techniques carried out through thoracoscopic access and a group of techniques using biodegradable materials are separately identified.

STABILIZATION USING CHEST TRACTION TECHNIQUES

The history of the method dates back to 1928, when Jones T. first published a method for the treatment of multiple rib fractures in a child. The method consisted in traction of the costal valve using bullet forceps, which made it possible to reduce the compression of the lung tissue and the risk of developing atelectasis and inflammatory changes [40]. It should be noted that this technique appeared earlier than the method of stabilizing the chest through mechanical ventilation. In 1946 Jaslow I. described the method of traction of the sternum during the formation of the anterior sternocostal valve. He used a hook from an ordinary hanger, which, through a small access under local anesthesia, was screwed into the sternum by no more than 5 turns, which made it possible not to go beyond the posterior cortical layer of the sternum. Then he hung the load to the hook through the block. The patient had to be in this position for 8 days [41]. The hanger became the prototype of the Shantz screws. In the early 50s of the XX century, the American surgeon Heroy W., in case of steering fractures of the ribs, screwed 2 metal screws into the sternum, for which he performed traction in the Fowler's position. Usually, within 24 hours, the screws broke out of the sternum and traction was continued using reduction forceps through the holes left by the screws (Fig. 1) [42].

Fig. 1. Traction of sternum after the installation of reduction forceps. (The photo from the article of Heroy W.W.)

The method of chest traction acquired various modifications; Thus, the Hungarian surgeon Constantinescu O. modeled a hook, which, when deployed in the tissues, turned into a T-shaped one and was fixed to a metal plate above the skin, due to which traction was carried out (Fig. 2) [43]. There were works by surgeons on the use of underwear hoes, corkscrews, but their essence was to create conditions under which the compression of the lung tissue decreased, the vital capacity of the lungs increased, and the risk of developing atelectasis decreased [39].

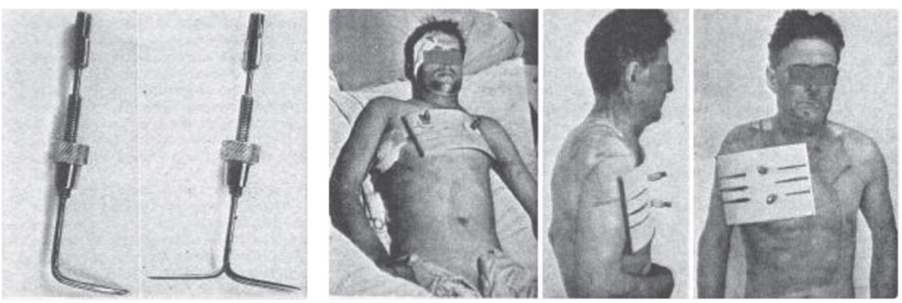

Fig. 2. The original Constantinescu's method of fixing ribs. (The photos from the article of Constantinescu O.)

Gryaznukhin E.G. in 2004, he suggested inserting 4 wires under local anesthesia using a drill into the body and the handle of the sternum through the intercostal space from different sides (in the plane of the sternum). The protruding tail ends of the wires were bent at the exit from the bone to the center of the sternum and fixed to one plate, which was used for traction [44]. In 2004, Balci A. et al. demonstrated the comparative results of the treatment of patients who underwent skeletal traction and treatment through the creation of PEEP. A 2-fold decrease in the duration of the need for mechanical ventilation and a decrease in mortality in the surgical treatment group by more than 10% were noted [45]. N.G. Ushakov (2010) also achieved positive results using this method. He noted a decrease in the duration of ventilation by 9 days and a decrease in mortality by 14.7% [46].

STABILIZATION USING EXTERNAL FIXATION DEVICES

The technique of using external fixation devices developed simultaneously with the methods of chest traction. In 1967 N.K. Goloborodko offered a technique for suturing rib fragments to a fixing splint located on the patient's skin and protruding beyond the fracture line by more than 5 cm. However, this method could not be applied in patients with bilateral rib fractures and sternum fractures [47].

In 1977 A.P. Paniotov offered a method of osteosynthesis by inserting into the pleural cavity through the center of the floating section of the chest a special trocar with a folding hinged four-link at the end. After the introduction of the trocar into the pleural cavity, the shoulders opened, resting against the inner surface of the affected ribs. From the outside, the trocar was fixed to an arc-shaped plastic panel with nuts, and the ends of the panel should protrude beyond the floating area [48].

In 2001, the Croatian surgeon M. Glava s suggested fixing the floating fragment with a Pallacos bone cement prosthesis. The prosthesis was located over the floating segment of the chest wall tangentially from the level from the top to the intact ribs. The ribs were attached to the prosthesis with sutures or wire [49]. In terms of efficiency, extrafocal extrapleural osteosynthesis has proven itself well. The external fixation apparatus includes rivet elements or rib hooks, a bearing rod, brackets and a stabilizing rod. The stabilizing bar is attached to the sternum, and the floating fragment is attached to the carrier bar. The system is fastened with brackets and nuts [50].

At the N.V. Sklifosovsky Research Institute in 2016 patented a device for external fixation of multiple and floating fractures of the ribs, clavicle and sternum. The design consisted of rods that had a thread at the inner end, through which the ribs were screwed into the outer cortical layer of the bone, and the outer ends were attached to the plate rod with nuts (patent No. RU 02637834 C2 20171207, author Sharipov I.A., Khubutiya M.Sh., Tarabrin E.A., Shakhshayev M.K.).

In 2018 V.D. Shatokhin et al. published an article that also presents the results of using an external fixator, which was fixed with anchors to stable areas of the ribs, clavicles, and pelvis [51]. Thus, the available methods of external fixation for multiple and floating rib fractures have proven their effectiveness and can be considered as methods of temporary or final stabilization.

STABILIZATION USING METHODS OF PERMANENT INTERNAL FIXATION

This technique involves the location of stabilizing devices inside the body without external fixing bases. One of the first publications on this type of chest stabilization belongs to the French surgeon V. Dor (1967). Stabilization was performed through thoracotomy using Kirschner wires [52]. Guernelli N. et al. (1979) described a similar method in which the stabilization of floating fractures was achieved by inserting two long Kirschner wires under the costal valve zones at the completion of the thoracotomy. The pins were removed in 30 days. The authors noted good results [53].

In 1991 Landreneau R. et al. described a technique using metal rods for external fixation with the Lunque system. The rods were inserted into the ribs through a thoracotomy approach to the area of the floating area and fixed using an external mechanism located in the soft tissues of the chest wall [54] (Fig. 3).

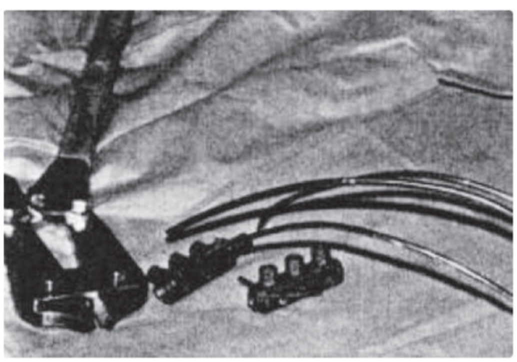

Fig. 3. Removed Lunque fixator. (|The photo from the article of Landreneau RS)

Soviet surgeon Yu.B. Shapot et al (1985) developed their own modification of the fixation of multiple rib fractures using Kirschner wires. The wires were bent according to the shape of the rib and placed above it and fixed with tantalum brackets; the removal was performed after 10 months [55].

Kirschner wires also formed the basis of intramedullary rib osteosynthesis. A metal pin was inserted through the cortical layer of the rib fragment into the brain canal and passed through the fracture zone into the second fragment. Kirschner wires have been used for intramedullary osteosynthesis for more than 50 years; however, complications such as implant cutting through the bone tissue, its migration, and rotational instability are associated with their use [8, 55].

According to the results of one of the biomechanical studies, it was shown that under load, the pin can be dislocated from the rib tissue due to its strength and reduced elasticity, which leads to possible damage to soft tissues and loss of carcass strength [56]. In order to reduce the described complications, intramedullary fixators (ribs splints) have been developed. According to biomechanical studies by Bottlang M. et al. (2010), these fixators stabilize the fracture site twice better than wires [57]. In addition, implant dislocation is very rarely observed with this method of fixation. There are isolated cases of implant migration that can cause pain [58]. The main advantage of intramedullary osteosynthesis over other methods is the simplicity of device placement and minimal invasiveness, which is provided by small skin accesses, which reduces the likelihood of postoperative complications [59].

The significant reduction in pain syndrome is also important, which was demonstrated by Ali Akil (2019), performing video-assisted intramedullary osteosynthesis (visual analogue scale — VAS, 2.6±0.3 after surgery versus 8±1.15 before surgery, p <0.0001) [60]. Redwan B received similar results. (2015) [61]. Another advantage of the intramedullary fixator is the ability to stabilize fractures in hard-to-reach areas of the chest, for example, under the scapula [62], on the posterior segment of the ribs, or in case of fractures of the first ribs [56]. However, according to the observations of Marasco S. et al. Despite the above benefits, only 9% of patients showed complete consolidation of bone structures 3 months after surgery [63].

STABILIZATION USING PLATE OSTEOSYNTHESIS

The most popular system for external osteosynthesis is MatrixRIB. It is a titanium plate, mechanically resistant to bending, clearly repeating the costal anatomy. The thickness of the plates is 1.5 mm, the length is variable and depends on the number of fixation holes (from 15 to 18) intended for attaching the plates to the rib using 2.9 mm fixing screws [64].

When comparing the Kirschner wires with the system of bone fixation in a biomechanical experiment, it was found that the dynamic load caused, on average, 3 times more deformation of the wires (1.2±1.4 mm, p = 0.09) than the bone structures (0.4 ±0.2 mm, p =0.09). It was also shown that the total strength of fixation with the use of bone screw structures is 48% higher than with the use of wires (p = 0.001) [57].

Screw osteosynthesis is widely used both in foreign and Russian practice in patients with multiple rib fractures and unstable chest [65] (Fig. 4).

Fig. 4. Osteosynthesis of ribs with MatrixRIB plate. (The photo from article of Benyan A.S.)

The main indicators of the effectiveness of plate osteosynthesis is the restoration of satisfactory values of the function of external respiration. So, Pushkin S.Yu. et al. (2014) showed that the increase in forced expiratory volume in 1 second (FEV1) by the time of discharge of the patient is more than 25% [66]. These results were made on the basis of observation of 5 patients with CCT. According to Bottlang M. et al. (2013), 3 months after surgery, 84% of patients showed restoration of proper FEV1 values [67].

An important aspect of the use of rib osteosynthesis is the reduction of pain, which was confirmed by the study of Wu W.-M. (2015), where the pain score decreased from 5.8 to 3.3 (p <0.05) according to VAS [68]. This analgesic effect was confirmed in a systematic review by de Jong M.B. (2014) [62]. Improvement in external respiration and adequate analgesia help to reduce the need for mechanical ventilation [69]. Thus, in the article Pieracci F.M. (2016) demonstrated a statistically significant decrease in the duration of mechanical ventilation from 5 (0–18) to 0 (0–8) days (p <0.01), moreover, this led to a decrease in the number of tracheostomies from 45.7% to 14.3% (p = 0.01) [70]. Jing-Qing Xu (2015) noted that the use of surgical stabilization of the ribs through osteosynthesis not only reduces the need for mechanical ventilation, but also reduces the incidence of pneumonia by 20–45% (p < 0.05) [71].

Taken together: better analgesic ability, no need for long-term mechanical ventilation, a decrease in the frequency of infectious pulmonary complications leads to a reduction in the bed-day in the intensive care unit by an average of 3-4 days ($p < 0.016$) and the total duration of hospitalization by 8-9 days [72]. However, it should be noted that there are literature sources demonstrating the absence of a positive effect from the use of surgical stabilization of the ribs [73]. The occurrence of complications in the early postoperative period was described in 8.9 patients (11.8%) [74], according to some results, in 7.4 (37%) [75]. Among the possible complications, various authors describe the development of sepsis, pleural empyema, suppuration of the postoperative wound [74]. In addition, there may be complications associated with technical malfunctions of the implant, such as a fracture of the fixator plate, its displacement, which necessitates a second operation [75]. Despite this, there are publications in which the authors describe an uncomplicated course of the early postoperative period, as well as optimal pain relief [67, 69].

Another screw system that has won its place in clinical practice is called RibLoc and is a U-shaped retainer, shorter than other implants, fastening the rib along the upper edge with screws attached to the surface of the rib in the anteroposterior direction.

RibLoc system makes it possible to reduce the size of the surgical approach due to its small size compared to other implants [76] (Fig. 5). In one of the biomechanical studies, when comparing these fixators with plate osteosynthesis, it was shown that when simulating the load that occurs during respiratory movements, the U -shaped fixator lost 0.12±0.03 N/mm (1.9%) of its rigidity, while the lamellar one is 0.72 ± 0.13 N/mm (9.9%) ($p = 0.001$), which allows us to conclude that the RibLoc system is more wear-resistant compared to bone plates [77]. When used in patients with rib fractures, this system showed satisfactory results of fixation, pain relief, and an uncomplicated postoperative period [78]. Also, according to Said S., after applying the described fixation technique, there are positive changes in FEV1 compared with the preoperative value and further improvement over the next 3 months [79].

Fig. 5.Ribloc system. (The photo from the article of De Palma A.)

Possible complications include the formation of a hematoma, breakage of the fixator, severe pain syndrome, which may be an indication for the removal of the fixator [80].

Thus, the main advantage of the U-lock system is the possibility of its installation from a minimally invasive approach. At the same time, this fixator is not inferior in its biomechanical characteristics to the plates of the bone system and can be effectively used in patients with rib fractures.

In addition to screw plate structures, there are also screwless ones. One of the first such systems was the Judet plate, which is a bone fixator made of fastening clips, connected by a bar between them. The clips are bent and thus compress the rib on both sides of the fracture, fixing the fragments to each other [81]. The method became the progenitor of the Stracos rib fixation system, which is currently successfully used for rib fixation [82] (Fig. 6).

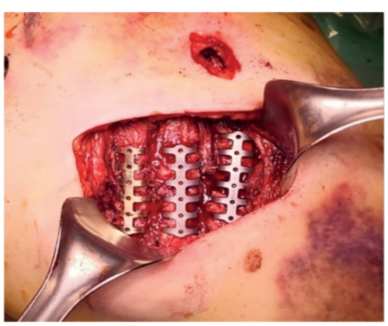

Fig. 6. Osteosynthesis with Stracos plates

Screwless bone fixators are also effective. So, in a study conducted by French specialists, it is noted that the surgical intervention is easy to perform, the design is flexible, which helps prevent plate fracture. There is also a significant decrease in the time of mechanical ventilation compared with the control group, which was treated conservatively (142±224 versus 74±125 hours, p =0.026). A similar positive result was also achieved with regard to the duration of hospitalization (32.3±19.3 versus 21.7±7.8 days, p =0.024) [82]. Comparable results were obtained by the Japanese surgeon Tanaka, who used Judet plates to fix rib fractures. He noted a decrease in the duration of mechanical ventilation (10.8±3.4 days versus 18.3±7.4 days, p <0.05), a decrease in the incidence of pneumonia (24% versus 77%; p <0.05) [83]. A breakdown of the fixation apparatus was observed in 20% of cases [84].

THE ROLE OF VIDEOTHORACOSCOPY IN RIB CAGE STABILIZATION

Since the beginning of 2,000 techniques using videothoracoscopy to reduce the trauma of rib osteosynthesis, are being developed. Zhestkov K.G. (2006) suggested a technique for fixing the ribs with pins under video-assisted thoracoscopic control. To fix the fracture, they were subjected to pericostal sutures on the stable and floating parts of the ribs. After reposition, pins were inserted subfascially. Tightening of the pericostal sutures led to fixation of the rib fragments to the wire and prevented flotation [85].

Sunkui K. (2013) performed 3 thoracoscopic surgeries in patients with floating chest. He used a Nass plate, which he positioned so that its ends extended beyond the floating area and were fixed to a stable part of the chest, so that paradoxical movement of the chest did not occur. The safety and efficacy of this technique has been noted [86].

External osteosynthesis, also performed under the control of a videothoracoscope, makes it possible to localize rib fractures more clearly, avoid damage to intercostal vessels and internal organs during reposition and fixation [87]. In addition, video-assisted thoracoscopic osteosynthesis accelerated rehabilitation and improved respiratory function, reduced the incidence of wound infection from 18% to 2.9% (p = 0.044) and accelerated discharge from the hospital (5.64±1.11 versus 7.58± 1.15 days, p <0.001) [88]. Pieracci F. (2019) performed several surgeries that used full thoracoscopic rib fixation with MatrixRIB plates. The plates were fixed on the inside of the ribs with screws screwed in with specially designed endoscopic screwdrivers (Fig. 7). The author reports good results and no infectious complications, but a comparative analysis has not yet been conducted [89]. In 2021, Zachary M. Bauman et al. demonstrated the results of treatment of a patient with multiple rib fractures. Rib fragments were fixed with a specially designed metal instrument for interpleural fixation under video thoracoscopic control [90].

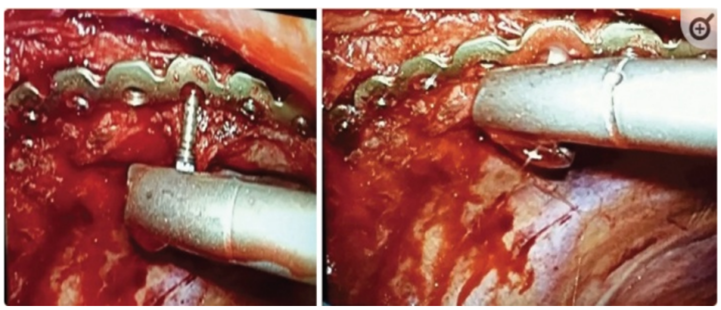

Fig. 7. Osteosynthesis via thoracoscopic access. (The photo from the article of Pieracci FM)

RIB FIXATION WITH BIODEGRADABLE SYSTEMS

A feature of the described osteosynthesis systems is their manufacture from non-resorbable materials. The patient wears the structure in his body for life, or a second operation is required to remove it. However, there are structures developed from resorbable materials. So, Mayberry J.C. (2003) used plates and screws made of biodegradable material, poly (L-lactide-co-D, L-lactide). There was a minimum number of surgical complications (in one case out of ten, suppuration of the surgical wound was noted, which required drainage) and satisfactory consolidation of fractures [91].

These implants can be fixed both to the outer and to the inner surface of the ribs using absorbable sutures (Fig. 8). They retain sufficient rigidity for the time required for fracture consolidation. In addition, the slow resorption of the structure leads to a gradual increase in the mechanical load on the bone, which prevents “stress-shielding” (local osteoporosis), a decrease in bone density and an increase in fragility due to the lack of load [92]. Similar complications may occur after the removal of metal structures [93].

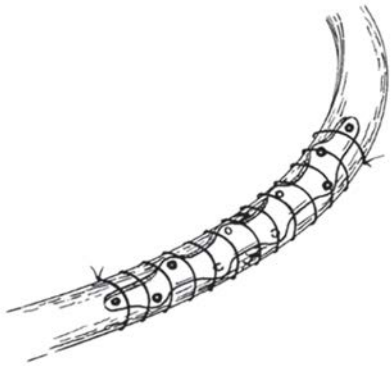

Fig. 8. Image of a biodegradable plate fixed to the rib with sutures. (The photo from the article of Mayberry J.C.)

In 2013, Marasco S.F. et al. performed a comparative analysis of the results of treatment of patients who underwent surgical treatment with absorbable plates made of polylactide copolymer and received conservative therapy was also carried out. He noted a positive effect in the form of a reduction in the average need for non-invasive ventilation from 50 to 3 hours (p = 0.01) and a decrease in the time spent in the intensive care unit from an average of 359 to 285 hours (p = 0.03) [63].

CONCLUSION

The presented review demonstrates the diversity of surgical methods for stabilizing the chest. A universal method that could be used for all types of fractures and complications has not yet been developed. Thus, surgical options in the treatment of patients with multiple rib fractures are not exhausted and are likely to improve with advances in the technological field.

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