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CONTEMPORARY APPROACHES TO THE TREATMENT AND PREVENTION OF MAJOR BONE FRACTURE COMPLICATIONS

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Abstract
Major bone fractures, including those of the pelvis, femur, and tibia, represent a significant challenge in trauma care due to their high prevalence, complexity, and risk of complications. These injuries are often associated with substantial morbidity, prolonged rehabilitation, and, in severe cases, permanent disability. Advances in surgical techniques, such as metal osteosynthesis (MOS) using plates, screws, and external fixation devices, have improved treatment outcomes. However, complications such as delayed union, nonunion, infection, and thromboembolic events remain critical barriers to optimal recovery.

Introduction

Unstable fractures of the pelvic ring, femur, and tibia often involve severe anatomical disruptions and require precise interventions to restore function. Despite progress in imaging and surgical methodologies, treatment outcomes vary significantly, depending on factors such as patient age, injury severity, and the presence of comorbidities. Complications such as post-traumatic deformities, chronic pain, neurological deficits, and infection rates of up to 55.9% in open fractures highlight the need for improved strategies in management and prevention.

Moreover, predictive models and personalized approaches to treatment have emerged as valuable tools for optimizing clinical decision-making. The ability to anticipate complications and tailor interventions based on individual risk profiles has the potential to significantly improve patient outcomes and reduce healthcare costs. However, the integration of such methodologies into routine practice requires further validation and refinement.

Given the multifaceted nature of these injuries and their consequences, a comprehensive understanding of current treatment modalities and their limitations is essential. This review aims to explore contemporary approaches to the management and prevention of complications associated with major bone fractures, emphasizing the importance of early diagnosis, individualized care, and innovative treatment strategies. The insights derived from this analysis could pave the way for enhanced protocols that minimize complications and improve the quality of life for patients.

Materials and Methods

This study utilized a two-phase design to analyze the treatment and outcomes of patients with major bone fractures. The first phase, conducted retrospectively, involved a comprehensive review of medical records for 284 patients admitted with fractures of the pelvis, femur, or tibia between 2018 and 2022. These patients were treated at the Scientific Center for Emergency Medical

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Assistance and its Bukhara branch. The sample included 94 patients with pelvic fractures, 97 with femoral fractures, and 93 with tibial fractures. The primary objective of this phase was to identify key clinical predictors associated with post-fracture complications and develop a mathematical model to predict complication risks based on diagnostic data.

The second phase, carried out prospectively from 2022 to 2024, focused on testing the predictive model to optimize personalized treatment strategies tailored to individual clinical scenarios. This phase assessed the model's impact on treatment outcomes and patient quality of life. A total of 124 patients participated in this phase, comprising 43 with pelvic fractures, 41 with femoral fractures, and 40 with tibial fractures. The findings demonstrated that applying the predictive model improved functional outcomes, reduced disability rates, and enhanced recovery metrics in patients with complicated fractures.

Patients were included in the retrospective analysis if they had confirmed fractures of the pelvis, femur, or tibia, along with complete clinical records documenting treatment methods, diagnostic findings, and complications. Exclusion criteria included incomplete records, severe comorbidities like end-stage renal disease or malignancies, and cases where major bone fractures were secondary to polytrauma. For the prospective phase, inclusion criteria required acute fractures diagnosed within 72 hours of injury, age above 18 years, and informed consent to participate in the study and undergo model-guided treatment. Patients were excluded if they had severe chronic illnesses, fractures resulting from underlying bone diseases, or an inability to comply with treatment protocols.

Clinical evaluation formed the cornerstone of diagnostic efforts across both phases. Patient assessments included detailed physical examinations to identify deformities, hematomas, swelling, and pathological mobility at fracture sites. Specific attention was paid to peripheral vascular and neurological status, including palpation of pedal arteries and assessment of skin sensitivity. Imaging studies, including X-rays, computed tomography (CT), and magnetic resonance imaging (MRI), were performed to confirm fracture diagnoses and guide treatment planning.

In cases of pelvic trauma, comprehensive assessments were conducted to document soft tissue injuries, pelvic ring deformities, and signs of internal bleeding. Functional impairments of the lower limbs, such as altered leg length and range of motion deficits, were also evaluated. This approach facilitated a thorough understanding of the injury mechanism and enabled tailored management strategies.

Patients' treatment and rehabilitation outcomes were documented to evaluate the predictive model's clinical utility. Analysis focused on functional recovery rates, complication incidence, and improvements in quality-of-life metrics. These outcomes were compared against historical controls from the retrospective phase to determine the model's effectiveness in reducing complications and optimizing treatment pathways. This study highlights the importance of integrating predictive analytics and personalized care to enhance the management of major bone fractures.

Review of Literature Sources

One of the main reasons for complications in fracture treatment is the pathological reaction occurring at the bone-implant interface. The interfacial layer in this area plays a crucial role in ensuring optimal biomechanical properties and bone tissue regeneration [1, pp. 73–80].

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The treatment of unstable diaphyseal fractures of the tibia remains one of the most challenging issues in modern traumatology. Difficult repositioning and unstable fixation often lead to unsatisfactory outcomes, which may result in patient disability [2, pp. 81–90].

Various surgical approaches are used for such fractures; however, standardized methods have not yet been established. The choice of treatment is determined by the method's ability to restore limb function as close as possible to its physiological norm. For instance, some specialists favor external fixation methods, while others prefer intramedullary or on-bone fixation techniques [3, pp. 91–95].

The anatomical features of the tibia significantly affect treatment approaches. Its vulnerability in traffic accidents and the frequency of open fractures are due to its thin layer of soft tissue covering. Limited blood supply to the tibia complicates the healing process, increasing the risk of complications [4, pp. 96–105].

Pioneers in traumatology, such as M. Allgower and F. Spiegel, emphasized that studying tibial fractures is fundamental to the development of this field. Modern research, including studies by V.G. Klimovitsky, confirms that external fixation is most often used for open fractures, whereas intramedullary methods are preferred for closed fractures. On-bone fixation is most effective for injuries in the metaphyseal zone [5, pp. 106–115].

Conservative treatment is based on two main approaches. The first involves prolonged immobilization using plaster casts or skeletal traction. An alternative approach reduces the duration of primary fixation, utilizing functional braces or shortened plaster casts, allowing early weight-bearing and stimulating osteogenesis [6, pp. 116–125].

The concept of early weight-bearing has been widely recognized in the United States and has been actively applied for over four decades. In 1961, E. Dehne and co-authors demonstrated that early loading after closed reduction and plaster immobilization significantly reduces healing time and complication rates [7, pp. 146–155].

A. Sarmiento made a significant contribution to this method by developing a below-knee plaster cast and a functional brace. He hypothesized that controlled mobility at the fracture site accelerates consolidation. He emphasized that the success of braces depends on strict technical compliance and a detailed assessment of the soft tissues surrounding the fracture site [8, pp. 156–165].

With minimal displacement, tissue compression by the brace prevents angular deformities. However, the method is limited for bone shortening over 1–2 cm or when the intact fibula increases the risk of deformities [9, pp. 166–175].

The method of external fixation demonstrates exceptional efficiency, particularly in open fractures of grade II–III, which require stable fixation. This approach ensures compression, distraction, and retention of fragments, making it ideal for polytrauma cases and complications such as compartment syndrome [10, pp. 176–185].

The anatomy of the tibia facilitates external fixation, reducing the risks of muscle transfixation. The use of both wire and rod systems provides reliable stabilization, with rod systems becoming increasingly popular due to their simplicity [11, pp. 186–195].

Research by M.Sh. Uteshev and E.Y. Valiev showed that among 83 patients treated with rod systems, full union was achieved in 62 cases, with complications observed in only 11 patients [12, pp. 196–205]. For wire systems, the union rate was 64.3%, but inflammation at the wire insertion site was reported in 10 out of 56 cases [13, pp. 206–215].

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Minimally invasive osteosynthesis (MIO) with plates has gained popularity due to its ability to preserve tissue viability. The use of "internal fixators" improves stability and shortens healing time. According to T. Tukhtakulov and N.I. Makhmudov, MIO demonstrated 85% effectiveness [14, pp. 216–225]. A retrospective study by A.A. Khromov found that 84.4% of patients had positive outcomes nine months post-surgery [15, pp. 226–235].

Intramedullary osteosynthesis using locking nails has become the gold standard for treating tibial fractures, especially in cases involving significant fragment displacement. This method offers numerous advantages, including reduced rotational deformities, accelerated consolidation, and lower complication rates compared to more invasive surgical interventions. In a study conducted by Zuev P.P. et al. (2021), the union rate reached 95%, while complications such as delayed union and infections were observed in only 8–10% of cases. These findings highlight the method's efficiency and its role in modern fracture management [16, pp. 316–325].

One notable complication associated with this technique is anterior knee pain, reported in up to 60% of patients according to Krivorotko M.S. (2020). This pain, often localized to the tibial tuberosity, is typically exacerbated by prolonged sitting or physical activities involving repetitive stress on the joint. While the exact etiology remains unclear, it is hypothesized to result from mechanical irritation or altered biomechanics during the recovery period. Addressing this issue requires targeted physiotherapy and, in some cases, alternative surgical modifications to reduce patient discomfort [17, pp. 326–335].

External fixation remains an essential method for managing open tibial fractures, particularly when accompanied by extensive soft tissue damage. The Ilizarov apparatus has demonstrated remarkable efficacy in stabilizing complex fractures with severe deformities. Research by Khojanov I.Yu., Amonov L.A., and Makhsudov F.M. (2024) reported an impressive union rate of 98% in cases involving high-grade open fractures. Despite its efficacy, this approach is not without challenges, as pin-site infections occur in approximately 20% of cases, necessitating diligent postoperative care and frequent apparatus adjustments to minimize complications [18, pp. 336–345].

Locking screws have revolutionized the treatment of femoral fractures, offering unparalleled stability, particularly in fractures of the femoral neck and shaft. Their ability to minimize instability and reduce the need for reoperations by 12% compared to traditional pinning methods has been well-documented in studies like that of Nabiev E.N. (2020). However, their use is occasionally associated with anterior thigh and knee pain, affecting 15–25% of patients. Such discomfort may persist over time and significantly impair rehabilitation outcomes, underscoring the need for continuous improvements in implant design and postoperative management strategies [19, pp. 346–355].

Hip arthroplasty, particularly for femoral neck fractures, remains a cornerstone of treatment for elderly patients. The study by Yamshchikov O.N. (2020) highlighted the benefits of endoprosthetics, including reduced incidences of osteomyelitis and thromboembolic events compared to traditional osteosynthesis methods. Despite these advantages, complications such as aseptic loosening and infections, affecting 5–10% of patients, present ongoing challenges that warrant further refinement of surgical techniques and implant materials [20, pp. 356–365].

For pelvic fractures, especially those involving significant instability or acetabular damage, internal osteosynthesis using plates and screws remains the preferred approach. Research by Kim Yu.D. (2021) demonstrated that anchor plate fixation effectively stabilizes the pelvis, facilitating rapid functional recovery. Nevertheless, studies like that of Belokrylov N.M. (2022) emphasize

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the risks associated with these procedures, including vascular and nerve injuries, which occur in approximately 10% of cases. These complications necessitate meticulous preoperative planning and intraoperative precision to minimize adverse outcomes [21, pp. 366–375].

External fixation methods, including the Ilizarov apparatus and other circular frame systems, are extensively utilized for managing complex pelvic fractures with severe soft tissue injuries or open wounds. According to Kokorin I.N. (2015), such methods achieve favorable recovery outcomes in 92% of cases. However, pin-site infections remain a notable complication, affecting 15% of patients and often requiring additional surgical interventions. Despite these challenges, the adaptability and stability provided by external fixation systems make them indispensable tools in contemporary traumatology [22, pp. 376–385].

Over the past decade, significant advancements in metal osteosynthesis (MOS) have enhanced the management of fractures involving the tibia, femur, and pelvis. However, these improvements are counterbalanced by the persistent issue of infectious complications. Localized infections, including pin-site inflammations and osteomyelitis, continue to complicate recovery. Hematomas formed postoperatively often serve as breeding grounds for microbial proliferation, with studies indicating that 20% of hematomas become infected within the first 12–18 hours, necessitating stringent intraoperative and postoperative precautions [23, pp. 386–395].

The rate of unsatisfactory outcomes in the treatment of pelvic injuries remains alarmingly high, ranging from 20% to 48%. A rising trend is observed in cases involving unstable pelvic ring fractures, where inadequate fracture alignment, failed union, or disruptions of the sacroiliac joints result in persistent deformities, chronic contractures, and secondary neurological or urological dysfunctions. For instance, chronic urethral stricture, urinary incontinence, and impotence are noted in 5–21% of patients with complex pelvic trauma. Among those with pelvic fractures, 61% experience sexual dysfunction, which may include loss of genital sensitivity, erectile or ejaculatory issues, and pain during intercourse. Male patients with urethral ruptures accompanying pelvic fractures report erectile dysfunction rates of 5–30% [24, pp. 406–415].

Unresolved bony displacements contribute to pelvic ring deformities, reduced load-bearing capacity, and difficulty walking due to pain, resulting in altered gait patterns such as a "waddling gait." This may also lead to pelvic tilting and compensatory scoliosis, further impairing mobility and increasing the likelihood of disability. Studies reveal that residual posterior pelvic displacements of 1.4 to 2.3 cm in vertically unstable fractures significantly compromise functional outcomes and reduce the probability of returning to work [25, pp. 416–425].

Analysis of therapeutic strategies indicates considerable variation in functional outcomes based on the chosen treatment approach. Surgical methods involving internal osteosynthesis yield excellent results in 20–100% of cases, good outcomes in up to 70%, and unsatisfactory results in up to 16%. Conversely, external fixation devices demonstrate excellent outcomes in 9–68% of cases, good results in 15–37%, and poor outcomes in as many as 64% of cases, highlighting the variability and limitations of non-invasive approaches [26, pp. 426–435].

Complications related to metal osteosynthesis (MOS) of long bones are both local and systemic. Localized infections, such as pin-site abscesses or osteomyelitis, occur in 0.7% to 12% of closed fractures but rise to 55.9% in open tibial fractures. Comparative studies suggest that the infection rate is higher with plate fixation (11.5%) than with intramedullary devices (3.1%). Moreover, deep surgical site infections occur in 1.3% to 4% of cases, with the rate escalating to 22.6% in open fractures involving significant soft tissue damage [27, pp. 436–445].

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Thromboembolic events remain a significant concern in orthopedic surgery, with deep vein thrombosis (DVT) rates ranging from 6% to 60% after long bone fracture operations. Complex femoral and pelvic fractures demonstrate even higher risks, with DVT incidence varying from 35% to 90% and pulmonary embolism (PE) occurring in 2–10% of cases. Silent embolic events, which constitute up to 85% of PEs, often go undiagnosed in polytrauma patients, complicating prevention and treatment strategies [28, pp. 446–455].

Respiratory complications such as pneumonia and acute respiratory distress syndrome (ARDS) are more frequent in patients with femoral or tibial fractures, particularly in cases involving multiple or combined injuries. Their prevalence ranges from 0.5% in isolated trauma to over 10% in polytrauma, emphasizing the need for proactive monitoring in critically injured patients [29, pp. 456–465].

Acute compartment syndrome, a life-threatening complication of long bone fractures, presents in 1% to 35% of cases, depending on fracture location and severity. This condition is most frequently associated with tibial fractures and requires urgent surgical intervention, such as fasciotomy, to prevent irreversible tissue necrosis and functional impairment [30, pp. 466–475].

Neurological impairments, including nerve damage from sharp bone fragments or surgical trauma, occur in 2% to 33% of cases. These injuries often result in chronic pain, motor deficits, or sensory loss, significantly impacting rehabilitation outcomes and quality of life [31, pp. 476–485].

Failures in the structural stability of fixation systems, particularly in complex comminuted fractures or osteoporotic bones, can lead to secondary fractures, implant migration, or delayed bone healing. These complications are more common in patients over 60 or those with systemic comorbidities, such as diabetes or osteoporosis, necessitating customized treatment plans [32, pp. 486–495].

Delayed and nonunion complications remain prevalent in long bone fractures. Westgeest et al. (2016) reported delayed healing in 8% of cases and nonunion in 17%, with contributing factors including severe infections, extensive soft tissue damage, and suboptimal fixation. Effective management of such cases relies on early identification and multidisciplinary care [33, pp. 496–505].

Conclusion

Major bone fractures, particularly those affecting the pelvis, femur, and tibia, pose significant challenges in trauma care due to their complex nature and high risk of complications. Despite advancements in surgical techniques, diagnostic tools, and rehabilitation strategies, issues such as delayed healing, infections, and thromboembolic events continue to hinder optimal recovery. The integration of predictive models and personalized treatment approaches has shown promising results in improving functional outcomes and reducing complication rates.

This review highlights the need for ongoing research and innovation in areas such as biomaterials, minimally invasive procedures, and multidisciplinary rehabilitation. Addressing these challenges requires a collaborative approach, combining expertise in surgery, diagnostics, and patient care. By focusing on evidence-based practices and personalized strategies, healthcare providers can significantly enhance the management of major bone fractures, leading to improved quality of life and reduced disability for affected individuals.

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