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MINIMALLY INVASIVE SURGICAL TECHNOLOGIES IN TRAUMATIC BONE FRACTURES: IMPORTANCE AND ADVANTAGES

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Abstract: Traumatic bone fractures remain a major cause of pain, disability, lost productivity, and long-term functional limitation worldwide. Over the past three decades, fracture surgery has undergone a substantial shift from extensive open approaches toward biologically respectful fixation strategies that preserve blood supply, minimize soft-tissue disruption, and enable earlier rehabilitation. Minimally invasive surgical technologies—such as minimally invasive plate osteosynthesis (MIPO), closed or semi-closed intramedullary nailing, percutaneous screw fixation, and modern external fixation systems—have become central to contemporary trauma care. This article reviews the clinical rationale, core principles, major techniques, and practical benefits of minimally invasive fracture surgery. The discussion focuses on how these approaches reduce iatrogenic tissue damage, decrease infection and wound complications, support fracture healing biology, and accelerate return to function. Indications, limitations, training requirements, imaging considerations, and complication patterns are also addressed. Although minimally invasive fixation is not universally applicable, growing evidence and clinical experience suggest it can improve outcomes when used for appropriate fracture patterns, in suitable patients, and by trained surgical teams equipped with modern imaging and implants.

Keywords: Traumatic fractures; minimally invasive surgery; minimally invasive plate osteosynthesis (MIPO); biological fixation; intramedullary nailing; percutaneous fixation; external fixation; fracture healing; soft-tissue preservation; rehabilitation.

Introduction

Fractures caused by trauma represent a high-burden condition across healthcare systems. Road traffic collisions, occupational injuries, falls, and sports trauma contribute to fracture incidence in both young adults and older populations. From a public health perspective, fracture care is not only about achieving bony union; it also aims to restore limb alignment, joint function, mobility, and quality of life while preventing complications such as infection, nonunion, malunion, and post-traumatic stiffness.

Historically, open reduction and internal fixation (ORIF) became widely adopted because it allowed direct visualization, precise anatomical reduction, and stable fixation. However, conventional open techniques can involve wide exposures, extensive periosteal stripping, devascularization of fracture fragments, and increased risk of wound problems—particularly in high-energy injuries where the soft tissues are already compromised. As an alternative, modern fracture surgery increasingly emphasizes the concept of "biological fixation," in which the surgeon prioritizes preservation of the fracture's blood supply, respects soft tissues, and seeks stable—but not necessarily rigid—fixation that supports healing.

Minimal invasion in fracture surgery is therefore not simply about smaller skin incisions. It reflects a broader strategy: avoiding unnecessary disruption of periosteal circulation, minimizing hematoma evacuation, limiting muscle detachment, and reducing surgical trauma while achieving adequate stability and acceptable alignment. International educational frameworks and principles, including those promoted by AO Foundation, have played a significant role in disseminating standardized approaches to fracture management.

This paper synthesizes key minimally invasive technologies used in traumatic fracture care, outlines their advantages, examines common indications and challenges, and presents practical considerations for clinical implementation.

Discussion

1. Conceptual Foundations: From "Open Anatomy" to "Fracture Biology"

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The biological environment of a fracture includes the fracture hematoma, local inflammatory mediators, periosteal blood supply, and the mechanical conditions created by fixation. Excessive exposure and stripping can compromise these factors, increasing the risk of delayed union or nonunion. Minimally invasive approaches strive to:

1. preserve blood supply and fracture hematoma,
2. minimize further soft-tissue injury,
3. maintain or restore limb alignment and length, and
4. provide adequate stability to permit early motion and function.

In many extra-articular fractures, particularly comminuted patterns, perfect anatomical reduction of every fragment may be neither feasible nor necessary. The focus shifts to restoration of overall limb axis, length, and rotation, using techniques such as indirect reduction, traction, and image-guided alignment. The resulting "relative stability" promotes callus formation and can be advantageous in multifragmentary injuries.

2. Major Minimally Invasive Technologies in Fracture Surgery

2.1 Minimally Invasive Plate Osteosynthesis (MIPO)

MIPO refers to insertion of a plate through small incisions proximal and distal to the fracture zone, typically with submuscular or extraperiosteal tunneling. The fracture site is not widely opened. Reduction is achieved indirectly, using traction, external aids, and fluoroscopic checks. Locking plates (e.g., locking compression plates) are frequently used, functioning as internal fixators rather than traditional compression plates.

Clinical advantages of MIPO include:

- reduced periosteal stripping and preservation of vascularity;
- lower rates of wound complications in selected regions (e.g., tibia);
- improved tolerance in high-energy fractures with compromised soft tissues;
- potential for earlier functional recovery due to less postoperative pain and swelling.

MIPO is especially valuable for metaphyseal fractures (distal femur, proximal tibia, distal tibia) where intramedullary nailing may be less optimal or where fracture geometry favors plating.

2.2 Closed or Semi-Closed Intramedullary Nailing

Intramedullary nailing is often considered a minimally invasive method because it can be performed through small incisions, with limited exposure of the fracture. For diaphyseal fractures of the femur and tibia, nailing provides strong mechanical stability aligned with the bone's axis, often permitting early weight-bearing in appropriate cases. Modern locked nails resist rotational and axial displacement.

Key benefits include:

- minimal disruption of fracture biology;
- mechanically favorable load-sharing;
- strong stabilization with relatively small soft-tissue footprint;
- potential for early mobilization and reduced immobilization-related complications.

However, intramedullary nailing requires careful attention to entry point, reduction, and rotation, and it depends heavily on imaging. Malalignment remains a risk if reduction is inadequate, especially in metaphyseal–diaphyseal junction fractures.

2.3 Percutaneous Screw Fixation and Limited Open Techniques

Certain fractures—particularly periarticular and intra-articular injuries—require precise reduction of joint surfaces. Minimally invasive strategies here include percutaneous lag screws, arthroscopically assisted reduction in selected joints, and "limited open" approaches that target key fragments while avoiding full exposure.

Examples include:

- percutaneous fixation of some ankle, calcaneal, and pelvic ring fractures;
- percutaneous cannulated screws in selected femoral neck fractures;
- hybrid methods combining minimal open reduction with percutaneous fixation.

In these cases, minimally invasive does not mean ignoring the joint; rather, it means achieving necessary precision with maximal tissue preservation.

2.4 External Fixation and Damage Control Orthopedics

External fixation can be minimally invasive in the sense that it avoids deep dissection at the fracture site. It is critical in polytrauma, open fractures, severe soft-tissue injury, and situations requiring temporary stabilization ("damage control orthopedics"). Modern external fixators also include circular fixators and hexapod systems capable of gradual deformity correction and stable fixation for complex fractures.

Advantages include:

- rapid stabilization with minimal surgical time;
- reduced physiological stress in unstable trauma patients;
- access to soft tissues for wound care and reconstruction;
- staged conversion to internal fixation when appropriate.

Pin-site infection is a recognized limitation, requiring meticulous technique and follow-up.

3. Clinical Advantages of Minimally Invasive Approaches

3.1 Soft-Tissue Preservation and Reduced Wound Complications

High-energy fractures are often "soft-tissue injuries with an associated bone fracture." Surgical approaches that further injure the soft tissues increase risk of infection, dehiscence, and delayed healing. Minimal exposure reduces devascularization and may support safer treatment in vulnerable anatomic zones (e.g., tibial shaft, distal tibia) where soft tissues are thin.

3.2 Reduced Blood Loss and Postoperative Pain

Smaller incisions and less dissection typically mean lower blood loss and less postoperative pain, which can facilitate early mobilization, reduce opioid requirements, and shorten hospital stay. These benefits are especially relevant for older adults, patients with anemia, or those with comorbidities.

3.3 Enhanced Fracture Healing Biology

By preserving periosteum and fracture hematoma, minimally invasive methods may reduce delayed union risk in selected patterns. This is most noticeable in comminuted fractures treated with bridging constructs that provide relative stability and stimulate callus formation.

3.4 Faster Functional Recovery and Rehabilitation

Function-focused care is central to modern trauma practice. Minimally invasive fixation often enables earlier range-of-motion exercises and reduces joint stiffness, particularly around the knee and ankle. Early rehabilitation also mitigates secondary complications such as muscle atrophy, thromboembolism, and loss of cardiovascular conditioning.

3.5 Potential Economic and System-Level Benefits

Shorter hospital stays, fewer wound complications, and faster return to function can reduce healthcare costs and societal burden. While advanced implants and imaging can be expensive, reduced complication rates and improved throughput may offer offsetting economic value.

4. Indications and Patient Selection

Minimally invasive techniques should be chosen based on fracture pattern, soft-tissue status, patient physiology, and available expertise. Typical indications include:

- comminuted diaphyseal fractures suitable for nailing;
- metaphyseal fractures suited for bridging plates (MIPO);
- fractures with compromised soft tissues where large exposures are risky;
- polytrauma cases requiring damage control stabilization.

Patient factors also matter: osteoporosis may affect screw purchase and plate choice; vascular disease and diabetes increase infection risks; and polytrauma necessitates physiologic prioritization.

5. Limitations, Risks, and Technical Challenges

5.1 Dependence on Imaging and Radiation Exposure

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Minimally invasive fracture surgery often requires fluoroscopic guidance. This raises concerns about cumulative radiation exposure to both patient and operating team. Radiation safety protocols, efficient technique, and training are essential.

5.2 Risk of Malreduction and Implant Malposition

Because the fracture is not fully visualized, risks include malalignment (varus/valgus), rotational errors, and incorrect implant positioning. Preventing these requires:

- rigorous intraoperative alignment checks;
- knowledge of reduction aids (traction tables, external distractors, reduction clamps);
- an understanding of acceptable alignment parameters for each bone and segment.

5.3 Learning Curve and Resource Requirements

True minimally invasive competence requires more than adopting new implants. It demands training, familiarity with indirect reduction principles, and team experience. Hospitals need fluoroscopy capability, appropriate implants, and postoperative rehabilitation infrastructure.

5.4 Not Always Appropriate

Some fracture patterns require direct visualization for safe management—particularly severely displaced intra-articular fractures or cases where closed reduction cannot restore congruity. Additionally, contaminated open fractures may require staged management and careful surgical timing.

6. Integration With Modern Trauma Systems and Rehabilitation

Optimal outcomes depend on more than the fixation method. Minimally invasive surgery works best within a multidisciplinary trauma system that includes timely imaging, soft-tissue management, infection control, physiotherapy, and patient education.

Early rehabilitation protocols emphasize:

- safe range-of-motion exercises;
- progressive strengthening;
- guided weight-bearing based on fixation stability and fracture type;
- close follow-up for alignment, union, and implant integrity.

At the population level, trauma prevention and safety policies remain essential. Organizations such as the World Health Organization highlight injury prevention as a major public health priority, complementing clinical advances in surgical care.

Conclusion

Minimally invasive surgical technologies have transformed the management of traumatic bone fractures by aligning surgical technique with fracture biology. By reducing soft-tissue disruption, preserving blood supply, limiting wound complications, and enabling earlier rehabilitation, minimally invasive approaches can improve functional recovery and patient experience when applied appropriately. Techniques such as MIPO, closed intramedullary nailing, percutaneous fixation, and modern external fixation form a versatile toolbox for contemporary trauma surgeons. However, these benefits depend on careful patient selection, correct technique, reliable imaging, and adequate training. Minimally invasive fracture surgery should therefore be viewed not as a universal replacement for open approaches, but as a strategy-guided framework that prioritizes biological preservation and functional restoration—key goals in modern trauma care.

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