Korean J Thorac Cardiovasc Surg 2016;49:1-8 □ Review □
ISSN: 2233-601X (Print) ISSN: 2093-6516 (Online) http://dx.doi.org/10.5090/kjtcs.2016.49.1.1

The Role of Minimally Invasive Plate Osteosynthesis in Rib Fixation: A Review

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More than a century ago, the first scientific report was published about fracture fixation with plates. During the 1950’s, open reduction and plate fixation for fractures were standardized by the founders of Arbeitsgemeinschaft für osteosynthesefragen/Association for the Study of Internal Fixation. Since the introduction of plate fixation for fractures, several plates and screws have been developed, all with their own characteristics. To accomplice more fracture stability, it was thought the bigger the plate, the better. The counter side was a compromised blood supply of the bone, often resulting in bone necrosis and ultimately delayed or non-union. With the search and development of new materials and techniques for fracture fixation, less invasive procedures have become increasingly popular. This resulted in the minimally invasive plate osteosynthesis (MIPO) technique for fracture fixation. With the MIPO technique, procedures could be performed with smaller incisions and thus with less soft tissue damage and a better preserved blood supply. The last 5 years rib fixation has become increasingly popular, rising evidence has becomeavailable suggesting that surgical rib fixation improves outcome of patients with a flail chest or isolated rib fractures. Many surgical approaches for rib fixation have been described in the old literature, however, most of these techniques are obscure nowadays. Currently mostly large incisions with considerable surgical insult are used to stabilize rib fractures. We think that MIPO deserves a place in the surgical treatment of rib fractures. We present the aspects of diagnosis, preoperative planning and operative techniques in regard to MIPO rib fixation.

Key words: 1. Ribs
2. Minimally invasive surgery
3. Plate

MINIMALLY INVASIVE PLATE OSTEOSYNTHESIS

More than a century ago, the first scientific report was published about fracture fixation using plates [1,2]. The pioneers in plating fractures were the Belgian surgeon Albin Lambotte (1866-1955) and the Scottish surgeon Sir William Arbuthnot Lane (1856-1938), who introduced internal plate fixation for fractures. During the 1950s, open reduction and plate fixation for fractures were standardized by the founders of the Swiss Association for the Study of Internal Fixation [1]. The ultimate goal of fracture treatment and internal fixation, as noted in the first edition of the ‘Arbeitsgemeinschaft für osteosynthesefragen,’ is to restore the function of the injured limb [3]. Plate osteosynthesis is capable of providing anatomical reduction and stable fixation, as well as allowing early functional mobilisation and usually leading to better clinical outcomes. Since the introduction of plate fixation for

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Received: December 29, 2015, Revised: January 21, 2016, Accepted: January 21, 2016, Published online: February 5, 2016
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fractures, several plates and screws have been developed, all with their own advantages and disadvantages. Material dysfunction was first described by Lane in 1895, who described corrosion, and Lambotte in 1909, who characterized the insufficient strength of the metal used [1,2]. In 1926, both alloys and stainless steel were introduced in fracture surgery, and from that moment on the quality of the implant material improved over the years. In order to achieve greater fracture stability, it was thought that thicker and heavier plates should be used for internal fixation. Although these heavy plates resulted in a strong and rigid fixation, they had the disadvantage of a compromised blood supply to the fractured bone, often resulting in bone necrosis and ultimately delayed union or non-union. In the search for a better plate, the dynamic compression plate was developed and eventually evolved into the limited-contact dynamic compression plate. A new type of plate was introduced with up to 50% less cortical contact than the dynamic compression plate, thereby preserving the periosteal blood supply [2]. With the search for and development of new materials and techniques for fracture fixation, less invasive procedures have become increasingly popular over the last few decades [4-6]. In order to accomplish reduction and ultimately a stable fixation of the fracture, large incisions have often been used for adequate exposure. The dissection and accompanying devitalization of the soft tissue and bone create a less favourable environment for bone healing and increase the risk of infection. The benefits of less invasive procedures are obvious in smaller surgical wounds, where they result in less postoperative pain, improved postoperative function, the preservation of blood supply, and fewer surgical site infections [4-6].

Due to an increasing demand for minimally invasive procedures, less invasive stabilisation systems became available in the late 1980s. These systems were designed to be inserted though small, strategically placed incisions. Following this development, minimally invasive plate osteosynthesis (MIPO) was introduced for fracture fixation [2,4,5,7]. With the MIPO technique, procedures could be performed with smaller incisions and thus with less soft tissue damage and a better preserved blood supply. MIPO has so far only been described in diaphyseal and metaphyseal fractures of the femur, tibia, and the humerus [4,5,7].

RIB FIXATION

Blunt thoracic trauma often leads to isolated or multiple fractured ribs, especially in elderly patients with osteoporotic bones [8]. In the United States alone, over 450,000 patients with fractured ribs present to the emergency department each year [9]. It has been reported that the presence of multiple fractured ribs is associated with a mortality rate of up to 30% and a major morbidity rate of up to 70% [10]. Fractured ribs can lead to respiratory problems, especially when fractured in more than one place, as in flail chest. Generally, patients with fractured ribs suffer from pain, resulting in less efficient breathing, impaired ventilation, and ultimately the development of pneumonia. Studies have shown that up to 30% of patients with isolated or multiple fractured ribs develop pneumonia [8]. This potentially lethal complication could lead to a prolonged hospital stay, the need for mechanically supported ventilation with all its associated complications (e.g., pneumothorax and ventilation-acquired pneumonia), and ultimately an increase in health care costs. However, even without pneumonia, the presence of fractured ribs is associated with the need for mechanical ventilation, especially in patients with flail chest. Flail chest is defined as three or more consecutive, ipsilateral, doubly broken ribs. These patients often show impaired ventilation due to the paradoxical movements of fractured ribs during normal breathing.

Although the majority of patients with fractured ribs can be treated conservatively, the surgical fixation of fractured ribs has become increasingly popular. The ultimate goal of surgical rib fixation is to reduce pain, optimise oxygenation and ventilation, and ultimately avoid the need for mechanical ventilation. No clear consensus exists in the literature regarding absolute indications for surgical rib fixation [11]. However, an increasing amount of evidence suggests that surgical rib fixation improves the outcome of patients with flail chest. Recent studies have shown that operative stabilization in flail chest patients is associated with fewer days on mechanical ventilator support and a lower incidence of pneumonia [12,13]. Relative indications for surgical rib fixation, such as delayed or non-union of fractured ribs, severely displaced fractured ribs, and excessive pain despite maximal analgesia, are still the subject of debate, and future studies must show

Fig. 1. Three-dimensional reconstruction of the computed tomography scan of a patient with multiple rib fractures on the left side.

whether patients with these conditions benefit from surgical rib fixation. Finally, surgical rib fixation has been used in patients undergoing thoracic surgery.

Many surgical approaches for rib fixation have been described in the older literature, but most of these techniques are now obscure [14]. In the early years of the twentieth century, the severe clinical consequences of flail chest were already recognized, with a reported mortality of up to 80%, mostly due to ventilatory problems [15,16]. This high mortality rate prompted many surgeons to develop techniques that could fix the fractured ribs, with the ultimate goal of improving ventilation and reducing mortality. In 1926, the first report of rib fixation in a patient with flail chest was described [17]. A bullet forceps on traction was used to percutaneously apply external support to the chest wall. Subsequently, several other, sometimes wacky, techniques have been used [14]. Some examples include the Cape Town limpet, analogous to a regular sink plunger that was applied to the chest wall, resulting in expansion of the thorax, and the introduction of a hook from a clothes hanger into the sternum, which was connected to a weight, resulting in traction on the chest wall [14]. The rationale of all these old-fashioned techniques was to restore the biodynamic characteristics of the chest wall and to reduce pain.

The first open surgical open reduction and fixation of fractured ribs was described in 1967 [18]. Two K-wires were used to fix the fractured ribs during thoracotomy. Following this report, many intramedullary techniques have been described, as well as suturing and bridging techniques with which the fractured ribs were surrounded or connected by metal wires and sutures. Since 1980, plate osteosynthesis has become more popular, probably due to the high complication rate and unsatisfactory results of the aforementioned techniques. Several specially designed plates and screws have been described, but only in small studies with a short period of follow-up [14]. Over the past decades, the quality of the plates and screws has improved, ultimately leading the current use of anatomic and angularly stable titanium plates that easily fit onto the fractured ribs.

THE ROLE OF MINIMALLY INVASIVE PLATE OSTEOSYNTHESIS IN SURGICAL RIB FIXATION

As described above, MIPO has become increasingly popular in orthopaedic surgery in patients who have experienced trauma, especially in patients with fractures of the long bones. So far, no case series or technical reports have described the role of MIPO in surgical rib fixation. Since a solitary rib could be seen as a long bone, similar to the tibia, humerus, and femur, although much more fragile, MIPO may be a promising alternative technique to the current maximally invasive approaches. Remarkably, in 1975, Paris et al. [19] reported a less invasive technique for rib fixation in a handful of patients, but this technique has never been described in further detail. Currently, large incisions with considerable surgical insult are most commonly used to stabilise rib fractures. We think that MIPO deserves a place in the surgical treatment of rib fractures. Therefore, we describe this technique in more detail below.

1) Localisation of rib fractures

In order to successfully apply the MIPO principles to rib fixation, it is crucial to position the patient correctly and to determine the correct location of the incision. Fractured ribs are difficult to palpate, and preoperative imaging techniques should therefore be used to determine the localisation of the

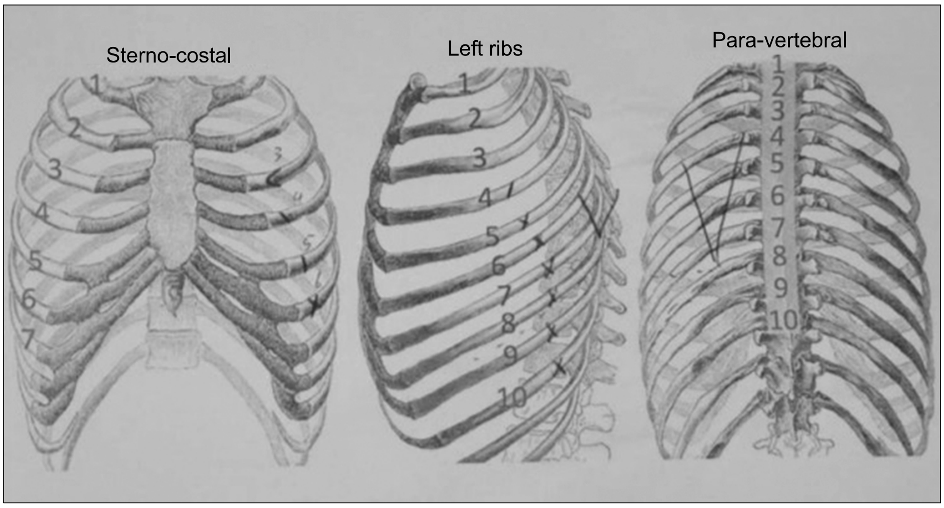

Fig. 2. Schematic of a patient with rib fractures; the symbol / indicates a non-displaced rib fracture, < indicates a slightly displaced rib fracture, and an X marks a displaced or comminuted rib fracture.

Fig. 3. A patient with anterior rib fractures localised using ultrasound.

fracture and, consequently, the location of the incision. In the preoperative setting, we think that a computed tomography (CT) scan is essential. The literature shows that plain chest X-rays underestimate the amount of fractured ribs, as well as the severity of the fractures [20-22]. In our opinion, plain chest X-rays should only be used to obtain general information about the number and severity of the fractured ribs. If there is any doubt about the diagnosis or if there is any clinical suspicion of multiple fractured ribs, a CT scan should be performed. With the CT scan, an exact localisation of the fractured ribs can be performed and the severity of the fractures can be assessed. Three-dimensionally (3D) reconstructed pictures of the rib cage are a helpful tool for obtaining a global overview of the fractured ribs (Fig. 1). Caution, however, is warranted, as the 3D technique tends to smoothen out the fracture lines of the ribs, with the ultimate risk of missing certain fractures. Therefore, we still depend on the conventional transverse slices of the CT scan for planning the operation.

Subsequently, all fractures are drawn in a schematic diagram, creating a roadmap for the operation (Fig. 2). At this point, a plan can be made to identify which ribs require correction and which can be left without surgical treatment.

The next step is to determine the location of the incision(s). This can be done by using four anatomical landmarks, which can always be found regardless of the phenotype of the patient: (1) jugular notch of the sternum, (2) xiphoidal point of the sternum, (3) mid-axillary line, and (4) scapular point.

The first three anatomical landmarks are always in exactly the same position, while the location of the scapular point is position-dependent. When using the scapular point as an anatomical landmark, it is essential to know whether the patient was positioned during the preoperative CT scan with the arm elevated or with the arm parallel along the torso. In the majority of cases, the location of the fractured ribs and, thus, the location of the incision can easily be determined using the aforementioned anatomical landmarks. If the surgeon needs an even more accurate localisation, ultrasound imaging can be used. The literature indicates that ultrasound in experienced hands is a reliable imaging tool for determining the location of the fractured ribs [22]. The day before the oper-

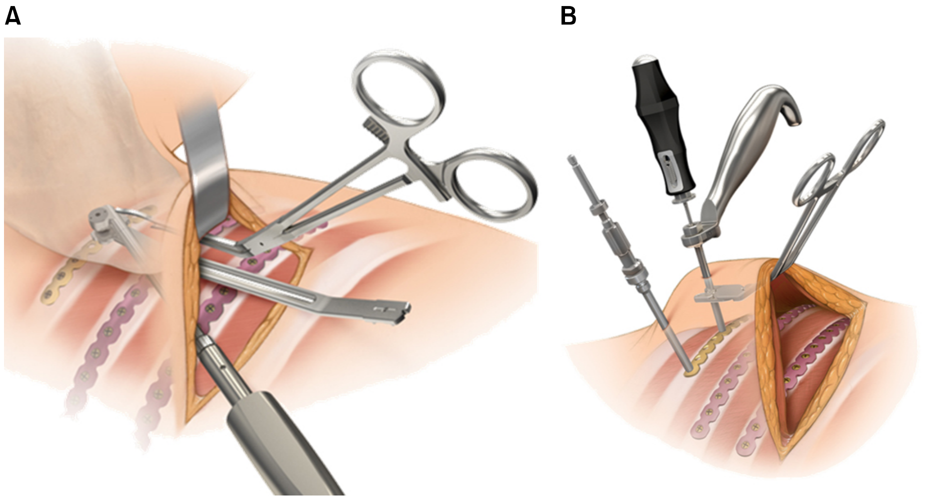

Fig. 4. Overview of the minimally invasive plate osteosynthesis instruments. (A) The 90 degree angle drill and screwdriver in combination with the drill guide and plate holding clamps. (B) Trocar in the plate with the clamp lifting up the soft tissue creating a working window, enabling visualisation of the plate on the rib.

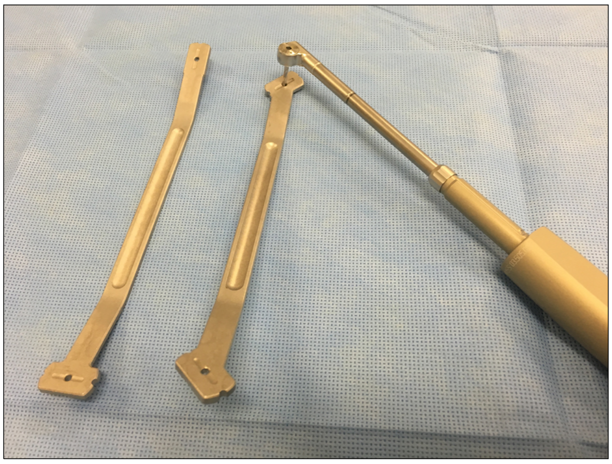

Fig. 5. Specific drill guides with four different angles ensuring perpendicular drilling in the centre of the hole of the plate. For the more experienced surgeon, additional notches have been created on the side, making it possible to drill three holes sequentially.

ation, we always perform an ultrasound to obtain an even more exact localisation. During the ultrasound, the radiologist positions the patient exactly as he or she will be placed during the operation. This last step is essential, as one can imagine that the location of the marked skin in relation to the fractured ribs will vary depending on the position of the patient. Fig. 3 shows a patient with the preoperative ultrasound localisation of four fractured ribs on the anterior chest wall.

2) Minimally invasive plate osteosynthesis tools

When initiating the operation, additional tools and techniques facilitate the application of the MIPO principles. The Alexis wound retractor is a frequently used instrument in thoracoscopic- and laparoscopic-assisted procedures. However, no scientific reports have yet described the use of the Alexis wound retractor in approaches to the chest wall and surgical rib fixation. When starting the MIPO procedure, the skin is incised at the predetermined location, followed by division of the subcutaneous tissue. Depending on the location of the fractures, muscle fibres are divided in a muscle-sparing manner until the chest wall is reached. Subsequently, a cavity is created between the chest wall and the overlying soft tissue, enabling the placement of the Alexis wound retractor. This retractor is available in several sizes, but we mainly use the retractor with a diameter of 4 cm. After placement of the inner ring between the chest wall and the soft tissue, the retractor is tensioned by rolling itself on the outer ring, creating an outward retracting force and forming a window through which the procedure can be performed. Another advantage of the Alexis wound retractor is that the rubber seal between the inner and outer ring has a haemostatic feature, creating a dry operating window.

Analogously to the MIPO technique used in long bone fractures, additional tools are needed to facilitate surgery. These additional tools are available in a separate MIPO matrix kit (Depuy-Synthes, West Chester, PA, USA) (Fig. 4).

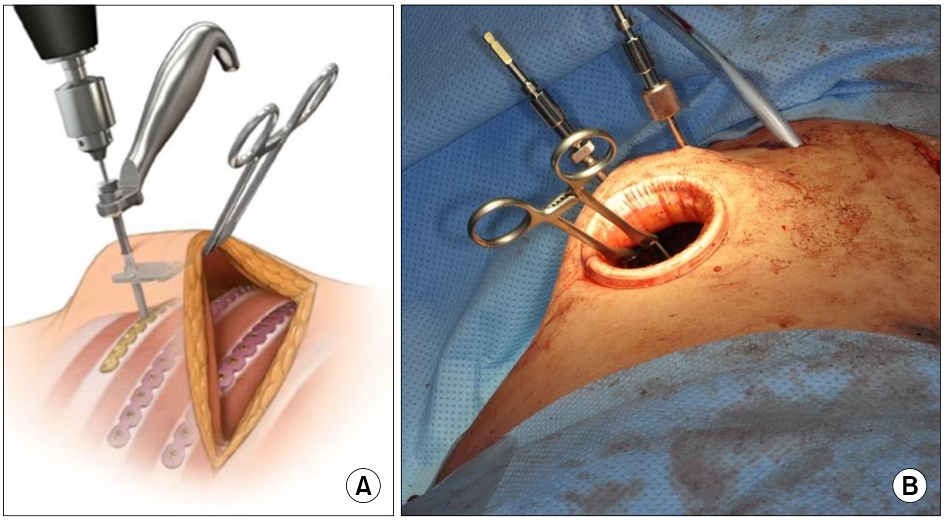

Fig. 6. (A, B) The position of the trocar in the plate and with the clamp around the trocar lifting up the soft tissue. In this patient, the plate was held in position with two threaded reduction tool devices.

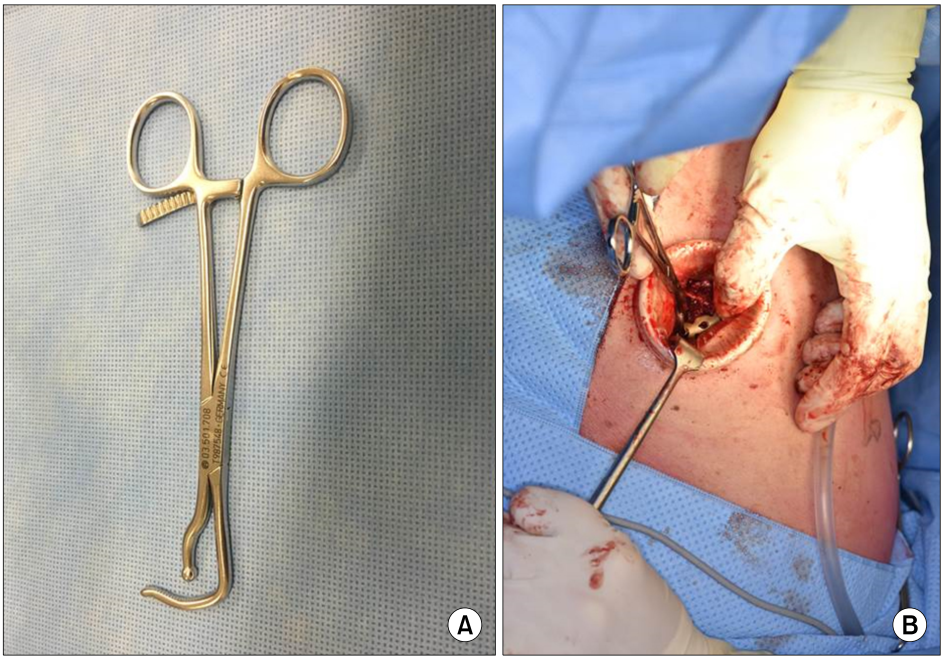

Fig. 7. (A, B) The upright clamp enabling fixation of the plate through a small incision in a perpendicular fashion.

This kit, together with the 90-degree drill and screwdriver, enables the surgeon to stabilize almost every fracture type. In the next paragraphs, we describe the MIPO technique with illustrative examples of its application in patients.

The 90-degree drill and screwdriver enable the surgeon to drill through a small incision in a perpendicular fashion to the plate and rib, ensuring the correct placement of the locking screws. The drill has a knob at the end, making it possible to manually drill a hole. Since ribs have a relatively thin cortex, manual drilling is relatively effortless. However, if power drilling is preferred, the rear knob can be substituted with a maxilla facial power drill or the Pendrive (Depuy-Synthes). The 90-degree drill device also functions as a 90-degree screwdriver if the drill bit is substituted with a screwdriver bit. The challenge with using the 90-degree drill device is to drill a hole perpendicular to the rib exactly in the middle of a well-positioned plate. It is important to realize that an off-angle placement with a maximum of only five degrees will be tolerated by the plate and screw. In order to facilitate this perpendicular drilling, two drill guides with four different approach angles are provided (Fig. 5).

The MIPO matrix kit contains several tools. One of these tools is a trocar set with a soft tissue clamp (Fig. 6). This trocar set facilitates fixing fractured ribs at some distance from the incision. The designated rib fracture is exposed underneath the soft tissue and reduced. An appropriate plate is pre-bent by the surgeon and positioned on the rib. Specific clamps can hold the plate in the correct place. Through a stab incision, a trocar is placed in a strategic manner enabling the placement of multiple screws. Next, through the trocar, a drill guide is placed in the designated hole and screwed in the thread of the plate. Additionally, a soft-tissue clamp is placed underneath the tissue envelope on the same trocar. When lifted and closed, the clamp will tension the soft tissue, creating a window through which the plate can be visualised and approached. Subsequently, the rib is drilled with the appropriate drill length, the drill guide is removed, and an appropriate-length screw is placed. This sequence is repeated until all screws are placed.

The MIPO kit also provides a threaded reduction tool (TRT), which is extrapolated from the less invasive stabilisation system used for long bone fractures. This TRT consists of a threaded drill with a nut at the end. With this tool, it is possible to temporarily fix the plate to a rib. The TRT should be inserted through the trocar and drilled into the designated rib. After drilling, the nut at the end of the TRT should be turned down, pushing the trocar with the plate onto the rib (Fig. 6). This results in a temporarily fixed plate, enabling the surgeon to drill and place all other screws into the plate. Finally, the TRT is removed and a screw can be placed, using the hole that was pre-drilled.

The last tool of the MIPO kit is a special upright reduction clamp. This clamp enables the perpendicular fixation of a plate onto a rib through a small incision (Fig. 7). One should, however, realise that the clamp has a limited range corresponding to the thickness of the rib.

3) Concerns related with minimally invasive plate osteosynthesis

The introduction of MIPO in rib fixation has led to new difficulties that are not likely to occur in conventional surgery. As addressed in the previous paragraphs, the location of the incision is crucial, since a certain number of rib fractures must be fixed through the same small incision. Furthermore, working through small incisions makes it challenging for the surgeon to determine the screw length. In the preoperative plan, the CT images are crucial for determining the rib thickness and, thus, the length of the screws. A helpful trick in regard to drilling and determining the screw length is to pay attention to the behaviour of the drill penetrating the first and second cortex and the remaining length of the drill in relation to the trocar. A surgeon experienced with this technique can use it to determine whether the chosen drill length was adequate. It may sometimes be necessary to adjust the length of the drill and screws, as an estimation made on the basis of the CT scan may not always prove accurate.

Another challenge is the contouring of the plate through small incisions. This is much more demanding than doing so through a large incision and requires some experience. All surgeons starting with the MIPO technique have to go through a learning process. It is essential not to rush the procedure, since an inaccurate contour or incorrect placement of the plate will result in insufficient osteosynthesis. Especially in surgeons who are not familiar with MIPO, these aforementioned concerns will translate into a longer operation time. However, as experience is gained, the operation time will gradually decrease.

4) Future aspects

As mentioned before, no scientific reports have so far described the use of MIPO for rib fixation. This reflects the fact that MIPO for rib fixation is a new and developing technique. Comparable with MIPO techniques for the long bone surgery, it is expected that in the near future, new tips and tricks will become available, resulting in improved patient care. The unique feature of a fractured rib compared to a fractured long bone is the pleural cavity underneath the rib. In theory, it may be possible to fix the fractured rib through a thoracoscopic approach, but no adequate tools or implants yet exist that would make this possible. Due to the continually increasing interest in surgical rib fixation, new developments and approaches are expected in the near future.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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