



Minimally Invasive Fracture Fixation Technique

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Abstract

Traumatic bone fracture injuries are among the most frequent orthopedic injuries treated worldwide and most often require surgical intervention to restore anatomical alignment and mobile function. Current conventional methods of treatment such as open reduction and internal fixation (ORIF) are typically accomplished by using plates, screws, or intramedullary rods to stabilize fractured segments of bone. However, these techniques typically require large surgical incisions resulting in extensive disruption of surrounding soft tissues, as well as extended recovery times for patients. Recently, there has been development of minimally invasive orthopedic procedures designed to decrease surgical trauma while still providing adequate mechanical support of bone fragments. Furthermore, the development of new biomaterials has led to the introduction of bioactive bone adhesives and calcium phosphate-based cements that improve the stabilization of fractures and support bone healing. The objective of this study is to propose a new concept for minimal invasive fracture fixation by integrating an expandable titanium wire stabilization system, injectable bio-adhesive bone bonding, and artificial intelligence (AI)-assisted imaging guidance using a C-arm fluoroscopy platform. The proposed device will consist of a micro instrumented titanium wire having an expandable, multi-arm tip configured to anchor itself to the internal anatomy to provide mechanical fixation to fracture fragments. Furthermore, the device will have a hollow internal channel allowing the biocompatible adhesive to be delivered directly into the fracture interface to further strengthen fixation. Additionally, artificial intelligence technology integrated into the imaging system allows for real-time assessment of fracture alignment and also provides visual support to surgeons during the surgical procedure. The combination of these technologies aims to reduce surgical trauma, limit blood loss, minimize operative times, and speed up recovery while ensuring that the fracture is functionally stable.

Keywords: Artificial intelligence, Bio-adhesive fixation, Expandable titanium wire, Minimally invasive surgery, Traumatic bone fracture

1. Introduction

Long bone traumatic fractures are one of the most common types of injuries treated by orthopedic surgeons. These types of fractures are most often due to high force trauma (e.g., falls, motor vehicle collisions) or high-energy sports injuries. Providing adequate support for bone fragments following a fracture is extremely important to restore anatomical alignment of the bone and facilitate successful healing of the fractured bone [4]. The standard treatment for many fractures is open reduction and internal fixation (ORIF) with the use of metal implants such as plates, screws or intramedullary nails. Despite creating significantly strong mechanical stability, the ORIF procedure typically

requires extensive surgical incisions and soft-tissue dissection, which can lead to complications such as infection, excessive blood loss, delayed healing and postoperative complications [6]. Research clearly demonstrates that ORIF procedures involving open fracture fixation are associated with frequent postoperative complications for patients in orthopaedic surgery. In the last few years, scientists have investigated new methods for surgically fastening bones and treating fractures, including using biocompatible adhesives and injectable cements made from ceramics as an alternative or supplement to traditional methods of fastening bones together according to the biological characteristics.



Over the last few years calcium phosphate-based adhesives and bioactive polymer composite materials have been researched extensively due to their ability to adhere to and stabilize bone tissue while also being biologically acceptable and mechanically strong. Another technological advancement in Orthopedic surgery has been the improvement of accuracy using biomedical engineers developing innovative imaging technologies incorporating AI technology. The combination of these two technologies has been used to assist surgeons in better analyzing fracture geometry and providing surgeons with real-time feedback which allows for improved alignment and stabilization of the fractured bone fragment. The purpose of this study is to describe a new minimally invasive technique used for stabilizing bone fractures that uses injectable bio-adhesives to fasten bones together via expandable titanium wire, along with using Assisted C-arm imaging and localization for guidance. The objectives of this study include presenting an overview of the conceptual design process, operational flow, and clinical benefits related to using this novel method for treating bone fractures.

1.1. Limitations of Conventional Fixation

To gain access to the fracture site using traditional surgical fixations will usually require large incisions which can create a higher risk of complications, tissue trauma, and long operative durations. Furthermore, metallic fixation devices (plate and screw) may need to be removed through a second surgery due to irritation or infection [6]. While Minimally invasive plate osteosynthesis aims to reduce these problems, rigid metallic hardware is still required. Additionally, drilling and screw placement increases surgical difficulty and additional risks to the surrounding tissues [8]. Recently, the development of orthopedic biomaterials has introduced adhesive-type fixation methods to reduce reliance on rigid implants. Bio-adhesive materials create a bond between the bone surfaces and help to distribute mechanical loading across fracture interfaces [13].

1.2. Advances in Biomaterials and Surgical Imaging

Recent research has been conducted in the field of

orthopedics into creating adhesives that can bond together multiple pieces of broken and fractured bones during their natural healing processes. Hydroxyapatite (calcium phosphate) bone cements and bio-inspired polymeric adhesives have shown good mechanical properties and suitable biocompatibility for fracture repair applications [16]. These biomaterials also aid in stabilizing fractured bones by bridging gaps between pieces of fractured bones, as well as providing temporary support during the early stages of biomechanics recovery [18]. In addition to advances in biomaterials for use in orthopedics, advances in medical imaging technology have greatly improved accuracy in performing medical procedures. Current imaging technology that utilizes artificial intelligence (AI) can provide real time evaluations regarding the alignment of the fractured bone with respect to the use of the implant, based on the analysis of post-operative X-rays [24]. With the assistance of these imaging technologies, the surgeon can perform minimally invasive procedures with increased accuracy and decreased operative time.

2. Method

2.1. Expandable Titanium Wire Fixation Device

The design of this fixation device includes a micro-instrumented titanium wire shaft made of medical grade titanium alloy (Ti-6Al-4V). This alloy has many applications in orthopedic implants because it possesses high strength; excellent corrosion resistance; and is biosafe (biocompatibility) [7]. The distal end of the device is outfitted with collapsible multi-arm expandable tips that are fully collapsed while inserting them through the fracture. When the device is placed at the fracture, you will activate its expansion mechanism with a control knob on the proximal end of the device. The arms of the expandable tips will deploy outward and become anchored in the bone to stabilize the fracture pieces. Research has been conducted using similar expandable fixation mechanisms within orthopedic engineering to improve anchoring strength while minimizing the bulk of fixation devices [25].

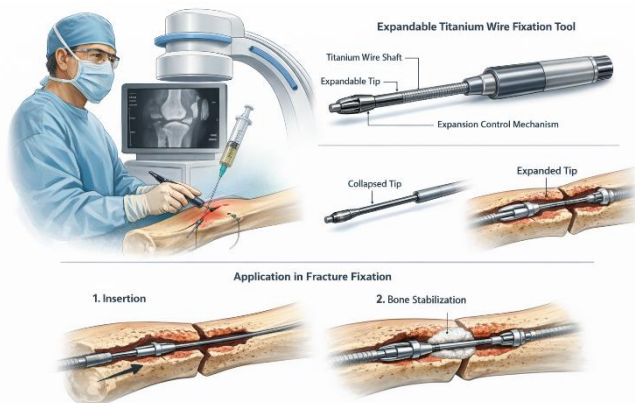


Figure 1 Expandable Titanium Wire Fixation System

This figure presents the structure and application of the expandable titanium wire fixation tool used for fracture stabilization. The device consists of a titanium shaft, an expandable anchoring tip, and an expansion control mechanism. The illustration demonstrates both the collapsed configuration for insertion and the expanded configuration for stabilizing bone fragments.

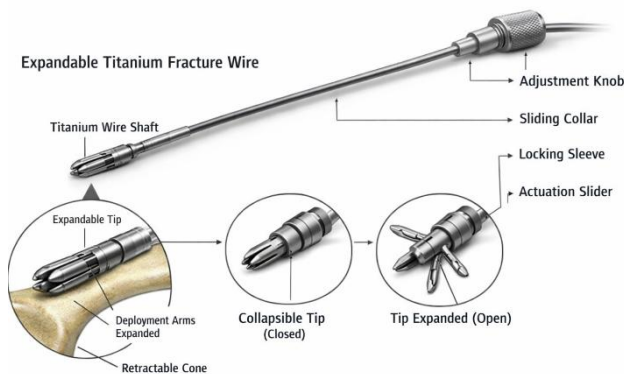


Figure 2 Design and Mechanism of the Expandable Titanium Fracture Wire

This figure illustrates the detailed mechanical design of the expandable titanium fracture wire, including the adjustment knob, sliding collar, locking sleeve, and expandable deployment arms. The diagram also shows how the tip expands within the bone to provide internal stabilization of the fracture site.

2.2. Internal Adhesive Delivery System

The device utilizes both a combination of mechanical fixation and an internal hollow center or channel to allow for the direct injection of injectable bone

adhesive to the fracture site. There have been many studies exploring the use of injectable materials, such as calcium phosphate-based cements, or bioactive polymer composites to assist in through the healing of fractured bones. These types of materials provide both a bonding effect to the fracture site and aid in regenerating tissue [9]. In addition to having the same effect as mechanical load distribution, these types of materials will create faster stabilization of the two fracture pieces [18]. After alignment of the fractured pieces using the fixation device has been achieved, the adhesive will be injected into the fracture site through the internal channel of the fixation device. The adhesive will polymerize in approximately 60–120 seconds, further stabilizing the fractures held together by the expandable titanium wire.

2.3. I-Assisted C-Arm Imaging System

C-arm imaging technology is used to obtain real time images of the bones while the surgery is taking place. The AI integrated into the C-arm examines the fracture shape and provides visual alignment indicators for the surgeon to see on the screen. The system uses colour coded lines to indicate whether the fracture is aligned or misaligned.

- Green line: aligned
- Red line: misaligned; requires adjustment

Surgical assistance via AI guided systems have shown to provide excellent improvements in accuracy and decreased time taken for surgical procedures in orthopaedics. [24].

Table 1. Surgical Workflow of the Proposed Minimally Invasive Fracture Fixation Technique

Step	Surgical Action	Purpose
Step 1	C-arm imaging and fracture identification	Determine fracture location and alignment
Step 2	Keyhole incision (5–8 mm)	Provide minimally invasive access
Step 3	Insertion of expandable titanium wire	Position fixation device across fracture

Step 4	Deployment of expandable anchoring tip	Stabilize bone fragments
Step 5	Injection of bio-adhesive through device	Reinforce fixation
Step 6	AI-assisted alignment verification	Confirm anatomical bone positioning
Step 7	Final stabilization and closure	Complete surgical procedure

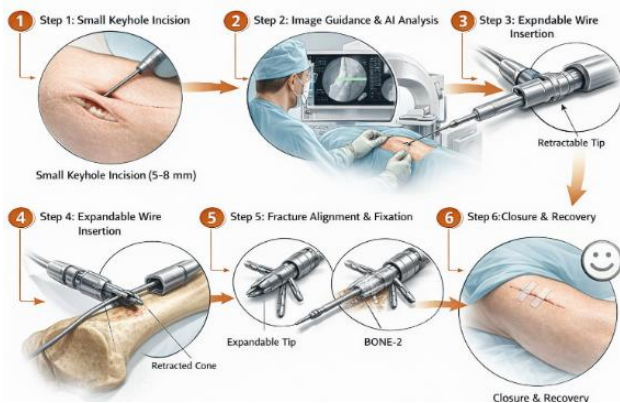


Figure 3. Surgical Workflow of the Proposed Minimally Invasive Fracture Fixation Technique

This figure shows the step-by-step workflow of the proposed surgical procedure. The process includes keyhole incision creation, AI-guided imaging analysis, insertion of the expandable titanium wire device, deployment of the expandable tip, injection of bone adhesive (BONE-2), and final closure of the incision. The workflow highlights the minimally invasive nature of the technique.



Figure 4 AI-Assisted C-Arm Surgical Guidance System

This figure illustrates the use of a C-arm imaging system integrated with artificial intelligence during the minimally invasive fracture fixation procedure. The system provides real-time visualization of bone alignment and displays color-coded indicators to assist the surgeon in accurately positioning the fixation device and correcting angular deviations during surgery.

3. Results and Discussion

3.1. Results

Although the suggested device is theoretical rather than having been previously tested clinically, it appears to be comparable to endoscopic, orthopedic approaches in terms of what was evaluated for theory; both methods appear to show their ability to achieve potentially beneficial results. The suggested device provides for internal bony stabilization by utilizing an expandable, titanium wire fixation method, thus eliminating the need for bulky, metallic plates or numerous screws. This finally could lead to a less complicated surgical procedure, while giving satisfactory mechanical support to the fractured bone ends at the fracture site. In addition, compared to the type of incision needed with open reduction and internal fixation, the type of incision made with the keyhole incision (which measures between 5–8 mm) would also provide less disruption of soft tissue. Conversely, an open reduction/internal fixation surgical incision could be as large as 5–15 cm long. As a result, the reduced surgical incisions will result in less intra-operative blood loss and in a shorter time to recover postoperatively [5]. By incorporating bio-adhesive materials into the fixation method, the stability of the fixation will be improved by filling in the voids between fracture fragments and better distributing mechanical forces through the fracture interface. Previous studies have shown the use of calcium phosphate-based bone adhesives has been able to provide temporary mechanical stabilization as well as assist during the bone healing process through the assistance of bone regeneration [9][16]. To enhance surgical assistance, AI-assisted C-arm imaging guidance also offers visualization in real-time of the alignment process of the fractured bones. In addition, the artificial intelligence module evaluates the geometry of the fractures and displays

colored indicators for alignment to aid the surgeon with the reduction of the fractured bones. These systems have been shown to improve the precision of surgery and reduce the duration to perform an image-guided orthopedic procedure [24]. To summarize, the utilization of expandable fixation devices; injectable adhesives; and intelligent imaging systems has the capability to greatly enhance surgical efficiency and the outcomes in fracture stabilization.

Table 2 Comparison Between Conventional Fixation and Proposed Technique

Parameter	Conventional ORIF Method	Proposed Expandable Wire Technique
Surgical incision	~5–15 cm	~5–8 mm keyhole incision
Blood loss	200–500 ml	<50 ml
Surgical duration	~60–120 minutes	~20–30 minutes
Fixation hardware	Plates, screws, rods	Expandable titanium wires
Soft tissue damage	Significant	Minimal
Hospital stay	3–7 days	Same day / 1 day
Recovery period	Several weeks	Early mobilization
Reoperation risk	Possible hardware removal	Minimal

Table 2 compares the proposed expandable wire fixation method with the conventional open reduction and internal fixation (ORIF) technique. The comparison highlights key differences in surgical incision size, blood loss, surgical duration, fixation hardware, recovery time, and risk of reoperation. The proposed method demonstrates potential advantages in terms of reduced surgical trauma and faster patient

recovery.

3.2. Discussion

The conceptual evaluation of this proposed system demonstrates various critical implications toward future minimally invasive orthopedic surgery. Traditional methods for fixation of fractured bones require extensive surgical exposure due to the use of rigid metal implant devices, resulting in excessive tissue trauma to the surrounding area. Although traditional devices provide high mechanical stability and strength, they contribute to prolonged recovery times as well as an increased risk for postoperative complications [6]. A minimally invasive titanium expandable wire fixation device can provide an alternative to traditional fixation methods by enabling the surgeon to insert surgical implants into the fractured bone(s) without large plates or multiple screws. By reducing or eliminating surgical trauma associated with implant insertion (and upon removal), patients may experience a more comfortable recovery period. The use of bio-adhesive materials for fracture fixation also adds a biological factor to the process of stabilizing fractured bones. Adhesive biomaterials will provide both mechanical reinforcement and will actively assist in the natural healing of broken bones; which promotes osteointegration at the fracture site [13]. Finally, another major benefit of this proposed system is that it incorporates the use of artificial intelligence (AI) assisted imaging guidance throughout the surgical process. AI-based surgical navigation platforms allow surgeons to receive accurate alignment information based on real-time imaging of their patient. This, in turn, reduces the chances of improperly aligned implants being placed in the patient's fractured bone. While some benefits are visible with the new method, there are still barriers to overcome in order to implement it in the clinic. For example, there are no data available that support the mechanical integrity of the expandable fixation device; there have not been any studies that assess the long-term safety of the adhesive materials; and we have not established the reliability of the AI-guided surgery systems. Future research should provide data via finite element models, biomechanical testing, and controlled experimental studies to verify the strength



and safety of the new fracture fixation system.

Conclusion

This research lays out a conceptual framework for a new kind of minimally invasive fixation technique that incorporates expandable titanium wires (flattened metal straps) to stabilize fractured ends of bones as well as use of injectable bio adhesive (or glue) to reinforce stabilization of the fractured ends; performing this with the aid of AI-assisted image guidance systems (C-arm Fluoroscopy) thereby increasing surgical accuracy, decreasing recovery time and reducing surgical trauma to patient as compared to traditional ORIF (open reduction internal fixation) practices [23]; and using a combination of expandable wire and gel to hold the bones stable after surgery would provide appropriate mechanical stabilization as opposed to the use of multiple screws and plates which provide mechanical stabilization (rigidity) to fractured ends of bones [26]; using bio-adhesives to provide load/pressure to both sides of femoral heads may help in establishing stability of fractured femoral heads early on during healing period ultimately accelerating healing of patients with fractured femoral heads [22]. By providing surgeons with accurate, real-time alignment information on fractured bone fragments, utilizing AI-assisted imaging guidance of C-arm fluoroscopes increases surgical precision and accuracy [25]. The aim of this study is to evaluate a less invasive method for fixing broken bones using orthopedic screw fixation (OSF), but there is also evidence that this type of surgery will be quicker and safer and allow patients to return to normal activities at a faster pace than traditional methods of fixing fractures. To confirm that we will achieve the same level of success with this new technology as demonstrated in earlier studies, future work should validate this model through mechanical evaluation using finite element analysis (FEA) and biomechanical testing (BT) on synthetic bone models, followed by mechanical testing on cadaver bone in order to evaluate mechanical properties, safety, and clinical performance.

Acknowledgements

This study would not have been possible without the help of multiple individuals in the areas of orthopedic

surgery, material science, and computer-assisted surgery, some of whom have already produced life-changing products and processes to help people who suffer from broken bones, including cementing technology for fractures, fracture stabilization systems through the use of artificial intelligence, and cementless fracture stabilization systems; thank you for contributing your time and expertise to help bring us here; I greatly appreciate it. Finally, I would like to recognize the efforts of the entire academic and research community for continuing to advance knowledge and expertise in the area of minimally invasive orthopedic surgery and new ways to stabilize fractures to help improve patient outcomes.

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