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REVIEW ARTICLES

Exploring Magnesium Membranes as a Promising Alternative in Guided Bone Regeneration: A Literature Review

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Abstract

Introduction: Alveolar ridge atrophy is an unavoidable consequence of tooth extraction, often resulting in Bone defects complicating ideal implant placement are a significant concern. Guided Bone Regeneration is a widely adopted technique that uses barrier membranes to enhance bone regeneration by preventing soft-tissue invasion and promoting bone growth.

Traditional resorbable membranes, while eliminating the need for secondary surgeries, often lack sufficient structural rigidity; in contrast, non-resorbable membranes provide stability but require re-entry procedures.

Recently, a resorbable magnesium alloy membrane (NovaMag®) has been introduced, offering both structural support and complete resorption.

A literature search was conducted using PubMed, Scopus, and Web of Science, encompassing in vitro, in vivo, animal, and clinical research. Findings indicate that magnesium membranes display favorable mechanical properties, biocompatibility, and controlled degradation, along with promising clinical outcomes in alveolar ridge preservation, guided bone regeneration, and mandibular reconstruction. Several surface treatments (e.g., MAO, HA, HF) have been investigated to optimize performance and degradation rates.

Conclusions: Magnesium membranes are a promising alternative to collagen membranes in guided bone regeneration (GBR), offering superior mechanical strength and reducing the risk of tearing—an issue commonly observed with collagen membranes, biocompatibility, and full resorbability.

Keywords: magnesium membrane; resorbable barrier membrane; dental implant; mandibular reconstruction; biodegradable implants.

Introduction

Alveolar ridge atrophy is the unavoidable consequence of tooth loss after extraction [1]. This progressive and irreversible phenomenon can interfere with an ideal implant placement for tooth replacement, giving rise to esthetic, functional, and prosthodontic challenges as well.

This dental atrophy, also known as a bone defect, results from trauma, disease, or surgery and presents a significant challenge in clinical treatment. For many years, the treatment of dental bone loss has been supported by the Guided Bone Regeneration (GBR) technique. This widely adopted strategy utilizes barrier membranes to promote bone healing and growth by preventing soft tissue invasion. [2, 3, 4, 5, 6]

These membranes are typically classified into two types: non-absorbable (e.g., titanium) and absorbable (e.g., collagen), each with its own set of advantages and disadvantages. [7]

The membrane used relies on barrier membranes to prevent unwanted cell migration and maintain space for new bone growth. [8]

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Traditional non-resorbable membranes, such as those made from dense or expanded polytetrafluoroethylene (dPTFE/e-PTFE) reinforced with titanium, provide essential volume stability for complex bone defects. [9] The membranes that we use are classified as: Resorbable membranes are advantageous in that they do not require a second surgical intervention for their removal. However, their main drawback is a lack of structural rigidity, which can make them less suitable for larger alveolar ridge defects that require significant structural support. Non-resorbable membranes (e.g., titanium-reinforced polytetrafluoroethylene (PTFE) membranes and titanium meshes) provide excellent shape-maintaining capabilities but necessitate a re-entry surgery for removal [7, 10, 11]

For membranes to be effective in GBR, they should possess several essential properties, including Biocompatibility, Easy integration into the host tissue, Simple clinical handling, Volume stability, and Appropriate mechanical and Physical properties [9]

The insufficient volume of the alveolar ridge, which we adjust with bone regeneration techniques, also impacts the long-term success of implant therapy, including the critical process of osseointegration. Achieving the best outcomes in implant therapy requires placing the implant in an anatomically favorable position, both biologically and prosthetically. [13, 7] In GBR, various types of membranes are used as physical barriers [18,10].

Their primary role is to seclude the bone defect from the rapidly migrating cells of connective and epithelial tissue. In this way, the much slower osteoprogenitor cells are allowed to fill the bone defect [11–15]. Membranes used in guided bone regeneration should have the following properties: biocompatibility, ability to integrate into the host tissue, easy clinical handling, volume stability, and appropriate mechanical and physical properties. In contrast, non-resorbable membranes (e.g., titanium-reinforced polytetrafluoroethylene (PTFE) membranes and titanium meshes) have excellent shape-maintaining capabilities. However, their most significant shortcoming involves the necessity for a re-entry surgery or the preparation of a larger flap during the implant placement. In terms of membrane exposure, complications are generally easier to control when using resorbable membranes [7–10]. However, a recent publication demonstrated that the occurrence of membrane exposure utilizing a non-reinforced PTFE membrane did not compromise the clinical outcome [11].

A resorbable membrane made of a magnesium alloy (NovaMag, botiss GmbH, Zossen, Germany) has recently been introduced, combining the advantageous properties of both resorbable and non-resorbable membranes [14].

This new membrane exhibits a similar structural rigidity to titanium mesh and has been shown to resorb completely by the 16th postoperative week. [15]. During the degradation process, the membrane is gradually converted into magnesium salts while hydrogen gas is released [16, 17].

It was demonstrated that the body completely resorbs the salts, while the cavities formed by the gas release spontaneously resolved and had no adverse effect on bone regeneration [14, 21, 10].

A previous animal study in beagle dogs compared the performance of this new magnesium membrane to the gold standard collagen membrane (Bio-Guide®, Geistlich Pharma, Wolhusen, Switzerland). The authors observed similar performances of the two membranes in terms of hard tissue gain and membrane degradation [15].

An initial step in this direction was reported in a publication by Barbeck et al. that showed the good biocompatibility of a new bioresorbable barrier membrane composed of a hydrofluoric acid (HF)-treated magnesium (Mg) mesh embedded in a native collagen membrane for volume-stable indications [20, 21]. This study will demonstrate the efficacy of a new membrane with a magnesium alloy, providing a novel approach to severe dental bone regeneration and simplifying the surgical technique while achieving results comparable to, or even better than, those of both resorbable and non-resorbable membranes currently used. Overall, magnesium has been reported to provide the necessary characteristics for a barrier membrane. Since 2021, a pure magnesium membrane (NOVAMag membrane, Botiss Biomaterials GmbH, Zossen, Germany) has been available in Europe following receipt of CE approval. Due to its excellent mechanical properties and biocompatibility, magnesium has been utilized for a long time in medical applications across various fields, including cardiovascular surgery, musculoskeletal surgery, and general surgery, thereby establishing it as a well-established material [22].

Magnesium (Mg) based materials, due to their lightweight and excellent combination of specific stiffness and strength, damping behavior, recyclability, thermal stability, and electromagnetic radiation resistance, play an essential role in a wide variety of structural applications in automobile, aerospace, defense, sports, and consumer electronics industries [23, 24].

In the recent past, Mg-based materials, for their advantageous properties for medical applications such as biodegradable capacity, good cytocompatibility, favorable mechanical properties, and elastic modulus closer to load-bearing bones, unique antibacterial and osteo-promotive properties, have emerged as a new class of biomaterials for orthopedic applications such as implants and fixation devices [22, 25].

Mg-based implants share a similar specific density to that of human bone, unlike commonly used permanent biomaterials such as stainless steel and titanium alloys [25, 26].

Materials and Methods

PubMed/MEDLINE, Scopus, and Web of Science were the official sources of all the information on this study. A total of 150 articles were reviewed, of which more than 80 were excluded for inappropriate subject matter. One investigator (I.B.P.) reviewed a total of 78 abstracts, Finally, a total of 20 reports met the criteria for the topic of interest. The studies reviewed showed heterogeneity in study types, including in vitro, in vivo, animal, and clinical studies, as well as variations in the animal models used, case reports or case series, follow-up periods, the composition of the magnesium material, and various outcome variables. Although a completely objective comparison of the studies was not possible, we would like to highlight some interesting and positive findings related to magnesium. The analysis of the mechanical properties of the magnesium membrane in oral tissue regeneration was considered.

In particular articles, information is provided about the cytologic adaptation of the magnesium membrane with human tissue, as well as a comparison of different magnesium membrane formations, whether treated or untreated. The following keywords were used in various combinations: "Guided Bone Regeneration," "GBR," "Tissue Regeneration," and "Magnesium Membrane."

Key terms: magnesium; biomaterials, biodegradation, endoprosthesis, mandibular reconstruction, magnesium membrane, resorbable barrier membrane, staged GBR, 3D evaluation, CBCT subtraction; magnesium membrane, magnesium screws, biodegradable dental implant, bone regeneration, cytotoxicity, degradation, MAO, pure Mg membrane, socket preservation, ridge preservation, NOVAMag membrane, resorbable metal, magnesium implant, cytocompatibility, biocompatibility, barrier membrane, dentistry, guided bone regeneration, macrophage.

Results

Elad et al. [31] have previously demonstrated that the magnesium membrane supports increased soft tissue adhesion, promotes gingival fibroblast adhesion, and facilitates rapid wound closure. In vitro studies have shown that gingival human fibroblast cells (Primary HGF-1 cells) adhere to and form confluent layers on the magnesium membrane surface, and they also migrate across the surface following a scratch test [27].

Therefore, there is no need to extract it during a second surgical procedure. During the degradation of the magnesium metal, the metallic structure is transformed into magnesium salts, and a small volume of hydrogen gas is released [13]. The composition of the magnesium salts has elements that are naturally present within the bone matrix, have good biocompatibility, and can become enveloped in new bone [28]. Due to the magnesium membrane's mechanical strength [13], it also can be used as a cortical plate.

Despite being mechanically strong, the magnesium membrane can be cut and bent to shape to perfectly match the contours of the defect, potentially making it more clinically manageable than using an autogenic or allogenic bone cortical plate. Once in position, the membrane provides a barrier between soft and hard tissues and fully resorbs after the critical healing period [14].

Steigmann et al. [32] conducted in vitro animal studies to identify the compatibility of the Mg membrane with human tissue. Both Mg membranes (treated and untreated) failed to meet non-toxicity criteria, showing cytotoxic effects across all assays. Untreated Mg membranes had higher metabolic activity and cell proliferation than the HF-treated Mg membrane, especially significant in the XTT assay. Titanium control surfaces displayed healthy, spindle-shaped, green-stained (viable) cells. Untreated Mg membranes showed mostly viable but non-adherent cells and gas bubbles, indicating corrosion.

These results indicate that, despite attempts to passivate magnesium with HF treatment, both Mg membranes exhibited poor cytocompatibility, with the treated version performing worse than the untreated one in some measures.

Shan et al. [33] In this study wanted to show the degradation of magnesium, the defect of the rapid degradation inserted in contact with the human tissue, and how to control it by in vitro study tests and in vivo study procedures on several 48 rabbits by using MAO-coated pure magnesium film, Pure titanium film, Blank control (no membrane). The MAO (micro-arc oxidation) coating significantly improves the microstructural uniformity and corrosion resistance of magnesium by reducing porosity, increasing impedance, and lowering corrosion rates [29, 30].

The MAO-coated magnesium (MAO-Mg) membrane exhibited significantly better corrosion resistance than pure magnesium after 14 days. The MAO-Mg membrane significantly promotes bone regeneration, with performance comparable to titanium membranes and superior to no membrane. It enhances early bone formation, improves bone density over time, and supports effective defect healing with good biocompatibility and stability.

Blašković et al. [34] In this study, the authors aimed to demonstrate how the Mg membrane has performed over the years and to apply its clinical use through a review of the literature, as well as a clinical case using Mg membrane, such as NOVAMag®, a pure, resorbable magnesium membrane used for Guided Bone Regeneration (GBR). To control degradation and improve bone regeneration, various coatings have been applied: MAO (Micro-Arc Oxidation) – improves corrosion resistance – neutralizes alkalinity and gas formation, HF (Hydrofluoric acid) – enhances cytocompatibility and reduces gas pockets, and Ca-P coatings – slow degradation and hydrogen production. Alloy Development: Mg-Zn-Y-Nd alloy offers a lower corrosion rate and high biocompatibility.

Palkovics et al. [35] This pilot clinical cases report discusses the application of a resorbable rigid magnesium barrier membrane (NovaMag®) for alveolar complex tissue reconstruction, especially in cases where conventional resorbable collagen membranes are not suitable due to significant defects requiring structural support. Magnesium membranes, being resorbable and rigid, offer a practical alternative. Promising results come from Animal studies, which indicate that membrane exposure may resolve spontaneously within 10 days, and no negative impact on healing was observed, despite initial concerns over hydrogen gas release. [10]

In two clinical cases, a tunnel flap and split-thickness flap approach were used, achieving horizontal and vertical bone augmentation without the need for tenting screws. Results after two years showed Stable peri-implant hard and soft tissue conditions and no signs of bone resorption or inflammation around the implants. The study suggests that the NovaMag® magnesium membrane may be a promising alternative to non-resorbable barriers, offering rigidity, biocompatibility, and resorbability in complex alveolar ridge reconstructions.

Rider et al. [36] The purpose of this study is to evaluate the degradation and regeneration potential of defects were filled with bovine xenograft and covered with either a magnesium membrane or collagen membrane observation post-implantation of 13 magnesium membrane-treated sites: 6 sites had temporary swelling (resolved within 2–4 days), two sites showed lesions, later healed with treatment, one site had redness that resolved by day 57.

Results from veterinarian observations and µCT imaging showed that the magnesium membrane supported routine healing. It had a good regenerative outcome. It degraded at a rate comparable to that of collagen membranes.

While more swelling was observed in magnesium-treated sites, this did not impact bone regeneration. No chronic inflammation was observed. Bone volume in the defect area was comparable to that in collagen membrane-treated sites throughout the study. No abnormal findings were linked directly to the magnesium membrane. The presence of redness or swelling can be explained by the perfusion of magnesium ions into the soft tissue after the degradation of the magnesium membrane. Similar observations have been made regarding human soft tissue complications in retrospective studies [27, 28].

Elad et al. [39] refer to individual clinical cases, ranging from small to large perforations of the Schneiderian membrane in maxillary sinus lifts, as well as to support graft material and separation from soft tissue in sinus lift augmentations treated with magnesium membranes. This case series is the first documented use of magnesium membranes in direct and indirect sinus lift procedures in regenerative. Clinical outcomes of the studies demonstrate successful healing, new cortical bone formation, complete separation of the sinus from the oral cavity, quick and easy shaping, stable support, and effective closure of oroantral communications.

Prasadh et al. [40] review the recent progress that has led to advances in developing magnesium materials for mandibular reconstruction, correlating with the biomechanics of mandibular defects. Mandibular defects resulting from trauma, tumors, or congenital conditions present significant challenges in restoring both function and aesthetics. The traditional reconstruction methods—such as vascularized fibula flaps and autogenous bone grafts—are adequate but limited in replicating the mandible's complex shape. They may also involve donor-site complications, as well as allergic responses due to metal ion releases, necessitating revision surgery to prevent long-term exposure of the body to toxic implant contents.

Biodegradable magnesium (Mg)-based alloys have emerged as a promising alternative, offering advantages like excellent biocompatibility, favorable mechanical properties, osteogenic properties, and a degradation rate that aligns with natural bone healing. They degrade into Mg^{2+} ions, which are naturally metabolized by the body and are used in temporary orthopedic implants [41, 42, 43, 44, 45, 46].

Further advancements in surface treatments and materials engineering are necessary to overcome the current high degradation rate, which leads to mechanical failure. Hydrogen gas accumulation, which can potentially affect implant integrity, and elevated pH and Mg^{2+} levels, which may hinder cell proliferation, can be mitigated by corrosion-resistant coatings (e.g., TiO_2, TiC, TiN) and biocompatible surface treatments. Grain refinement techniques, such as hot deformation and rapid solidification, are used to enhance resistance to cracking and corrosion, thereby developing magnesium alloys with optimized mechanical and biological properties.

Conclusion

Magnesium membranes are a promising alternative to collagen membranes in guided bone regeneration (GBR), offering superior mechanical strength and reducing the risk of tearing—an issue commonly observed with collagen membranes, biocompatibility, and full resorbability.

Their rigidity improves handling and maintains their shape during the critical early stages of bone regeneration, acting as a tenting structure that supports the defect area before gradually degrading.

They can also replace autologous bone plates, thereby reducing the need for second-stage surgeries and morbidity. Surface modifications have shown promise in controlling degradation and improving clinical outcomes. Additionally, their ability to be shaped intraoperatively adds versatility, allowing them to adapt to complex defects. However, these findings, while encouraging, are based on limited sample sizes.

While early clinical results (e.g., with the NovaMag membrane) are encouraging, with successful outcomes in both short- and long-term applications, larger controlled trials are needed to confirm their long-term safety and effectiveness. Despite their potential, magnesium membranes face limitations due to rapid degradation and corrosion (corrosion with abrasion). Ongoing research into degradation control and clinical validation is necessary to provide essential scientific data, ensuring their long-term safety and supporting wider clinical adoption.

COI Statement: This paper has yet to be submitted in parallel, presented fully or partially at a meeting, podium, or congress, published, or submitted for consideration beforehand.

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Abbreviations

GBR - Guided Bone Regeneration; MAO - Micro Arc Oxidation; HyA – Hyaluronate Acid; HF - Hydrofluoric Acid; PTFE – Polytetrafluoroethylene; CBCT - Cone Beam Computed Tomography; ePTFE – expanded Polytetrafluoroethylene; HA - Hydroxyapatite: dPTFE – dense Polytetrafluoroethylene; XXT - (sodium 3'-[1-(phenylamino)-carbonyl]-3,4-tetrazolium]-bis (4 methoxy-6-nitro) benzene-sulfonic acid hydrate) assay; Zn – Zink; Y – Yttrium; Nd – Neodymium; TiO2 - Titanium Dioxide; TiC - Titanium Carbide; TiM - Titanium Nitride;

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