Minimally Invasive Reduction and Fixation in Orthopedic Trauma

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In China, approximately, 4.41 million individuals sustain fractures every year. With the rapid development of economy, industrialization, and urbanization as well as the aging of the Chinese population, it is predictable that the number of traumatic fractures will inevitably increase dramatically in the near future. According to the nation-wide data on the clinical epidemiology of orthopedic trauma during 2010–2011, fractures occurring in young and mid-aged patients reached 72%, representing the predominant injuries, and the corresponding percentage of fractures in elderly people was 14.7%.[1] Most of the fractures require operative treatment. Open reduction and internal fixation (ORIF) via a large incision was once a commonly used method in the treatment of traumatic fractures, which remains an important choice of treatment algorithm for fractures. However, ORIF is often associated with relatively extensive invasion and increased incidence of infections and nonunion of the fractures. Minimally invasive surgery (MIS) has gained its popularity in many specialties in the last two decades or so, due to its minimal invasion, fewer complications, quick recovery, and the reduced expense.[2-4] In the field of orthopedic trauma, minimally invasive reduction and fixation, which is the ultimate goal that patients and surgeons have been in persistent pursuit of for a long time, has been achieved, benefiting from sustained attention and the emerging of various new concepts and techniques. Among them, biological osteosynthesis (BO) is one of the currently and widely applied concepts in the management of orthopedic trauma. BO has gained considerable popularity since its advent for fracture management and subsequent successful application in basic research and clinical application. The techniques of less invasive stabilization system for long bone fractures, the internal compression fixation technique via a minimally invasive incision for displaced intra-articular calcaneal fractures,[5,6] and other percutaneous reduction and fixation techniques,[7,8] all embody the advantages and successful application in the treatment of traumatic fractures following BO concept.

During the procedure of minimally invasive treatment of fractures, the key success factor is minimal or closed reduction, namely ensuring the satisfactory reduction of the fracture before skin incision and fixation. It is impossible to achieve the minimally invasive fixation (MIF) before desired reduction is accomplished. If anatomical or satisfactory alignment could not be achieved before skin incision, limited open reduction and even complete open reduction should be performed in some complex cases. For the pursuit of anatomical or at least satisfactory alignment, Hippocrates invented the famous Hippocrates' traction table. With societal progress and technological development, especially with the application of X-rays in medical practice, fracture could be reduced accurately and safely with the aid of this revolutionary affordable technique. Afterward, researchers and surgeons continuously invented and developed creative tools for fracture reduction. Currently, the most commonly used tool for fracture reduction is the traction table for fractures of the lower limbs,[9] using a boot as upholder for pulling force and perineal post for resistance. However, there are some weaknesses existing in the traction table-based reduction technique. The biggest limitation is the

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inconsistency between the direction of generated traction force and that of the muscle contraction in the lower limbs. As a result, in case of young adult patients with significantly displaced or old fracture, a larger force and prolonged traction are required to reduce the fracture, leading to stretch injury of the foot, pudendal nerve trauma, perineal ulcers, peroneal nerve palsy, and even compartment syndrome.[10,11] Second, skin traction is performed during fracture reduction procedure by the traction table, which only provides lower traction force of 5–10 kg. Third, traction table could be only indicatively applied in the proximal and shaft fractures of the femur, but not for open fractures, tibial fractures, ankle and foot fractures, or fractures of the amputated limbs. In addition, other disadvantages, including large bulking, heavy weight, and inconvenience for carriage and field application, have been described in detail. Arbeitsgemeinschaftfür Osteosynthesefragen (AO) traction reductor is another fracture reduction instrument applied with Schanz screws stretching the fracture site, which may also lead to an eccentric force for reduction. In addition, application of this instrument occupies a large space, influencing the optimal surgical incision, visualization of anatomic structures around fracture sites, and the placement of osteosynthesis plates or intramedullary nail (IMN) due to Schanz screws placed passing through the medullary canal. To address the above‑mentioned technical limitations, various techniques and instruments for fracture reduction in a minimally invasive fashion have been introduced and applied in the clinical application.

Our team invented a rapid reductor for the closed reduction of the fractures of all the four extremities.[12] The rapid reductor was designed to combine the advantages of the traction table and AO traction reductor techniques and to simultaneously avoid their potential disadvantages. The main elements include reduction scaffold, traction bow, traction pin, connecting rod, auxiliary reduction pin, and proximal connecting device. The remarkable feature is the application of skeletal traction connecting anterior superior iliac spine through a Schanz pin and the distal end of long bone or calcaneus via its traction bow. The rapid reductor shows obvious advantages in clinical practice, which could provide consistent mechanical axis with muscles' running, generate enormous force to reduce displaced fractures, and avoid the complications related to skin traction‑relating traction table. Furthermore, the rapid reductor is simple and convenient to perform and does not hinder injured limb adduction or abduction when the operative procedures are needed, such as reduction, fluoroscopic examination, and IM nailing (IMN). In addition, this rapid reductor could correct various deformations of overlapping, anterior, posterior, and lateral displacement and rotation. This instrument can be used in the reduction of displaced fractures of the femur, tibia, humerus, and radius and ulna, as well as ampulated limbs.

Another trend in the development of MIS technique in orthopedic trauma is to improve the ability of restoring both the anatomical and biomechanical features in the irregular‑shaped bones, such as clavicle and spinal vertebrae. Previously, ORIF is commonly used to treat this injury, with subsequent increased complications relating bone, soft tissue, or implant. After continuous struggles and attempts, percutaneous kyphoplasty (PKP) and clavicular closed distractor were invented to solve these issues. PKP was first used in 1998 for the treatment of vertebral compression fractures. With the guidance of intraoperative fluoroscopy, the needle is percutaneously punctured into the compressed vertebrae to make up a work channel. Then, a special balloon was delivered and placed into the center of vertebrae through the channel to inflate the compressed fractures, followed with bone cement injected for maintaining affordable reduction. We creatively applied this technique in the treatment of ischemic necrosis and ganglion cyst of semilunar bone and acquired satisfactory outcomes.[13] Clavicle is characterized by an "S" shape, and a fracture more often in the intermediate third, commonly accompanied by a significant displacement. Dissatisfactory reduction might lead to increased complications such as nonunion, malunion, delayed union, and nerve irritation symptoms. Based on the anatomical research and clinical investigation, we found that posterior extension of the shoulder and upward holding up the back facilitated the distraction of clavicle, and according to this key principle, we developed the closed distractor for clavicular fracture. During the operation, we fix patients' bilateral shoulder and handle the supporting device placed under the back to push the trunk upward, thereby making the bilateral shoulders extended posteriorly to reduce the overlapped clavicular fractures. Meanwhile, we could reduce the residual lateral displacement by manipulation after distracting the overlapping displacement of clavicle.

MIF embodies the core concept of MIS and represents the most important step for successful operation, which emphasizes the stabilization of the fracture until bone union. Based on this theory, a series of MIF devices are developed and widely applied in the management of periarticular, metaphyseal, and diaphyseal fractures. Among them, IMN is the most typical representative device for treating long bone fractures. IMN is inserted into the medullary cavity of the long bones with both ends away from fracture site, therefore avoiding damage in the surrounding soft tissues. During the procedure, it is necessary to insert a guide wire into the distal medullary cavity from the proximal cavity passing the fracture site, prior to implant the IMN. However, there are many troubles in the process of the insertion of the guide wire and subsequent nail fixation when encountering residual displacement after initial closed reduction of fracture or severely comminuted fracture. The commonly used device for guide wire insertion such as "gold finger" often fails to solve this issue in such conditions. A new IM reduction device has been invented, which facilitates the insertion of a guide wire into the distal medullary cavity of the long bones in a closed and controllable manner. The IM reduction device can be used to adjust the direction of the guide wire to facilitate its insertion into the cavity, which can be also applied as a "joystick" to restore the alignment of the long bones before IMN insertion into a proper position.[14] Furthermore, the development of digitalized three-dimensional (3D) navigation techniques, especially novel electromagnetic distal targeting system, greatly facilitates the precise placement of locking screws with reduced time, less attempts, and using fluoroscopy as replacement.

From the view of traditional manufacturing industry, it might be difficult to design and produce the implants of complete fitness with bone morphology for individuals. Some implants need to be specifically reshaped in accordance with the anatomical features of bones to facilitate percutaneous insertion to the fracture site. With the advent of computer-assisted and 3D printing technology, personalized customized implants and prosthesis can be expected to be designed and produced, according to the size, configuration, anatomical characteristics, and biomechanical features of the bones of individual patients. In 2014, the world's first artificial customized vertebral body fabricated by 3D printing was applied in the treatment of atlanto-axial tumors in Peking University Third Hospital, giving us more courage and strength on the walking road of MIS. Percutaneous minimally invasive pedicle screw fixation is an ideal treatment method for spinal fractures. However, percutaneous screw placement is a technically challenging procedure with a significant complication profile for misplaced screws. Various recently invented intraoperative image guidance techniques, including computed tomography navigation system, 3D fluoroscopy-based navigation, and O-arm technology, have been shown to provide superior accuracy in the minimally invasive placement of spinal instruments.[15] In 2015, researchers from Peking Jishuitan Hospital have successfully completed the world's first complex thoracolumbar surgery in the minimally invasive fashion assisted by robots and navigation, which will certainly lead the new medical trend in the world. We believe, in the near future, more and more innovative ideas, techniques, implants, and instruments, relating MIS and precise medicine will be proposed, invented, and applied in the minimally invasive management of orthopedic trauma, which will promote the development of Chinese orthopedic trauma and better serve our patients.

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