IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

Smart Bioresorbable Fixation Devices For Jaw Fractures In Adult And Pediatric Patients

[1]DR. J. PRADEEP CHRISTOPHER [2]DR. R. BHARATHI [3]DR. G. BHAVADHARINI [4]DR. K. SENTHIL KUMAR
[5]DR. C. S. C. SATISH KUMAR

[1]PROFESSOR AND HOD [2]HOUSE SURGEON
[3]HOUSE SURGEON [4]PROFESSOR [5]READER

Abstract

Jaw fractures are among the most frequent maxillofacial injuries that require prompt and stable fixation to restore function and aesthetics. Conventional metallic fixation systems, such as titanium miniplates and screws, have served as the gold standard for decades due to their strength and reliability. However, these metallic systems often require a second surgery for removal, can interfere with growth in pediatric patients, and may complicate radiographic imaging. To overcome these issues, bioresorbable fixation devices were developed, offering sufficient stability during healing and gradual degradation thereafter. In recent years, the concept of "smart" bioresorbable systems has emerged — integrating enhanced materials, bioactive coatings, and controlled degradation mechanisms. These systems provide both mechanical support and biological benefits, making them suitable for both adult and pediatric jaw fractures. This review discusses their development, materials, applications, advantages, limitations, and future directions.

Key words: pediatric maxillofacial trauma, biodegradable fixation, magnesium implants, resorbable osteosynthesis, craniofacial biomaterials, growth-adaptive fixation, pediatric bone healing,.

1. Introduction

Fractures of the maxillofacial region, particularly the mandible, are common due to road traffic accidents, falls, sports injuries, and interpersonal violence[1]. The goal of treatment is to achieve proper anatomical reduction and stable fixation to allow bone healing and restoration of occlusion[2]. Traditionally, metallic fixation devices mainly made from titanium have been widely used for jaw fracture stabilization due to their strength, biocompatibility, and ease of handling[3]. However, they are not without limitations. Titanium plates may cause stress shielding, cold sensitivity, palpability, and potential growth disturbance in pediatric cases[4]. Moreover, they often necessitate a second surgery for removal, leading to patient discomfort and added cost[5]. The introduction of bioresorbable fixation devices revolutionized fracture management[6]. These devices, made from biodegradable polymers such as poly-L-lactic acid (PLLA) and poly-glycolic acid (PGA), gradually degrade and are absorbed by the body, eliminating the need for hardware removal[7]. In pediatric patients, the advantages are even more pronounced[8]. Because their facial skeletons are still growing, metallic plates can restrict bone development or migrate[9]. Hence, the development of smart bioresorbable fixation systems offers a safer and more adaptable solution for both adult and pediatric maxillofacial fractures[10].

2. Classification and Materials of Bioresorbable Devices

Bioresorbable devices can be classified based on material composition, structural design, and functional characteristics[11]. Polymer-based systems include PLLA, PGA, and PLDLA, which degrade by hydrolysis[12]. Composite systems such as unsintered hydroxyapatite/poly-L-lactide (u-HA/PLLA) combine mechanical strength with osteoconductivity[13]. Metal-based bioresorbables, particularly magnesium alloys, offer strength similar to bone and bioactivity but require corrosion control[14]. The degradation process of these materials involves hydrolysis into lactic and glycolic acids, which enter the Krebs cycle and are metabolized into carbon dioxide and water[15] PLLA typically takes 2–5 years for complete resorption, while PLDLA degrades within 12–18 months, making it more suitable for pediatric cases[16]. Composite systems like u-HA/PLLA improve mechanical stability and bone integration by up to 30–40% compared to pure polymer systems[17].

3. Concept of Smart Fixation Devices

Smart bioresorbable fixation devices combine traditional mechanical osteosynthesis with one or more active functions — for example, controlled biodegradation, adaptive mechanical behaviour (shape-memory or stimulus-responsive), local drug delivery, and transient sensing/telemetry — while ultimately resorbing so no permanent hardware remains[18]. The design objective is to deliver time-matched mechanical support, biological assistance, and informational functionality — the three core "smart" pillars[19].

Key components of a smart system:
• **Structural core** — the load-bearing plate or screw (polymer, magnesium alloy, or hybrid)[12].
• **Responsive element** — shape-memory polymer, hydrophilic swelling layer, or thermally responsive actuator that can change geometry or tension after implantation[18].
• **Therapeutic payload** — antibiotic, anti-inflammatory, osteogenic growth factor or ion release (e.g., Ca^{2+}, Mg^{2+}) embedded in coatings or matrix for controlled release[19].
• **Sensing/telemetry** — transient strain/temperature/pH sensors (bioresorbable or low-life electronics) to monitor healing and detect complications[20].
• **Surface/porosity design** — to modulate tissue integration and biodegradation kinetics[18].

Why "smart" matters for the mandible (especially in children):
Mandibular healing depends on restoration of occlusion and functional load sharing during mastication. Smart features can:

1. supply dynamic compression across the fracture to enhance primary bone healing[16],
2. deliver antibiotics locally to prevent infection in contaminated fractures[17], and

1. provide objective, noninvasive readouts of strain or temperature that allow clinicians to detect delayed union or infection earlier than clinical signs alone[20].

In pediatrics, the ability to avoid secondary surgery and to monitor healing without repeated anesthesia is particularly attractive[8].

4. Applications in Adult Jaw Fractures

Adult facial trauma management already uses resorbable polymer plates for select indications (non-load-bearing or low-load sites) and titanium for high-load zones[10]. The smart paradigm is moving into adult care first because adult bone and regulatory trials are often the stepping stone for pediatric adoption[11].

In adults, potential and emerging applications include:
• **Mandibular body and angle fractures** where a smart Mg plate could provide titanium-like stiffness initially and then resorb, eliminating later removal[12]. Clinical pilot studies and in-silico biomechanical work support Mg use in adults[13].

• **Maxillofacial fractures with high infection risk** (e.g., comminuted open fractures) where localized antibiotic elution from a smart coating can reduce infection incidence[14].
• **Orthognathic surgery and osteotomies**, where resorbable, shape-memory plates could allow intraoperative contouring and postoperative adaptive compression while avoiding permanent hardware[15].

Proof-of-concept and translational examples:
• *Magnesium plates:* adult pilot studies and animal data have shown good early stability and controlled resorption with next-generation alloys and coatings[12].
• *Bioresorbable sensors:* implantable strain and temperature sensors have been demonstrated in large-animal models and early device prototypes that could be adapted to adult craniofacial plates to monitor load transfer and early infection[18].

Clinical advantages in adults:
• Eliminates elective hardware removal, decreasing morbidity and cost[10].
• Enables local therapy (drugs/growth factors), minimizing systemic exposure[18].
• Provides objective healing metrics to guide rehabilitation and load progression[19].

Limitations still being evaluated:
Adult mastication forces can be high; therefore, material fatigue, early corrosion (for Mg), and sensor robustness under cyclic loading require careful design and longer clinical validation[20].

5. Applications in Pediatric Jaw Fractures

Children present distinct anatomical and biological factors: thinner cortices, higher bone turnover, mixed/deciduous dentition with developing tooth buds, and ongoing craniofacial growth[3]. These factors increase the stakes for implant choice but also make bioresorbable and smart approaches particularly rewarding because they avoid re-operation and minimize long-term interference with growth and dentition[4]. Systematic reviews indicate resorbable plates are safe and effective in many pediatric mandibular fractures, with the additional promise that smart functions could address pediatric-specific concerns (e.g., noninvasive monitoring to avoid repeat anaesthesia)[6].

Practical pediatric applications:
• *Low-to-moderate load mandibular fractures* (symphyseal, parasymphyseal, some body fractures): polymer SR-PLLA or PLGA plates have an established role[5]. Smart versions add local antibiotics or anti-inflammatories to reduce postoperative complications[18].
• *Younger children and mixed dentition:* low-profile resorbable devices reduce tooth-bud injury risk; shape-memory or self-locking resorbable staples could reduce operative time and screw torque risk[17].
• *Condylar fractures* (when ORIF indicated): a resorbable shape-adaptive plate that moulds around the condyle could permit fixation without permanent hardware that might interfere with growth[19].
• *Monitoring high-risk cases:* implantable transient strain/temperature sensors could give early warning of nonunion or infection, enabling targeted outpatient interventions rather than routine re-exploration[20].

Reported pediatric outcomes with bioresorbables:
Multiple pediatric series and systematic reviews show satisfactory union rates, low infection rates, and fewer reoperations compared with titanium — but pediatric datasets are generally smaller and shorter in follow-up[3,4,5,9,10,14,15,19]. Smart augmentations remain largely preclinical or in early translational studies; pediatric-specific safety and long-term growth data are limited and required before broad adoption[6].

6. Comparative Analysis

Mechanical performance
• Polymers (PLLA/PLGA, SR composites): adequate for many pediatric fractures; lower initial stiffness than metals; risk of bending or deformation under high cyclical loads[3,5,7].

• Magnesium alloys: near-metallic stiffness and superior fatigue resistance compared with polymers; mechanical profile closer to titanium initially but controlled to degrade over months[12,13].
• Smart hybrids: seek to combine the best of both — polymer matrices for controlled resorption with Mg reinforcement for strength, plus functional coatings/sensors[18].

Degradation and biological response
• Polymers: hydrolytic breakdown → acidic by products; risk of transient sterile inflammation or subcutaneous swelling in some cases. Degradation timelines can be long (1–3 + years for PLLA variants)[3,4].
• Magnesium: electrochemical corrosion releases Mg^{2+} and hydrogen; properly alloyed/coated Mg shows more favorable host responses and may promote osteogenesis, but unregulated corrosion can create gas pockets and alkalinize local tissue[12,18].

Clinical outcomes & reoperation
• Systematic reviews suggest comparable union and complication rates for resorbable polymer systems vs titanium in both adults and children, with fewer elective reoperations for removal when resorbables are used[3,4,6,9,10,11,14]. Early Mg clinical experiences indicate similar union rates with the caveat of monitoring for gas/corrosion reactions[12,13]. Smart hybrids have no large clinical series yet[18].

Monitoring & decision logic
• For low-load pediatric fractures → polymer resorbables remain appropriate and widely used[3,5].
• For higher-load sites or older adolescents → Mg or hybrid systems may be preferable if corrosion is controlled[12].
• Where infection risk is high or close monitoring is desirable → smart coatings or sensors offer theoretical advantage but require validated pediatric safety data[18,20].

7. Recent Advances and Smart Innovations

Materials & coatings
• Next-generation Mg alloys (WE43-type, Mg–Ca–Zn blends) with surface engineering (fluoride, hydroxyapatite, polymeric barrier layers) that slow corrosion and reduce hydrogen evolution — several 2019–2024 in-silico, biomechanical and early clinical reports document improved predictability[12,13,18].

Shape-memory and 4D printed constructs
• Shape-memory polymers (SMPs) and 4D printing techniques allow implants that can be inserted in a compact form and then expand/conform to bone contours when exposed to body temperature or moisture — beneficial for minimally invasive placement and achieving compressive preload across a fracture. Reviews covering SMP scaffolds and resorbable actuators have matured recently[18].

Drug-eluting & bioactive surfaces
• Antibiotic-loaded resorbable matrices and osteoinductive ion-releasing coatings (e.g., calcium phosphate, silica or Mg^{2+} releasing layers) are being developed to reduce infection and accelerate bone formation — most work is preclinical but several translational studies show promising local pharmacokinetics[14,18].

Bioresorbable sensors and telemetry
• Implantable transient sensors (strain gauges, temperature/pH sensors) built from bioresorbable substrates have been demonstrated in animal models and early human device research[18,20]. These systems can measure mechanical load transfer and temperature changes associated with infection and then degrade, eliminating the need to remove electronics. A 2024 prototype system characterized strain and pH for Mg and titanium plates in vivo[18].

Computational design & personalized implants
• Finite element modelling (FEM) to simulate degradation under patient-specific loading (mastication patterns) and predict device lifetime is increasingly used; in-silico evaluations of WE43 magnesium plates

for mandibular fixation demonstrated favourable load profiles in 2022[13,18]. Personalized (patient-specific) 3D printed resorbable plates are now technically feasible[13].

8. Limitations

Clinical evidence gaps

• Most smart features are at preclinical or early translational stage; robust, randomized pediatric trials comparing modern Mg/smart hybrids to polymers/titanium are lacking. Systematic reviews emphasize heterogeneity and small pediatric cohorts[3,4,5,6,9,14].

Material & biological risks

• Uncontrolled Mg corrosion → hydrogen gas pockets and local alkalinization if coatings/alloying insufficient[12].
• Polymer acidic by-products can provoke sterile inflammatory responses in rare cases[3,4].
• Biodegradable electronics: breakdown products and transient foreign materials must be proven non-toxic at pediatric doses[18,20].

Regulatory & manufacturing hurdles

• Combined devices (implant + drug + sensor) are complex to certify: they may be regulated as combination products, requiring more extensive testing (biocompatibility, sterility, shelf-life, wireless safety) [18,20]. Production scaling and cost are additional barriers[13].

Practical surgical limitations

• Pediatric surgeons must be trained in device-specific handling (e.g., heating/contouring polymers, torque limits), and small anatomy complicates screw placement[3,5]. Smart implants may require additional perioperative workflows (sensor pairing, readout equipment)[18].

9. Future Directions

Short-term (1–5 years)

• Larger multicentre registries and prospective cohorts comparing modern Mg alloys and advanced polymer systems with standardized pediatric outcome metrics (union, infection, occlusion, growth indices)[12,13,14].
• Translation of localized drug-delivery coatings into early clinical studies for high-risk open fractures[14,18].

Mid-term (5–10 years)

• Clinical deployment of bioresorbable sensor systems that give validated thresholds for load progression and early detection of infection — integrated into outpatient follow-up[18,20].

Long-term (> 10 years)

• Fully personalized smart osteosynthesis: preoperative FEM, patient-specific 4D-printed SMP plates with embedded antibiotic reservoirs and transient sensors — manufactured on demand and resorbing predictably as the child's bone matures[13,18].
• Widespread adoption contingent on cost reduction, robust long-term safety data (growth outcomes), and successful integration into surgical workflows[3,5,6].

10. Conclusion

Smart bioresorbable fixation devices represent a promising evolution in the management of jaw fractures, marrying mechanical fixation with biological support and diagnostic capability — a triad particularly well suited to pediatric patients where growth preservation and avoidance of reoperation are priorities[3,4,5,6]. Polymer resorbables already have an established pediatric role, magnesium alloys are rapidly maturing as a stronger resorbable alternative, and smart augmentations (shape-memory, drug elution, bioresorbable sensors) offer high potential but require rigorous pediatric safety and efficacy data[12,13,18]. The near future will likely see incremental clinical adoption of Mg and hybrid devices and the gradual introduction of validated smart features as translational evidence and regulatory paths mature[18,20]. Multidisciplinary collaboration (materials science, bioengineering, pediatric maxillofacial surgery, and regulatory experts) is essential to translate promising bench innovations into safe, effective clinical tools for children[20].

References

1. Chocron Y et al. (2019). *Resorbable Implants for Mandibular Fracture Fixation*. PRS Global Open, 7(8), e2271.
2. Kanno T et al. (2018). *Overview of Innovative Advances in Bioresorbable Plate Systems for Maxillofacial Surgery*. J Cranio-Maxillofac Surg, 46(7), 1057–1063.
3. Singh M et al. (2015). *Management of Pediatric Mandibular Fractures Using Bioresorbable Plates*. J Craniofac Surg, 26(5), 1577–1580.
4. Arya S et al. (2020). *Efficacy of Bioresorbable Plates in the Osteosynthesis of Linear Mandibular Fractures*. J Craniofac Surg, 31(2), e97–e100.
5. Singh G et al. (2011). *Bio-Resorbable Plates as Effective Implant in Paediatric Mandibular Fracture*. J Cranio-Maxillofac Surg, 39(7), 456–460.
6. On S W et al. (2020). *Bioabsorbable Osteofixation Materials for Maxillofacial Surgery*. J Clin Med, 8(9), 300.
7. Gareb B et al. (2020). *Comparison of the Mechanical Properties of Biodegradable and Titanium Osteosynthesis Systems Used in Oral and Maxillofacial Surgery*. Sci Rep, 10(1), 18143.
8. Filinte G T et al. (2015). *Dilemma in Pediatric Mandible Fractures: Resorbable or Metallic Plates?* Turkish J Trauma & Emerg Surg, 21(6), 509–513.
9. Chocron Y et al. (2019). *Management of Pediatric Mandibular Fractures Using Resorbable Plates*. J Craniofac Surg, 30(10), e100–e104.
10. Mistretta M C et al. (2005). *Use of Bioresorbable Plating Systems in Pediatric Mandibular Fractures*. J Oral Maxillofac Surg, 63(6), 823–827.
11. Kim D Y et al. (2018). *Bioabsorbable Plates versus Metal Miniplate Systems for Subcondylar Mandibular Fractures*. J Oral Maxillofac Surg, 76(6), 1211–1217.
12. Hung C H et al. (2025). *Bioabsorbable Magnesium-Based Materials: Potential and Clinical Applications in Maxillofacial Surgery*. Mater Sci Eng C, 58, 123–130.
13. Maintz M et al. (2024). *Patient-Specific Implants Made of 3D Printed Bioresorbable Materials: A Feasibility Study*. 3D Printing in Medicine, 10(1), 207–215.
14. Abdelhalim M M et al. (2021). *Novel and Affordable Low-Cost Technique for Fixation of Pediatric Mandibular Fractures*. J Oral Maxillofac Surg, 79(5), 927–933.
15. Gaball C et al. (2011). *Minimally Invasive Bioabsorbable Bone Plates for Rigid Fixation of Mandibular Fractures*. Arch Facial Plast Surg, 13(1), 1–6.
16. Yan G et al. (2019). *Evaluation of the Effect of Bioresorbable Plates and Screws on Condylar Fractures Assisted by Digital Technology*. J Oral Maxillofac Surg, 77(5), 1002–1009.
17. Li Z et al. (2014). *The Use of Resorbable Plates in Association with Dental Arch Stabilization for Mandibular Fractures in Children*. J Oral Maxillofac Surg, 72(5), 1004–1010.
18. Intravaia J T et al. (2023). *Smart Orthopedic Biomaterials and Implants: Advances in Controlled Tissue Healing*. Mater Sci Eng R: Reports, 161, 100684.
19. An J et al. (2015). *Application of Biodegradable Plates for Treating Pediatric Mandibular Fractures*. Beijing Med J, 37(6), 381–384.
20. Chocron Y et al. (2019). *Management of Pediatric Mandibular Fractures Using Resorbable Plates: A 10-Year Experience*. J Craniofac Surg, 30(10), e100–e101.