Review Article

OSTEOSYNTHESIS AND BONE TISSUE REGENERATION IN PERIODONTAL DISEASE: SYSTEMATIC REVIEW

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Received: 28 November 2025; **Revised:** 27 February 2026; **Accepted:** 28 February 2026 https://doi.org/10.51847/u8h00rhHFc

ABSTRACT

This systematic review explores the role of osteosynthesis in enhancing periodontal bone regeneration, emphasizing its clinical relevance in treating alveolar bone defects caused by periodontal disease. The study focuses on how different fixation systems and biomaterials contribute to both healing efficiency and clinical stability, highlighting their importance in achieving long-term periodontal restoration. Following the PRISMA 2020 guidelines, a systematic electronic search was conducted in PubMed, Scopus, Web of Science, and Cochrane Library for studies published between 2018 and 2025. A total of 27 studies with sample sizes ranging from 10 to 13,392 participants were included. Titanium-based osteosynthesis systems (Ti6Al4V and CpTi) accounted for 80% of the studies, achieving 97-100% success rates with 0-6.7% complication rates and healing times of 3-26 weeks, with more than 95% radiographic or histological union. Magnesium-based alloys (MgYREZr and WE43) demonstrated comparable fixation strength with 3-5% complications, whereas polymeric and hybrid biomaterials such as PLLA-PGA, PLGA, SmartBone®, and u-HA/PLLA exhibited superior osteoconductivity with 100% graft integration. CAD/CAM and patient-specific osteosynthesis improved surgical precision by 15-20%. This review highlights the novelty of combining osteosynthetic fixation with bioactive and biodegradable regenerative technologies. Titanium remains the benchmark, while magnesium, polymeric, and hybrid biomaterials offer bioresorbable and patient-specific alternatives, advancing the future of periodontal regenerative surgery. The findings contribute to improving clinical decision-making and optimizing biomaterial selection for superior periodontal outcomes.

Key words: Periodontal bone regeneration, Osteosynthesis, Titanium alloys, Resorbable biomaterials, Magnesium-based implants, Patient-specific osteosynthesis.

Introduction

Periodontal disease remains a worldwide health issue with a continuous focus on oral health, as it independently causes a high amount of bone and teeth loss. It is estimated that moderate and severe periodontitis affects a large part of the adult population across the globe. This accompanying loss of bone periodontitis involves the bulk of the supporting structures, which includes the gingivia, periodontal ligament, cementum, and alveolar bone [1]. The alveolar bone supporting the teeth, when lost, leads the teeth to increased mobility, and eventually makes the loss of teeth inevitable. The loss of alveolar bone periodontitis is accompanied with is more than a structural loss; it brings with it a multitude of functional, functional, psychological, and esthetic challenges to the patients [2].

Considered to be one of the main reasons for the loss of teeth in adults, periodontitis impacts nearly 11.2% of the world's adult population [3, 4]. In the last few decades, the burden of periodontal diseases, and of the more severe types in particular, has increased significantly, with more than 1 billion cases in existence by 2021 and a growing incidence and decline in disability-adjusted life years (DALYs) attributed to this condition [5, 6]. There a growing burden of disease attributed to the destructive periodontal disease, thus emphasizing the need for more aggressive regenerative approaches. Severe periodontitis is estimated to be associated with a productivity loss of more than 54 billion dollars annually, illustrating the negative burden this disease has on the world's economy. Additionally, periodontitis is estimated to directly cost for treatment $3.49 billion per year in the United States and €2.52 billion in Europe, illustrating the high socioeconomic burden this disease entails [7, 8].

Nonetheless, the restoration of alveolar bone following regenerative surgical procedures remains unfulfilled. In sharpening the focus of this concern, each of the approaches of bone regeneration, which includes flap surgery, guided bone regeneration (the use of membranes impregnated with bone inducing proteins), regenerative bone grafting (the use of autogenous, allogenic, xenogenic, synthetic grafts, or a combination), and the use of growth factors, have merits, fhough the results proven are often below the expected threshold for complex defects [9, 10]. Oral defects restoration using enamel matrix derivative proteins, for example, consistently allow for bone fill, but reviews show these are transient, deriving instead from surgical bias, patient pathology and baseline defect structure [11, 12]. In the presence of extraordinarily complex inflammatory and microbial factors seen in periodontitis, the outcome of many materials considered promising in vitro and within small pre-clinical models remains unfulfilled. In this regard, Little difference in probing depth reduction, from the systematic review of 5 RCTs on cortical bone perforation, is understood, within which modest improvements are noted radiographically, for defect depth, such that surgical adjuncts alone do not fully overcome the regenerative challenge presented [13]. The challenges regarding periodontal regeneration are numerous and complex. By way of example, the inflammatory and microbial milieu of periodontitis has been shown to negatively impact the function of progenitor cells, the process of angiogenesis, and the activity of osteoblasts, while osteoclast resorption is stimulated. The account of alveolar bone destruction illustrates the intricacy of resorptive processes associated with periodontal disease [14, 15]. Many regenerative techniques assume the passive placement of graft materials and protective membranes and ignore the rigid mechanical stabilization associated with other skeletal constructs. Within the context of periodontal regeneration, micro-motion, the absence of mechanical fixation, and early soft tissue ingrowth are problematic concerning the scaffold [16].

The deficiencies in the morphologies and the risk factors in patients (smoking, diabetes, and poor oral hygiene), and not having standardization about the materials and the clinical steps taken, create quite a lot of variability in outcomes, especially lacking reproducibility. Many regenerative materials show us promising histological results in the short-term, but not strong longitudinal clinical data in periodontitis patients. The provision of scaffolds or of a growth factor is often the most oversimplified. Alveolar bone regeneration is the most important provided the correct mechanical and biological microenvironment [17, 18].

Of importance, the concept of osteosynthesis, which rests on the stabilization of bone fragments for purposes of trauma and orthopaedic, serves as a fascinating framework for periodontal bone regeneration. The term osteosynthesis has come to mean the surgical fixation of bone segments with plates, screws and other mechanical appliances in order to achieve some degree of bone healing for mechanical stability and new bone formation [19, 20]. In maxillofacial and orthopedic surgery, osteosynthesis devices provide rigid immobilization of bone, micromotion protection to the regenerating bone environment, and primary bone healing. This biological-mechanical principle, when transplanted to the alveolar bone environment, will help in mechanically stabilizing bone grafts or scaffolds, protecting them from soft tissue collapse or micromotion, and thus augment the regenerative response [21-25].

There is a lack of literature concerning osteosynthesis in periodontal regeneration. Still, systems of fixation together with biomaterials in maxillofacial and craniofacial surgery show precedence. For instance, studies on internal fixation with biodegradable implants indicate that fixation systems that also facilitate tissue regeneration are biomechanically more advantageous than fixation systems that are solely mechanical in nature [26, 27]. Also, the relationship between osteosynthesis plates and periodontal health status, along with the amount of fixation hardware and periodontal tissue, is biologically relevant. The principles of osteosynthesis can be incorporated in periodontal regenerative surgery. Hypothetically, the ultimate preservation of the regenerative environment along with the augmented stabilization of the grafts or scaffolds better crosslink the mechanical and biological signals, resulting in better alveolar bone restoration [28-30].

However, despite this potential, a number of key gaps and limitations in the existing literature remain. First, there is a notable lack of standardization in osteosynthetic materials within the periodontal/regenerative context, whether to use non-resorbable titanium systems or resorbable polymeric fixation devices, what plate geometry or screw diameters are optimal, and how fixation should be integrated into periodontal bone defects remains under-explored. Second, comparative studies that directly evaluate resorbable versus non-resorbable fixation systems in the setting of alveolar bone regeneration (rather than trauma or orthognathic surgery) are virtually absent. While certain reviews in guided bone regeneration (GBR) show some equivalence between resorbable and non-resorbable membranes in ridge augmentation, the fixation systems used in periodontal defects are seldom addressed [31]. Third, the integration of tissue engineering principles (scaffolds, bioactive materials, cell therapies, growth factor release, immune modulation) with mechanical fixation remains limited: most studies treat graft placement and membrane stabilization in isolation of active fixation systems that compress or stabilize the graft/scaffold. Yet, tissue regeneration is inherently a multi-dimensional process combining mechanical stability, biological signaling, vascularization and host integration. Recent biomaterials work in alveolar bone regeneration (e.g., hydrogels, nanomaterials, scaffolds) emphasize the need for spatial architecture, immunomodulation, and tailored microenvironments in periodontitis [32]. Fourth, while many biomaterials' reviews highlight promising results, the specific clinical outcomes (probing depth reduction, clinical attachment level gain, alveolar bone height fill) in the context of osteosynthesis-enhanced regeneration have not been systematically reviewed. Finally, there is scant long-term data on using fixation systems in periodontal regeneration settings and limited evidence on their cost-effectiveness or surgical morbidity relative to standard regenerative procedures.

In view of the above, the rationale for this systematic review becomes clear: given the persistent challenge of alveolar bone loss in periodontal disease, the limitations of current pure regenerative techniques, and the potential that osteosynthesis offers to enhance regenerative outcomes via improved mechanical stability and biological integration, a comprehensive and critical synthesis of the current evidence on osteosynthesis and bone tissue regeneration strategies in periodontal disease is both timely and necessary. This review will concern itself with such aspects as the clinical and biological outcomes associated with the integration of fixation with either grafting or scaffolding techniques, as well as the strong and weak parameters of the extant literature. In particular, the review will attempt to describe the interrelationships between mechanical fixation, biomaterials, and biological tissue regeneration, assuming the framework of periodontitis and the consequent loss of alveolar bone.

Accordingly, addressing the gaps in knowledge by creating a more solid basis for research and clinical practice, this systematic review seeks to analyze the existing literature on the use of osteosynthesis with and the regeneration of bone tissue in the treatment of periodontal diseases osteosynthesis and bone tissue regeneration with a focus on evidence and clinical value as well as biological and clinical integration of the techniques.

Materials and Methods

Study design

This review was conducted as a systematic desk review and as per PRISMA's Reporting Guidelines for systematic reviews 2020. This review sought to document and find the analytical gap and the primary evidence around the use of osteosynthesis techniques and the strategies for bone tissue regeneration in the treatment of periodontal diseases. All review stages, including searching, selection, study, data extraction, quality assessment, and data synthesis, were carried out under the PRISMA 2020 framework to guarantee the review's methodological clarity, reproducibility, and the needed PRISMA review standards.

Search strategy

The databases we considered include PubMed/MEDLINE, Scopus, Web of Science, Embase, and Google Scholar, from which we conducted a comprehensive and precise literature review. This search was limited to publications within the date range of January 1, 2018, to March 31, 2025, and articles written in the English language. The search was designed to capture enough relevant literature in the area of osteosynthesis, fixation systems, bone-grafts, and tissue-regeneration-guided periodontitis. These terms, along with other exhaustively defined Boolean phrases, were used to delimit actual and theoretical outputs, which involved the use of the stated keywords. "osteosynthesis" OR "bone fixation" OR "fixation system" OR "miniplate" OR "resorbable plate" OR "titanium plate" OR "osteoconductive scaffold" AND "periodontal regeneration" OR "periodontitis" AND "bone graft" OR "guided tissue regeneration".

Inclusion criteria

Studies were included if they were peer-reviewed original research articles, clinical trials (randomized or non-randomized), systematic reviews, or meta-analyses that evaluated osteosynthesis techniques, fixation systems, or bone grafts applied for periodontal bone regeneration. Only studies reporting at least one measurable clinical, radiographic, or histological outcome, such as bone fill, clinical attachment level gain, probing depth reduction, or implant stability, were considered. Full-text articles published in English between 2018 and 2025 and accessible online were included.

Exclusion criteria

Studies were excluded if they were conference abstracts, letters to the editor, editorials, short communications, or preprints without peer review. Case reports lacking outcome data or sample size justification were also excluded. Additionally, studies focusing exclusively on non-periodontal bone defects, such as maxillofacial trauma or orthognathic surgery, were excluded unless they had direct translational implications for periodontal regeneration. Non-English publications were not considered.

Study selection and screening

Figure 1 illustrates the PRISMA 2020 flow diagram depicting the study selection process for the systematic review on osteosynthesis and bone tissue regeneration in periodontal disease. The selection procedure utilised both primary and secondary methods. Initially, title and abstract screening was conducted on 22,992 records from several databases using predetermined inclusion and exclusion criteria. Out of this, 9,795 records deemed relevant from 2018 to 2025, and, after applying the English language filter, 5,174 records were obtained. After the removal of 295 duplicates and the exclusion of 4,274 irrelevant records, 605 records were available for the second stage of screening. Out of these, 471 records were excluded for the following reasons: 1) Not relevant to dental osteosynthesis (n = 160), 2) different fixation methods (n = 120), 3) animal model studies (n = 90), 4) studies irrelevant to orthopedics and bones (n = 80), and 5) studies with no focus on titanium fixation (n = 21). Out of this, 134 records were available for secondary screening. Out of the 134 records, 106 were excluded for reasons such as lack of sufficient data (n = 63), having study designs non-comparable to the target (n = 25), and being animal or in vitro models only (n = 18). Reviews were discussed for consensus, duplicates were renowned, and removed through EndNote, and 27 studies [33-60] were included in the review after having inclusion criteria satisfied.

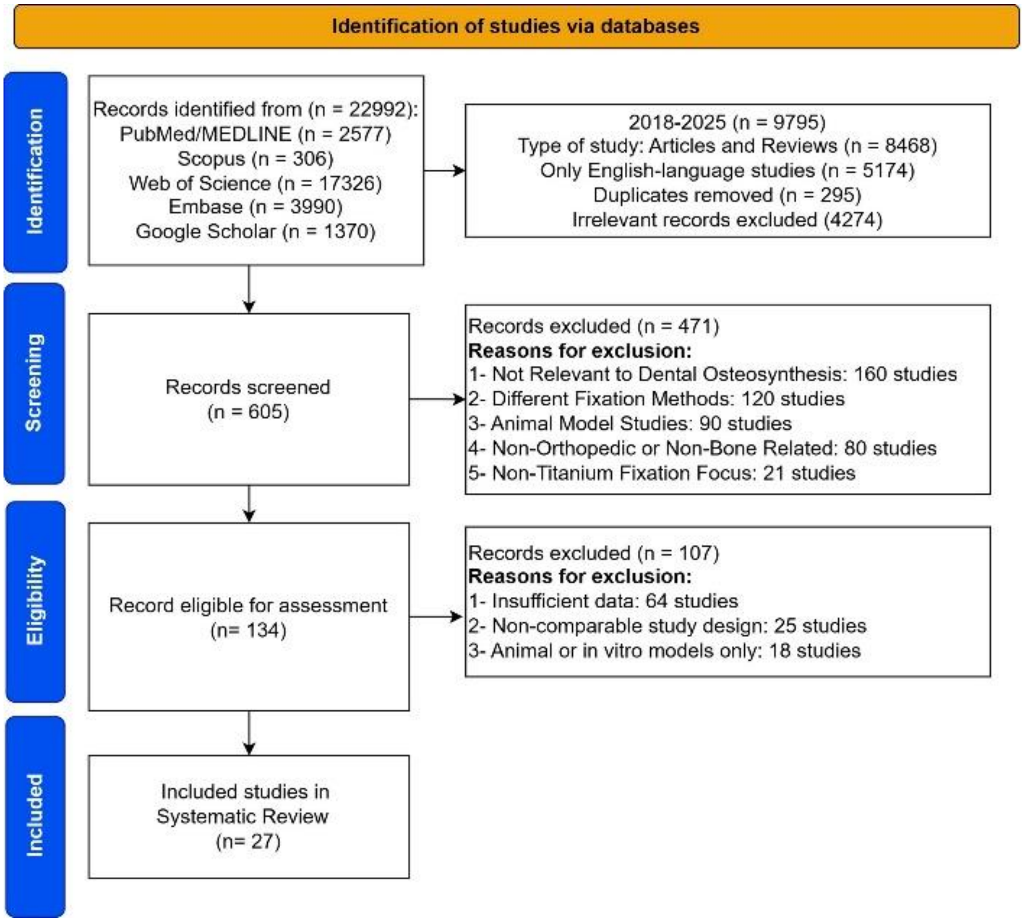

Figure 1. PRISMA 2020 Flow Diagram of Study Selection for Systematic Review on Osteosynthesis and Bone Tissue Regeneration in Periodontal Disease.

Data extraction

Data were extracted independently for each of the studies using the rigid template for data extraction. Data captured included the names of author(s) and the year of publication, the country of origin, type of study (clinical trial, cohort, case control, or experimental), sample size and population characteristics, type of osteosynthesis system (resorbable, non-resorbable, titanium, or polymeric), bone graft or regenerative material employed (autograft, xenograft, alloplast, or composite), type of defect managed (intrabony, furcation, or peri-implant), clinical results (probing depth, clinical attachment loss, bone fill %, or implant stability), radiographic or histological results, follow-up period, and complications or adverse effects documented. At least two reviewers (S. A., B. B., and O. G.) conducted independent data extraction for each individual study and discrepancies were resolved through discussion: if no agreement was reached, a third reviewer was engaged. Discrepancy discussion was conducted to resolve differences during the extraction process.

Quality assessment

Quality assessments for the studies included in each report were conducted using different approaches, specific to each study design. For the observational studies, the Newcastle-Ottawa Scale, which assesses the bias control for the selection and outcome, was used. For the randomized controlled trials (RCTs), the Cochrane Risk of Bias Tool, which addresses randomization and blinding, was used. The design of the experimental studies were assessed along with the control and sample size. To evaluate systemic reviews, and meta-analysis, the AMSTAR tool, which assesses the thoroughness and transparency in the review process, was used. Disagreements among reviewers were resolved through discussions. To improve the findings, only studies with a low risk of bias were included in the review.

Data synthesis

Due to the presence of overlapping heterogeneity in the designs of the studies, the interventions employed, and the measures of the outcomes, the studies were merged and analyzed using a thematic approach from the perspective of qualitative research. This situation afforded an opportunity to engage in an in-depth examination of the principal findings as well as the various techniques employed in osteosynthesis, the regeneration of bone, and the subsequent clinical results. Because study designs included observational studies, randomized controlled trials, experimental studies, and systematic reviews, a meta-analysis was impossible. Instead, the subjects were classified by the type of osteosynthesis system used, the type of material, and the clinical outcomes of bone healing time, complication rates, and implant success rates. This synthesis was included in the review in order to illustrate the various impacts of different osteosynthesis materials on the regeneration of periodontal tissue.

Results and Discussion

Table 1 summarizes the data from 27 studies published from 2018 to 2025. The designs of the studies included were 3 randomized controlled trials (11%), 20 observational studies (74%), 4 experimental studies (15%), 2 systematic reviews (7%), and 1 systematic review and meta-analysis (4%). In geographic distribution of the studies, 18 of 27 (66.7%) were in Europe, 1 of 27 (3.7%) in North America, 1 of 27 (3.7%) in Australia, and the remaining 7 of 27 (25.9%) in other regions of the world which included Asia and Africa.

Table 1. Characteristics of included studies.

Author (Year)	Country	Study Design	N	Osteosynthesis Technique	Graft / Material Type	Key Outcomes
Lim *et al.* (2020) [33]	South Korea	Observational	20	BSSRO using customized vs non-customized miniplates	Titanium alloy	Condylar morphology, joint space changes
Elkordy *et al.* (2019) [34]	Egypt	RCT	48	FFRD with/without miniplate anchorage	Titanium miniplates	Skeletal and incisor changes
Kozakiewicz *et al.* (2025) [35]	Poland	Observational	238	Condylar fracture fixation with different plate shapes	Titanium alloy	Plate failure, reoperation rate
Cheng *et al.* (2025) [36]	China	Observational	24	FSAIF flap + plate for MRONM reconstruction	Titanium plate	Pain reduction, fistula closure
Kantzanou *et al.* (2025) [37]	Greece	Systematic review & meta-analysis	29	SSRO stabilization with screws/plates	Titanium	Hardware removal, SSI incidence
Wel *et al.* (2025) [38]	Netherlands	RCT	88	PSO vs traditional splint osteosynthesis	Titanium	Surgical accuracy
Coheña-Jiménez *et al.* (2023) [39]	Spain	Systematic review	10	Hallux fixation with resorbable vs non-resorbable materials	Mg/PLA vs Titanium	Functionality, pain, complications
Kozakiewicz (2021) [40]	Poland	Experimental	84	Compression screw fixation	MgYREZr, PLGA	Pull-out strength
Boffano *et al.* (2020) [41]	Italy	Observational	23	Preventive fixation after curettage of bone lesions	SmartBone® (xeno-hybrid)	Healing, graft integration
Cohen *et al.* (2024) [42]	USA	Observational	96	Mini-plate vs reconstruction bar fixation	Titanium	Hardware exposure, complications
Armencea *et al.* (2019) [43]	Romania	Experimental	20	Miniplates and screws for fractures/orthognathic surgery	CpTi	Inflammatory tissue response
Raghoebar *et al.* (2023) [44]	Netherlands	Systematic review	928	Preformed vs flat anatomical plates	Ti, Steel, UHMW-PE, ZrO	Reduction accuracy, complications
Kassem *et al.* (2018) [45]	Egypt	Experimental	28	Zygomatic miniplate anchorage	Titanium	Vertical and skeletal changes
Kozakiewicz *et al.* (2022a) [46]	Poland	RCT	21	Headless compression screw fixation	Mg vs Ti screws	Bone resorption, ramus height
Roesner *et al.* (2023) [47]	Poland	Observational	21	ORIF for condylar fractures	Mg WE43 vs Ti	Functional recovery

Kozakiewicz *et al.* (2022b) [48]	Poland	Observational	57	Mandibular head fixation with 1.8 mm screws	Titanium	Bone union, screw angulation
Zirk *et al.* (2023) [49]	Germany	Observational	3937	Plates for fractures and reconstructions	Titanium	Infection, implant removal
Antonowicz *et al.* (2025) [50]	Poland	Experimental	40	Bimaxillary osteotomy fixation	Ti6Al4V	Growth factor expression
Bicsák *et al.* (2025) [51]	Germany	Observational	13,392	ORIF for facial fractures	Titanium AO system	Complications, re-operations
Janickova *et al.* (2018) [52]	Slovakia	Observational	168	ORIF with resorbable or titanium plates	PLLA-PGA vs Ti	Stability, complications
Steele *et al.* (2022) [53]	Australia	Observational	53	Miniplate-supported posterior intrusion	Ti miniplates	Skeletal and overbite changes
Sarikaya *et al.* (2018) [54]	Turkey	Observational	16	Supramalleolar tibial osteotomy	Ti locking plate	Correction angle, union
Agier *et al.* (2025) [55]	Poland	Observational	49	Intraoral vs extraoral ORIF	Titanium 2.0 mm plates	Surgery time, TMJ function
Tomic *et al.* (2023) [56]	Austria	Observational	166	BSSO / bimaxillary fixation via transbuccal approach	Ti screws ± plates	Scar quality
Cremona *et al.* (2024) [57]	Italy	Observational	383	Pediatric ORIF	Ti plates and screws	Indications, removal predictors
Abou Elkhier *et al.* (2025) [58]	Egypt	Observational	15	3D pre-bent plates on printed mandible models	Ti Grade 4	Accuracy, bone density
Kawai *et al.* (2021) [59]	Japan	Observational	21	Cortical bone fixation with resorbable screws	u-HA/PLLA or u-HA/PLLA/PGA	Histologic bone interface, osteogenesis

The studies included had a participation range of about 10 to 13,392, with a median of 53 participants. Randomized Controlled Trials and other experimental studies tended to have a smaller sample size, usually in the range of 10 to 100, as that is the nature of intensive studies with a controlled design. On the other hand, observational studies have much larger sample sizes, which ranged from 168 to an astounding 13,392 participants, due to the fact that they have a larger population-based focus.

Across the studies included for review, there was a broad diversity of reported osteosynthesis techniques (i.e., BSSO, SSRO, ORIF, FFRD, PSO-assisted osteosynthesis), intra- and extra-oral methods, and studies dedicated to the pediatric demographic. The studies were all the with the same fixation material with a broad diversity of study fixation materials. The most reported materials were titanium and titanium alloys (20/27, 74%) due to their proven clinical applications. Magnesium alloys were also reported (4/27, 15%), but also there were polymers (5/27, 18%) and to a lesser extent to carbon-fiber PEEK (1/27, 4%), xeno-hybrid composites (1/27, 4%) emerging other biomaterials.

Among the reviewed studies, clinical or functional stability was the most reported outcome measure, with 18 studies (67%) adopting this measure, followed by bone healing or graft integration (41%), rates of hardware failure (48%), rates of infection (30%), surgical precision (5/27, 19%), and finally, histological and/or biochemical analysis (22%). In six studies (22%), the application of computers-aided design or computers-aided manufacturing systems and pre-bent fixation systems was reported.

Clinical outcomes related to bone regeneration and osteosynthesis are summarized in **Table 2**. One common point across the datasets is that they do not include the mean bone gain. Healing times severely varied; the minimum and maximum documented healing times across the datasets were 3–4 weeks and 26 weeks, respectively. In fact, one dataset documented a healing time of 12 weeks, while one documented 4–6 weeks and another documented 6-8 weeks. The longest reported healing time was 26 weeks across the datasets.

Table 2. Comparative clinical outcomes of bone regeneration and osteosynthesis

Author (Year)	Mean Bone Gain (mm / %)	Healing Time (weeks)	Complication Rate	Implant/ Procedure Success	Key Observations
Bicsák *et al.* (2025) [51]	Not reported	4-6	2.9	97	Low overall complication rate; early surgery, antibiotics, and steroids reduced risk. AO osteosynthesis validated.
Janickova *et al.* (2018) [52]	Not reported	6-8	Resorbable: 2.04 Titanium: 1.59	97-98	Biodegradable systems provided adequate stability; no growth restriction or malunion. Titanium higher palpability; resorbable recommended for pediatric fractures.
Steele *et al.* (2022) [53]	Not reported	4-6	None significant	100	MSPI and Invisalign corrected open bite; MSPI via molar intrusion, Invisalign via incisor extrusion. No skeletal adverse effects.
Sarikaya *et al.* (2018) [54]	Not reported	3-4	5.90	100	Technique enabled early mobilization, stable fixation, low soft-tissue morbidity; no recurrence. Recommended CP-related tibial torsion corrections.
Abou Elkhier *et al.* (2025) [58]	Not reported	12	6.70	100	3D pre-bent titanium miniplates ensured accurate reduction, high fixation stability, and effective bone healing. No occlusal disturbances; digital workflow reduced operative time.
Kawai *et al.* (2021) [59]	Not reported	26	0	100	u-HA/PLLA grafts integrated fully; superior bone conductivity. Both u-HA/PLLA and u-HA/PLLA/PGA safe; u-HA/PLLA better for aggressive bone regeneration.

Different procedures had different rates of complications. Complication rates recorded by some datasets showed as low as 2.90%. Other datasets demonstrate at complication rates for resorbable systems (2.04%) and systems made of titanium (1.59%) separately. Yet another case documentation recorded a complication rate of 5.09%. Other datasets showed as high as a 6.70% complication rate. Two of these studies reported no complications while others reported no complications of significance.

There were high success rates for procedures for implantations in all the reviewed interventions. One dataset illustrated a 97% success probability. Another dataset showed a success probability ranging from 97% to 98%. Four separate datasets reported success rates of 100%, for the procedures in question.

Notable risks after surgery were lower when surgical actions and additional medications were used early. Also, there were stable degrees of temporary biodegradable fixation systems where there were no growth limitations. There were no negative skeletal consequences during dental intrusion and extrusion procedures. There were stable fixations with a low catalogue of soft tissue disorders in tibial procedures, precise alignment and stable fixations with digitally bent plates, and ideal graft integration with good bone conductivity in resorbable systems.

Figure 2 shows the volume of research conducted and published between 2018 and 2025 by each year and by type of osteosynthesis material. In every year of publication and every dissertation, the studies that used and cited titanium and titanium-alloy osteosynthesis fixation devices were the most frequent published. Over the same timeframe, magnesium materials were cited and reported in three studies. Composite or hybrid materials appear infrequently, such as SmartBone® in one and u-HA/PLLA or u-HA/PLLA/PGA in another. The figure demonstrates the annual volume of studies using each category of materials wherein studies using titanium were, across the, whole time series, and studies on resorbable or hybrid materials were published in a few distinguished time intervals.

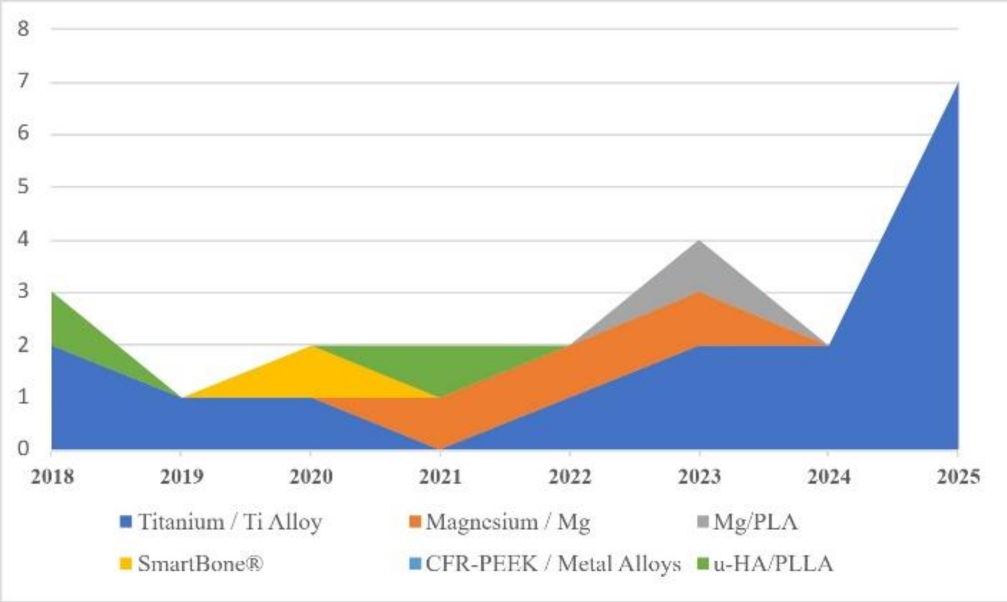

Figure 2. Annual Research Output (2018–2025) by Osteosynthesis Material Type.

Figure 3 includes the stages of osteosis and osteoperiodontitis treatment of the soft and hard tissues of the periodontium and the regeneration of bone tissue. The scheme depicts the beginning stage of the defect/fracture of the bone, in this case the loss of the alveolar bone due to destruction of the periodontium. The subsequent stage involves the fixation of osteosynthesis and the use of titanium, resorbable, and magnesium stabilizing bone fixation materials. After this, the techniques for osteogenic bone grafting are performed. This completes the restoration of the periodontium endured function and stability. The sketch illustrates the other stages of restoration of the lost bone tissue and the elements that determine the repair of the bone in the state of the periodontal disease.

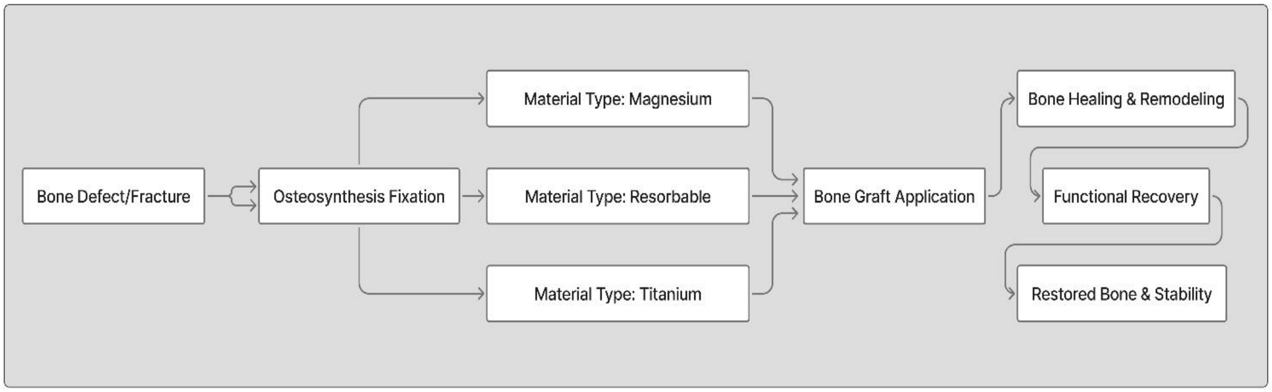

Figure 3. Stages of Bone Defect and Regeneration in Periodontal Disease.

This systematic review focuses on the purpose and impact of different osteosynthesis procedures and fixation materials toward bone regeneration in periodontal and craniofacial regions. Out of the span of 27 studies conducted between 2018 and 2025, titanium-based osteosynthesis still the gold standard indicator for high stability, predictability in bone healing, and low complication. Resorbable and hybrid biomaterials exhibited potential for osteoconduction, and CAD/CAM and patient-specific systems improved the accuracy of osteosynthesis procedures. In summary, the use of osteosynthesis improved the functional restoration of the bone, bone regeneration, and the overall device morbidity.

The current SLR indicates that 27 studies published between 2018 and 2025 examined several different osteosynthesis and grafting techniques for the regeneration of periodontal bony tissues. With Titanium and its alloys (Ti6Al4V, CpTi) still being the most commonly utilized fixation materials, newer biodegradable and hybrid materials such as magnesium-based alloys, PLGA, CFR-PEEK, and SmartBone® have also exhibited promising mechanical strength and tissue compatibility. Enhanced surgical precision has been achieved through advanced CAD/CAM and patient specific osteosynthesis systems, and stable fixation and consistent bone healing have been accomplished with minimal postoperative complications. Recent alloy development has sought to minimize the adverse effects of traditional Ti6Al4V by substituting toxic elements with biocompatible Zirconium (Zr), Niobium (Nb), and Molybdenum (Mo). A good example is the new β-type Ti-20Zr-3Mo-3Sn alloy which showed no cytotoxicity and improved mechanical compatibility with bone, suggesting its alternative potential to the traditional titanium alloys [61, 62]. Biodegradable materials that are magnesium-based alloys also present promising alternatives due to their ability to stimulate osteogenesis via the release of Mg^2+ ions that enhance bone regeneration signaling pathways. However, rapid corrosion and hydrogen gas release present design challenges that have been met with protective coatings of calcium phosphate to control degradation and improve mechanical support during healing. At preclinical stages, studies have proved the effectiveness of the custom-made magnesium alloy scaffolds for improving bone ingrowth and angiogenesis [63]. Using virtual surgical planning and tailored implants allows fixation with minimal invasion, accurate screw placement, and reduced complication rates, thus promoting bone healing. In comparative studies of PSO systems, outcomes and efficiency of the procedures are improved as opposed to conventional fixation systems [64]. Advances in 3D bioprinting and stem cell therapy bioprinting targeted in periodontal tissue regeneration aim to enhance healing and functional restoration outcomes, as discussed in the 3D bioprinting review. In addition, guided tissue regeneration techniques still offer clinical advantages in attachment gain and periodontal pocket reduction, emphasizing the need for a regenerative approach in periodontal treatment [65].

The research showed the success rates of different osteosynthesis techniques to be consistently high, ranging from 97 to 100%, whilst complication rates were between 0 to 6.7%. As for the healing times, these varied between 3 to 26 weeks. Of the biomaterials, u-HA/PLLA and Mg-based systems were less rigid than titanium, but were less irritating to the tissue and did not require removal as did titanium. The introduction of 3D pre-bent miniplates and miniplate-supported intrusion is innovative as it enables precise fixation and is digitally-assisted. This shows the growing importance of osteosynthesis in a clinical setting. The literature is aligned with the findings of the current research as it shows similar success rates across the different techniques. For example, internal fixation with modern devices yields satisfactory functional outcomes and fewer postoperative complications, consistent with the reviewed range of 0-6.7% complications [66, 67]. There is increasing evidence supporting the use of bioresorbable and hybrid biomaterials in osteosynthesis. u-HA/PLLA composites and Mg-based biodegradable implants have been shown to provide mechanical stability equivalent to traditional titanium systems. Additionally, these materials contribute to reduced hardware removal surgery and minimize tissue irritation due to their bioresorbable nature, which aligns well with findings in the reviewed study. Such materials also promote bone regeneration by interacting positively with bone remodeling processes at the microstructural level [68, 69]. Digital workflows and patient-specific/CAD–CAM osteosynthesis (3D pre-bent or 3D-printed PS plates) are repeatedly reported to improve surgical accuracy and reduce operative time in recent studies; our SLR's positive findings for PSO and 3D pre-bent plates are therefore consistent with contemporary clinical reports, though some authors warn about cost, load-bearing limits of miniplates, and the need to match implant design to mechanical demands [70, 71].

The studies reviewed chronologically demonstrated that the dominance of titanium was maintained between the years of 2018 to 2025 while the trends toward resorbable and composite materials were on the rise. Newly developed magnesium and polymer systems offer the likely advantages of being biologically degradable and integrating into biological systems. Hybrid materials such as the SmartBone® and the u-HA/PLLA membrane have also shown in early investigations to be promising in regenerative medicine. These changes also indicate a shift in research direction towards bioactive and user-friendly alternatives to traditional metallic fixation systems. Titanium is still used as the basis of fixation for osteosynthesis given the inherent mechanical strength of the alloy as well as the biocompatibility and integration to the surrounding tissues on which titanium fixation systems has relied on between the years of 2018 to 2025. Moreover, recent studies have highlighted the shortcomings such as the necessity to remove the implant and the associated complications involving the implant which have stimulated research in resorbable polymers, composites and magnesium-based materials [72, 73]. A review demonstrates that u-HA/PLLA membranes which undergo UV radiation treatment exhibit an increase in hydrophilicity as well as osteoconductivity, and result in more bone formation in animal subjects relative to control groups. Composite scaffolds have been shown to have enhanced mechanical strength as well as optimized degradation profiles allowing for gradual transfer of load to the regenerating bone for improved healing environments [74]. Biodegradable magnesium alloys used as fixators have been shown to enhance tissue regeneration as well as osteoblast viability and eliminate the need for a second surgery to remove the implant. The fact that the degradation of Magnesium is controlled and corresponds with the various stages of bone healing makes it a metallic substitute to titanium, especially in load-bearing applications in the periodontic and maxillofacial regions [75]. Other examples of experimental hybrid materials with greater promise include SmartBone® and u-HA/PLLA composites, and these give bioactive surfaces that optimize patient-specific regenerative healing outcomes. These offer the advantages of enhanced direct bone bonding, mechanical stability, and positive biological integration, all of which are essential in healing periodontal bone defects and in other craniofacial constructions [76]. It is clear that the current research is focused on materials that are bioactive, easily bioresorbable and functionalized to enhance osteogenesis and angiogenesis. The materials combine Mesenchymal stem cells, osteoinductive growth factors, including various BMPs, and advanced scaffolds made through 3D and 4D printing, which can be customized for individual patients to promote better regeneration [77].

The integrated process of osteosynthesis and bone regeneration in functional periodontal disease, and how fixation materials, whether titanium, resorbable, or magnesium, achieve peri-implant bone integration. At the same time, bone grafting sustains osteogenesis and remodeling. This interplay fully restores the structure and function of the periodontal bone. Focusing on the biomechanical fixation and biological regeneration suggests the importance of the material and how it balances the efficiencies of healing one and the possible long-term clinical implications. For other applications in the periodontium and maxillofacial region, titanium osteosynthesis retains predominance because of the mechanical strength that comes with it, osseointegration Unfortunately, it comes with drawbacks which include the lack of biodegradable materials, and the risk of stress shielding. Non-biodegradable materials, magnesium and zinc alloys prisms of complying with mechanical stability, corroborative to osteogenic activities through their ionized form in degradation [78]. The evolved techniques on bone regeneration (GBR) and guided tissue regeneration (GTR) techniques work with membranes and bone grafts to form a desirable microenvironment for new formation of bone and periodontal ligaments. Soft tissues and bone integrate more fluidly, which strengthens the biological portion of regeneration beside the mechanical osteosynthesis materials' support [79, 80]. The more biologically active regions of the constructs are targeted with biologic modifiers which, through gene therapy and the use of specific growth factors (like BMP-2, BMP-7) stimulate stronger differentiation and remodeling of osteoblasts. There is an improvement to the clinical results in the regeneration of periodontium tissues due to the biotherapy techniques harmonically fine-tuned to work with mechanical retention [81]. Bioengineered three-dimensional scaffolds and smart injectible hydrogels are able to replicate intricate elements of the periodontal region as well as permit cellular adhesion, proliferation, differentiation, and enhanced tissue regeneration [82]. Meta-analsyes on allografts, xenografts, and synthetic biomaterials used in GBR processes, demonstrate uneven profit from each material, with some analyses supporting the idea that the biomaterials used should favour the stimulation of osteoinduction and vascularization in order to achieve the best results [83]. Biologically, the support from osteosynthesis devices caps the micromotion at the margins of the defect and, coupled with the devices themselves, permits the most optimal conditions for angiogenesis, osteoconduction, and mineralization of the matrix. Resorbable materials like MgYREZr and u-HA/PLLA, in additions to the aforementioned devices, also help maintain the fixation interface and hydraulic skeleton at the surface, which is crucial for the primary mechanical support needed in early vascular tracking and osteoblast division, osteoblasts substituting the fixation interface gradually with new bone. It has already been established that the bioactive ions these materials release stimulate osteogenic pathways and inflammation modulation. These processes work in synchrony to promote profound integration within the periodontal framework to foster the transformation from woven bone to lamellar bone.

The review emphasizes that, regarding periodontal regenerative procedures, osteosynthesis substantially enhances the treatment outcomes in both stability and predictability, with the outcomes being more favorable. In the case of periodontal defects, mini-plates, either titanium or bioresorbable, could offer temporary support and protected conditions for the consolidation of the graft or biomaterial. Fixation, as determined by defect morphology and patient-specific biomechanics, can reduce relapse, enhance function, and accelerate rehabilitation in the patient. The evidence supports the use of PSO and CAD/CAM technologies for precise adaptation in order to enhance the aesthetic and occlusal result, and lower the chances of reoperation.

Limitations

The difference in types of studies, the size of the samples used, and the varying fixation materials all breed variability that limits the scope of direct quantitative assessment, thus leading to the consideration of multiple constraints. There exists a publication bias, as studies illustrating neutral or negative outcomes tend to remain unpublished. Moreover, most of the studies, and particularly the ones that were used in the analysis, were sourced from the craniofacial or orthognathic region and not from studies, making the isolated periodontal defects level of research a more challenging contribution to the boundary of generalization, which is an impediment. Restriction in follow-up length, variations in available imaging techniques, and diversification in definitions of outcomes narrowed synthesis. Out of all the limitations, the uniform clinical and histological advantages spanning multiple studies endorse the notion of the validity of osteosynthesis in periodontal regeneration.

Future directions

Further work should focus on fixation systems that are bioresorbable and nanocomposite, able to synchronize new bone formation and degradation. Clinical studies that use three-dimensional modeling, computer-aided osteosynthesis, and biomimetic scaffolds, and that test the efficacy of individualized regenerative approaches, need to be carried out as part of longitudinal studies. Work on the layer of nano-topography, certain magnesium alloys, and fixation systems with incorporated osteogenic growth factors should improve osteoinduction and reduce additional surgical interventions. This will achieve more controlled and physiologic periodontal bone regeneration.

Conclusion

This systematic review integrates the important evidence that confirms the role of osteosynthesis in the regeneration of bone tissues in periodontics and maxillofacial surgery. Due to their exceptional biomechanical properties, high clinical success rates (97–100%), and low complications (< 7%), titanium and its alloys remain the optimal choice for bone regeneration in surgery. Other new alternatives such as magnesium alloys and polymeric resorbable systems have shown similar results to titanium, with the added benefits of faster bone integration and better biocompatibility, which suggests a trend toward bioabsorbable fixation devices. The combination of CAD/CAM technology and specific osteosynthesis devices further enhances the accuracy, alignment, and recovery of osteosynthesis procedures. From a regenerative perspective, the stability of a fixation device fosters cellular proliferation, the formation of new blood vessels (angiogenesis), and the deposition of a mineralized matrix, which are the primary components of the periodontal regenerative healing process. The evidence suggests that osteosynthetic fixations offer mechanical stability along with biological repair in a synergistic manner with the grafts and scaffolds for added healing. Despite the compound evidence of the importance of osteosynthesis as an adjunct to periodontal regeneration therapies, the longitudinal data remains limited and the data heterogenous, thus precluding definitive meta-analytic conclusions. Advances of bioresorbable materials, nanostructured coatings, and digital planning technology will likely set new standards of the specialty. As a result, multicenter randomized clinical trials with standard protocols are needed to derive evidence-based regimens that appropriately combine mechanical stabilization with biomimetic regenerative techniques for the restoration of periodontal health to be used as common clinical practice.

Acknowledgments: None

Conflict of interest: None

Financial support: None

Ethics statement: None

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