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ACQUIRED EDENTULISM AND ALVEOLAR BONE RESORPTION: USE OF BONE GRAFTING MATERIALS COMBINED WITH SIMVASTATIN FOR POST-EXTRACTION SOCKET PRESERVATION AND ALVEOLAR BONE RECONSTRUCTION - A LITERATURE REVIEW

Running title: ALVEOLAR BONE REGENERATION - RELEVANCE AND FUTURE PROSPECTS – REVIEW

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HIGHLIGHTS

1. Acquired tooth loss remains a major clinical and public health problem affecting function, aesthetics, psychological well-being, and general health.
2. Post-extraction alveolar bone resorption can substantially reduce bone volume, especially during the first months after tooth extraction.
3. Adequate alveolar bone volume and quality are essential for predictable dental implant placement and prosthetic rehabilitation.
4. Alveolar ridge preservation, socket preservation and bone augmentation procedures rely on autogenous, allogeneic, xenogeneic, and synthetic bone grafting materials.
5. Simvastatin combined with bone grafting materials may enhance osteogenesis, improve alveolar bone regeneration, and shorten rehabilitation.

ABSTRACT

Background: Acquired edentulism and subsequent alveolar bone loss are increasingly important problems in contemporary dentistry. Insufficient alveolar bone volume often complicates dental implant placement and prosthetic rehabilitation. This literature review examines current studies addressing the aetiology, prevalence, and health effects of acquired edentulism, methods for the rehabilitation of dental arch defects, approaches to alveolar bone preservation and reconstruction, surgical techniques, bone grafting materials and strategies for their improvement.

Objective: To analyse the literature on acquired edentulism, post-extraction alveolar bone resorption, methods for rehabilitating dental arch defects, the use of bone grafting materials for post-extraction socket preservation and reconstruction of lost alveolar bone volume, and approaches to improving bone substitutes, including their modification with bioactive components and pharmacological agents, particularly Simvastatin, which can stimulate osteoblastic activity and osteogenesis, and also to identify promising directions for further research.

Study design: Literature review

Materials and Methods: This literature review was based on 70 scientific articles identified using Google Scholar, PubMed, Wiley Online Library, ResearchGate, ScienceDirect, Elsevier, MDPI, Springer Nature, eLibrary, and CyberLeninka. Searches were conducted using keywords relevant to the review topic, with particular attention given to studies published within the previous five years.

Results: The literature review therefore confirmed the relevance and high prevalence of acquired edentulism and post-extraction alveolar bone resorption. An especially important area is the use of bone grafting materials for post-extraction socket preservation and alveolar bone reconstruction, together with investigation of their effects on bone regeneration when combined with bioactive agents, growth factors, and pharmacological compounds, particularly Simvastatin, which possesses osteogenesis-stimulating properties.

Conclusions: The reviewed literature indicates that acquired edentulism and post-extraction alveolar bone resorption are clinically relevant and widespread problems. A promising approach to restoring lost alveolar bone volume is the further investigation and development of improved bone grafting materials with osteoconductive and pronounced osteoinductive properties. These properties may be achieved by locally incorporating biological and pharmacological agents that stimulate osteogenesis and improve the rate and quality of bone regeneration. Simvastatin is one such pharmacological agent with osteogenesis-stimulating potential and is currently under active investigation.

Keywords: tooth loss; alveolar bone loss; bone regeneration; alveolar bone grafting; Simvastatin.

INTRODUCTION

Acquired tooth loss remains one of the most common conditions affecting the maxillofacial region in contemporary dental practice. Epidemiological studies indicate that tooth loss affects a proportion of the population, determining its social and medical significance. [10, 17, 66]

Tooth loss not only reduces quality of life by causing impaired masticatory function, aesthetic and speech disturbances, dental arch deformities, occlusal changes, and temporomandibular joint (TMJ) disorders, but may contribute to systemic complications, including cardiovascular dysfunction and digestive disorders. [20, 26, 65] The absence of one or more teeth affects patients psychological and emotional well-being and may impair social and occupational functioning.

A consequence of acquired tooth loss is alveolar bone loss resulting from the absence of functional loading. Contemporary dentistry faces the challenges of preserving alveolar bone volume, restoring bone tissue, and preventing post-extraction alveolar bone resorption.

During the first year after tooth extraction, alveolar bone volume may decrease by up to 50%, with the greatest bone loss occurring within the first three months. [12]

This process complicates dental rehabilitation and limits dental implant placement and prosthetic treatment. Maintaining adequate alveolar bone volume and quality, including homogeneity and density, after tooth extraction may reduce the need for surgery and shorten rehabilitation.

Approaches to replacing missing teeth include prosthodontic methods, such as fixed and removable dental prostheses, and treatment involving dental implant placement followed by prosthetic rehabilitation. The latter provides functional and aesthetic outcomes but requires sufficient bone volume at the implant site. [16, 23, 68] In certain cases, surgical techniques are used to prevent alveolar bone resorption and create conditions for implant placement. One approach is alveolar ridge preservation, also referred to as socket preservation, using bone grafting materials. [11, 19, 43, 67]

Acquired tooth loss is accompanied by alveolar bone resorption, which complicates treatment and rehabilitation, particularly dental implant placement and prosthetic rehabilitation. Post-extraction socket preservation and alveolar bone reconstruction have become components of treatment. Socket preservation aims to prevent bone loss after tooth extraction and is based on filling the extraction socket with biocompatible autogenous, allogeneic, xenogeneic, or synthetic bone grafting materials. This approach preserves alveolar bone volume and architecture at the extraction site. [11, 12, 13, 19, 43] These materials are used in lateral-window sinus floor elevation, guided bone regeneration (GBR), and alveolar ridge splitting to restore alveolar bone volume. Bone grafting materials are classified by origin, morphology, resorbability, and biological activity. [4, 59, 64] Their characteristics include osteoinductivity, osteoconductivity, biocompatibility, and safety. [59, 62] Their effectiveness depends on their ability to promote osteogenesis and restore bone volume, configuration, density, and metabolism during healing. [18]

Attention is being paid to the pharmacological enhancement of regeneration during oral surgical procedures aimed at preserving and restoring alveolar bone volume. In particular, the synergistic effects of statins combined with bone grafting materials on bone regeneration have become an area of research. [1, 36] Simvastatin is the most studied statin. It promotes osteogenesis by enhancing the osteogenic differentiation of mesenchymal stem cells (MSCs), inhibiting osteoclast formation, and reducing inflammatory responses. [28]

These properties offer prospects for oral and maxillofacial surgery and warrant further investigation. The clinical integration of bone grafting materials combined with pharmacological agents may improve the rate and effectiveness of alveolar bone regeneration, shorten postoperative rehabilitation, and provide durable, high-quality treatment outcomes. [30]

1. TOOTH LOSS (ACQUIRED EDENTULISM): CLINICAL RELEVANCE, PREVALENCE, AND HEALTH IMPACT

Acquired tooth loss, defined as the loss of one or more teeth, remains a problem in dentistry and public health. This condition affects patients physiological function and psychological well-being. Acquired tooth loss may result from dental caries, pulpitis, apical periodontitis, periodontal disease, trauma, or inappropriate prosthodontic treatment. The condition affects younger and older individuals, making it relevant to public health. Its significance is increasing with life expectancy, population ageing, and the prevalence of dental caries and periodontitis. [9, 10]

According to epidemiological data, tooth loss is among the most prevalent conditions in adults, and edentulism affects individuals across age groups and socioeconomic strata. [10, 47] Its causes include age-related changes in the dentoalveolar system, periodontal disease, poor oral hygiene, and delayed treatment. In some cases, tooth loss follows inappropriate prosthodontic treatment, leading to deterioration of the teeth and dentoalveolar system. Acquired tooth loss represents a healthcare problem requiring diagnosis, treatment, and prevention.

The prevalence of acquired tooth loss varies among countries but remains high worldwide. Studies indicate that tooth loss is more common in developing countries, with the highest prevalence in Latin America; the global burden of edentulism continues to increase and is expected to affect more than 660 million people by 2050. [47]

The number of individuals with acquired tooth loss has increased because of delayed or inadequate dental treatment and improper oral care. [10] This highlights the need to improve oral health literacy, prevention, and access to dental care. [17, 47, 65]

Acquired tooth loss has physical and psychological consequences. It causes changes in the maxillofacial region. Dental arch deformities, malocclusion, and traumatic occlusal contacts may develop. The absence of one or more teeth disrupts masticatory force distribution, accelerates deterioration of the remaining teeth, and increases the risk of temporomandibular joint disorders. One of the most significant consequences is reduced alveolar bone volume. [19] Delayed or inappropriate prosthodontic or multidisciplinary treatment may aggravate the condition.

In addition to its effects on the dentoalveolar system, severe tooth loss may affect health. This condition may adversely affect cardiovascular system. [20] Research indicates that acquired tooth loss may contribute to gastrointestinal dysfunction and deterioration of general health. [65]

Beyond its substantial functional impairment, acquired tooth loss may cause psychosocial problems. Patients with extensive tooth loss experience difficulties in social interaction and reduced self-esteem. These effects are pronounced among young and middle-aged individuals, for whom appearance influences social participation. Tooth loss causes changes in appearance and speech impairment, resulting in communication difficulties, reduced self-confidence, and poorer psychological well-being.

Patients with acquired tooth loss frequently experience nutritional problems. [26, 47] Multiple missing teeth and severe alveolar bone atrophy may require dietary modification, resulting in inadequate nutrient intake, vitamin deficiencies, metabolic disturbances, and reduced immune function. Calcium and B-vitamin deficiencies may aggravate alveolar bone loss and increase the risk of osteoporosis and other mineral-deficiency disorders. A soft or liquid diet because of impaired mastication may reduce functional stimulation of the periodontium surrounding the remaining teeth.

Restoration of dental arch integrity and function and reconstruction of the alveolar bone are essential but require financial and time resources and specialised expertise. Dental implant treatment and prosthetic rehabilitation are effective, but their high cost limits accessibility for some population groups. Improving access to dental care and implementing preventive programmes are important for reducing tooth loss and its consequences. [17, 65]

Acquired tooth loss remains a major problem in dentistry. This condition affects patients physiological and psychological well-being. [26, 31] Addressing it requires measures ranging from prevention of dentoalveolar diseases to access to contemporary treatment and prosthetic rehabilitation. Early diagnosis and professional intervention are essential for preventing serious complications.

2. METHODS FOR THE REHABILITATION OF DENTAL ARCH DEFECTS

Dental arch defects, the principal manifestation and consequence of acquired tooth loss, are among the most common problems in contemporary dentistry. The loss of one or more teeth compromises smile aesthetics and may cause functional disturbances affecting the dentoalveolar system, mastication, speech, and health. Dentistry offers options for restoring dental arch integrity. Prosthetic rehabilitation and dental implant treatment are widely used approaches.

Prosthetic rehabilitation remains a method for restoring defects caused by the loss of one or more teeth. Dental prostheses may be removable, clinician-removable, or fixed. Fixed prostheses, including crowns and fixed dental prostheses, are supported by the remaining teeth or dental implants and provide stability and durability. This treatment restores masticatory function, corrects aesthetic deficiencies, and reduces the risk of dentoalveolar deformities and alveolar bone loss by restoring the distribution of masticatory forces. Fixed prostheses are fabricated from zirconia, ceramics, composites, and metals. Prosthetic designs can be adapted to patient needs. Ceramic crowns are used because their colour and texture resemble those of natural teeth. Restorations fabricated using computer-aided design and computer-aided manufacturing (CAD/CAM) provide precision, improving patient comfort and long-term clinical performance. [56] Clinician-removable prostheses are secured to the remaining teeth or dental implants and can be removed when required. They are used as provisional restorations while definitive prostheses are fabricated. Removable prosthodontic treatment is used in complete or partial edentulism. These prostheses may be complete or partial, with removable partial dental prostheses incorporating clasps for retention on the remaining teeth. Acrylic- or nylon-based designs provide patient comfort. This approach is affordable and less invasive.

Dental implant placement is part of an approach to restoring dental arch integrity and involves inserting an implant into the alveolar bone to support a prosthetic restoration. It is an option for replacing one or more missing teeth. This method provides a stable foundation for replacing missing dental arch units without preparing adjacent teeth, as required for conventional tooth-supported prostheses. Dental implants are manufactured from titanium, titanium alloys, or zirconia, which provide biocompatibility and mechanical strength. Implant treatment comprises several stages. An oral surgeon places the implant into alveolar bone, followed by healing and osseointegration with surrounding bone. Adequate alveolar bone volume, density, and homogeneity are essential for implant stability and osseointegration. A healing abutment is then placed to shape the peri-implant soft-tissue contour, followed by the definitive abutment and prosthetic restoration. Treatment may take several months to one year; however, the restoration can closely reproduce the functional and aesthetic characteristics of natural teeth. [15]

A multidisciplinary approach incorporating dental specialties is used to manage acquired tooth loss. For example, in patients with bounded edentulous spaces, orthodontic treatment may be required to correct malpositioned teeth before implant placement and prosthetic rehabilitation. The integration of these modalities provides durable outcomes combining functional and aesthetic benefits.

Technological advances in dentistry continue to evolve. The development and implementation of new techniques, equipment, instruments, and materials improve clinical outcomes. Three-dimensional printing and CAD/CAM technologies are increasingly used to fabricate accurate, patient-specific prosthetic restorations reproducing the individual anatomy of the teeth and dental arches, thereby improving treatment quality and durability. Computer-generated models incorporated into prosthetic workflows reduce errors and complications and provide more predictable outcomes. Digital diagnostic and treatment-planning methods improve treatment effectiveness and safety. [56] Laser technologies enable minimally invasive surgical procedures and may shorten postoperative rehabilitation.

The implementation of advances, including modern equipment and materials, improves treatment effectiveness, efficiency, quality, safety, and comfort. Dental implant surgery and prosthetic rehabilitation represent advanced approaches to acquired tooth loss and provide favourable functional and aesthetic outcomes. Contemporary diagnostic, treatment-planning, and therapeutic methods should be based on each patient s anatomical characteristics and health status. A multidisciplinary approach incorporating advanced technologies is fundamental to restoring dentoalveolar function and aesthetics.

3. PHYSIOLOGICAL CHANGES IN ALVEOLAR BONE VOLUME FOLLOWING TOOTH LOSS AND THE IMPORTANCE OF ITS PRESERVATION FOR SUCCESSFUL REHABILITATION

A major challenge in contemporary dentistry is restoring dental arch integrity in patients with acquired tooth loss, defined as the absence of one or more teeth. Tooth extraction or loss initiates alveolar bone resorption, the extent and rate of which depend on the patient s age, sex, metabolism, chronic and systemic diseases, periodontal status, and functional loading of the jaws. Within the first few months after tooth extraction, the alveolar bone begins to lose its morphological and structural characteristics, resulting in progressive atrophy. [12, 40, 49, 68] The greatest reduction in alveolar bone volume occurs during the first year after extraction, when bone loss may exceed half of the initial volume. [11] This process results from the absence of physiological functional loading in the edentulous region. Without mechanical stimulation, the alveolar bone becomes more porous and releases calcium and other minerals, reducing its total mass. Prolonged bone atrophy complicates the restoration of dentoalveolar function and aesthetics by creating unfavourable conditions for implant placement and contributing to dentoalveolar deformities and occlusal changes.

Preservation of alveolar bone volume after tooth extraction, or its restoration through bone augmentation, is a principal prerequisite for successful implant placement and prosthetic rehabilitation. Adequate bone volume is required for stable implant osseointegration. [16, 23, 68] This is essential for primary and secondary implant stability and for preventing peri-implantitis and failed osseointegration.

Approaches to restoring alveolar bone volume and properties include bone grafting materials, bone grafts, synthetic and polymer-based composites, guided bone regeneration (GBR) membranes, and growth factors. [4] These technologies reconstruct alveolar bone and improve its quality, increasing the likelihood of successful treatment.

Promising areas include growth factors, bioactive agents, biological stimulants, pharmacological compounds, biomimetic and programmable bone grafting materials, and personalised treatment based on each patient s health status and clinical conditions. [27, 38, 62] Cell-based technologies and bioengineering are also important. [52, 55, 70]

Accordingly, preserving alveolar bone volume after tooth extraction and restoring it through lateral-window sinus floor elevation, guided bone regeneration (GBR), or alveolar ridge splitting are essential for rehabilitating patients with acquired tooth loss and severe alveolar bone atrophy. Contemporary bone augmentation techniques and bioactive materials improve the predictability and long-term outcomes of oral surgical treatment.

4. POST-EXTRACTION SOCKET HEALING AND ALVEOLAR RIDGE PRESERVATION (SOCKET PRESERVATION)

Post-extraction socket healing is a sequence of biological stages leading to the formation of new bone tissue at the site of a lost or extracted tooth. After extraction, a blood clot forms within the socket and is gradually replaced by granulation tissue. [7, 40] During the first weeks, active cell proliferation, formation of the primary bone matrix, and initial vascular ingrowth occur. This is followed by modelling and remodelling of the bone tissue within the socket, resulting in reduced local density and changes in the spatial dimensions of the bone. Both horizontal and vertical bone loss usually occur, with most of the volume lost during the first months after extraction. [12, 40]

The extent and rate of resorption may vary depending on the patient s individual health status, the type and location of the tooth, the thickness of the socket walls, and the condition of the surrounding soft tissues. [7, 40] The greatest atrophy is reported on the buccal aspect in the molar region, whereas the least pronounced atrophy occurs in the anterior jaw region. [11]

One of the key elements for maximising the preservation of alveolar bone volume is an atraumatic tooth extraction technique, which helps prevent damage to the socket walls and trauma to the alveolar bone. [8] Surgical planning of tooth extraction and strict adherence to operative principles substantially improve outcome predictability and minimise alveolar bone loss. Accurate selection of the surgical extraction protocol is also important and should be based on tooth location, tooth group, socket wall thickness, adjacent anatomical structures, and the condition of the surrounding soft tissues.

Conventional methods for post-extraction socket management involve the formation of a blood clot, with possible placement of iodine-containing materials and suturing of the soft tissues. This approach promotes rapid closure and healing of the defect; however, it does not prevent subsequent alveolar bone volume loss caused by physiological resorption.

A contemporary alternative to conventional methods is alveolar ridge preservation, also referred to as socket preservation. Its principle consists of filling the post-extraction socket with a bone grafting material or placing a barrier membrane. [4, 11, 12, 34] This approach makes it possible to minimise bone volume loss immediately after tooth extraction and preserve the anatomical contour of the alveolar ridge for subsequent dental implant placement and prosthetic rehabilitation.

Various bone grafting materials are currently used for socket filling and closure, including autogenous, xenogeneic, allogeneic, and synthetic materials. [11, 12, 18, 44, 58, 67] Each has specific characteristics. Autogenous materials have the greatest osteogenic potential but require an additional surgical procedure, which increases overall rehabilitation time and may increase the risk of local postoperative complications at the donor site; xenogeneic and allogeneic materials demonstrate high biocompatibility and relatively slow resorption, with the latter being closest to the patient s own alveolar bone in biological and morphological properties; synthetic bone substitutes, such as hydroxyapatite and tricalcium phosphate, serve as reliable scaffolds for new bone formation. [14, 44, 50]

Barrier membranes, either resorbable or non-resorbable, are used to isolate and protect the healing site. [4, 39] Collagen membranes are the most widely used because of their biological inertness and ease of handling. In some cases, autogenous connective tissue grafts are used to improve socket closure and stimulate regeneration. [69]

To enhance regenerative potential, biological adjuncts are increasingly used, including platelet concentrates - platelet-rich fibrin (PRF) and platelet-rich plasma (PRP) - obtained from the patient s own venous blood, as well as biological agents containing growth factors. [12] In addition, collagen-containing materials are used to improve healing [35, 45] , and studies are being conducted on nanomicelles as statin carriers [16] , the effects of rosuvastatin solutions [54] , Simvastatin-loaded graphene oxide-based nanocomposites [51] , and hyaluronic acid [49] . According to study findings, their use promotes accelerated formation of mature bone tissue and shortens patient rehabilitation time. Materials based on α-calcium sulphate [58] , partially demineralised dentin matrix [68] , and tooth dentin-derived grafts are also being developed. [42, 68]

Alveolar ridge preservation using bone grafting materials, membranes, and bioactive agents improves the preservation of alveolar bone volume after tooth extraction.

5. BONE GRAFTING MATERIALS AND ADJUNCTS USED IN ORAL AND MAXILLOFACIAL SURGERY FOR ALVEOLAR RIDGE PRESERVATION AND ALVEOLAR BONE RECONSTRUCTION

Bone grafting materials and adjuncts used in oral and maxillofacial surgery are often integral to contemporary methods of alveolar bone reconstruction. [34] They are widely used to fill extraction sockets to prevent alveolar bone loss; to restore and augment alveolar bone volume during procedures such as lateral-window sinus floor elevation, guided bone regeneration (GBR), and alveolar ridge splitting; and to repair osseous defects resulting from trauma, disease, or surgical intervention. Numerous methods have been developed to preserve alveolar bone quantity and quality following tooth extraction and to restore its volume during bone augmentation procedures. The use of bone grafting materials with osteoconductive and osteoinductive properties is considered a promising approach because these materials not only fill osseous defects effectively but may also stimulate bone regeneration. [43, 52, 62]

These materials may be used to replace lost bone and promote new bone formation, thereby improving the functional and aesthetic outcomes of treatment. Their selection largely depends on the patient s health status, clinical indications, the characteristics of the planned alveolar bone reconstruction site, and other factors. Consequently, each clinical case is unique and requires an individualised approach.

Contemporary Classification of Bone Grafting Materials

Several classifications of bone grafting materials have been proposed based on their origin, mechanism of action, and biocompatibility. Grafts are most commonly classified as autogenous, allogeneic, xenogeneic, or synthetic. [4, 9, 25, 59, 64]

Autogenous bone grafts consist of bone harvested from the patient. They are the most biocompatible grafts because they minimise the risk of rejection. Autogenous bone has a high capacity for osseointegration and osteogenesis, making it the gold standard in surgical practice, particularly for reconstruction of the maxillofacial skeleton. [13, 18] However, their use is associated with several limitations. An additional surgical procedure is required to harvest the graft, introducing further risks, including postoperative complications, and prolonging the rehabilitation period because the donor site must also heal. Furthermore, the available graft volume is limited, which may restrict the use of autogenous bone in extensive alveolar bone reconstruction or repair of large osseous defects.

Allogeneic bone grafts are obtained from donors of the same species as the recipient. Their close biological and morphological similarity to the patient s own alveolar bone provides a favourable degree of integration and compatibility. Allogeneic bone grafting materials are used for alveolar bone augmentation and reconstruction and for the repair of osseous defects. These grafts exhibit pronounced osteoconductive properties. To enhance their osteoinductive potential, studies have investigated their combination with bioactive agents, growth factors, and pharmacological compounds with osteogenic effects. During manufacturing, allografts undergo specialised processing, including lyophilization (freeze-drying), which promotes successful integration, ensures sterility, and reduces the risks of rejection and infectious disease transmission. Although immune reactions may occur in some recipients, contemporary manufacturing and preprocessing methods are intended to substantially reduce this risk. [13, 18, 67]

Xenogeneic bone grafting materials are derived from animal bone, most commonly bovine bone. They subsequently undergo thorough industrial processing to remove potentially immunogenic components, ensure sterility, and reduce the risk of an immune response. Xenogeneic materials provide good mechanical stability, although their biological activity, particularly their osteogenic potential, is limited. [18, 25, 67] Xenogeneic materials are also available as scaffolds, including chitosan-based scaffolds - chitosan being an aminopolysaccharide derived from crustacean shells [2, 3] - and scaffolds derived from marine sponges. [61]

Synthetic bone substitutes include biocompatible polymers and ceramic compounds, particularly hydroxyapatite, tricalcium phosphate, and poly-3-hydroxybutyrate. These materials are being actively investigated for use in oral and maxillofacial surgery. [14, 44, 45, 50, 59, 60] Scaffold-based forms have also been developed [9, 41, 50] , including scaffolds manufactured using three-dimensional printing. [27] Synthetic materials provide favourable mechanical stability, may be used to replace lost bone tissue, and can be further modified, for example, by incorporating Simvastatin. [57]

Evaluation of the Effectiveness of Bone Grafting Materials

The effectiveness of bone grafting materials should be evaluated with consideration of several factors, including biocompatibility, the ability to integrate with host bone, biological activity, biodegradability or resorbability, and final functional and aesthetic clinical outcomes. Each type of biological bone grafting material used for bone augmentation and alveolar ridge preservation has specific advantages and characteristics. Consequently, the selection, investigation, evaluation, and further improvement of these materials remain important areas of research and clinical practice in oral and maxillofacial surgery. [14, 18, 25, 64]

Autogenous bone grafts exhibit high biological activity because they contain viable cells capable of promoting bone regeneration. This provides favourable osteoinductive and osteoconductive properties and supports effective osseointegration and osteogenesis. [13, 43] Nevertheless, their use involves limitations related to the need for an additional graft-harvesting procedure and the possibility of subsequent complications, including pain and swelling, as well as a prolonged rehabilitation period. In addition, the limited volume of autogenous bone available for harvesting may complicate its use in surgical procedures requiring the reconstruction of large bone volumes. [25, 38]

Allogeneic materials demonstrate lower osteogenic activity because they do not contain viable cells. However, because these grafts are obtained from bone tissue of donors belonging to the same species as the recipient, they exhibit a high degree of biological compatibility. They also possess sufficient mechanical strength and stability to be used for the repair of large defects. Contemporary manufacturing and processing methods substantially reduce the risks of immune reactions and infectious disease transmission. [13, 18, 67]

Xenogeneic materials provide high mechanical stability and may serve as effective grafting materials for the repair of bone defects. However, their biological activity is limited, and they do not possess pronounced osteogenic potential. In some cases, xenogeneic grafts are combined with other therapeutic approaches, including the addition of growth factors or mixing with autogenous bone. [5, 18, 67]

Synthetic materials, including hydroxyapatite, tricalcium phosphate, and poly-3-hydroxybutyrate, are used in maxillofacial surgery because of their stability and the possibility of controlling the healing process. These grafts possess favourable osteoconductive properties and can provide a reliable scaffold for alveolar bone regeneration. Recent advances in synthetic biomaterials also allow them to be combined with bioactive agents, thereby increasing the effectiveness of bone regeneration. [44, 50] A review of studies conducted by Russian authors confirms the potential of synthetic bone grafting materials for use in oral and maxillofacial surgery. [9, 14, 60]

Use of Bone Grafting Materials for Post-Extraction Socket Preservation and Alveolar Bone Reconstruction During Bone Augmentation Procedures

The preservation and restoration of alveolar bone volume through post-extraction socket preservation and bone augmentation procedures, including lateral-window sinus floor elevation, guided bone regeneration (GBR), and alveolar ridge splitting, are among the most important objectives in contemporary oral and maxillofacial surgery. These procedures are required to prevent or correct pathological changes such as alveolar bone resorption, insufficient bone volume, and low bone density, as well as to prevent the development of osseous defects or infectious complications at the surgical site. [11, 12, 34, 58, 67]

In such clinical situations, bone substitutes play a decisive role in preserving and restoring alveolar bone volume, thereby enabling effective subsequent oral surgical treatment, dental implant placement, and prosthetic rehabilitation. [22, 34, 40]

The selection of a bone grafting material for use in oral and maxillofacial surgery requires careful consideration and depends on numerous factors. Each material has specific characteristics that must be considered to achieve the most favourable outcomes in bone reconstruction.

6. STATINS AND THEIR EFFECTS ON BONE REGENERATION

Statins are a class of drugs used to reduce blood cholesterol levels. In recent years, these agents have been extensively investigated for their effects on bone regeneration. [6, 28] Published studies indicate that statins influence not only lipid metabolism but also bone metabolism, opening new areas of research and potential applications in bone biology, general surgery, oral and maxillofacial surgery. [21, 30]

Statins and Their Mechanism of Action

The mechanism of action of statins is associated with inhibition of 3-hydroxy-3-methylglutaryl-coenzyme A reductase (HMG-CoA reductase), an enzyme involved in cholesterol biosynthesis. Statins also promote the proliferation of mesenchymal stem cells (MSCs) and their differentiation into osteoblasts and increase the production of growth factors, including the osteogenic factor bone morphogenetic protein 2 (BMP-2) and the angiogenic factor vascular endothelial growth factor (VEGF). According to published findings, these effects enhance bone formation and mineralization, angiogenesis, and local blood supply. [21]

Simvastatin and Its Osteogenesis-Stimulating Potential

Simvastatin is considered one of the most extensively studied statins with a pronounced ability to stimulate osteogenesis. [28] Experimental findings [1, 6, 55] indicate that Simvastatin promotes cell proliferation and osteoblastic differentiation, subsequently increasing new bone formation. Increased expression of the gene encoding bone morphogenetic protein 2 (BMP-2) has also been reported, leading to the osteogenic differentiation of mesenchymal stem cells. [29]

Statins in Dental Practice

In recent years, increasing attention has been given to the possibility of improving dental treatment protocols through the use of pharmacological agents, particularly Simvastatin. Studies [63] have demonstrated that the local administration of Simvastatin accelerates dental implant osseointegration. Reference [37] reports that Simvastatin may be used as an adjunctive agent in tooth replantation procedures. According to studies [33, 53] , local statin administration improves the clinical outcomes of periodontal therapy. In orthodontic practice, systemic administration of a statin has also produced favourable results by accelerating bone remodelling following rapid maxillary expansion. [48] Study findings additionally indicate that Simvastatin reduces the severity of inflammation in the temporomandibular joint (TMJ) and promotes ligament repair. [23]

Statins Combined with Bone Grafting Materials

Combining statins with bone grafting materials, particularly hydroxyapatite, bioactive glass, collagen membranes, and chitosan, represents a promising approach to improving alveolar bone regeneration. [6, 41, 46] Experimental data indicate that incorporating Simvastatin enhances osteogenesis, shortens healing time, and improves the quality of newly formed bone. [1, 6, 21, 23, 24, 54] Studies are being conducted on the development and application of Simvastatin-loaded scaffolds. [3, 41, 50] Furthermore, a novel synthetic osteoinductive bone grafting material based on poly-3-hydroxybutyrate loaded with Simvastatin has been shown to markedly accelerate osteogenesis in vivo. [60]

7. FUTURE PROSPECTS AND DIRECTIONS FOR RESEARCH

Further progress is associated with developing local statin-delivery systems and reducing systemic adverse effects. [16, 21, 57] Combining statins with bioactive materials and growth factors is also promising and may provide new opportunities for bone regeneration. [2, 3, 32, 51, 55]

Numerous studies, including systematic reviews and meta-analyses [1, 6, 21, 23, 29, 30, 46, 54], support further investigation and clinical use of Simvastatin and other statins to stimulate osteogenesis and improve alveolar bone regeneration. Evaluating the efficacy and safety of this approach remains an important objective in oral and maxillofacial surgery and requires further research.

CONCLUSION

The literature on acquired tooth loss, dental arch rehabilitation, alveolar bone preservation and reconstruction, bone grafting materials, and their improvement confirms the importance of continued research in these areas for oral and maxillofacial surgery.

Tooth loss and dental arch defects affect patients physical and functional status and their psychological and social well-being. [10, 31, 65]

Acquired tooth loss affects a substantial proportion of the global population. [10, 17, 26, 47, 66] The loss of even one tooth may impair quality of life, while population ageing and the increasing prevalence of dental caries and periodontitis further increase the relevance of this problem. [10, 31, 65]

Alveolar bone atrophy is a principal consequence of tooth loss. [12, 19, 22] Preserving adequate alveolar bone volume is essential for successful dental implant placement. [16, 23, 68]

Dental arch defects are managed primarily through dental implant placement and prosthetic rehabilitation. [15, 22, 56, 65] Successful treatment requires adequate bone volume, which depends on timely alveolar ridge preservation and effective alveolar bone reconstruction. [22, 27]

Among methods for preventing alveolar bone atrophy and preserving bone volume, alveolar ridge preservation, also referred to as socket preservation, using bone grafting materials has an important role. [11, 12, 13, 19, 43, 58, 67] These materials, used in extraction sockets and bone augmentation procedures, prevent resorption and enhance alveolar bone regeneration, creating favourable conditions for implant placement and prosthetic rehabilitation. [11, 22, 34, 35, 49, 68]

Contemporary bone grafting materials include autogenous, allogeneic, xenogeneic, and synthetic grafts, each with specific advantages and characteristics. [4, 9, 18, 25, 45, 59, 64] Evaluating their properties, effectiveness, and methods of improvement remains an important research priority.

Published findings indicate that statins, particularly Simvastatin, may stimulate osteogenesis and accelerate bone regeneration during dental and maxillofacial surgical procedures. [1, 6, 21, 24, 28, 29, 30, 46, 48, 54, 55, 63] Overall, the evidence supports a comprehensive approach to acquired tooth loss and alveolar bone atrophy, including improved methods for restoring dental arch defects, preventing post-extraction alveolar resorption, and reconstructing alveolar bone during augmentation, as well as developing improved bone grafting materials and investigating their interactions and potential synergistic effects with bioactive agents, growth factors, biological stimulants, and pharmacological compounds.

Research on preventing alveolar bone resorption, preserving and reconstructing alveolar bone, optimising dental surgical protocols, and developing biologically and pharmacologically enhanced bone grafting materials provides opportunities to improve clinical treatment outcomes.

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