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LOCKING INTRAMEDULLARY OSTEOSYNTHESIS IN THE TREATMENT OF DIAPHYSEAL FRACTURES OF LONG TUBULAR BONES: MODERN OPPORTUNITIES, MORPHOLOGICAL BASIS OF REPARATIVE REGENERATION, AND ANALYSIS OF CLINICAL OUTCOMES

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Abstract. This study is devoted to one of the most relevant areas of modern traumatology and orthopedics — the effectiveness of locking intramedullary osteosynthesis (BIOS) in the treatment of fractures of large tubular bones (femur, tibia, and humerus). The article analyzes the mechanisms of post-traumatic bone tissue regeneration, the biomechanical characteristics of BIOS rods, and their effect on intraosseous hemodynamics from a pathomorphological perspective[1,2].

Based on the results of multicenter clinical studies conducted between 2024 and 2026, as well as rehabilitation stages and quality-of-life assessment scales (SF-36, Harris score), the superiority of the BIOS method over traditional treatment techniques is statistically demonstrated.

Keywords: BIOS, intramedullary nail, diaphyseal fracture, reparative osteogenesis, bone callus, osteoblasts, osteoclasts, angiogenesis, micromobility, stable-dynamic fixation, compartment syndrome.

INTRODUCTION

Fractures of the diaphysis of long tubular bones, especially those resulting from high-energy trauma, present complex challenges for modern medicine. Worldwide, 15–20 femoral fractures per 100,000 population occur annually, and the majority of these injuries affect individuals of working age[3,4,5].

Traditional treatment methods, such as open osteosynthesis, require extensive periosteal exposure, which disrupts up to 70% of the bone blood supply and increases the risk of nonunion (pseudarthrosis) up to 15%.

The BIOS technique, by combining minimal invasiveness with biomechanical stability, reduces these complications to 1–2%. By 2026, BIOS has been accepted as the "gold standard" in more than 85% of leading trauma centers worldwide.

Reparative regeneration of tubular bones consists of four main morphological stages, and the BIOS method optimizes these processes.

The first stage involves inflammation and hematoma formation. Because the BIOS technique does not open the fracture focus, it preserves growth factors present in the hematoma, such as TGF-beta, BMP-2, and BMP-7. These factors play a crucial role in the differentiation of mesenchymal cells into osteoblasts[6,7,8].

The second stage is the formation of soft bone callus (pro-callus). The controlled micromobility provided by the BIOS nail (0.2–0.5 mm) is extremely important at this stage. This micromobility mechanically stimulates osteoblast activity and accelerates the transformation of cartilage tissue into bone through endochondral ossification.

From a morphological standpoint, the BIOS nail is positioned inside the medullary canal, distributing the axial load evenly along the bone walls. Locking screws (locking bolts) prevent rotational displacement and shortening of fracture fragments. As a result of such stable-dynamic fixation, the third stage — formation of hard bone callus — occurs 25–30% faster compared to traditional methods[9,10,11].

Microscopic analyses demonstrate that in bones treated with BIOS, the structure of osteons nearly returns to normal within three months after injury. Although the fourth stage — bone

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remodeling — may continue for years, BIOS allows patients to begin full weight-bearing within 12–16 weeks.

Table 1. Anatomical and functional outcomes of the BIOS method in fractures of long tubular bones (statistics 2024–2026)

Bone type	Average surgery time (min)	Blood loss (ml)	Bone union rate (%)	Early complications (%)
Femur	45–70	150–250	98.5	1.2
Tibia	35–55	80–150	96.8	2.4
Humerus	30–50	50–100	94.2	3.1

Instrumental diagnostics plays a crucial role in the success of BIOS procedures. During surgery, electronic-optical converter (EOC) navigation allows precise insertion of the nail into the medullary canal and accurate locking of the screws at the millimeter level.

Since 2025, many centers have introduced electromagnetic navigation systems for distal locking, which have reduced radiation exposure by approximately 60%.

In the postoperative period, CT densitometry enables objective assessment of bone healing by measuring the density of the bone callus. According to statistical data, when the density of the bone callus reaches 300–400 Hounsfield Units (HU), full weight-bearing is recommended[12,13,14].

One of the specific complications of the BIOS method, fat embolism, has been thoroughly studied in terms of its pathogenesis. During insertion of the intramedullary nail, the intramedullary pressure may exceed 100 mmHg, which can cause fat particles from the bone marrow to enter the bloodstream.

However, modern nails introduced in 2026, such as new-generation reamers according to AO/ASIF standards, have special channels that reduce intramedullary pressure. As a result, the risk of fat embolism has been reduced to approximately 0.3%, even in patients with cardiological or pulmonary insufficiency[15,16,17].

Table 2. Comparative economic and clinical analysis of the BIOS method and plate osteosynthesis (LCP)

Indicator	BIOS method	Plate osteosynthesis (LCP)
Hospital stay	3–5 days	10–14 days
Start of rehabilitation	Day 2 (active movement)	Day 14 (after suture removal)
Risk of infectious complications	Very low (<1%)	Moderate (5–7%)
Implant removal	After 12–18 months (easy)	After 18–24 months (more complex)
Economic efficiency	High (rapid return to work)	Low (long-term rehabilitation)

The morphological and metallurgical characteristics of BIOS nails are also continuously improving. Currently used titanium alloys (Ti-6Al-4V) have an elastic modulus close to that of bone (Young's modulus), which reduces the phenomenon of "stress shielding." This prevents bone resorption around the implant[18,19,20].

Statistical analyses indicate that when titanium nails are used, the strength of the regenerated bone after union is approximately 15% higher than when steel nails are used[21,22].

CONCLUSION

Locking intramedullary osteosynthesis represents not only a mechanical fixation method but also a high-technology technique that stimulates biological regeneration in the treatment of

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fractures of large tubular bones. Its minimal invasiveness, preservation of bone blood circulation, and the possibility of early weight-bearing have significantly improved clinical outcomes.

Statistical data from 2024–2026 show that the use of the BIOS method can increase patient turnover in trauma hospitals by 40% and reduce overall treatment costs by approximately 25%.

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