biodegradable screws in orthopaedics, with scientific background, material types, advantages & disadvantages, clinical applications, challenges, and future directions by “Dr. Pothireddy Surendranath Reddy” specifically to biodegradable screws.

Table of Contents

---

1. Introduction

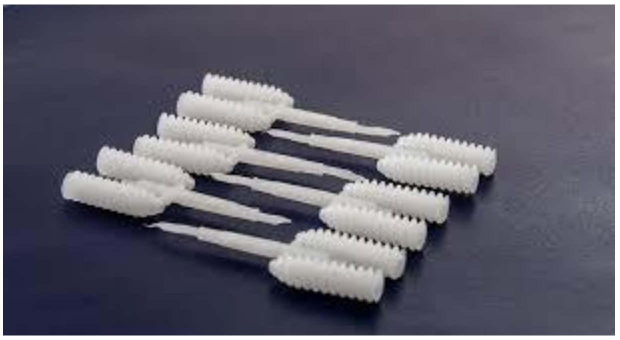
In recent decades, orthopedic surgery has increasingly explored the use of **biodegradable (bioabsorbable)** **implants,** including screws, plates, and anchors. The primary motivation is to provide temporary fixation that supports bone or soft-tissue healing, then degrades, reducing long-term complications such as implant removal surgery, stress shielding, and metallic corrosion.

Biodegradable screws, in particular, play a critical role in internal fixation, ligament reconstruction, and pediatric orthopaedics. These devices are designed to maintain mechanical strength during the healing phase, then gradually resorb in the body, ideally being replaced by natural bone or tissue.

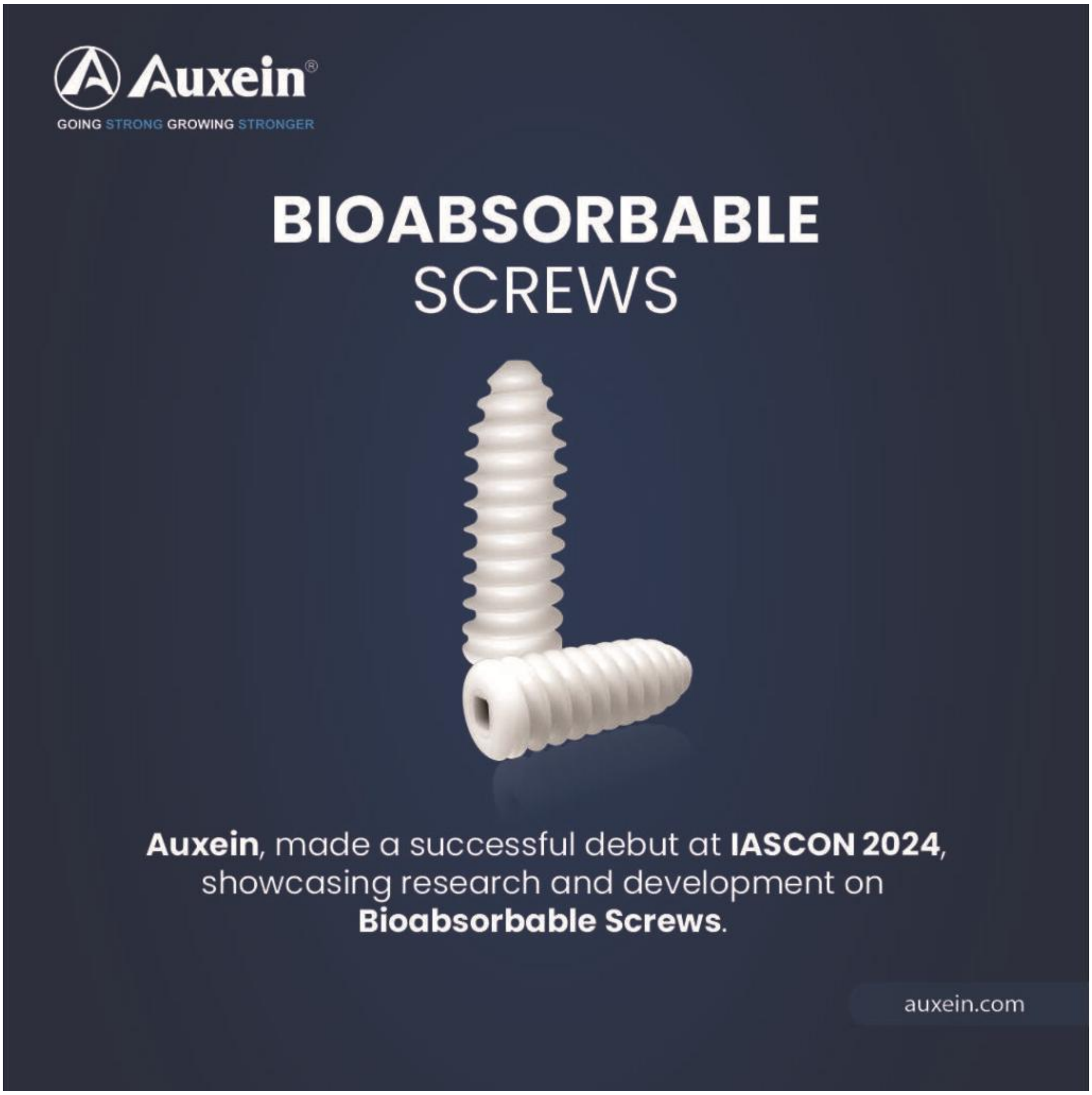
This article delves deeply into biodegradable screws in orthopaedics: their materials, design, performance, clinical use, benefits, challenges, and the future landscape.

---

2. What Are Biodegradable Screws?



A **biodegradable screw** is a surgical implant made from materials that degrade over time in the physiological environment. Unlike permanent metallic screws (e.g., titanium), these screws gradually lose mass via hydrolysis or corrosion and are eventually absorbed, metabolized, or excreted by the body.



They are often used for:

- **Ligament graft fixation**, such as in anterior cruciate ligament (ACL) reconstruction.
- **Fracture fixation**, especially in non-load-bearing or low-load regions.
- **Pediatric orthopaedics**, where permanent implants can interfere with growth.
- **Soft tissue–bone anchoring**, e.g., suture anchors for tendon repair.

Biodegradable screws must balance **mechanical strength**, **degradation rate**, and **biocompatibility**, ensuring that they support healing long enough but then safely disappear.

3. Materials Used in Biodegradable Screws

The choice of material is fundamental: it determines the screw's mechanical strength, degradation kinetics, biocompatibility, and manufacturing method.

3.1. Polymeric Materials

Polymers are among the earliest and most studied biodegradable materials.

3.1.1. Polylactic Acid (PLA / PLLA)

- **Poly-L-lactic acid (PLLA)** is a common choice. It degrades by hydrolysis into lactic acid, which the body metabolizes.
- Advantages: good mechanical strength, well-known biocompatibility.
- Drawbacks: relatively slow degradation; potential for acid accumulation; sometimes foreign-body reactions.
- Clinical data: A randomized controlled trial comparing PLLA screws vs. metallic screws in ACL reconstruction found comparable outcomes after 24 months.
- Biomechanical: older biomechanical tests comparing a self-reinforced PLLA screw to metal screws in a bovine bone–patellar tendon–bone model found that the PLLA screw had similar load-to-failure as some metallic screws.

3.1.2. Polyglycolic Acid (PGA) & PLGA

- **PGA** degrades faster than PLA, but can lose mechanical strength relatively quickly.
- **PLGA (co-polymers of lactic and glycolic acid)** can be tuned to control degradation rate by adjusting lactic:glycolic ratio.
- These polymers are used in some interference screws or suture anchors.

3.1.3. Polycaprolactone (PCL)

- **PCL** is another biodegradable polymer with a slower degradation rate and good flexibility.
- It is less acidic during degradation than PLA, but its mechanical strength is lower.
- An interesting development: researchers have made composite bone screws from **PCL, silk fibers, and magnesium oxide (MgO)**.

- In a study, a composite containing 10% MgO and 20% silk in PCL (called MSP) showed significantly enhanced mechanical strength compared to PCL alone: 1.7× tensile strength, 7.5× modulus.
- Degradation: this MSP composite showed accelerated degradation in vitro (2.7× after 60 days in PBS) compared to plain PCL.
- In vivo: subcutaneous implantation in rats showed moderate early inflammation that subsided; no major systemic toxicity was noted in vital organs.

3.1.4. Composite Polymers

- Composite materials combine polymers with fillers (ceramics, nanoparticles, fibers) to optimize performance.
- Example: **MgO-silk-PCL**, as above. The synergy of MgO (for strength) and silk (for modulus) improved performance.
- These composites can be molded into screws with reasonably good pull-out strength: in synthetic bone, the MSP composite screw had double the pull-out strength compared to PCL-only screw.

3.2. Biodegradable Metals

Metallic biodegradable implants often rely on magnesium (Mg) alloys, which corrode in the physiological environment. These have recently received considerable attention.

3.2.1. Magnesium (Mg) Alloys

- Magnesium has favorable properties: it is biocompatible, relatively lightweight, and degrades via corrosion producing magnesium ions, hydrogen, and hydroxides.
- Several studies have shown promising in vitro and in vivo behavior.
- A clinical trial: Sun et al. (2023) reported a **randomized controlled study** comparing biodegradable magnesium screws, conventional titanium screws, and direct embedding fixation in pedicled vascularized iliac bone graft transfer for osteonecrosis of the femoral head (ONFH).

- Results: magnesium screws performed well in fixation, and their degradation supported angiogenesis (blood vessel growth), which is favorable in bone grafting.

- Design considerations: Newer designs use finite element analysis to optimize magnesium buttress-threaded screws for fracture fixation, ensuring adequate strength, pull-out resistance, bending, and torsional resistance during degradation.

3.2.2. Other Metals

- Beyond Mg, research is ongoing in other biodegradable metals like **zinc alloys** (Zn) and other combinations, though Mg remains the most clinically advanced.

---

4. Mechanism of Biodegradation

Understanding how screws degrade in the body is essential for predicting performance, biocompatibility, and potential complications.

1. **Hydrolysis (Polymers):** Polymers like PLLA, PLGA, PCL degrade via hydrolysis, breaking ester bonds in the polymer chain to generate monomers (like lactic acid or glycolic acid). These monomers are metabolized or cleared by the body.
2. **Corrosion (Metals):** Biodegradable metals (e.g., Mg) corrode in the aqueous environment of body fluids:

$$\text{Mg} \;+\; 2\;\text{H}_2\text{O} \;\rightarrow\; \text{Mg(OH)}_2 + \text{H}_2 \uparrow$$

- Hydrogen gas is released; accumulation can cause gas pockets, which is a known challenge.
- $Mg(OH)_2$ may convert into more stable magnesium salts depending on body chemistry.
- The rate of corrosion depends on alloy composition, surface treatment, and microstructure.

3. **Cellular Resorption:** Over time, host cells (osteoblasts, macrophages) may participate in degrading or remodeling the implant area, especially in porous designs.
4. **Mechanical Load Influence:** Load-bearing can accelerate degradation via micro-motion, fatigue, or stress corrosion.

---

5. Design and Manufacturing of Biodegradable Screws

Designing a biodegradable screw requires balancing structural integrity, degradation, and biological integration.

5.1. Traditional Molding

- For composite polymers (e.g., PCL–MgO–Silk), custom molds are used to cast the screw.
- This method is relatively simple but offers limited flexibility in internal architecture (e.g., porosity).

5.2. Additive Manufacturing / 3D Printing

- **3D printing** (additive manufacturing) allows for highly customized screws with complex internal structures, such as pores, channels, or gradients.
- A key study: researchers 3D-printed **porous biodegradable screws** using layer-by-layer deposition.
- In that study: by adjusting print parameters (fill density, speed), they achieved optimal pore sizes (~ 259 × 207 × 200 μm) while maintaining mechanical strength (e.g., compressive strength ~ 24.58 ± 1.36 MPa).
- Biological performance: these porous screws supported adhesion of human mesenchymal stem cells, proliferation, and mineralized matrix formation over 21 days in vitro.
- In vivo: when implanted subcutaneously in rats, porous screws showed **increased vascularization** compared to non-porous controls.
- Advantages of porous design:
    - Enhanced bone or tissue ingrowth.

    - Better nutrient and waste exchange.
    - Gradual load transfer as the material degrades.

5.3. Finite Element Design Optimization

- Finite Element Analysis (FEA) helps in designing screws that maintain necessary strength and performance even as they degrade.
- For magnesium buttress-threaded screws, FEA has been used to optimize:
    - Pull-out resistance
    - Bending under load
    - Torsional strength during insertion
    - Behavior under combined loading (tension + bending) during degradation
- Topological optimization (removing unnecessary material) and vibration analysis also help improve design safety and longevity.

---

6. Biomechanical Performance

Key to clinical success is how well biodegradable screws can mimic the mechanical performance of permanent implants.

6.1. Strength & Fixation

- Biodegradable screws must provide **initial fixation strength** comparable to metallic screws to support healing.
- Example: in a bovine bone–patellar tendon–bone model, a self-reinforced PLLA screw had mean force-to-failure (~1358 N) comparable to some metal screws (~1081 N for an AO cancellous screw) in that test.
- Composite PCL–MgO–Silk screws showed **pull-out strength** double that of pure PCL screws in synthetic bone.
- Porous 3D-printed screws (see above) maintained compressive strength (~24 MPa) while allowing biological ingrowth.

6.2. Comparison with Metallic Screws

- Clinical comparative studies show mixed results:
    - A prospective comparative study of **bioabsorbable vs. metallic interference screws** in ACL reconstruction (hamstring graft) found no significant difference in functional outcomes at six months.
    - In another pilot study (Jaipur, India), biodegradable PLLA screws and metallic screws were used in ACL reconstruction; the Lysholm score was slightly higher in the biodegradable group (93.13 vs. 89.70), but overall results were similar.

6.3. Insertion / Surgical Considerations

- Surgeons must account for **torque limits**. Biodegradable screws may fracture if over-torqued.
- Design improvements like **perforated screws** (i.e., screws with holes) have been studied to improve bone ingrowth. For example, a “cage-like” perforated design did not significantly reduce torsional strength compared to unperforated screws.
- The bio-material’s flexibility (in polymers) or brittleness (in ceramics/composites) affects handling.

---

7. Biocompatibility and Biological Response

Biodegradable implants must be tolerated by the body and ideally promote tissue regeneration.

7.1. Cell Adhesion, Proliferation & Differentiation

- In the 3D-printed porous screws study, human mesenchymal stem cells adhered to the pores, proliferated, and produced mineralized matrix over 21 days in vitro.
- Composite screws (MgO–Silk–PCL) supported good cell viability and adhesion, showing the potential for biocompatible design.

7.2. Inflammatory Response

- In vivo implantation in rats (subcutaneous) of the composite PCL-based screws induced **moderate inflammation at 2 weeks**, which subsided by week 4, suggesting acceptable host response.
- For metallic biodegradable screws (Mg), hydrogen evolution and local pH changes are concerns; controlling corrosion rate is critical to minimize adverse tissue reactions.

7.3. In Vivo Studies & Animal Models

- Animal models validate both safety and performance. The composite screw (PCL–MgO–Silk) was implanted subcutaneously in rats with no toxicity in organs.
- For magnesium screws, studies have shown that degradation products can promote bone healing, angiogenesis (blood vessel formation), and eventual integration in bone graft contexts.

---

8. Clinical Applications in Orthopaedics

8.1. Ligament Reconstruction (e.g., ACL)

- **Anterior Cruciate Ligament (ACL)** reconstruction is perhaps the most common setting: interference screws fix the graft in bone tunnels. Biodegradable interference screws avoid leaving permanent metal hardware.
- As noted earlier, clinical studies comparing biodegradable interference screws vs metal screws report similar functional outcomes.
- However, concerns exist about **tunnel widening**, cyst formation, or incomplete osseous integration. A recent prospective study with a **biocomposite (PLGA + calcium components) interference screw**, known as *Biosure Regenesorb*, showed ~44% resorption over 2 years with only minor (<1%) new bone formation in the tunnel.

8.2. Fracture Fixation

- For non-load bearing fractures or in pediatric bones, biodegradable screws can serve to stabilize bones without the need for removal.
- Composite screws like PCL–MgO–Silk may be suitable for soft-bone fixation (e.g., metaphyseal fractures).
- Magnesium screws are promising: in the ONFH (osteonecrosis of femoral head) study, biodegradable Mg screws were used in pedicled iliac bone graft transfer.

8.3. Pediatric Applications

- Children may particularly benefit because their bones are still growing, and the removal of hardware can be more complex or harmful.
- Biodegradable screws reduce the long-term foreign body load and minimize the requirement for secondary surgeries.

---

9. Advantages of Biodegradable Screws

1. **Elimination (or significant reduction) of implant removal surgery** — since screws degrade, there is often no need for a second surgery to remove hardware.
2. **Reduced stress shielding** — as the implant degrades, the load is gradually transferred to healing bone, potentially promoting more natural remodeling.
3. **Lower long-term foreign body risk** — less risk of long-term metal-related complications like corrosion, cold welding, or metallic debris.
4. **Improved imaging** — no metal artifacts in MRI / CT when the implant is gone or has significantly degraded.
5. **Customizability** — especially with advanced manufacturing (3D printing), one can design porous, patient-specific screws.
6. **Better for growing skeletons** — children benefit from temporary support and reduced interference with growth plates.

---

10. Risks, Challenges, and Limitations

Despite many benefits, biodegradable screws have several challenges:

1. **Degradation Rate Control:** If they degrade too fast, mechanical support may be lost before healing; too slow, and long-term remnants may persist.
2. **Inflammatory Response:** Degradation by-products (e.g., acidic monomers, hydrogen gas) can provoke inflammation, cysts, or gas pockets (especially with Mg).
3. **Mechanical Strength:** Some biodegradable materials have lower initial strength compared to metals; risk of breakage if mishandled.
4. **Surgical Handling:** Surgeons need to adapt to the torque and insertion behavior of these screws, which may differ from metallic ones.
5. **Cost:** Biodegradable implants can be more expensive, especially when made with advanced composites or 3D printing.
6. **Regulatory Approval:** Medical device regulators require rigorous testing; new materials have to prove safety and consistency.
7. **Long-Term Data:** While short and mid-term studies exist, long-term clinical data (10+ years) for many biodegradable screws remain limited.

---

11. Regulatory, Manufacturing & Cost Considerations

- **Regulatory Pathways:** Biodegradable screws are class III medical devices in many jurisdictions; they must undergo preclinical testing (mechanical, biocompatibility), animal studies, and clinical trials.
- **Manufacturing:** Techniques like injection molding or 3D printing need strict quality control. Reproducibility, batch-to-batch consistency, sterility, and mechanical reliability are critical.
- **Cost Factors:** Composite materials, nanoparticles (e.g., MgO), silk fibers, and high-precision manufacturing increase cost. However, avoiding removal surgeries may offset costs in the long run.
- **Reimbursement:** In many healthcare systems, reimbursement for biodegradable implants versus standard metal implants may be variable, influencing adoption.

---

12. Recent Advances & Research Trends

Some of the recent and emerging trends include:

1. **Porous and Additively Manufactured Screws:** As discussed, 3D-printed porous structures enhance biological integration.
2. **Nano-composites:** Use of nanoparticles (e.g., MgO) and natural fibers (silk) to strengthen polymeric screws.
3. **Optimized Mg Alloy Designs:** Finite element–optimized magnesium screws with buttress threading for durability.
4. **Biocomposite Resorbable Screws:** Combining polymers with bioceramics (calcium phosphate) to stimulate bone ingrowth while resorbing.
5. **Clinical Trials of Mg Screws:** The randomized controlled study on Mg screws in bone graft for osteonecrosis is a notable step.
6. **Systematic Reviews:** A recent systematic review of biodegradable implants in orthopaedics (2024) showed comparable efficacy to metallic implants, with significantly fewer hardware removal procedures.
7. **Design Innovations:** Perforated screw architectures to allow bone ingrowth without compromising mechanical insertion strength.

---

13. Case Study / Example Innovation

Porous Biodegradable Screw via 3D Printing

- As per the 2020 study (PubMed): Screw was printed with varying pore sizes; 45% fill density provided interconnected pores (~40% porosity) while maintaining ~24.6 MPa strength.
- Biological results: In vitro, human mesenchymal stem cells adhered and proliferated; in vivo (rat model), there was enhanced vascularization vs non-porous controls.
- Implication: Such screws might better integrate in bone, support tissue regeneration, and degrade in a biologically favorable way.

Composite MgO–Silk–PCL Screw

- Developed composite with 10% MgO and 20% silk in PCL.
- Showed enhanced tensile properties, controlled degradation (in vitro), and good biocompatibility in rats.
- Pull-out strength was double that of pure PCL screw in synthetic bone.
- Potential use: soft bone fixation, ligament graft fixation where absorption is beneficial.

---

14. Future Directions

Looking ahead, the field of biodegradable screws in orthopaedics is likely to evolve in the following ways:

1. **Personalized Implants:** Patient-specific screws created via imaging + 3D printing to match defect geometry, load requirements, and degradation profile.
2. **Smart Materials:** Development of materials that respond to environment (pH, load) to modulate degradation dynamically.
3. **Hybrid Implants:** Combination of biodegradable metal cores (e.g., Mg) with a polymer coating to regulate corrosion and control mechanical behavior.
4. **Clinical Trials Expansion:** More multicenter, randomized, long-term clinical trials comparing degradable vs permanent implants in various applications (ligament surgery, fracture fixation, pediatrics).
5. **Regulatory Harmonization:** Global standards for bioabsorbable implants to streamline approvals.
6. **Cost Reduction:** Better manufacturing processes, economies of scale, and local production (especially in low- & middle-income countries) to reduce costs.
7. **Drug-Delivering Screws:** Implants that not only fix but also deliver therapeutic agents (antibiotics, growth factors) as they degrade.

---

15. Conclusion

Biodegradable screws represent a transformative technology in orthopaedic surgery. By offering temporary mechanical support and then safely degrading, they reduce the need for implant removal, promote more natural bone healing, and potentially reduce long-term complications.

Key materials include **polymers** (PLA, PLGA, PCL) and **biodegradable metals** (especially magnesium). Advances in additive manufacturing and materials science (e.g., composites) are helping overcome earlier limitations like mechanical strength and unpredictable degradation.

However, challenges remain: controlling degradation kinetics, ensuring biocompatibility, achieving consistent manufacturing, and accumulating robust long-term clinical data.

As for **Dr. Pothireddy Surendranath Reddy**, while he appears to practice as an orthopaedic surgeon (LinkedIn profile), I found **no published research** by him specifically on biodegradable screws. It is possible that he uses these implants clinically, but without publication, there’s no way to analyze his specific contribution or case reports in the public domain.

---

16. References & Further Reading

Here are some of the key references used in this article — plus suggestions for further reading:

- Additive manufacturing of biodegradable porous orthopaedic screw.
- Development of bone screw using novel biodegradable composite biomaterial (MgO-Silk-PCL) and its in vitro/in vivo evaluation.
- Perforated biodegradable interference screws for enhanced osseous integration.
- Resorption characteristics of a biocomposite interference screw (Biosure Regenesorb) following ACL reconstruction.
- Biodegradable vs metallic interference screws randomized controlled trial.
- Biodegradable magnesium screw in bone graft surgery for osteonecrosis of femoral head.
- Systematic review on efficacy of biodegradable implants in orthopedic surgery.

- Review on biodegradable implants in orthopaedics (materials to clinical success).
- Finite element analysis of biodegradable buttress-threaded Mg-alloy screws.