UNIVERSIDADE FERNANDO PESSOA

FACTORS INFLUENCING ALVEOLAR BONE REMODELING AFTER TOOTH EXTRACTION: A SCOPING REVIEW

[Fatores que influenciam a remodelação óssea alveolar após extração dentária: uma revisão de escopo]

Dissertação de Mestrado

[Mestrado Integrado em Medicina Dentária]

Pauline Alice Sylvine Aulagner

Orientadora:

Doutora Otília Adelina Pereira Lopes

Co-orientadora:

Doutora Ana Rita Nóbrega

Setembro 2025

FACTORS INFLUENCING ALVEOLAR BONE REMODELING AFTER TOOTH EXTRACTION: A SCOPING REVIEW

[Fatores que influenciam a remodelação óssea alveolar após extração dentária: uma revisão de escopo]

Dissertação de Mestrado

[Mestrado Integrado em Medicina Dentária]

Pauline Alice Sylvine Aulagner

Orientadora:

Doutora Otília Adelina Pereira Lopes

Co-orientadora:

Doutora Ana Rita Nóbrega

Setembro 2025

ACKNOWLEDGMENTS

Gostaria de expressar a minha profunda gratidão à minha orientadora, a Dra. Otília Adelina Pereira Lopes, pelo seu acompanhamento, disponibilidade e conselhos esclarecedores ao longo deste trabalho. O seu rigor científico e benevolência foram para mim uma fonte de motivação e aprendizagem.

Gostaria também de agradecer à minha coorientadora, a Dra. Ana Rita Nóbrega.

Os meus agradecimentos estendem-se também a todos os professores de Medicina Dentária da Universidade Fernando Pessoa, que contribuíram para a minha formação, partilhando os seus conhecimentos e a sua paixão pela nossa disciplina.

Un grand merci à tous mes camarades d'études, avec qui j'ai partagé ces merveilleuses années d'études, leurs encouragements, leur amitié et les nombreux moments de complicité ont rendu ce parcours plus léger et me laisseront des souvenirs inoubliables.

Un merci tout particulièrement pour mes amis Nathan, Camille et Thaïs. Avec une mention particulière pour ma binôme Thaïs avec qui j'ai partagé mes inquiétudes en clinique, nos premiers patients et des heures entières à partager l'intimité de nos vies. Et Camille, mon soutien indéfectible depuis 7 ans, des premiers jours d'études aux derniers, nous avons su affronter les hauts et les bas de la vie ensemble, pour avoir su trouver les mots justes dans les moments de doute et pour tout ce tu es, merci. Je suis très reconnaissante de vous avoir dans ma vie, et j'espère pouvoir continuer toutes les prochaines étapes de notre vie à vos côtés, de près ou de loin.

À mon amie Sophie, qui aujourd'hui a une place spéciale dans mon coeur, merci d'illuminer ma vie au quotidien par ta présence, merci d'avoir été à mes côtés, de m'avoir écouté et épaulé sans jugement, et pour ces discussions qui, souvent, valaient toutes les thérapies.

À mon amie Maeva, merci pour tous ces moments de complicité et d'amitié véritable, de m'avoir fait rire quand j'étais triste, de m'avoir conseillé dans les moments difficiles, je garderai en moi précieusement tous nos souvenirs qui demeureront une source inestimable de joie et de réconfort.

À Célia et Andrea, mon duo de chipies préféré, merci pour ces moments passés ensemble et pour encore et toujours plus de bêtises.

À ma sœur, ma meilleure amie, ma confidente et ma moitié. Aucun mot n'est assez fort pour traduire l'immensité de l'amour que je ressens pour toi. Tu es celle qui me comprend sans que j'aie besoin de parler, celle qui partage mes joies comme mes peines, et qui me soutient sans relâche. Je t'aime infiniment et je suis fière de t'avoir à mes côtés. Aussi, je garde à jamais la certitude que, tant que tu es là, je ne serai jamais seule, et pour tout ça, merci.

À mes parents, les piliers de ma vie et un trésor inestimable. Votre amour inconditionnel m'a construite, votre soutien m'a porté, et votre exemple m'inspire chaque jour. Ce travail est aussi le vôtre, car il est le fruit de tout ce que vous m'avez donné et appris. Je vous aime profondément et je vous serai éternellement reconnaissante d'avoir toujours cru en moi, de votre patience et pour les sacrifices silencieux que vous avez faits pour que je puisse réaliser mes rêves.

Tous les trois vous êtes le plus beau cadeau que la vie m'ait offert, aucun mot n'est assez fort pour exprimer la gratitude que je ressens de vous avoir comme famille.

Enfin, je dédie ce travail à toutes les personnes qui m'ont soutenue, de près ou de loin, et qui ont cru en moi. Leur amour et leur appui resteront pour moi des souvenirs précieux de cette étape de ma vie.

RESUMO

Antecedentes: Após a extração dentária, o osso alveolar se remodela por meio da reabsorção e da formação de osso novo. Alterações dimensionais precoces podem comprometer a futura reabilitação protética ou com implantes. Identificar os fatores que influenciam é crucial para obter resultados ótimos. **Objetivo**: Esta revisão exploratória mapeou os fatores biológicos, ambientais e mecânicos que afetam a remodelação do osso alveolar em adultos. **Métodos**: Realizadas de acordo com PRISMA-ScR e PICo, as pesquisas foram realizadas no *PubMed*, *Scopus*, *Cochrane*, *Web of Science* e *Google Scholar* (2005-2025). Os estudos elegíveis foram revisões sistemáticas ou narrativas, estudos observacionais e ensaios clínicos em inglês ou português. As exclusões incluíram estudos apenas com implantes, doenças sistémicas raras ou técnicas cirúrgicas altamente específicas. Dos 788 registos, 168 duplicados foram removidos, 620 selecionados, 72 avaliados na íntegra e oito incluídos. **Resultados**: As alterações dimensionais foram mais pronunciadas nos primeiros 3 a 6 meses, com perda horizontal de até 63% e vertical de até 22%, principalmente na parede bucal. Os fatores biológicos incluíram idade, condições sistémicas e medicamentos. Influências ambientais, como tabagismo, higiene oral e nutrição, também contribuíram. Fatores mecânicos - espessura da parede bucal, morfologia da cavidade, tipo de dente e técnica cirúrgica - afetaram significativamente a estabilidade da crista. A preservação da crista reduziu a perda óssea em ~2 mm em comparação com a extração isolada, embora a reabsorção permanecesse inevitável. **Conclusão**: A remodelação óssea alveolar após a extração resulta de uma interação complexa de fatores biológicos, ambientais e mecânicos. As técnicas de preservação atenuam, mas não podem impedir a reabsorção. São necessários métodos padronizados e mais estudos. A avaliação específica do paciente continua a ser essencial para um planeamento ideal.

Palavras-chave: Perda óssea alveolar; extração dentária; remodelação óssea; cicatrização do alvéolo; fatores de risco; adultos.

ABSTRACT

Background: Following tooth extraction, the alveolar bone remodels through resorption and new bone formation. Early dimensional changes may compromise future prosthetic or implant rehabilitation. Identifying influencing factors is crucial for optimal outcomes. **Objective:** This scoping review mapped biological, environmental, and mechanical factors affecting alveolar bone remodeling in adults. **Methods:** Conducted according to PRISMA-ScR and PICo, searches were performed in PubMed, Scopus, Cochrane, Web of Science and Google Scholar (2005–2025). Eligible studies were systematic or narrative reviews, observational studies, and clinical trials in English or Portuguese. Exclusions included implant-only studies, rare systemic disorders, or highly specific surgical techniques. Of 788 records, 168 duplicates were removed, 620 screened, 72 assessed in full, and eight included. **Results:** Dimensional changes were most pronounced in the first 3–6 months, with horizontal loss up to 63% and vertical up to 22%, mainly at the vestibular wall. Biological factors included age, systemic conditions, and medications. Environmental influences such as smoking, oral hygiene, and nutrition also contributed. Mechanical factors—vestibular wall thickness, socket morphology, tooth type, and surgical technique—significantly affected ridge stability. Ridge preservation reduced bone loss by ~2 mm compared with extraction alone, though resorption remained unavoidable. **Conclusion:** Alveolar bone remodeling after extraction results from a complex interplay of biological, environmental, and mechanical factors. Preservation techniques mitigate but cannot prevent resorption. Standardized methods and further studies are needed. Patient-specific assessment remains essential for optimal planning.

Keywords: Alveolar bone loss; tooth extraction; bone remodeling; socket healing; risk factors; adults.

TABLE OF CONTENTS

INDEX OF FIGURES

INDEX OF TABLES

LIST OF ABBREVIATIONS

®	Registered Brand
ARP	Alveolar Ridge Preservation
CBCT	Cone Beam Computed Tomography
e.g.	Example
mm	Millimeter
PICo	Population, Phenomenon of Interest, Context
PRISMA-ScR	Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews
RCT	Randomized Controlled Trial

1. INTRODUCTION

After tooth extraction, the alveolar bone follows a natural remodeling process, characterized by a sequence of healing phases involving clot formation, granulation tissue development, and new bone apposition (Devlin & Sloan, 2002; Cardaropoli et al., 2003). This dynamic process first involves resorption, followed by coordinated reconstruction of the alveolar hard tissues. It plays an essential role in restoring tissue continuity, maintaining masticatory function and preserving the stability of the maxillary and mandibular arches. However, this phenomenon is inevitably accompanied by changes in ridge morphology. The first 6 months following extraction are particularly decisive: horizontal bone loss varies from 29 to 63%, and vertical loss from 11 to 22%, with the vestibular wall being the most vulnerable to resorption (Tan et al., 2012; Van der Weijden et al., 2009).

Several factors are involved in these changes, such as biological factors including gender, age, hormonal status, and certain systemic diseases. For example, poorly controlled diabetes disrupts collagen matrix formation and accentuates bone loss, while postmenopausal osteoporosis and radiotherapy also compromise the quality of remodeling (Udeabor et al., 2023). The use of certain medications, particularly bisphosphonates and corticosteroids, can also slow down healing (Khan et al., 2015). Mechanical factors concern local elements such as the thickness and integrity of the vestibular wall, the type of tooth extracted, the morphology of the alveolus, the surgical technique used, like flap elevation or the use of alveolar preservation techniques (ARP). Histological and clinical data highlight the decisive role of the vestibular wall in ridge stability, the loss of which leads to accelerated resorption (Araújo et al., 2015). Finally, environmental factors such as oral hygiene, eating habits and access to care influence healing and long- term bone stability. Also, smoking leads to an average of approximately 0.5 mm of additional resorption compared to non-smokers (Udeabor et al., 2023; Ramanauskaite & Juodzbalys, 2014). Poor plaque control and poor adherence to maintenance therapy have also been associated with higher rates of tooth and bone loss (Chambrone et al., 2010).

Scientific data indicate that the most significant changes occur between the third and sixth months post-extraction, with the vestibular wall being particularly susceptible to

resorption. A systematic review and meta-analysis showed that alveolar ridge preservation significantly reduces bone loss, on average of +1.89 mm in width, +2.07 mm in vestibular height and +1.18 mm in lingual height compared to extraction alone, with more pronounced benefits when membranes and grafts are used (Avila-Ortiz et al., 2014). Nevertheless, pooled analyses confirm an average loss of approximately 2.73 mm in width and 1.71mm in height after six months, showing us that the resorption was more important in molar sites and when the vestibular wall was thin (Couso-Queiruga et al., 2021). At the same time, some narrative reviews point out that although alveolar bone has the capacity for self-regeneration, large or unstable defects often heal incompletely, resulting in significant dimensional loss (Sculean et al., 2019).

From a clinical point of view, these dimensional changes complicate implant placement, influence prosthetic planning and can compromise aesthetics. Several authors emphasize that ridge resorption is multifactorial, depending on anatomical conditions, surgical techniques and systemic factors specific to the patient (Udeabor et al., 2023; Couso-Queiruga et al., 2021). Although the use of biomaterials combined with barrier membranes can limit these dimensional losses, resorption remains inevitable (Jung et al., 2013; MacBeth et al., 2017). The future remodeling of hard tissues depends heavily on the specific conditions of each patient, the site involved and the precision of the procedure. Understanding the interactions between biological, mechanical and environmental factors is therefore essential for optimizing clinical decision-making and adapting treatment strategies, highlighting the need for individualized planning guided by the prosthetic project (Tonetti et al., 2019).

Furthermore, despite the abundance of publications, the overall quality of the evidence remains variable and sometimes limited, calling for cautious interpretation of the results (Fok & Jin, 2024). Despite the wealth of literature, the available studies differ widely in terms of methodology, population characteristics, follow-up duration and evaluation criteria, which complicates the comparison of results. This heterogeneity justifies conducting a scoping review to map and categorize the available data on factors influencing alveolar bone remodeling.

The objective of this review is to identify and classify the biological, mechanical and environmental factors influencing alveolar bone remodeling after tooth extraction in adults. The aim is to provide a solid knowledge base to guide clinical protocols, promote personalized treatment planning, and highlight areas for further research.

2. METHODOLOGY

This study is a scoping review conducted in accordance with the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews) guidelines. The objective is to identify and map the biological, environmental and mechanical factors that influence alveolar bone remodeling after tooth extraction in adult patients. A scoping review involves systematically mapping existing literature in order to clarify concepts, identify the types of evidence available, and highlight gaps in knowledge. This type of review is particularly well suited to answering an exploratory research question such as this one (Arksey & O'Malley, 2005; Peters et al., 2020).

To conduct the research, the following databases were used: PubMed, Scopus, Cochrane Library, Web of Science and Google Scholar. Each was chosen for its complementary nature: PubMed for its biomedical coverage, the Cochrane Library for its summaries and clinical trials, Scopus and Web of Science for their multidisciplinary indexing and citation tracking, and Google Scholar to access additional works that are sometimes missing from major databases. Their combination has ensured sensitive and relevant research, well adapted to dentistry, clinical trials, and interdisciplinary approaches.

The search strategy was constructed based on the following PICo elements:

- Population (P): Adults undergoing tooth extraction.
- Phenomenon of interest (I): Bone remodeling in the alveolus after extraction.
- Context (Co): Biological, environmental and mechanical factors influencing this process.

Research question: "What biological, environmental, and mechanical factors influence alveolar bone remodeling after tooth extraction in adults?"

Using the following keywords: bone remodeling, tooth extraction, bone loss, alveolar process, alveolar socket, socket healing, tooth socket, influencing factors, bone resorption, and oral surgical procedures. And with the need of the Boolean operators « AND » and « OR » to assure the full integration of various keywords.

Inclusion criteria were defined, namely, articles published in the last twenty years (2005-2025), an a priori time window was considered but no eligible studies were

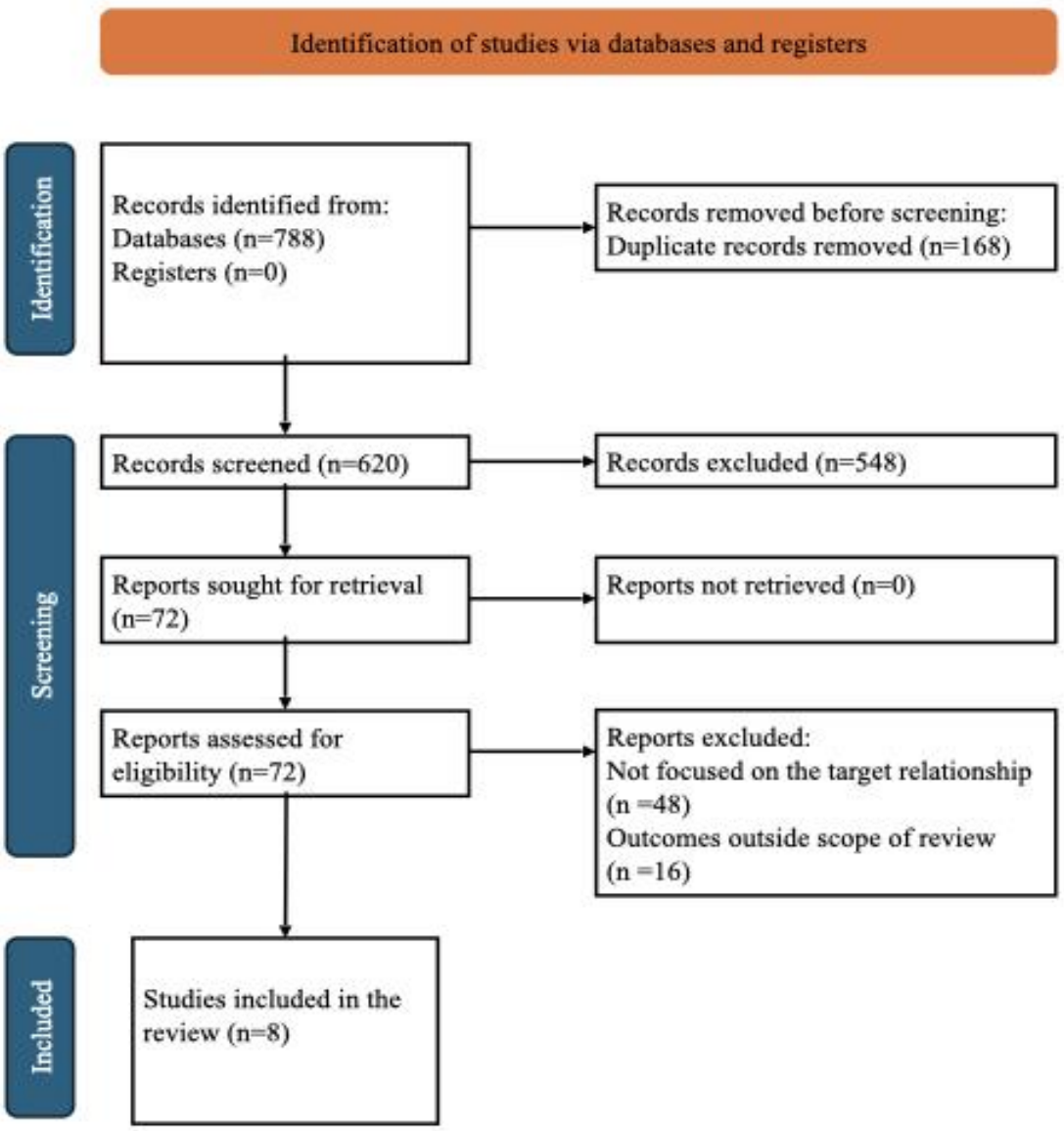
published before 2009 and after 2024. However, the studies selected were finally reduced to 2009-2024 after rigorous screening. Written in English or Portuguese to ensure maximum comprehension and transcription. The studies had to involve adult humans, without sex restrictions. Systematic reviews, meta-analyses and narrative reviews that provide relevant insights into factors influencing bone remodeling were used. Exclusion criteria were defined as follows: studies focusing on bone remodeling outside the alveolar socket, include patients with rare bone disorders that may alter physiological bone remodeling (e.g., osteogenesis imperfecta, bone dysplasias), or exclusively address topics such as dental implants, guided bone regeneration, or other specialized interventions without discussing the natural post-extraction bone remodeling process.

The selection of articles was carried out in several successive stages, in accordance with the PRISMA-ScR recommendations. A total of 788 articles were identified on databases (no additional articles were retrieved from registers). After the automatic and manual removal of 168 duplicates, 620 articles remained for screening. Titles and abstracts were first evaluated to exclude clearly irrelevant studies, which considerably reduced the number of potentially eligible. 72 articles were read in full and evaluated according to the predefined inclusion and exclusion criteria. 64 were excluded because some of them concerned specific populations (e.g. pediatric patients or patients with rare diseases) and others focused exclusively on implants, the rest of them were not exclusively on implant or very specific surgical techniques but had no direct link to natural post-extraction bone remodeling. At the end of this process, 8 studies were selected for inclusion in this scoping review. The process of identification, screening, and inclusion of studies was conducted by one reviewer under the supervision of the academic advisor and is presented in Figure 1, according to the PRISMA-ScR flow diagram.

Data extraction captured for the synthesis: authors and year, study type, title, population, factor categories (biological, mechanical, environmental) and key results, to ensure transparency and methodological rigor.

Figure 1

PRISMA-ScR flow diagram



Adapted from "The PRISMA 2020 statement: An updated guideline for reporting systematic reviews." M. J., Page, J. E., McKenzie, P. M., Bossuyt, I.,Boutron, T. C., Hoffmann, C. D., Mulrow, D.Moher, 2021, BMJ, 372, n71. (https://doi.org/10.1136/bmj.n71) Copyright 2021 from the authors

3. RESULTS

3.1. Study flow

A total of 788 records were identified through database searches. No additional records were retrieved from registers. After removing 168 duplicates, 620 unique references remained for screening. Following title and abstract screening, 72 full-text articles were assessed. Of these, 64 were excluded due to their focus on implant-only outcomes, highly specific surgical techniques or restricted populations. Ultimately, eight studies met the eligibility criteria and were included in this review. The study selection process is presented in the PRISMA 2020 flow diagram (cf. Figure 1).

3.2. Characteristics of included studies

The included studies, which were published between 2009 and 2024, consisted of five systematic reviews (three of which included meta-analyses) and three narrative reviews. Most analyzed clinical human data, while some incorporated histological or animal evidence to illustrate biological mechanisms. Follow-up times ranged from one to 12 months, and measurement methods included clinical evaluation, radiography and CBCT scanning. The sites evaluated both molar and non-molar extractions. Table 1 summarizes the main characteristics and findings of the included studies.

3.3. Study Results:

All of the included studies confirmed that tooth extraction is followed by measurable dimensional changes to the alveolar ridge, which are most evident during the early healing period.

Tan et al. (2012) reported horizontal bone loss ranging from 29% to 63% and vertical loss ranging from 11% to 22% within the first three to six months, with the most pronounced resorption occurring at the vestibular wall. Similarly, van der Weijden et al. (2009) found an average reduction of 3.87 mm in ridge width and 1.67 mm in vestibular height after six months. During this time, the socket partially filled with approximately 2.57 mm of new bone.

Araújo et al. (2015) provided histological evidence describing healing as a sequence of overlapping stages leading to lamellar bone formation within 8–12 weeks. They highlighted the integrity of the buccal plate as a critical factor: when intact, resorption was limited, but when thin or absent, ridge contraction was markedly accelerated.

A quantitative synthesis by Couso-Queiruga et al. (2021) confirmed these trends. Pooled estimates showed an average horizontal reduction of 2.73 mm clinically and 2.54 mm radiographically at six months, as well as a vertical mid-facial loss of 1.71 mm. Resorption was greater in molar sites and in sockets with a thin buccal plate. Narrative reviews emphasized the regenerative potential and limitations of alveolar bone. Sculean et al. (2019) found that small or contained defects often healed spontaneously, while larger or unstable extraction sites exhibited incomplete regeneration and substantial dimensional loss. Udeabor et al. (2023) examined systemic and environmental influences, finding that smoking increased ridge resorption by approximately 0.5 mm compared to nonsmokers. Poorly controlled diabetes, postmenopausal osteoporosis, and radiotherapy were also found to impair bone quality and delay healing. Factors such as oral hygiene, diet, and access to care were also recognized as important modulators of outcomes.

Evidence on ARP was positive overall but varied in magnitude. Avila-Ortiz et al. (2014) demonstrated that ARP reduces dimensional changes compared to extraction alone. On average, there was +1.89 mm of width preservation, +2.07 mm of vestibular height preservation, and +1.18 mm of lingual height preservation, particularly when membranes and grafting materials were used. However, Fok and Jin (2024) concluded that, despite decades of research, the overall certainty of the evidence supporting ARP remains low due to marked heterogeneity across studies and a limited ability to generate standardized recommendations.

3.4. Gaps and Heterogeneity

Despite consistent evidence of significant ridge reduction after tooth extraction, differences in study design complicate comparisons. Differences in study design (systematic versus narrative reviews), tooth types, measurement methods (clinical, radiographic, cone-beam computed tomography [CBCT], and histological), and follow-up periods (one to 12 months) contribute to variability. Additionally, although ARP

techniques have demonstrated measurable benefits, the effectiveness of specific biomaterials and protocols remains unclear due to inconsistent methodologies. Important gaps for future research include the rare investigation of environmental influences such as nutrition, oral hygiene, and socioeconomic status.

Table 1

Summary of included studies and key results

Authors (year)	Type of study	Title	Population	Factors identified	Key results
Tan et al. (2012)	Systematic review	A systematic review of post-extractional alveolar hard and soft tissue dimensional changes in human	Adult humans	Biological, mechanical	Most dimensional reductions occur during the first 3 to 6 months following extraction. Horizontal bone loss is estimated at between 29% and 63%, while vertical loss is between 11% and 22%. The vestibular wall resorbs more quickly than the lingual/palatal wall, resulting in a significant reduction in crest width.
Van der Weijden et al. (2009)	Systematic review	Alveolar bone dimensional changes of post- extraction sockets in humans	Adult humans	Biological, mechanical	The average reduction in width was approximately 3.87 mm and the loss of vestibular height was 1.67 mm at 6 months. The alveolar socket partially filled in with an average of 2.57 mm. These results show the predictable resorption of the ridge after extraction.
Araújo et al. (2015)	Narrative review	Alveolar socket healing: what can we learn	Humans & animals	Biological, mechanical	Alveolar healing has four phases and they lead to the formation of lamellar bone after approximately 8 to 12 weeks. It systematically causes bone resorption, which is more pronounced on the buccal wall, with an average loss of 30 to 60% in width and 10 to 20% in height in the first six months. Local, systemic and surgical factors influence this process and alveolar preservation techniques can limit, but not eliminate, these losses.

Authors (year)	Type of study	Title	Population	Factors identified	Key results
Fok & Jin (2024)	Review (overview of SRs)	Learn, unlearn, and relearn post-extraction alveolar socket healing	Adult humans	Biological, mechanical and environmental	Alveolar healing occurs in four overlapping phases (hemostasis, inflammation, proliferation, remodeling). The evidence base for alveolar preservation was judged to be of critical quality. Biomaterials can help maintain ridge dimensions, but results are highly dependent on patient-specific factors. This review insists on the importance of an individualized approach guided by the prosthetic plan.
Couso-Queiruga et al. (2021)	Systematic review & meta analyze	Post-extraction dimensional changes: A systematic review and meta-analysis	Adult humans	Biological, mechanical	At 6 months, clinical data showed an average horizontal loss of approximately 2.73 mm and a vertical vestibular loss of 1.71 mm. Radiographic analyses confirmed these results with a horizontal loss of approximately 2.54 mm. Resorption was more pronounced in molar sites and when the buccal wall was thin, highlighting the significant and predictable nature of ridge dimensional loss.
Sculean et al. (2019)	Narrative review	Self-regenerative capacity of intra-oral bone defects	Humans & animals	Biological, mechanical	The alveolar bone has a strong capacity for self-regeneration, particularly in small defects that are contained or located at the level of periapical and cystic lesions, where spontaneous healing is often favorable. On the other hand, tooth extractions and large or unstable defects heal incompletely, with significant bone resorption and more pronounced dimensional loss, influenced by local and systemic factors.

Authors (year)	Type of study	Title	Population	Factors identified	Key results
Udeabor et al. (2023)	Narrative review	Current Knowledge on the Healing of the Extraction Socket	Adult humans	Biological, mechanical and environmental	Alveolar healing can be slowed down by several systemic conditions. Smoking slows down healing and increases bone resorption due to its toxic effects on tissue (approximately 0.5 mm more crestal reduction compared to non-smokers). Poorly controlled diabetes disrupts collagen matrix formation and aggravates bone loss. Postmenopausal osteoporosis and radiotherapy also compromise remodeling and reduce the quality of bone regeneration.
Avila-Ortiz et al. (2014)	Systematic review & meta analyze	Effect of alveolar ridge preservation after tooth extraction	Adult humans, non-molar teeth	Biological, mechanical	Alveolar preservation significantly reduces bone loss compared to extraction alone. On average, it preserves +1.89 mm in width, +2.07 mm in buccal height, and +1.18 mm in lingual height. The beneficial effect is enhanced by the use of membranes as well as xenografts or allografts.

Table 2

Summary of biological, environmental, and mechanical factors influencing alveolar bone remodeling

Biological factors	Environmental factors	Mechanical factors
– **Demographics:** age, gender, hormonal status. – **Systemic conditions:** poorly controlled diabetes, osteoporosis, prior head & neck radiotherapy. – **Medications:** bisphosphonates, corticosteroids.	– **Smoking:** ~0.5 mm additional crestal loss vs. non-smokers. – **Oral hygiene:** plaque control and compliance. – **Nutrition:** general dietary adequacy. – **Access & adherence:** socioeconomic factors, follow-up.	– **Buccal plate:** thin/absent plate ® greater resorption. – **Socket morphology:** contained vs. large/unstable defects. – **Tooth/site:** molars & posterior sites show larger dimensional loss. – **Surgical technique:** atraumatic extraction, flap elevation, alveolar ridge preservation (membrane + graft).

4. DISCUSSION

4.1. General Interpretation of Findings

The present scoping review emphasizes the multifactorial nature of alveolar bone remodeling following tooth extraction. While bone turnover is universal, the extent and pattern of ridge contraction vary with systemic conditions, local anatomy, and surgical approach, and this variability cannot be explained by time alone. Despite differences in methodology, all included reviews converged on the observation that significant ridge contraction is unavoidable (Darby & Chen, 2008). However, the magnitude of this remodeling and the ability to mitigate it varied across studies.

4.2. Patterns and Timing of Dimensional Changes

One of the most consistent findings was the temporal concentration of remodeling. Tan et al. (2012) and van der Weijden et al. (2009) both reported that most dimensional reduction occurs during the initial healing period, usually within the first three to six months. This aligns with the histological data of Araújo et al. (2015), which documents overlapping phases of inflammation, proliferation, and bone deposition that culminate in lamellar bone formation after eight to twelve weeks. Together, these data suggest that the "window of risk" for ridge reduction is narrow and predominantly occurs during the first semester after extraction. This has direct clinical implications for the timing of interventions such as implant placement or ridge preservation procedures.

4.3. Magnitude and Distribution of Ridge Reduction

While all studies confirmed resorption, the degree of loss varied depending on the measurement method and study design used. For example, Tan et al. (2012) quantified horizontal reduction as between 29% and 63%, and vertical loss as between 11% and 22%. In contrast, Van der Weijden et al. (2009) reported changes in absolute values, measuring nearly 3.9 mm of horizontal reduction and 1.7 mm of vertical reduction after six months. Couso-Queiruga et al. (2021) further consolidated these findings through meta-analysis, showing pooled mean reductions of 2.7 mm horizontally and 1.7 mm vertically. Despite differences in reporting units (percentages versus millimeters, clinical

versus radiographic), the trend remains consistent: dimensional changes are significant, measurable, and clinically relevant.

The vestibular aspect of the socket was identified as the site of greatest vulnerability by all studies (Tan et al., 2012; Araújo et al., 2015; Couso-Queiruga et al., 2021). This finding underscores the pivotal role of buccal plate thickness and integrity in shaping the final ridge profile. From a surgical standpoint, this emphasizes the need to preserve or support the vestibular wall whenever possible, as its loss dramatically accelerates resorption.

4.4. Biological Determinants

Although biological influences on socket healing were not addressed uniformly, they remain critical. Systemic conditions such as poorly controlled diabetes, osteoporosis, and prior head-and-neck radiotherapy reduce the socket's regenerative potential and affect the quality of newly formed bone (Khan et al., 2015; Udeabor et al., 2023). Age-related changes in metabolism may also slow regenerative processes. However, evidence on sex differences or hormonal status was inconsistent. Overall, biological determinants appear to modulate the pace and completeness of healing. However, their relative impact compared with local mechanical factors remains difficult to quantify.

4.5. Environmental Influences

Environmental variables emerged as significant yet underexplored contributors. Smoking was the most consistently reported factor and was associated with approximately 0.5 mm of additional resorption compared to nonsmokers (Udeabor et al., 2023; Ramanauskaite & Juodzbalys, 2014). The importance of oral hygiene and adherence to periodontal maintenance has also been confirmed as critical predictors of bone stability (Chambrone et al., 2010). Few studies have systematically assessed the role of oral hygiene, nutrition, or socioeconomic factors, despite their likely impact on long-term outcomes. The lack of robust data on these factors is an important research gap. From a practical perspective, however, these factors are modifiable, meaning targeted patient counseling could improve healing outcomes.

4.6. Mechanical and Local Conditions

Local anatomy and surgical technique have been consistently identified as key modulators of remodeling. Araújo et al. (2015) demonstrated that an intact buccal plate preserves ridge volume, whereas its absence accelerates collapse. Couso-Queiruga et al. (2021) confirmed that molar sites and thin-walled sockets are particularly susceptible to resorption. Clinical meta-analyses have echoed these observations, reporting that ridge reduction is greater in posterior sites than in anterior ones.

Surgical technique also influences outcomes. Atraumatic extractions and avoiding flap elevation were associated with reduced dimensional changes. However, evidence of this association is less robust than evidence of the association between anatomical determinants and dimensional changes. These findings suggest that, although surgical precision is beneficial, the biological predisposition of the socket (e.g., buccal plate thickness) may override technical factors in predicting outcomes.

4.7. Effectiveness of Alveolar Ridge Preservation (ARP)

The role of ARP was one of the most extensively studied topics in the reviews. Avila-Ortiz et al. (2014) demonstrated through randomized clinical trials that ARP reduces dimensional loss by nearly 2 mm in width and vestibular height. This benefit increased when membranes and grafts were used together. However, ARP did not eliminate resorption entirely, indicating that remodeling is an inherent part of the healing process. Narrative syntheses, such as that by Fok and Jin (2024), emphasized the limitations of the current evidence base. Despite its widespread clinical adoption, the supporting data were deemed to be of low to critically low quality, with significant heterogeneity across protocols, biomaterials, and study populations. These findings raise questions about the generalizability of outcomes and the ability to establish standardized guidelines. While ARP remains clinically valuable, it should be applied with individualized judgment rather than as a universal solution.

4.8. Integrative Interpretation

When viewed collectively, the evidence indicates that alveolar remodeling is shaped by an interplay of biological, mechanical, and environmental factors. Mechanical

determinants, particularly buccal plate integrity, emerge as the strongest predictors of dimensional loss. Biological factors act as modulators, slowing or complicating healing in at-risk populations. Environmental influences, though less studied, have significant potential for clinical intervention due to their modifiable nature.

The contrast between systematic reviews with quantitative outcomes (e.g., Tan et al., 2012; Couso-Queiruga et al., 2021; Avila-Ortiz et al., 2014) and narrative reviews that emphasize context (e.g., Araújo et al., 2015; Sculean et al., 2019; Udeabor et al., 2023) illustrates the difficulty of making universal conclusions. Quantitative evidence consistently demonstrates the magnitude of bone loss, while narrative syntheses enrich interpretation by identifying clinical scenarios in which outcomes deviate from averages. This combination highlights the need to balance quantitative findings with contextual factors when guiding clinical decisions (Tonetti et al., 2019).

From a clinical perspective, this synthesis underscores the importance of patient-specific risk assessment and tailored treatment planning. Preventive measures such as smoking cessation, glycemic control, and perioperative plaque management may be as decisive for ridge stability as surgical techniques themselves. Incorporating these modifiable risk factors into clinical protocols could substantially improve long-term prosthetic and implant outcomes.

4.9. Clinical Implications

From a clinical standpoint, these findings support several principles. First, preventive strategies should focus on the early post-extraction period, as resorption is most pronounced during this time. Second, preserving or augmenting the vestibular wall should be prioritized given its pivotal role in ridge stability. Third, ARP should be considered for sites where dimensional stability is critical; however, patients should be counseled that some loss is inevitable. Finally, pre- and postoperative management of environmental and systemic risk factors is essential and should include smoking cessation, glycemic control, nutritional support, and oral hygiene optimization (Ferrus et al., 2010; Januário et al., 2011).

4.10. Limitations

This review has inherent limitations. As a scoping review, no critical appraisal of study quality was performed. The included studies were heterogeneous in design, population, follow-up, and measurement methods, which limits comparability. Environmental influences, such as nutrition and socioeconomic factors, remain underrepresented in the literature. Restrictions based on language (English and Portuguese only) and time may have excluded additional relevant evidence.

4.11. Research Priorities

Future studies should:

- Standardize outcome measures and follow-up intervals at 1, 2, 6, and 12 months.

- Focus on underrepresented determinants, such as nutrition, oral hygiene, and socioeconomic status.

Investigate high-risk subgroups, including smokers, diabetic patients, and individuals undergoing antiresorptive therapy.

Conduct well-designed, randomized, controlled trials with consistent protocols to evaluate ARP materials and techniques.

They should also bridge the gap between quantitative outcomes and contextual interpretation to ensure that clinical guidelines reflect both evidence and patient-specific variables.

5. CONCLUSION

This scoping review mapped the evidence on factors influencing alveolar bone remodeling after tooth extraction. The analysis confirmed that alveolar remodeling of the ridge is inevitable, with the most substantial reductions occurring during the initial healing period. These changes are not uniform but result from a complex combination of biological, environmental, and local mechanical factors.

Current knowledge emphasizes the critical role of the buccal plate and socket morphology in predicting resorption. Systemic conditions, lifestyle habits, and surgical decisions also influence outcomes. Although preservation techniques can reduce the extent of ridge contraction, no intervention can fully prevent remodeling, and the quality of the evidence remains heterogeneous.

Clinically, this review reinforces the importance of individualized planning, integrating biological risk factors, surgical strategies, and patient-related variables to optimize rehabilitation outcomes. Beyond surgical precision, effective perioperative risk management and patient education emerge as critical components of socket preservation. It is essential to optimize future rehabilitation by tailoring extraction and preservation strategies to each patient.

Future research should prioritize the standardization of study protocols, particularly in terms of measurement methods and follow-up intervals, while addressing underexplored determinants such as nutrition, oral hygiene, and socioeconomic status. Expanding high-quality randomized controlled trials will be essential to develop evidence-based guidelines capable of supporting predictable and patient-centered clinical decision-making.

6. BIBLIOGRAPHIC REFERENCES

Araújo, M. G., Silva, C. O., Misawa, M., & Sukekava, F. (2015). Alveolar socket healing: What can we learn? *Periodontology 2000, 68*(1), 122–134. https://doi.org/10.1111/prd.12082

Arksey, H., & O'Malley, L. (2005). Scoping studies: towards a methodological framework. *International Journal of Social Research Methodology, 8*(1), 19–32. https://doi.org/10.1080/1364557032000119616

Avila-Ortiz, G., Elangovan, S., Kramer, K. W. O., Blanchette, D., & Dawson, D. V. (2014). Effect of alveolar ridge preservation after tooth extraction: A systematic review and meta-analysis. *Journal of Dental Research, 93*(10), 950–958. https://doi.org/10.1177/0022034514541127

Cardaropoli, G., Araújo, M., & Lindhe, J. (2003). Dynamics of bone tissue formation in tooth extraction sites. An experimental study in dogs. *Journal of Clinical Periodontology, 3*0(9), 809–818. https://doi.org/10.1034/j.1600-051x.2003.00366.x

Chambrone, L., Chambrone, L. A., & Lima, L. A. (2010). Predictors of tooth loss during long-term periodontal maintenance: a systematic review of observational studies. *Journal of Clinical Periodontology, 37*(7), 675–684. https://doi.org/10.1111/j.1600-051X.2010.01587.x

Couso-Queiruga, E., Stuhr, S., Tattan, M., Chambrone, L., & Avila-Ortiz, G. (2021). Post-extraction dimensional changes: A systematic review and meta-analysis. *Journal of Clinical Periodontology, 48*(1), 126–144. https://doi.org/10.1111/jcpe.13368

Darby, I. B., & Chen, S. T. (2008). Bony healing after tooth extraction and ridge preservation. *Clinical Oral Implants Research, 19*(Suppl 5), 168–177. https://doi.org/10.1111/j.1600-0501.2008.01531.x

Devlin, H., & Sloan, P. (2002). Early bone healing events in the human extraction socket. *International Journal of Oral and Maxillofacial Surgery, 31*(6), 641–645. https://doi.org/10.1054/ijom.2002.0263

Ferrus, J., Cecchinato, D., Pjetursson, E. B., Lang, N. P., Sanz, M., & Lindhe, J. (2010). Factors influencing ridge alterations following tooth extraction in a non-submerged healing model. *Journal of Clinical Periodontology, 37*(7), 688–695. https://doi.org/10.1111/j.1600-051X.2010.01592.x

Fok, M. R., & Jin, L. (2024). Learn, unlearn, and relearn post-extraction alveolar socket healing. *International Journal of Oral Science, 16*(2), 24. https://doi.org/10.1038/s41368-024-00256-8

Januário, A. L., Duarte, W. R., Barriviera, M., Mesti, J. C., Araújo, M. G., & Lindhe, J. (2011). Dimension of the facial bone wall in the anterior maxilla: a cone-beam computed tomography study. *Clinical Oral Implants Research, 22*(11), 1168–1171. https://doi.org/10.1111/j.1600-0501.2010.02086.x

Jung, R. E., Philipp, A., Annen, B. M., Signorelli, L., Thoma, D. S., Hämmerle, C. H. F., & Schmidlin, P. (2013). Radiographic evaluation of different techniques for ridge preservation after tooth extraction: a randomized controlled clinical trial. *Journal of Clinical Periodontology, 40*(1), 90–98. https://doi.org/10.1111/jcpe.12027

Khan, A. A., Morrison, A., Hanley, D. A., Felsenberg, D., McCauley, L. K., O'Ryan, F., Peters, E. (2015). Diagnosis and management of osteonecrosis of the jaw: a systematic review and international consensus. *Journal of Bone and Mineral Research, 30*(1), 3–23. https://doi.org/10.1002/jbmr.2405

MacBeth, N., Trullenque-Eriksson, A., Donos, N., & Mardas, N. (2017). Hard and soft tissue changes following alveolar ridge preservation: a systematic review. *Clinical Oral Implants Research, 28*(8), 982–1004. https://doi.org/10.1111/clr.12911

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ, 372*, n71. https://doi.org/10.1136/bmj.n71

Peters, M. D. J., Marnie, C., Tricco, A. C., Pollock, D., Munn, Z., Alexander, L., McInerney, P., Godfrey, C. M., & Khalil, H. (2020). Updated methodological guidance for the conduct of scoping reviews. *JBI Evidence Synthesis*, 18(10), 2119–2126. https://doi.org/10.11124/JBIES-20-00167

Ramanauskaite, A., & Juodzbalys, G. (2014). Influence of smoking on outcomes of alveolar ridge preservation: a systematic review. *Clinical Oral Implants Research, 25*(4), e93–e104. https://doi.org/10.1111/clr.12168

Sculean, A., Stavropoulos, A., & Bosshardt, D. D. (2019). Self-regenerative capacity of intra-oral bone defects. *Periodontology 2000, 79*(1), 22–36. https://doi.org/10.1111/prd.12250

Tan, W. L., Wong, T. L. T., Wong, M. C. M., & Lang, N. P. (2012). A systematic review of post-extractional alveolar hard and soft tissue dimensional changes in humans. *Clinical Oral Implants Research, 23*(S5), 1–21. https://doi.org/10.1111/j.1600-0501.2011.02375.x

Tonetti, M. S., Jung, R. E., Avila-Ortiz, G., Blanco, J., Cosyn, J., Fickl, S., Chen, S. (2019). Management of the extraction socket and timing of implant placement: consensus report and clinical recommendations. *Periodontoly 2000, 79*(1), 203–212. https://doi.org/10.1111/prd.12283

Udeabor, S. E., Heselich, A., Al-Maawi, S., Alqahtani, A. F., Sader, R., & Ghanaati, S. (2023). Current knowledge on the healing of the extraction socket: A narrative review. *International Journal of Implant Dentistry, 9*, 10. https://doi.org/10.1186/s40729-023-00492-8

Van der Weijden, F., Dell'Acqua, F., & Slot, D. E. (2009). Alveolar bone dimensional changes of post-extraction sockets in humans: A systematic review. *Journal of Clinical Periodontology, 36*(12), 1048–1058. https://doi.org/10.1111/j.1600-051X.2009.01482.x

ANEXOS

Anexo A. PRISMA_ScR_Checklist

This checklist follows the 22 official PRISMA-ScR (Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews) items (Tricco et al., 2018). Each item is numbered exactly as in the original checklist and indicates where it is reported in the thesis.

Item	Section	Description	Reported in thesis
1	Title	Identify the report as a scoping review.	Title page
2	Abstract	Provide a structured summary including background, objectives, methods, results, and conclusions.	Abstract (pp. ix–xi)
3	Rationale	Describe the rationale for the review in the context of what is already known.	Introduction (pp. 1–2)
4	Objectives	Provide an explicit statement of the questions and objectives being addressed.	Introduction (p. 2)
5	Eligibility criteria	Specify characteristics of the sources of evidence used as eligibility criteria.	Methodology (pp. 3–4)
6	Information sources	Describe all information sources in the search (databases, registers, etc.).	Methodology (pp. 3–4)
7	Search	Present the full electronic search strategy for at least one database, including limits used.	Methodology (p. 4)
8	Selection of sources of evidence	State the process for selecting sources of evidence.	Methodology (pp. 4–5; Figure 1)
9	Data charting process	Describe methods of charting data from included studies (e.g. forms, calibration, independent reviewers).	Methodology (p. 5)
10	Data items	List and define all variables for which data were sought.	Methodology (p. 5)
11	Critical appraisal of individual sources of evidence	If done, provide rationale for conducting critical appraisal.	Not applicable (p. 16)
12	Critical appraisal of individual sources of evidence – methods	If done, describe the methods used for critical appraisal.	Not applicable
13	Critical appraisal of individual sources of evidence – results	If done, present data on critical appraisal of included sources.	Not applicable
14	Synthesis of results	Describe methods of handling and summarizing the data that were charted.	Results (pp. 7–12; Tables 1–2)
15	Selection of sources of evidence – results	Give numbers of sources screened, assessed, and included, with reasons for exclusions.	Results (p. 7; Figure 1)
16	Characteristics of sources of evidence	Present characteristics of each source of evidence and provide citations.	Results (pp. 7–8; Table 1)
17	Results of individual sources of evidence	Present relevant data from each included source of evidence.	Results (pp. 8–12; Table 1)
18	Synthesis of results – summary	Summarize and present the main results and themes across sources.	Results (pp. 7–12); Discussion (pp. 13–16)
19	Summary of evidence	Summarize the main findings and their relevance to key groups.	Discussion (pp. 13–16)
20	Limitations	Discuss limitations of the scoping review process.	Discussion (p. 16)
21	Conclusions	Provide a general interpretation and implications for future research and practice.	Conclusion (pp. 19–20)
22	Funding and conflicts of interest	Describe sources of funding and disclose potential conflicts of interest.	Not applicable / no funding or conflicts declared