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Design and Fabricate a Prototype of a Magnetically Responsive Dynamic Plate-Screw System for Controlled Mechanical Modulation in Fracture Non-Union Management

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***Abstract*— Background: Fracture non-union is still considered a big deal, especially with respect to long bone fractures from high-energy injuries. While juxta-articular and intra-articular fractures may have the option of replacement surgery, the biologic healing of a diaphysis of the healing of fracture ends is dependent upon the stability of the fixation mechanically. The Diamond Concept emphasizes the importance of combining mechanical and biological factors, however, traditional internal fixation systems provide a static environment. This can cause stress shielding or too little stimulus for callus formation. This study discusses a new magnetically responsive dynamic plate-screw system for non-invasive post-operative mechanical modulation.**

***Method: From medical-grade Stainless Steel 304 (SS304) helps to fabricate The system consists of a low-profile bone plate and specialized screws. Magnetic properties were imparted to the screw via an impulse magnetization procedure performed with the Impulse 2k228e magnetizer. Human-like 3D-printed TBL bone models were employed for biomedical validation. Design optimization was performed using CAD & Finite element analysis.**

***Result: You can use this method in both clinical and preclinical studies to tweak the distance between bone fragments after they've been implanted, and you won't need another surgery to do it. Computer modelling showed that the system lined up perfectly with the 3D-printed TBL bone surface. Tests also proved that the internal screw could be controlled magnetically to apply both compressive and distractive forces between the bone fragments.**

***Conclusion: The obtained magnetically responding system prototype combines the adjustability of the external fixator used in open fractures with the stability offered by the internal fixation system, an extra-medullary plate. It provides a promising tool for creating a mechano-biological environment in the treatment of complex and resistant non-unions by enabling controlled dynamization.**

I. INTRODUCTION

Healing a bone isn't just about biology or just about stability — it's both. (1) The body goes through inflammation, then repair, then remodelling. Each stage needs the right signals. You need good blood flow, the bone fragments to be stable and in contact, plus the right cells and growth factors at the site. If any one of those is off, healing gets compromised and you can end up with a non-union. (2)

The Diamond Concept, proposed by *Paul Andrzejowski* and *Peter V. Giannoudis*, provides one of the most comprehensive frameworks for understanding the biology of fracture healing and the requirements for successful bone formation. It brings together five things: the osteogenic cells, a scaffold for them to grow on, signals that trigger bone formation, mechanical stability, and adequate vascularity to create an optimal biological microenvironment. (3) Like other theories, it comes down to the same basics — you need stability, blood flow, bones in contact, and a rich environment of stem cells and growth factors for healing to succeed.

The mechanical environment plays a critical role in determining both the outcome and quality of bone healing. An unfavourable mechanical setting can delay healing. Excessive motion at the fracture gap can prolong inflammation, interfere with cell differentiation, and prevent proper healing from even starting. On the other hand, fixation that is too rigid can also be harmful. It can suppress the small interfragmentary movements needed for secondary bone healing and for proper callus formation. (4)

Mechanobiology explains how mechanical forces influence cell activity and tissue differentiation during bone healing. In contrast, controlled compression combined with shear promotes bone formation through both intramembranous and endochondral ossification. (5)

Interfragmentary movement describes the relative motion between fracture fragments under normal body loads or external forces. This movement creates a strain pattern across

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the fracture gap, and it plays a major role in how the fracture heals. The extent of this movement depends on implant stiffness and fracture contact area. (6) How much movement you get comes down to how stiff your fixation is, how well the bone ends are touching with amount and direction of pull of muscles. (7)

To address this, Dynamic Compression Plate (DCP) and the Locking Compression Plate (LCP) which provide a largely static mechanical environment after implantation can only be dynamized with an additional surgical procedure. (8) In intramedullary nails dynamization is done by removing a locking bolt so that the bone slide and compress on weight bearing. (9) The concept of controlled dynamization recognizes that mechanical conditions should be changed across different stages of fracture healing. So to modulate the mechanics at the right time, we need to design implants like dynamic compression plates in such a way that they allow movement only when it is beneficial. Unlike external fixators, current internal fixators do not allow post-operative adjustment or reversal of interfragmentary strain.

External fixators like the Ilizarov apparatus and LRS enable controlled, gradual compression and distraction at the fracture site through adjustable mechanical components. However, external fixators come with notable drawbacks. The downside is that having metal frames outside the body causes problems: pin infections, pain, trouble moving around, stress, and patients often don't stick with treatment. Use them for too long and it really affects how patients feel and cope day to day.(10)

An ideal system would merge the advantages of dynamization with the benefits of internal fixation. What's needed is an internally implanted fixation device that allows fracture mechanics to be regulated from outside the body. Therefore, an optimal internally adjustable dynamic fracture fixation device should have the following features:

- Adequate mechanical strength to support fracture healing
- Controlled interfragmentary motion to promote callus formation
- Capability to adjust compression and distraction after surgery
- Minimal patient morbidity and better acceptance
- Enhanced biological stimulation of repair through a controlled mechanical environment

In the last few years, new materials, smart implants, and magnetic tech have really pushed orthopedic implants forward. Breakthroughs in bioactive materials, magnetic nanoparticles, 3D printing, and remotely controlled medical devices now make it possible to fabricate implants that actively interact with both the biological and mechanical environment. (11,12) The technology of magnetic orthopaedic implants can generate controlled motion or force when exposed to external magnetic fields. This capability of magnetic implants has gained interest in translational musculoskeletal research because it allows non-invasive modulation of implant performance after surgery.(13)

Magnetic implants can produce controlled motion under external fields, enabling non-invasive post-surgical tuning. Such implants can tailor mechanical forces at the fracture site to match different healing phases, while still retaining the stability and comfort of internal fixation. (14) Mechanical stimulation using remotely operated magnetic orthopedic implants may facilitate a conducive mechanical environment for fracture healing by controlling the interfragmentary strain, stimulating callus formation, inducing osteogenesis, and performing gradual dynamization during fracture recovery.(15)

Although magnetic intramedullary devices such as the PRECICE Nail exist for limb lengthening, and deformity correction the application of magnetically actuate principles for internal fixation devices appears to be sparse at best(16). However, the use of magnetic actuation in internal fixation devices remains largely unexplored. Existing systems focus on reconstruction rather than on dynamic control of compression-distraction at the fracture site.

So the idea here is to build and test a proof-of-concept: a magnetic screw built into a dynamic plate that we can control from outside with a local magnetic field. This would let us compress or distract the fracture as needed during healing, without going back to surgery.

II. MATERIALS & METHODS

The development of the prototype began with a review of literature in 7 key areas:

1. **Mechanobiology:** Cells in the fracture decide what to become — fibrous tissue, cartilage, or bone — based on how much and in what direction they're strained.(4)
2. **Strain Theory :** *Perren's* theory states that tissue differentiation in the fracture gap depends on interfragmentary strain.(8)
3. **Compression plates :** Prior work on DCP and LC-DCP was studied to understand their compressive function and impact on periosteum.(17)
4. **Dynamization:** Dynamization refers to a controlled reduction in the rigidity of a fracture fixation system. The goal is to introduce axial loading and controlled interfragmentary motion to enhance fracture healing.
5. **Biomechanics of External Fixation:** Ilizarov devices and the Limb Reconstruction System (LRS) were reviewed for their principle of "tension-stress" leading to bone and soft tissue regeneration.(18)
6. **Magnetic Biomaterials:** Magnetic biomaterials have drawn much attention in orthopaedic tissue engineering, regenerative medicine and smart implant design.(19)
7. **Shape Memory Alloys:** Shape Memory Alloys (SMAs) are materials capable of returning to a predefined shape upon thermal or mechanical activation.(20)They have been investigated for orthopedic applications including

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compression staples, spinal implants, intramedullary devices, and dynamic fracture fixation systems.(21)

Anthropometric Measurement of Tibial Dimensions

To establish anatomically accurate dimensions for the plate design, a retrospective cross-sectional measurement study was performed on plain radiographs of the tibia obtained from the Radiology Department. The measurement was taken as follows (figure 1).

- **Proximal tibia**: at the level of the fibular neck
- **Distal tibia**: 3.5 cm proximal to the tibial plafond

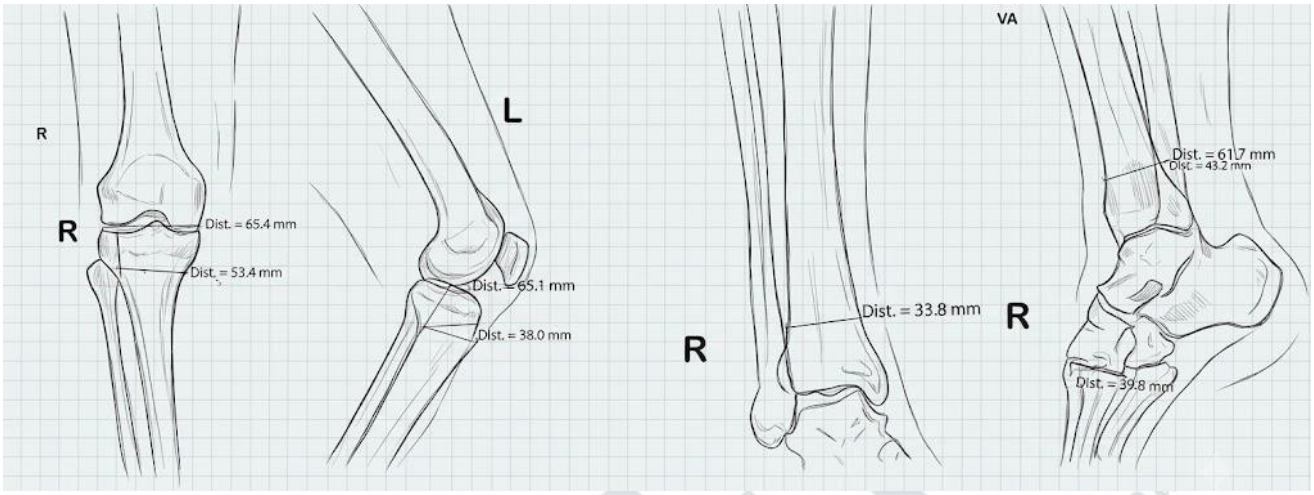


Figure 1. Showing the measurement taken in the proximal and distal end of tibia

Bone Model Fabrication by 3D Printing

A 3D tibial model was developed through reverse engineering, 3D scanning, CAD, and additive manufacturing. The generation of a representative 3D bone geometry via reverse engineering from medical imaging data is a well-established approach for surgical planning and biomechanical evaluation.

Average dimensions from 324 tibial X-rays were used to create a schematic profile, which was then converted into a digital CAD model using standard reverse engineering methods. This approach of converting medical images into CAD models is commonly used for surgical planning.(22)

To capture the exact outer shape, Surface geometry was validated by scanning a tibial specimen with an EinScan SE structured-light 3D scanner (accuracy ≤0.1 mm, 1.3 MP camera).

Three-Dimensional Printing of Tibial Bone Model

Once the digital model was finalized, we exported it as an STL file and loaded it into Cura for slicing. The model was sliced into thin layers and machine readable G code instructions were generated. We set the layer thickness to 0.1–0.3 mm, infill to 20–50%, and print speed to 40–60 mm/s. Supports were added wherever needed.(23)

The bone model was fabricated using Fused Deposition Modeling (FDM) with polylactic acid (PLA) filament due to its stability, low cost, and suitability for anatomical models. Literature reports FDM bone models to have mean errors of 0.00–0.13 mm compared to CAD data and maximum errors less than 1 mm. (24) [Figure-2]

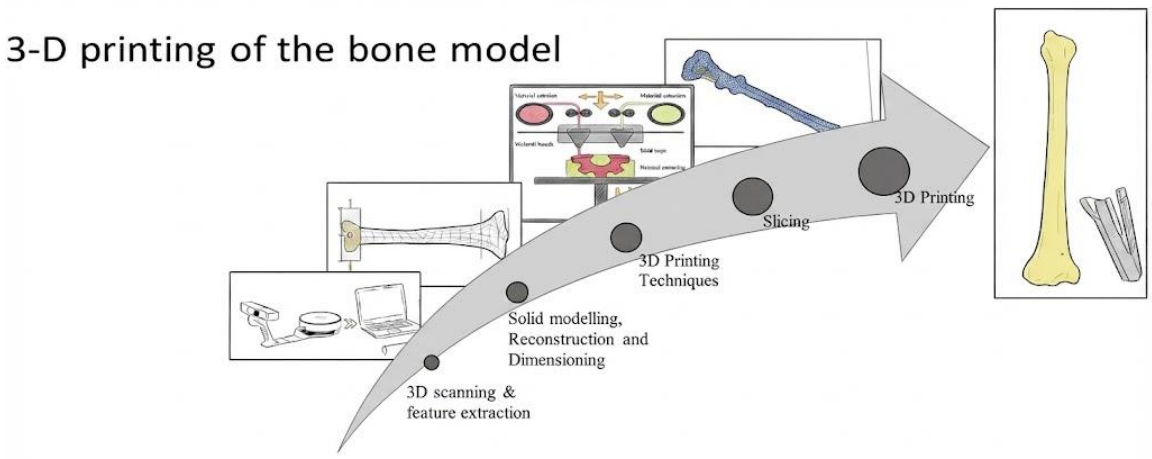


Figure 2. Demonstrating the Process of Printing the Tibial Bone Model

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Design and Dimensions of the Dynamic Plate and Magnetic Screws

The dynamic plate-screw system was conceptualized using literature review, anatomical data, and CAD modelling.

Design Objective: To develop a plate that could generate controlled axial compression or distraction at the fracture site using an external magnet, without the need for additional surgery.

We started with rough sketches [Figure 3 & Figure 4] and turned them into 3D CAD models with these goals in mind:

- Ability to provide controlled compression and distraction at the fracture site.
- Adequate mechanical stability for load-bearing in long bone fractures.
- Integration with magnetic screws that respond to an external magnetic field.



Figure 3. Rough sketches showing the drawings of parts of the plate (a, b) and the integrated plate (c)

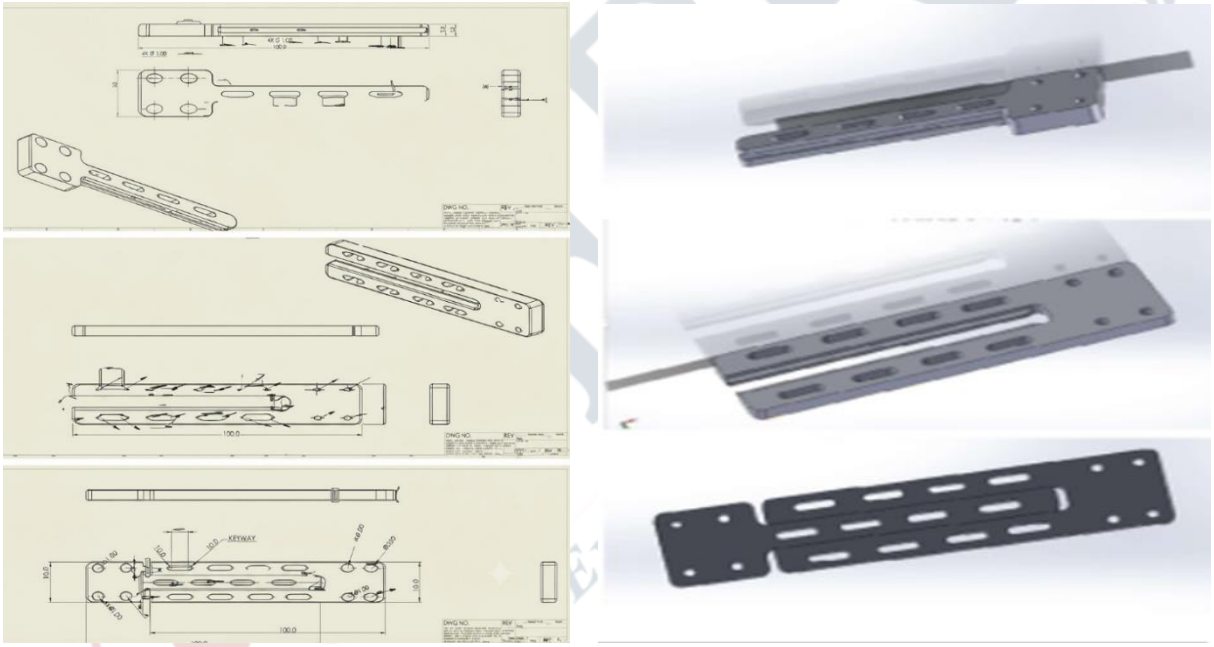


Figure 4. Formal CAD models with respect to the parts of the plate

Screw Dimensions

We sized the screws using standard cortical screw dimensions for tibial plates, but adjusted them to fit our 3D printed tibia and the anatomy data we collected. To test the concept, we made two types of magnetic screws — one north pole and one south pole. By changing the polarity of the external magnet, we could show both compression through attraction and distraction through repulsion at the fracture.

Material Selection and Properties

For the prototype we used SS304 stainless steel.

The reason: in its normal annealed state it's not magnetic, but once we cold-work it, it develops a mild magnetic property. That gives us the ability to control magnetization, while still keeping good corrosion resistance and strength for an implant.

Magnetisation of SS304 Screws

Equipment: M-Pulse 2k228e Impulse Magnetiser

To magnetize the SS304 screws, we used an M-Pulse 2k228e impulse magnetizer from Germany with a custom-made solenoid coil [Figure 5]. Regular magnets wouldn't work here because cold-worked SS304 only has weak, strain-induced magnetism. So we needed Tesla-level fields to get proper magnetization. The M-Pulse 2k228e is a capacitor-discharge system that delivers high-current pulses

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for magnetizing components with low to moderate magnetic permeability, such as cold-worked austenitic stainless steels.

III. RESULTS

The anthropometric of the tibial dimensions were as follows (table 1).

Table 1. Mean Tibial Dimensions (n = 324 radiographs)

Region	Level of Measurement	Mean AP Width (mm)	Mean Lateral Width (mm)
Proximal Tibia	At neck of fibula	43.77	40.10
Distal Tibia	3.5 cm from tibial plafond	29.40	26.71

Components of the Fabricated Implant System

The component of the system is enumerated in (table 2).

Table 2. Components of the implant and its description

Component	Description
Dynamic plate	Metallic plate with controlled sliding mechanism
Magnetic screws	Ferromagnetic screws responsive to external magnetic field
Coupling interface	Mechanical interface permitting controlled axial translation
External magnetic actuator	External magnetic source for noninvasive actuation

Magnetic Response Characteristics of the Implant (Table 3)

Table 3. Magnetic response characteristics of the implant

Parameter	Observation
Magnetic responsiveness	Present
Direction of movement	Axial
Reversibility	Achieved
Repeatability	Consistent
Structural integrity after repeated cycles	Maintained

Observed Interfragmentary Movement During Testing (table 4)

Table 4. Inter-fragmentary movement during testing

Mode of actuation	Observed effect
Magnetic compression	Reduction in gap between T and U plate
Magnetic distraction	Increase in gap between T and U plate
Repeated actuation	Stable performance
Construct alignment	Maintained

The Implant so Produced is shown in [Figure 5.]



Figure 5. (a) Plate with screw construct viewed from the front; (b) plate with screw construct viewed from the side, showing the broken base site; (c) movement of the magnetic screw producing movement at the broken base site

IV. DISCUSSION

The goal of this study was to design and build a proof-of-concept implant that can be controlled with a magnet to help treat non-unions in long bones. The implant has two plates that fit together, with magnetic screws attached. When we apply an external magnetic field, it creates controlled compression or distraction at the fracture without more surgery. The design is grounded in current principles of fracture mechanobiology, interfragmentary strain theory, controlled dynamization, and smart orthopaedic implant technology.

Our results show that the implant we built can be adjusted to create controlled movement using magnetic screws, without losing stability. The T and U plates fit together to make this possible.

This work aims to combine the biomechanical benefits of external dynamization systems with the biological and patient-related advantages of internal fixation. The findings are discussed below in relation to existing literature and current orthopaedic fixation technologies.

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Mechanobiology of Fracture Healing and its Relevance to the Present Study

The focus of this study was mainly on the mechanical aspects of the environment within the fracture gap. The idea behind the magnetic dynamic implant is simple: if we can fine-tune the movement between bone fragments after surgery, we can create a better environment for healing and possibly help more callus to form.

Inter-Fragmentary Strain Theory and Controlled Micromotion

The results of the present study work on the anticipation that if controlled axial micromotion is generated non-invasively through magnetic actuation, it may result in ample callus formation if the fracture tends to go into non-union. This generation of micromotion is anticipated to be non-invasive, smooth and reproducible.

Dynamization and Mechanical Modulation

The implant achieved stable, reversible movement between T and U plates using magnetic actuation. Potential advantages:

- Non-invasive postoperative adjustment.
- Repeated compression/distraction cycles.
- Tunable mechanical stimulation during healing.
- External control of fracture mechanics, no revision surgery required.

Comparison with External Fixation Systems

This implant concept aims to combine the mechanical stability of external fixators with the biological and comfort advantages of internal plates. As the device is entirely implanted, it could potentially eliminate complications related to prolonged external fixation.

Comparison with Magnetically Actuated Orthopaedic Devices

External magnetic fields can drive motion or force in medical devices without physical contact.(25) With recent work in micro-robotics and implantable devices, magnetic actuation has become much more common.(8) As Yan noted, the big advantages are that you can control it remotely, it's minimally invasive, and you can tune it very precisely. (25).One of the most successful clinical examples in orthopaedics is the use of PRECICE Nail, which permits gradual internal limb lengthening using an externally controlled magnetic mechanism. (26). The PRECICE Nail is a leading orthopaedic application, allowing gradual limb lengthening via external magnetic control. Its success proves that magnetic actuation in implants is viable. The device relies on a magnetically driven unidirectional motor and is mainly indicated for limb lengthening and bone transport. However, its use in acute fracture fixation and for modulating interfragmentary mechanics remains limited.

The present implant differs from currently available magnetic systems because:

Existing Magnetic Systems	Present Innovation
Intramedullary distraction systems	Plate-and-screw fixation system
Primarily unidirectional distraction	Bidirectional compression/distraction
Reconstruction applications	Fracture healing applications
Large distraction distances	Controlled micromotion
Limb lengthening focus	Dynamization and fracture modulation

Thus, the present work represents a conceptual expansion of magnetic orthopaedic technology into fracture fixation biomechanics.

V. LIMITATIONS OF THE PRESENT STUDY

1. The study represents a proof-of-concept experimental investigation without in vivo biological evaluation.
2. Histological assessment of fracture healing and callus formation was not performed.
3. Advanced fatigue testing and finite element analysis were not included.
4. Long-term biocompatibility and corrosion behaviour of magnetic components remain to be investigated.
5. Optimization of magnetic field strength, orientation, and tissue penetration requires further study.
6. Clinical applicability requires miniaturization and refinement of implant design.

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Conflict of Interest:

The authors declare no conflict of interest.

REFERENCES

[1] Zura R, Mehta S, Della Rocca GJ, Steen RG. Biological Risk Factors for Nonunion of Bone Fracture. JBJS Rev. 2016 Jan 5;4(1):e5. doi:10.2106/JBJS.RVW.O.00008 PubMed PMID: 27490008.

[2] Brinker MR, O'Connor DP. The Biological Basis for Nonunions. JBJS Rev. 2016 Jun 28;4(6):e3. doi:10.2106/JBJS.RVW.15.00078

[3] Andrzejowski P, Giannoudis PV. The 'diamond concept' for long bone non-union management. J Orthop Traumatol Off J Ital Soc Orthop Traumatol. 2019 Dec;20:21. doi:10.1186/s10195-019-0528-0 PubMed PMID: 30976944; PubMed Central PMCID: PMC6459453.

[4] Mori Y, Kamimura M, Ito K, Koguchi M, Tanaka H, Kurishima H, et al. A Review of the Impacts of Implant Stiffness on Fracture Healing. Appl Sci. 2024 Jan;14(6):2259. doi:10.3390/app14062259

[5] Jagodzinski M, Krettek C. Effect of mechanical stability on fracture healing--an update. Injury. 2007 Mar;38 Suppl 1:S3-10. doi:10.1016/j.injury.2007.02.005 PubMed PMID: 17383483.

[6] Glatt V, Evans CH, Tetsworth K. A Concert between Biology and Biomechanics: The Influence of the Mechanical

Environment on Bone Healing. Front Physiol. 2016;7:678. doi:10.3389/fphys.2016.00678 PubMed PMID: 28174539; PubMed Central PMCID: PMC5258734.

[7] Epari DR, Taylor WR, Heller MO, Duda GN. Mechanical conditions in the initial phase of bone healing. Clin Biomech. 2006 Jul;21(6):646–55. doi:10.1016/j.clinbiomech.2006.01.003 PubMed PMID: 16513229.

[8] Perren SM. Evolution of the internal fixation of long bone fractures. The scientific basis of biological internal fixation: choosing a new balance between stability and biology. J Bone Joint Surg Br. 2002 Nov;84(8):1093–110. doi:10.1302/0301-620x.84b8.13752 PubMed PMID: 12463652.

[9] Claes L. [Dynamization of fracture fixation : Timing and methods]. Unfallchirurg. 2018 Jan;121(1):3–9. doi:10.1007/s00113-017-0455-6 PubMed PMID: 29318341.

[10] Maheshwari V, Raja BS, Bahadur B, Regmi A, Dhingra M, Gowda AKS. Outcome analysis of ilizarov and monorail fixators in the treatment of nonunion of long bones: A systematic review and proportion meta-analysis. J Clin Orthop Trauma. 2023 May 18;40:102170. doi:10.1016/j.jcot.2023.102170 PubMed PMID: 37293684; PubMed Central PMCID: PMC10245124.

[11] Intravaia JT, Graham T, Kim HS, Nanda HS, Kumbar SG, Nukavarapu SP. Smart Orthopedic Biomaterials and Implants. Curr Opin Biomed Eng. 2023 Mar;25:100439. doi:10.1016/j.cobme.2022.100439 PubMed PMID: 36642994; PubMed Central PMCID: PMC9835562.

[12] Cecen B, Hassan S, Li X, Zhang YS. Smart Biomaterials in Biomedical Applications: Current Advances and Possible Future Directions. Macromol Biosci. 2024 Mar;24(3):e2200550. doi:10.1002/mabi.202200550 PubMed PMID: 37728061.

[13] Yao J, Yang Y, Li M, Chen XB. Micro/nano-robotic medical device: preparation, actuation mechanisms and their applications in medicine. RSC Adv. 15(45):37728–75. doi:10.1039/d5ra05398f PubMed PMID: 41080683; PubMed Central PMCID: PMC12509628.

[14] Yan B. Actuators for Implantable Devices: A Broad View. Micromachines. 2022 Oct 17;13(10):1756. doi:10.3390/mi13101756 PubMed PMID: 36296109; PubMed Central PMCID: PMC9610948.

[15] Haffner-Luntzer M, Liedert A, Ignatius A. Mechanobiology of bone remodeling and fracture healing in the aged organism. Innov Surg Sci. 2016 Dec 1;1(2):57–63. doi:10.1515/iss-2016-0021

[16] Masci G, Palmacci O, Vitiello R, Bonfiglio N, Bocchi MB, Cipolloni V, et al. Limb lengthening with PRECICE magnetic nail in pediatric patients: A systematic review. World J Orthop. 2021 Aug 18;12(8):575–83. doi:10.5312/wjo.v12.i8.575 PubMed PMID: 34485104; PubMed Central PMCID: PMC8384613.

[17] Augat P, Hollensteiner M, von Rüden C. The role of mechanical stimulation in the enhancement of bone healing. Injury. 2021 Jun 1;52:S78–83. doi:10.1016/j.injury.2020.10.009

[18] Seenappa HK, Shukla MK, Narasimhaiah M. Management of complex long bone nonunions using limb reconstruction system. Indian J Orthop. 2013;47(6):602–7. doi:10.4103/0019-5413.121590 PubMed PMID: 24379467; PubMed Central PMCID: PMC3868143.

[19] Shi S, He S, Lin Q, Sun S. Magnetic Nanocomposite Hydrogels in Orthopedics: Applications and Perspectives. Int J Nanomedicine. 2025 Dec;Volume 20:15379–94. doi:10.2147/IJN.S539423

[20] Turkmen M, Issa A, Awayssa O, El-Hassan H. Incorporation of Nitinol (NiTi) Shape Memory Alloy (SMA) in Concrete: A Review. Materials. 2025 Sep 24;18(19):4458. doi:10.3390/ma18194458 PubMed PMID: 41095284; PubMed Central PMCID: PMC12525672.

[21] Misir A. Current developments in orthopaedic implant technology. J Orthop Surg. 2025 Oct 28;20:927. doi:10.1186/s13018-025-06279-w PubMed PMID: 41152964; PubMed Central PMCID: PMC12560316.

[22] Viceconti M, Zannoni C, Pierotti L. TRI2SOLID: an application of reverse engineering methods to the creation of CAD models of bone segments. Comput Methods Programs Biomed. 1998 Jun;56(3):211–20. doi:10.1016/S0169-2607(98)00011-X

[23] Smith EJ, Anstey JA, Venne G, Ellis RE. Using additive manufacturing in accuracy evaluation of reconstructions from computed tomography. Proc Inst Mech Eng [H]. 2013 May;227(5):551–9. doi:10.1177/0954411912474612 PubMed PMID: 23637265.

[24] Liu L, Xu S, Bai S, Xu J, Li Y, Bonavina L, et al. The development and application of magnetic surgery in clinical treatment. Biomed Eng OnLine. 2026 Jan 29;25:36. doi:10.1186/s12938-026-01526-5 PubMed PMID: 41612329; PubMed Central PMCID: PMC12924363.

[25] Nc DrN, K DrV. Establishing the efficacy of limb reconstruction system (LRS) in the management of complex long bone non- union: A prospective study. Int J Orthop Sci. 2018 Apr 1;4(2h):511–7. doi:10.22271/ortho.2018.v4.i2h.79

[26] Masci G, Palmacci O, Vitiello R, Bonfiglio N, Bocchi MB, Cipolloni V, et al. Limb lengthening with PRECICE magnetic nail in pediatric patients: A systematic review. World J Orthop. 2021 Aug 18;12(8):575–83. doi:10.5312/wjo.v12.i8.575 PubMed PMID: 34485104; PubMed Central PMCID: PMC8384613.