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Regenerative Therapy for Peri-Implantitis: Clinical Evaluation and Theoretical Insights into Collagen-Based OsGrowth Application

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Abstract: ***This study reviews 68 recent publications on regenerative treatments for peri-implantitis and analyzes three clinical cases involving Chenggu Kuai® OsGrowth, a collagen-based bone graft material. Traditional regenerative materials often suffer from low osseointegration and poor degradation synchrony. In contrast, Chenggu Kuai® OsGrowth demonstrates enhanced clinical efficacy, with follow-up data indicating new bone formation rates of 65% to 88%. The study introduces a novel conceptual model- "collagen scaffold, angiogenesis, and inflammation regulation"- to explain the material's therapeutic potential. Findings suggest that Chenggu Kuai® OsGrowth offers a viable, clinically promotable solution for moderate to severe peri-implantitis. This article aims to evaluate the effectiveness of Chenggu Kuai® OsGrowth in the treatment of peri-implantitis through literature analysis and clinical case studies, while proposing a new theoretical model for collagen-based regenerative mechanisms.***

Keywords: Peri-implantitis, Collagen scaffold, Bone regeneration, OsGrowth, Dental implant therapy

1. Introduction

Globally, the application of dental implants is experiencing explosive growth. It is estimated that approximately 12 million dental implants are placed each year [1,2], which means that over a million patients annually achieve significant restoration of oral function and substantial improvement in facial aesthetics. However, this widespread use has also led to a rising incidence of peri-implantitis, emerging as a pressing global dental health concern [3-5]. Epidemiological studies indicate that 20%-22% of implant patients will develop peri-implantitis [6]. The average 5-year, 10-year, and 20-year incidence rates of peri-implantitis are 12% (95% confidence interval: 7%-19%), 14% (95% confidence interval: 9%-20%), and 22% (95% confidence interval: 11%-36%), respectively [6,7]. These data underscore the urgency of identifying risk factors as early as possible and formulating preventive strategies before implant placement. Smoking, diabetes, and alcohol consumption significantly increase the risk of peri-implantitis. Patients with a history of periodontal disease or active periodontitis are at a notably higher risk of developing peri-implantitis.

According to the criteria from the 2017 World Symposium [8], the diagnosis of peri-implantitis requires a probing pocket depth of at least 6 mm and marginal bone resorption of at least 3 mm to classify it as peri-implantitis. The high incidence of peri-implantitis implies that over 2 million implant users worldwide face the threat of inflammation each year. Mild cases result in gingival redness, swelling, and bleeding, affecting masticatory function; moderate to severe cases (with >4 mm bone resorption) can lead to implant loosening and dislodgement, not only resulting in the loss of occlusal function but also necessitating secondary implantation, which increases financial burden. Additionally, aesthetic concerns may result in psychological distress and reduced quality of life. Traditional regenerative materials suffer from issues such as low osseointegration efficiency and asynchronous degradation with osteogenesis. For instance, xenogeneic bone (ABX) exhibits horizontal bone resorption ranging from 0.065 to 2.8 mm [9], while synthetic materials demonstrate a new bone formation rate of less than 30%. Even the internationally mainstream Bio-Oss material only achieves a 15% increase in bone density after 12 weeks [10] and suffers from slow degradation [11]. Clinically, there is an urgent need for novel bioactive materials.

Through case analysis, this study dissects the bone regeneration mechanism of Chenggu Kuai® OsGrowth (an oral bone grafting material produced by Xiling (Zhenjiang) Medical Technology Co., Ltd.), refines the "material-host-inflammatory microenvironment" interaction theory, and fills the research gap regarding the mechanisms of collagen-based materials in the treatment of peri-implantitis. One study pointed out that the inflammatory regulatory mechanisms of collagen matrices in the repair of peri-implantitis remain unclear, and their therapeutic efficacy depends on the synergistic interaction between the material and the host's immune microenvironment [12]. Meanwhile, collagen-based materials need to clarify their regulatory pathways on immune cells within the inflammatory microenvironment, particularly the recruitment mechanism of anti-inflammatory macrophages. The "collagen scaffold - angiogenesis - inflammation regulation" model of Chenggu Kuai® OsGrowth precisely addresses this international academic need for exploration. By optimizing the application protocol of Chenggu Kuai® OsGrowth based on clinical data, this study provides practical treatment

strategies for cases of moderate to severe bone defects, aiming to reduce the rate of implant failure.This research addresses a critical clinical gap in the regenerative treatment of peri-implantitis by introducing a multifunctional biomaterial and providing a theoretical model that can influence future biomaterial development and surgical protocols.

2. Research Methods

2.1 Literature Research Method

Systematically review 68 relevant articles from the PubMed and CNKI databases spanning the years 2020-2025, with a focus on analyzing the AO/AAP consensus [1] and clinical studies . Literature Screening Criteria:

Inclusion Criteria:

1) The study types include clinical randomized controlled trials (RCTs), cohort studies, systematic reviews, meta-analyses, and consensus documents issued by authoritative organizations (such as those from AO/AAP).
2) The study subjects are patients diagnosed with peri-implantitis (meeting the diagnostic criteria of the 2018 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions) or studies focusing on the material mechanisms of bone defect repair around dental implants.
3) The intervention involves the use of collagen-based materials, particularly Chenggu Kuai® OsGrowth.
4) The outcome measures include:
   - Clinical examination indicators: probing depth (PD), bleeding on probing (BOP), gingival recession (GR), swelling, and purulence.
   - Functional and aesthetic evaluations: masticatory function and aesthetic outcomes.
   - Imaging evaluations: Changes in bone level, including bone density, new bone formation rate, and implant stability.

Exclusion criteria:

1) Literature with duplicate publication or overlapping data;
2) Studies solely involving animal experiments (e.g., bone defect models in rats or canines) without clinical translational value;
3) Literature with excessively low methodological quality (e.g., articles published in JCR Q4 journals lacking sample size estimation or control designs);
4) Literature for which the full text is unavailable or core data is missing.

A stratified evaluation system was adopted: For clinical RCT studies, the Cochrane Risk of Bias Assessment Tool was used (evaluating seven dimensions such as random sequence generation, allocation concealment, and blinding implementation); for systematic reviews/meta-analyses, the AMSTAR 2 scale was employed (assessing 16 items including research question definition and literature search completeness); for consensus documents, the focus was on verifying the authority of the issuing organization (e.g., AO/AAP) and the evidence grading annotations (e.g., GRADE classification).

2.2 Case Analysis Method

Interpretation of three typical cases involving the treatment of moderate to severe bone defects using Chenggu Kuai® OsGrowth (including radiographic follow-up data).

3. Results

3.1 Among the 68 finally included articles, there were 52 high-quality ones (with low risk of bias/RCTs or high methodological quality/reviews), accounting for 76.5%, including the AO/AAP 2024 consensus [1]. The primary treatment approach for moderate to severe peri-implantitis is surgical intervention, which can be divided into resective surgery and regenerative surgery.

Resective Surgery (Flap Debridement):

- Method: After flap elevation, inflammatory granulation tissue is excised, the edges of the bone defect are trimmed, and the clean surface of the implant is exposed.
- Prognosis: The success rate of resective surgery can reach 33%–75%; however, follow-up over 1–5 years shows that 3%–14% of implants are lost [13].

Regenerative Surgery (Centered on GBR Technology):

- Core Principle: Bone defects are filled with bone grafting materials, and a barrier membrane is used to isolate soft tissue, creating a space for bone regeneration.
- Prognosis: Follow-up data over 5–7 years indicate that, with regular periodontal and peri-implant maintenance, 51%–58% of cases of peri-implantitis can achieve treatment success after regenerative surgery, with an implant loss rate of 3%–25% over 1–5 years [13].

3.2 Clinical Evidence of Chenggu Kuai® OsGrowth

3.2.1 Typical cases:

Case 1:

Basic Information: The patient is a 65-year-old male who underwent dental implant restoration therapy 10 years ago. He sought treatment in June 2023 due to recurrent swelling and pain of the gingiva around the lower left posterior teeth. He has no history of diabetes or smoking.

Clinical Examination: The implants at #36 and #37 are stable. The buccal gingiva is red and swollen. Probing depths around the buccal aspect of #37 range from 8-10 mm, with purulent exudate.

The panoramic radiograph reveals significant alveolar bone resorption around the #37 implant, reaching the middle one-third of the root. The height of bone resorption around the implant is 5-7 mm, with a crater-like bone defect (Figure 1).

Diagnosis: Peri-implantitis with bone defect around the #37 implant.

Treatment: Under local anesthesia, a crescent-shaped tunnel knife was used to make an intrasulcular incision around the gingiva of the #37 implant. The inflammatory

granulation tissue, peri-implant inflammatory tissue, and infectious material were thoroughly scraped away using curettes. The area was then cleaned with ultrasonic subgingival instruments, polished, and repeatedly rinsed with gentamicin injection. Chenggu Kuai® OsGrowth, soaked in gentamicin injection, was implanted. The interdental papilla was sutured using a mattress suture technique. Local medication was applied. The sutures were removed 2 weeks postoperatively.

Follow-up: On July 11, 2023, during the follow-up visit, the gingiva appeared firm and pink in texture. The patient reported no pain, and no purulent exudate was observed.The patient reported no pain, and no purulent exudate was observed. The implant remained stable. Radiographic examination showed evident signs of healing in the alveolar bone around the #37 implant (Figure 2). On May 15, 2024, during the follow-up visit, the gingiva remained firm and pink. Radiographic examination revealed a further increase in the density of the alveolar bone around the #37 implant (Figure 3). On June 18, 2025, during the follow-up visit, the gingiva was still firm and pink; the probing depth around the implant was less than 4 mm. Radiographic examination showed a further increase in the density of the alveolar bone around the #37 implant (Figure 4). On November 11, 2025, during the follow-up visit, the gingiva remained firm and pink, and radiographic examination showed stable height and density of the alveolar bone around the #37 implant (Figure 5).

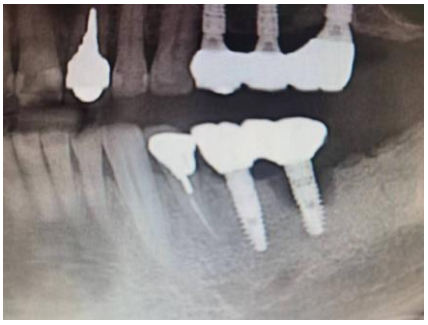


Figure 1: Significant alveolar bone resorption around implant #37

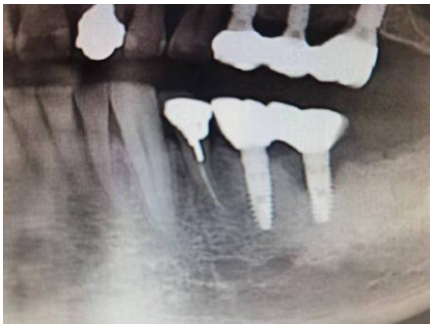


Figure 2: The alveolar bone around implant #37 has significantly increased

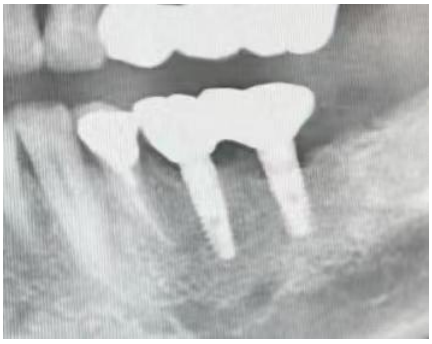


Figure 3: The alveolar bone density around the #37 implant is significantly increased.

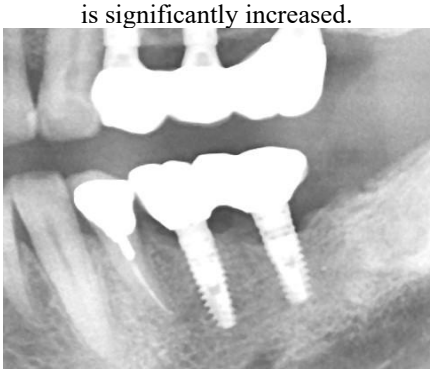


Figure 4: Alveolar bone around implant #37 remains consistent with the previous follow-up.

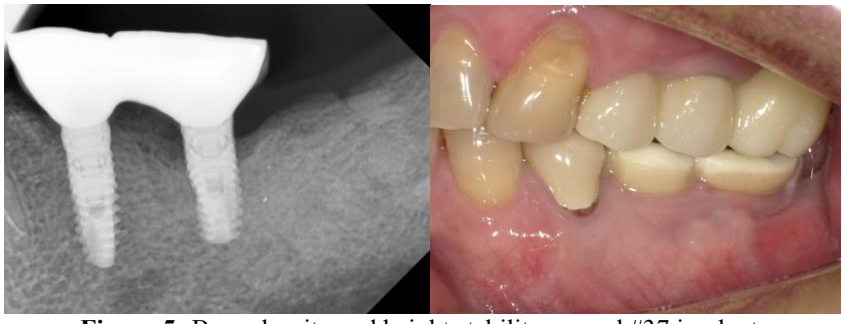


Figure 5: Bone density and height stability around #37 implant.

Case 2:

Basic Information: The patient is a 62-year-old male who has undergone dental implant restoration therapy for approximately 5 years. He sought treatment in February 2025 due to recurrent swelling and pain in multiple gingival areas and discomfort during occlusion. He has a 5-year history of diabetes, with stable blood glucose control, and no smoking history.

Clinical Examination: The implants at #14, #13, #23, #24, #34, #36, #32, and #42 are stable, with red and swollen gingiva and purulent exudate. Periodontal probing depths range from 6-10 mm. The maxillary metal-ceramic fixed bridge is a poorly fitting prosthesis.

The panoramic radiograph reveals varying degrees of alveolar bone resorption around the implants at #14, #13,

#23, #24, #34, #36, #32, and #42, with the most severe resorption reaching the apical one-third. There is a residual root at #22 with a radiolucent area around it (Figure 6).

Diagnosis: Peri-implantitis with bone defects around the implants at #14, #13, #23, #24, #34, #36, #32, and #42.

Treatment: Under local anesthesia, a crescent-shaped tunnel knife was used to make intrasulcular incisions around the gingiva of the implants at #14, #13, #23, #24, #34, #36, #32, and #42. Inflammatory granulation tissue, peri-implant inflammatory tissue, and infectious material were thoroughly scraped away using curettes. The area was then cleaned with ultrasonic subgingival instruments, polished, and the residual root at #22 was extracted. The site was repeatedly rinsed with gentamicin injection. Chenggu Kuai® OsGrowth, soaked in gentamicin injection, was implanted. The interdental papilla was sutured using a mattress suture technique. Local medication was applied. The sutures were removed 2 weeks postoperatively.

Follow-up in November 2025: Local gingival recession of 1-2 mm was observed, with firm and pink gingiva, no swelling, and no purulent exudate. The implants remained stable. Radiographic examination showed significant bone reconstruction around the implants (Figure 7).

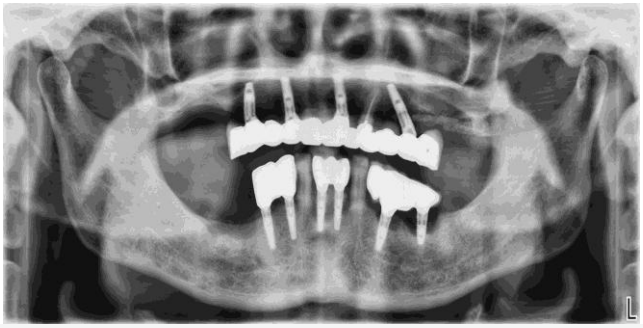


Figure 6: Peri-implant bone resorption in implants #14, #13, #23, #24, #34, #36, #32, and #42.

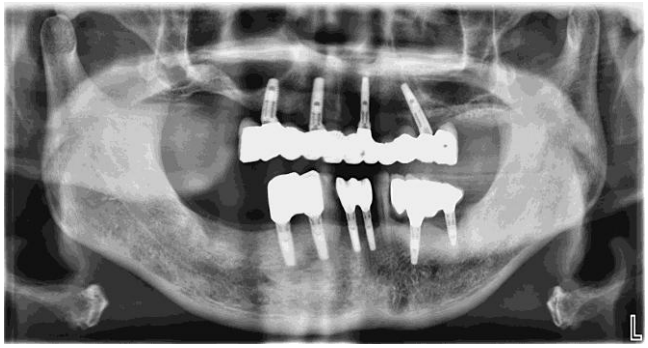


Figure 7: Significant peri-implant bone remodeling observed in implants #14, #13, #23, #24, #34, #36, #32, and #42.

Case 3

Basic Information: A 42-year-old male patient, who underwent dental implant treatment six years ago, sought treatment on April 22, 2023, due to redness, swelling, and bleeding of the gingiva around the lower left posterior teeth, accompanied by pain. He is in good health, with no history of diabetes or smoking.

Clinical Examination: Both implants at #36 and #37 are stable. The gingiva surrounding the implants is red, swollen, and painful, with a large amount of purulent blood exuding upon probing. The probing depth is 8 mm, the width of the keratinized mucosa is insufficient, and oral hygiene is generally poor (Figure 8).

The panoramic radiograph reveals significant alveolar bone resorption around the #36 implant, reaching the middle one-third of the root.

Diagnosis: Peri-implantitis around the #36 implant and peri-implant mucositis around the #37 implant.

Treatment: Under local anesthesia, a crescent-shaped tunnel knife was used to make an intrasulcular incision around the gingiva of the implants. The mucoperiosteal flap was elevated, and inflammatory granulation tissue, peri-implant inflammatory tissue, and infectious material were thoroughly scraped away using curettes. The area was then cleaned with ultrasonic subgingival instruments, polished, and repeatedly rinsed with gentamicin injection. Chenggu Kuai® OsGrowth, soaked in gentamicin injection, was implanted. A collagen membrane was cut to create a hole similar in diameter to the implant, which was then threaded through and placed over the surface of the implant and collagen bone. The edges of the membrane were inserted approximately 5 mm into the buccal and lingual mucoperiosteum, and the wound was closed with mattress sutures (Figure 9). Local medication was applied, and the sutures were removed 2 weeks postoperatively.

Follow-up Visits: On November 12, 2023, during the follow-up visit, the gingiva around #36 and #37 appeared firm and pink, with no swelling or pain, and the symptoms of purulent exudate had disappeared. Radiographic examination showed no progressive bone resorption around the implants at #36 and #37, with stable osseointegration and normal occlusal function (Figure 10). On November 23, 2024, during the follow-up visit, the gingiva around #36 and #37 remained firm and pink, with no swelling or pain. Radiographic examination revealed significant bone reconstruction around the #36 implant, with a marked increase in the bone density shadow around the implant (Figure 11).

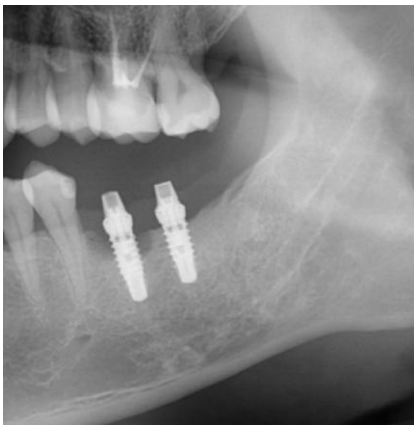
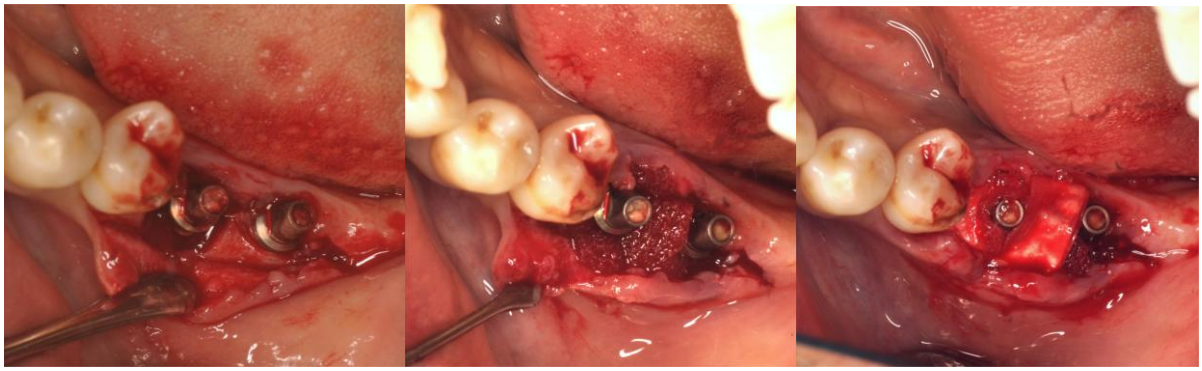


Figure 8: Preoperative bone resorption around implant #36.



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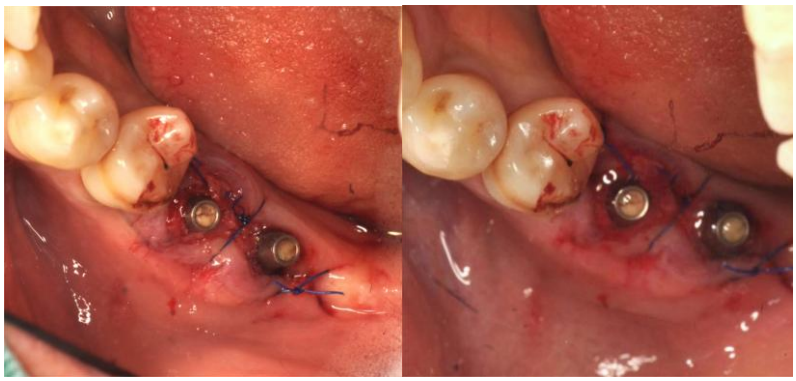
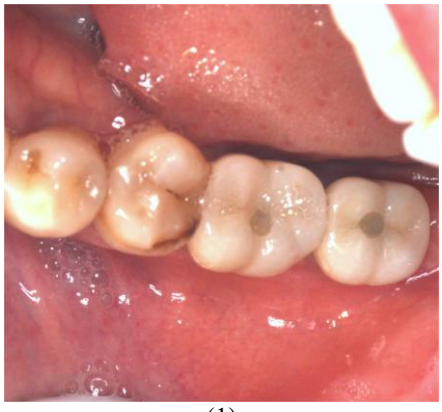


(4) (5)

Figure 9: Treatment process for peri-implantitis. (1) Incision and flap elevation; (2) Implantation of Chenggu Kuai® OsGrowth after debridement; (3) Coverage with Chenggu Kuai® Collagen Membrane; (4) Suturing; (5) Application of antibacterial gel to the wound surface.



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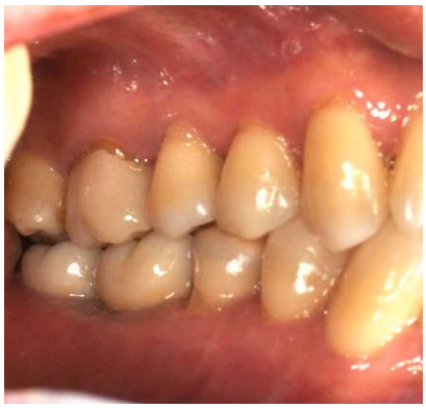

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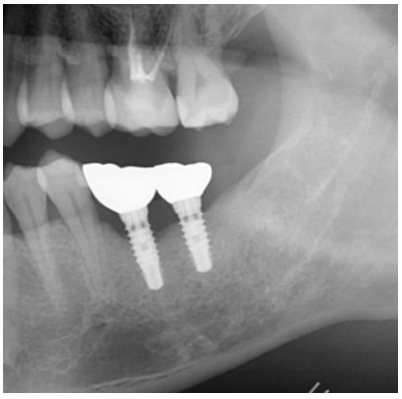

(3)

Figure 10 (1)-(3): Follow-up examination on November 12,2023 showed no progressive alveolar bone resorption around implants #36 and #37, with stable osseointegration.

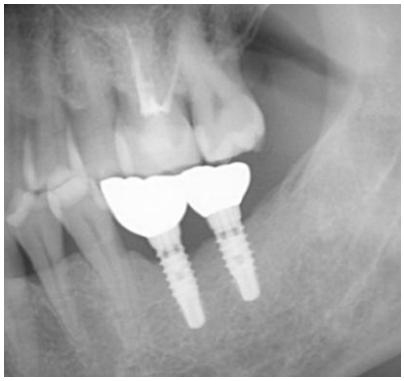

Figure 11: Follow-up visit on November 23,2024: #36 Implant periosteal bone remodeling is evident.

3.2.2 Steps for effectively treating moderate to severe peri-implantitis:

1) Appropriate case selection. High-risk patients whose risk factors cannot be eliminated are not suitable for this treatment protocol; loose implants should be removed; additionally, severely malpositioned implants are also not applicable.
2) Provide sufficient surgical access for implant debridement.
3) Ensuring abundant blood supply is essential for success, and early soft tissue closure provides necessary protection for subsequent bone regeneration.
4) Implantation of an appropriate amount of Chenggu Kuai® OsGrowth, along with gingival sealing.
5) Standardized maintenance management- patients must be willing to return to the hospital every 3 months for maintenance and monitoring, and strictly adhere to a home oral care routine. If the patient is uncooperative or refuses to follow the maintenance protocol, this treatment is not suitable.
6) The surgical procedure must be conducted by qualified professionals experienced in bone and soft tissue grafting.

4. Discussion

Plaque-induced inflammation of the soft and hard tissues surrounding dental implants is characterized by the formation of periodontal pockets and bone resorption, which, in severe cases, can lead to implant loosening. Its pathological mechanism differs fundamentally from that of periodontitis, manifesting in five key aspects:(1)

Differences in Etiological Basis: Peri-implantitis occurs at the implant-bone interface, with the core contradiction being an "imbalance in the adaptation between the biomaterial surface and the host immune microenvironment." As a foreign body, the implant (e.g., titanium alloy) has surface roughness and oxide layer conditions that influence plaque adhesion efficiency. Studies have shown that rough titanium surfaces (roughness parameter Sa > 1 μm) may provide an ideal environment for oral bacteria to form pathogenic plaque biofilms [14], and lack the dual functions of "mechanical buffering-immune defense" provided by the natural tooth periodontal ligament. In contrast, periodontitis is based on chronic infection of the natural tooth periodontal tissues (gingiva, periodontal ligament, alveolar bone), with the etiology focusing on "the destruction of periodontal ligament fibers by plaque biofilms," without immune responses mediated by foreign materials. (2)

Differences in Histological Structure: The absence of the periodontal ligament—a key structure around implants—results in a "direct osseointegration" with bone tissue (no fibrous tissue intervenes at the bone-implant interface). During inflammation, there is no "barrier" provided by periodontal ligament fiber bundles, making it easier for inflammation to directly invade the bone-implant interface. In contrast, natural teeth are surrounded by a periodontal ligament, and inflammation is initially confined to the gingival-periodontal ligament space, with bone resorption typically occurring later than soft tissue inflammation [15].(3)

Differences in Pathogenic Bacterial Spectrum: Although both conditions are predominantly associated with Gram-negative anaerobic bacteria, daSilva et al. [16] used 16S rRNA cloning technology for DNA sequencing and found that anaerobic bacteria such as Fusobacterium, Parvimonas, and Streptococcus were more prevalent in peri-implantitis. Domestic researchers Li Zhijie et al. [17] conducted high-throughput DNA sequencing on plaque from peri-implantitis and normal implant sites, noting high detection rates of periodontitis-related bacteria but also emphasizing differences in genera such as Treponema, Herbaspirillum, Butyrivibrio, and Lutibacterium between peri-implantitis patients and healthy individuals. (4)

Differences in Inflammatory Spread Pathways: In peri-implantitis, inflammation spreads vertically along the "implant surface → bone-implant interface." Since there is no periodontal ligament space between the implant and bone, inflammatory mediators (e.g., LPS, TNF-α) can directly penetrate bone tissue through micro-gaps on the implant surface, leading to rapid destruction of osseointegration. In contrast, periodontitis inflammation primarily spreads horizontally along the "periodontal pocket wall → periodontal ligament → alveolar bone." The collagen fiber bundles of the periodontal ligament can temporarily block inflammation, and bone resorption often presents as "pit-shaped" rather than the "circumferential bone resorption" seen around implants. Studies [18-20] confirm that circumferential bone resorption occurs in 55% of peri-implantitis cases, while pit-shaped bone resorption accounts for approximately 35.2% of all bone defects in periodontitis patients.(5)

Differences in Treatment Response: Bone regeneration after peri-implantitis treatment requires simultaneous repair of both the "bone-implant interface" and "soft tissue attachment." Due to potential residual plaque biofilms on the implant surface, the recurrence rate of peri-implantitis during the postoperative maintenance period ranges from 20% to 55% [21]. Given the lower success rate of treating peri-implantitis compared to periodontal diseases like periodontitis, a prevention-oriented approach should be emphasized in implant therapy [22-23]. In contrast, after periodontitis treatment, the periodontal ligament can achieve a certain degree of regeneration through fibroblast proliferation, making bone repair relatively less challenging.

Peri-implantitis, as a condition akin to a chronic non-healing wound, can disrupt bone homeostasis. Against this backdrop, the chronic persistence of peri-implant inflammation and its cumulative cellular damage over time may, to a certain extent [24], explain the numerous reported challenges in treating peri-implantitis and its persistently high recurrence rate. Similar to natural dentition, implants with insufficient keratinized tissue exhibit significantly more inflammatory responses in the peri-implant mucosa compared to those with adequate keratinized tissue. The presence of sufficient keratinized tissue may reduce plaque accumulation around the implant and lower the incidence of peri-implant mucosal recession. Additionally, a cross-sectional study by Monje et al. [25] found that in patients with inadequate implant maintenance therapy, when the width of keratinized tissue

was <2 mm, there was greater alveolar bone resorption and a higher incidence of peri-implantitis, reaching up to 53.8%.

Traditional guided tissue regeneration (GTR) theory posits that biocompatible barriers are used to isolate soft tissues, thereby guiding osteoblasts to preferentially colonize the site, with the core emphasis on the material's biocompatibility and spatial maintenance capacity. The osseointegration theory emphasizes the formation of a direct structural connection between the implant and bone tissue, requiring materials to possess both mechanical strength and osteoinductive properties. However, traditional bone materials struggle to achieve true bone regeneration.Material classifications include xenografts (ABX/CBX), synthetic materials (hydroxyapatite), and collagen-based materials, among which collagen-based materials have become a research focus due to their superior biocompatibility. Studies have confirmed the advantages of collagen membranes combined with bone substitutes in regenerative surgical treatment of peri-implantitis [26], although issues such as insufficient mechanical strength persist.

Theoretical innovation of Chenggukuai®: It proposes a trinity bone regeneration model of "collagen scaffold - angiogenesis - inflammation regulation," elucidating the synergistic repair mechanism of Chenggu Kuai® OsGrowth in the repair of bone defects caused by peri-implantitis. This model transcends the limitations of the traditional binary model of "material - bone formation" by incorporating, for the first time, the regulation of the inflammatory microenvironment into the core framework of the bone regeneration mechanism of collagen-based materials. The specific dimensions and synergistic logic are as follows:

Core Dimension 1: Structural Support and Cellular Anchoring Mechanism of the Bionic Collagen Scaffold:
Chenggu Kuai® OsGrowth utilizes decellularized bovine cancellous bone as raw material, employing cryogenic freeze-drying technology to construct a three-dimensional porous structure with pore sizes ranging from 50 to 500 μm and a porosity exceeding 85%. Its type I collagen fibers are arranged in an ordered, interwoven pattern, which not only physically maintains the spatial stability of bone defects around dental implants (avoiding bone loss caused by the collapse of traditional collagen membranes) but also facilitates specific binding between the RGD sequence (arginine-glycine-aspartic acid) on the collagen molecule surface and integrin α2β1 on osteoblast surfaces. This interaction activates the FAK (focal adhesion kinase) signaling pathway, promoting osteoblast adhesion, proliferation, and secretion of type I collagen and osteocalcin. Simultaneously, the scaffold undergoes gradual degradation (with a degradation cycle of 8–12 weeks), yielding small-molecule peptides that can be reutilized by host bone tissue, achieving synchronicity between "degradation and osteogenesis." This addresses the issue of "material retention competing for space with new bone formation" caused by the excessively long degradation cycle (18–24 months) of traditional xenografts.

Core Dimension 2: Nutrient Supply via Angiogenesis and the Initiation Mechanism of Bone Regeneration:
The three-dimensional scaffold structure of Chenggu Kuai® OsGrowth provides migration channels for vascular endothelial cells (VECs). During its degradation process, released collagen fragments activate the expression of platelet-derived growth factor (PDGF) and vascular endothelial growth factor (VEGF). Animal experiments demonstrate that four weeks after implantation of Chenggu Kuai® OsGrowth, a significant aggregation of new osteoblasts is observed, with up to 65% of VECs forming tubular structures within the scaffold pores. Angiogenesis not only supplies osteoblasts with oxygen and essential nutrients (such as calcium and phosphorus ions) but also regulates osteoblast differentiation through TGF-β1 (transforming growth factor β1) secreted by perivascular cells, establishing a positive feedback loop of "angiogenesis-osteogenesis initiation." As a critical process in bone regeneration [27], vascularization is increasingly recognized for its importance. It not only provides indispensable nutrients and oxygen for bone regeneration but also accelerates bone tissue repair by secreting various cytokines that promote the recruitment and differentiation of bone cells.

Core Dimension 3: Targeted Regulation of the Inflammatory Microenvironment and Immune Balance Mechanism:
Addressing the chronic inflammatory characteristics of peri-implantitis (typified by infiltration of pro-inflammatory M1 macrophages and elevated expression of TNF-α and IL-6), Chenggu Kuai® OsGrowth achieves inflammatory regulation through two pathways:

Direct action: Its collagen molecules bind to scavenger receptor SR-A on macrophage surfaces, inhibiting activation of the NF-κB signaling pathway. This reduces pro-inflammatory cytokine secretion by M1 macrophages while promoting their polarization into anti-inflammatory, tissue-repairing M2 macrophages.

Indirect action: By enhancing local immune cell infiltration through angiogenesis (as described in Dimension 2), IL-10 and TGF-β secreted by M2 macrophages further suppress inflammatory responses. Additionally, these macrophages secrete bone morphogenetic protein 2 (BMP-2) to promote osteoblast differentiation, creating a synergistic effect of "inflammation resolution - bone regeneration promotion."

Synergistic Logic of the Three dimensions: Holistic Repair from "Structure - Function - Microenvironment":
The three dimensions do not act independently but form a progressive synergy: First, the bionic collagen scaffold provides a physical substrate for angiogenesis and inflammatory regulation (without the scaffold, VECs and immune cells lack migration and anchoring sites). Second, angiogenesis supports inflammatory regulation by supplying nutrients (inflammation resolution requires substantial energy, while hypoxic conditions exacerbate M1 macrophage accumulation) and delivering key factors to osteoblasts. Finally, inflammatory regulation creates a "non-inflammatory microenvironment" essential for scaffold functionality and angiogenesis (chronic inflammation disrupts collagen scaffold integrity and inhibits VEGF

expression). These components collectively establish a regenerative feedback system supporting structural repair and inflammation resolution. Unlike traditional models focusing solely on the unidirectional relationship between "scaffold structure and bone formation," this model better aligns with clinical realities where "inflammatory microenvironment dictates bone regeneration success." It provides a novel theoretical framework for studying the mechanisms of collagen-based materials in peri-implantitis treatment.

5. Conclusion

The fundamental challenge in repairing peri-implantitis after treatment lies in the absence of the biological activity and regenerative regulatory systems inherent to natural teeth, which results in unique difficulties in restoring both osseointegration interfaces and soft tissue attachment. Consequently, treatment success rates and long-term stability are markedly lower than those for periodontitis therapy. Clinicians must develop specialized treatment strategies addressing these challenges, including thorough debridement of implant surfaces, optimized selection of bone grafting materials and soft tissue management, along with rigorous postoperative maintenance, to improve treatment outcomes. Chenggu Kuai® OsGrowth, with its unique three-dimensional porous structure (porosity up to 85%), provides stable spatial support for bone tissue regeneration. Its rich type I collagen composition effectively promotes osteoblast adhesion and colonization while exhibiting anti-inflammatory properties and synchronized degradation-osteogenesis. This study innovatively proposes the "collagen scaffold - angiogenesis - inflammation regulation" theoretical model. Clinical data demonstrate that after 12 months of treatment with Chenggu Kuai® OsGrowth, new bone formation rates reach 65%-88%, significantly outperforming traditional regenerative materials. The findings support the clinical applicability of Chenggu Kuai® OsGrowth in managing moderate to severe peri-implantitis.

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