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Abstract

Introduction: Guided bone regeneration (GBR) is a validated technique with satisfactory outcomes during 30 years of follow-up.
The use of polytetrafluoroethylene (PTFE) membrane for vertical augmentation has been studied extensively.
However, studies have reported exposure rates of up to 31%, there is no consensus on the management of postoperative exposure.
The objective of this study was to propose a management approach for postoperative exposure of polytetrafluoroethylene (PTFE) membranes in alveolar ridge reconstruction.

Material and method: An electronic search in PubMed Central's and additional electronic databases was performed. The search strategy was limited to human studies, full-text English or French articles published from 1990 until april 2023.
The extracted data included defect location, membrane type, biomaterials, time to postoperative exposure, and Fontana classification stage.
Protocol bias assessment was performed using an adaptation of the QUADAS-2 tool.
This review has been registered on PROSPERO (ID: CRD42023445497).

Results: A total of 43 articles were found to be eligible, and 11 of these met the predefined inclusion and exclusion criteria.
Based on the results of this systematic review, an algorithm for the management of PTFE membrane exposure is proposed.

Conclusion: Postoperative membrane exposure is not a determining factor for the success of bone grafting.

In cases with postoperative complications, the majority of cases still achieved adequate implant-prosthetic rehabilitation.
Lastly, this series of 11 articles was insufficient to draw conclusions regarding good practice recommendations. A larger series is required to validate the specific management approaches.

Management of postoperative outcomes of polytetrafluoroethylene membranes in alveolar ridge reconstruction: a systematic review

Introduction

The high success rate of the principles established by Branemark et al. (1) for the replacement of teeth using dental implants in 1983 has made them a reliable treatment option for partially or completely edentulous patients. The aim of implant-prosthetic rehabilitation is to restore the function and aesthetics. Implant positioning must take both the quality and quantity of bone into consideration (2). Optimal results can be achieved by placing the dental implants within bone that has a sufficient volume for osseointegration and stability. However, such an ideal situation may not always exist in post-extraction conditions. Reconstruction of the edentulous alveolar bone is extremely challenging when multiple dimensions need to be restored (2). There is currently a lack of consensus on the technique (3,4), but autologous bone grafts are considered the gold standard for bone reconstruction because of their osteogenic, osteoinductive, and osteoconductive potentials (2,5,6). However, the available quantity of autologous bone is limited, a second donor site surgery is required, and varying degrees of resorption can occur depending on the harvested area.

Bone substitutes with osteoconductive scaffold properties are also available for clinical application (7). Some authors supplement particulate autogenous bone with inorganic bovine-derived minerals to reduce the resorption rate of the graft and minimize autogenous

bone harvesting (8–11). Several studies have demonstrated that the use of composite grafts is an effective approach for ridge regeneration (12,13). Guided bone regeneration (GBR), based on principles established in previous studies (14,15), is a validated technique with satisfactory outcomes during 30 years of follow-up. It allows an average horizontal increase of 5.68 mm (16) and a vertical increase of 4–5.5 mm (17),(18).

There are four types of non-resorbable membranes made of PTFE: expanded PTFE (e-PTFE), dense PTFE (d-PTFE), titanium reinforced expanded PTFE (TR-e-PTFE) and titanium reinforced dense PTFE (TR-d-PTFE).

Although previous studies have shown that a larger pore size would enhance biological effects (19), more recent d-PTFE membranes tend to replace e-PTFE ones (17,20,21) to limit bacterial adhesion and post-operative infections (22,23).

The use of titanium-reinforced polytetrafluoroethylene (TR-PTFE) membrane for vertical augmentation has been studied extensively (24,25). These membranes can be molded and shaped to stabilize particulate bone, maintain soft tissue spaces, and promote fibroblast proliferation. However, they can only be used when primary closure is possible and can be maintained throughout the healing period. Premature exposure can influence clinical outcomes and increase the risk of postoperative infection (24).

Although studies have reported exposure rates of up to 31% (26), there is no consensus (27) on the management of postoperative exposure. The current literature presents conflicting evidence because much of the reported information is not evidence-based and relies on surgeon experience. The objective of this study was to propose a management approach for postoperative exposure of polytetrafluoroethylene (PTFE) membranes in alveolar ridge reconstruction.

Materials and Methods

This systematic review adhered to the Declaration of Helsinki (1965) and its later amendments regarding medical protocol and ethics, as well as the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Owing to the bibliographic nature of our study, the Ethics Review Board of the University of Nice (Nice, France) and the University of Lille (Lille, France) waived the need for consent. This review has been registered on PROSPERO (ID: CRD42023445497).

Focused Question

What is the management of postoperative exposure of non-resorbable PTFE membranes?

Search Strategy

An electronic search on PubMed was conducted to identify eligible articles in English. In the PubMed library, a combination of MeSH terms and non-MeSH indexed keywords was used. The search equation was: (((((((Périodontal) OR (Oral)) OR (Buccal)) OR (((((Implant) OR (Dental Implant therapy)) OR (Endosseous dental implantation)) OR (Dental prosthesis)) OR (Edentulous))) AND (((((((Managing) OR (Management)) OR (Effect)) OR (Minimizing)) OR (Recommendations)) OR (Correction)) OR (Results))) AND ((((((((((((((Bone Graft) OR (Guide bone regeneration)) OR (GBR)) OR (Vertical ridge augmentation)) OR (Alveolar ridge augmentations)) OR (lateral ridge augment)) OR (horizontal ridge augment)) OR (Bone Substitute regeneration)) OR (Bone incrementation)) OR (Bone transplantation)) OR (Grafted Bone)) OR (Localized ridge augmentation)) OR (Hard-tissue augmentation)) OR (Particulate bone grafting)) OR (Induced membrane technique)) OR (guided tissue regeneration))) AND (((((((((Exposure) OR (Complication)) OR (Infection)) OR (Inflammation)) OR (Soft tissue complication)) OR (Postoperative exposure)) OR (GBR complications)) OR (Bone resorption)) OR (Tissue reaction)) OR (Surgical wound

dehiscence))) AND ((((((((((((Membrane) OR (d-PTFE)) OR (e-PTFE)) OR (PTFE)) OR (Dense PTFE)) OR (polytetrafluoroethylene)) OR (High-density polytetrafluoroethylene membranes)) OR (Nonresorbable membrane)) OR (non-resorbable membrane)) OR (expanded-polytetrafluoroethylene)) OR (dense-polytetrafluoroethylene)) OR (titanium-reinforced d-PTFE membrane)) OR (titanium)). Filters were applied to include human studies translated in French and English, limiting the search to prospective and retrospective reviews. The search included all articles published between 1990 and April 2023.

Additional electronic databases were used as sources in the search for studies satisfying the inclusion criteria: Web of Science, LILACS, Google Scholar, Science Direct.

Additionally, a manual search was conducted in topic-specific journals, including the International Journal of Oral and Maxillofacial Implants, Clinical Oral Implants Research, Journal of Oral and Maxillofacial Surgery, International Journal of Oral and Maxillofacial Surgery, Clinical Implant Dentistry and Related Research, Implant Dentistry, Journal of Periodontology, Journal of Clinical Periodontology, and Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics.

Two authors independently selected the articles based on the title and abstract, and then reviewed them in their entirety. Studies were eligible if they dealt with PTFE membranes in dental implantology and met the inclusion and exclusion criteria.

The inclusion criteria were as follows:

1. Human studies involving participants of any age requiring alveolar bone grafting prior to implantation, including smokers and non-smokers.
2. Patients who underwent vertical or horizontal augmentation or GBR with non-resorbable PTFE membranes (either titanium-reinforced or non-reinforced).
3. Studies addressing postoperative complications related to PTFE membranes, specifically membrane exposure versus surgical site infection.

4. Studies describing the management of these complications and reporting short- to medium-term outcomes (>4 months).
5. Postoperative exposure defined as the surgical site reopening, leading to the membrane's underlying exposure.

The exclusion criteria were systematic reviews or meta-analyses on the same subject, animal studies, studies lacking a complication management protocol, bone grafting in the alveolopalatal zone, interventions involving grafts with simultaneous implantation, studies in languages other than French or English, and unavailability of the full paper.

Data Extraction

The extracted data included defect location, membrane type, biomaterials, time to postoperative exposure, and Fontana classification stage.

Wound healing complications were classified according to the Fontana classification (28) as follows: small membrane exposure (≤ 3 mm) without purulent exudate (Class I), large membrane exposure (> 3 mm) without purulent exudate (Class II), membrane exposure with purulent exudate (Class III), and abscess formation without membrane exposure (Class IV). For articles where exposure was not directly associated with the Fontana classification, an estimation based on size and infection criteria was used. A concordance check with clinical photographs was systematically performed whenever possible. The classifications were reviewed by independent investigators and any disagreements were resolved by the clinicians involved in this review.

For studies classified as Fontana type I, data regarding the membrane type, time to exposure, management (including the use of 0.12% Chlorhexidine mouthwash, Topical application of 1% Chlorhexidine gel, and topical application of 0.12% Chlorhexidine) attempted closure, and time till membrane removal were collected.

For Fontana type II studies, the collected data included the membrane type, exposure time, management (including the use of 0.12% Chlorhexidine mouthwash, topical application of Chlorhexidine, and topical application of 3% Hydrogen Peroxide), attempted closure, delay, and modalities for membrane removal.

For Fontana type III studies, the data included the membrane type, exposure time, management (including the use of 0.12% Chlorhexidine mouthwash and amoxicilin-clavulanic acid therapy [2g/day for 7 days]), and modalities for membrane removal.

For Fontana type IV studies, the data included the membrane type, exposure time, management (including the use of 0.12% Chlorhexidine mouthwash and amoxicilin-clavulanic acid therapy [2g/day for 7 days]), and modalities for membrane removal.

Assessment of Protocol Bias

Protocol bias assessment was performed using an adaptation of the QUADAS-2 tool. Prospective/retrospective acquisition of data, number of subjects, duration of the follow-up, and quality of the clinical data described were assessed.

Prospective/retrospective acquisition of data: we considered studies at high risk of bias when data was collected retrospectively, and at low risk when data was collected prospectively.

Number of subjects: case reports or case series (< or equal to 8 cases) were considered at high risk of bias and studies with more than 8 patients were considered at intermediate risk of bias.

Duration of follow-up: we considered studies at high risk of bias when the medical follow-up was less than 3 months, at intermediate risk of bias between 3 and 6 months, and at low risk of bias when the medical follow-up was longer than 6 months.

Quality of the clinical data described: we considered studies at high risk of bias when data the quality of clinical data were judged insufficient by authors, and at low risk when the description of clinical outcomes and management were sufficiently detailed.

Results

The electronic search on PubMed/MEDLINE yielded 7,053 articles using the search equation, and 39 of these were finally selected based on their titles and abstracts. Additionally, 4 articles were manually identified from the selected journals and nine additional electronic databases. Duplicate articles have been removed. A total of 43 articles were found to be eligible, and 11 of these met the predefined inclusion and exclusion criteria (Figure 1).

The studies that met the inclusion and exclusion criteria regarding the management of PTFE membrane exposure are summarized in Table 1. Among these 11 studies, some met one or more Fontana criteria. Regarding low to moderate exposures, four articles met the Fontana type I criteria (29–32) and six articles met the Fontana type II criteria (30–35). Regarding severe exposures and infections without membrane exposure, six articles met the Fontana type III criteria (31–33,36–38) and two articles met the Fontana type IV criteria (31,39). Data collected from these studies are summarized in Tables 2–5.

The results of bias assessment of the selected studies are listed in Figure 2. Based on the QUADAS-2 tool, studies had a high or intermediate risk of bias, particularly due to the retrospective acquisition of the data and the low number of cases described.

Based on the results of this systematic review, an algorithm for the management of PTFE membrane exposure is proposed in Figure 3.

Discussion

Membranes can be categorized as resorbable or non-resorbable. Resorbable membranes are generally easier to handle and are useful for the treatment of dehiscences and small fenestrations that frequently occur before, during, or after implant placement. Wang and Alsham (40) proposed the classification of bone defects into three categories: horizontal, vertical, and combined defects. Conversely, non-resorbable membranes are preferred for extensive horizontal and vertical defects, creating a protective barrier against soft tissues for bone regeneration.

There are four types of non-resorbable membranes made of PTFE: expanded PTFE (e-PTFE), dense PTFE (d-PTFE), titanium reinforced expanded PTFE (TR-e-PTFE) and titanium reinforced dense PTFE (TR-d-PTFE). Like other types of non-resorbable membranes (e.g. titanium membranes), the most frequent complication associated with PTFE use is postoperative exposure (41). Rigid non-resorbable membranes are more prone to early exposure due to their tendency to return to their original shape after being adapted to the bone defect (42). e-PTFE membranes have higher porosity and are quickly invaded by microorganisms within 3 to 4 weeks upon exposure to the oral environment (22). Conversely, d-PTFE membranes consist of two high-density layers with lower micrometric porosity, providing greater resistance to contamination and bacterial penetration (23).

In 2006, Wang (43) described four fundamental principles for GBR (PASS) to achieve predictable results: primary intention healing, vascular supply, space maintenance, and stable blood clot formation. However, studies have reported a membrane exposure rate of up to 31% (26) for PTFE membranes, and more recently a rate of 72.2% (44). To avoid complications and optimize results, some authors suggest analyzing the risk factors (27). The following factors should be taken into account: patient selection, defect type, blood

supply, antibiotic treatment, flap passivation, delayed implant placement, combination of autogenous bone with xenograft or allograft bone, rigid membrane fixation, removal after 6–9 months, complications, and soft tissue management in aesthetic areas.

In 2022, Poomprakobsri *et al.* (44) compared the exposure rates of resorbable membranes, non-resorbable membranes, and titanium mesh. They concluded that resorbable membranes have a lower exposure rate and are mainly indicated for horizontal defects, although they may also allow limited vertical gain.

In the 2016 consensus (27), a working group suggested that resorbable membranes should be used for horizontal augmentations and small vertical augmentations, while non-resorbable membranes should be used for vertical augmentation of large defects.

Besides the type of barrier used during grafting, other factors can also influence the exposure rate. These factors include graft material, graft location, graft purpose, surgeon's experience, and habitual or occasional tobacco use. Tobacco has been the subject of numerous studies (32,45) as a negative factor in wound healing. Smoking negatively affects angiogenesis and wound healing, impairs fibroblast function, and compromises the function of neutrophils and macrophages (46). Furthermore, nicotine affects bone metabolism by slowing down osteoblast formation and reducing the number of osteoclasts (47). Smoking is also believed to have a negative effect on GBR, with the maxillary bone being 1.6 times more susceptible to its adverse effects than the mandible (48). A previous study (32) showed lower success rates and increased post-surgical resorption in smokers, which was four times higher than in non-smokers (49). In a study of the effects of smoking on e-PTFE membrane exposure, the success rate for non-smokers was 95%, while that for smokers was 63%. Despite this, tobacco is considered a potentially controllable risk factor. There is currently a lack of data on the duration of preoperative smoking cessation. However, clinical experience suggests that smoking should be discontinued several months before surgery. In periodontal tissues, smoking effects have an estimated half-life of 1.5 years (50).

In 2011, Fontana *et al.* (28) published the most comprehensive classification of postoperative complications related to non-resorbable membranes, along with the proposed management for each type:

- Class I: The membrane should not be immediately removed but left in place for one month. Topical application of 0.12% chlorhexidine gel twice a day and careful monitoring. In certain situations, removal of the exposed portion may be accompanied by soft tissue grafting.
- Class II: The membrane should be immediately removed to avoid interfering with the healing process. The regeneration area should be left in place.
- Class III: The membrane should be immediately removed, and underlying infected particles and inflammatory tissues should be curetted.
- Class IV: The membrane should be immediately removed, followed by complete curettage of the graft, local antibiotic irrigation, and oral administration of systemic antibiotics.

However, there is still no consensus on the management of postoperative exposure of non-resorbable membranes.

Studies have shown reduced bone regeneration in cases of exposure regardless of the barrier type (44). A systematic review (51) of the effect of PTFE membrane exposure on GBR outcomes in peri-implant sites and edentulous ridges concluded that the weighted mean difference in horizontal bone gain in edentulous ridges could reach −76.24% between sites with membrane exposure and sites without exposure.

Despite variations (52) in bacterial growth dynamics depending on the types of commercially available membranes, satisfactory results can sometimes be achieved even after membrane exposure. In fact, the effectiveness of PTFE membranes against bacterial penetration has been demonstrated in an *in vitro* study (53).

Simion *et al.* (22) reported that bacterial penetration is delayed due to the low porosity of e-PTFE. According to this study, colonization of the regenerating tissue begins 3 to 4 weeks after exposure and then stops. Therefore, immediate removal of an exposed but uninfected membrane seems theoretically inappropriate. However, Fontana *et al.* (28) have included membrane removal in their protocol for Class II exposures, even in the absence of acute infection, to avoid any interference with the healing process of the regenerating tissue.

In a retrospective study of 237 consecutively treated GBR sites by Shanaman (54), membrane exposure did not negatively impact GBR if adequate postoperative hygiene was maintained. Thus, postoperative membrane exposure is not a determining factor for the success of bone grafting. In a 2022 study (55), the authors categorized postoperative exposures based on their clinical consequences in the context of implant rehabilitation and timing of intervention.

- Category 1: Most regenerated tissues are not compromised, and implants can be placed after a sufficient healing period of 6 to 9 months for bone regeneration.
- Category 2: A portion of the graft did not transform into bone or was removed. Cone-beam computed tomography (CBCT) is performed to determine the additional volume needed for implant placement. If there is insufficient bone, additional augmentation may be necessary, possibly combined with simultaneous implant placement.
- Category 3: The majority of the graft is lost. After a healing period of 2 to 3 months, a new GBR procedure will be indicated.

Table 6 presents the final clinical outcomes of implant rehabilitation among the articles included in this study. In cases with postoperative complications, the majority of cases still achieved adequate implant-prosthetic rehabilitation. Under favorable conditions, no additional procedures were necessary, while in other cases, successful implant rehabilitation required additional procedures.

The placement of a membrane in the context of GBR serves two key purposes: to increase the bone volume and to enhance emergence without hindering implant placement or affecting the final clinical outcomes.

A cross-sectional study (31) involving 80 postoperative complications related to d-PTFE membranes allowed for the development of a management protocol based on the experience of a single private practitioner between 2010 and 2017. The author suggests that the coronal position of the alveolar ridge should be taken into consideration along with the Fontana criteria (postoperative exposure time, exposure size, and infectious nature of the area).

One limitation of these studies and classifications was the non-inclusion of the membrane edges. Despite good biocompatibility (56) with the surrounding structures and integration capabilities (22) with gingival connective tissue, an exposed edge facilitates bacterial ingress beneath the membrane, negatively influencing the amount of regeneration (55). However, certain authors, such as Ronda *et al.* (57) and Urban *et al.* (58), have reported exposure rates of 0%. This demonstrates that proper planning and consideration of risk factors, along with surgical experience, can lead to predictable mucosal closure and postoperative maintenance, even in cases of simultaneous implant placement.

Table 7 summarizes management approaches of Ronda et al and Urban et al for preventing exposures.

Among the two studies with 0% exposure rates, certain common factors were identified that could potentially be favorable. These included a low or absent proportion of tobacco use, pre- and post-operative antibiotic prophylaxis, tension-free flap management, a high proportion of autogenous bone in the composite mixture, two-layer suturing, and follow-up and suture removal after a minimum of 14 days postoperatively.

Several studies have proposed protocols for proactively preventing postoperative exposures:

- In 2011, Ronda *et al.* (59) presented a technique for managing the lingual flap in GBR procedures in the mandible, demonstrating the importance of proper soft tissue management for achieving stable primary wound closure without tension. This technique can contribute to preventing postoperative exposures.
- In 2014, Urban *et al.* (58) suggested adding a resorbable collagen membrane over the non-resorbable membrane in cases where the edges are not sufficiently adapted. This additional step aims to close any open spaces in the grafted area, reducing the risk of exposure.
- In 2010, Torres *et al.* (60) proposed the use of platelet-rich plasma (PRP) to limit the risk of exposure in GBR with non-resorbable mesh-titanium membranes. Their study showed that in the PRP group, no exposures occurred, while 28.5% of the cases in the control group developed exposures. The use of PRP and platelet-rich fibrin (61) is suggested to enhance early wound resistance, reduce patient morbidity, and control pain.
- In 2013, Cheng *et al.* (62) recommended the use of antibiotic-loaded membranes to reduce the adherence of major periodontopathogenic bacteria without significantly altering the membrane's charged structures.

Guided bone regeneration is a predictable surgical procedure (63) when the membrane is well-adapted and stabilized, and flap closure is maintained during the healing phase. According to the literature, the implant survival in newly formed bone during GBR is highly predictable (4), achieving success rates of up to 98.5%, similar to implants placed in native bone (64),(65). This makes GBR a viable long-term pre-implant therapy with low morbidity. Some authors, including Ronda *et al.* (57) and Urban *et al.* (58), have reported exposure

rates of 0%, indicating that proper attention to risk factors, along with surgical experience, allows predictable mucosal closure and postoperative maintenance. However, the risk of postoperative complications remains high despite multiple recommendations and best practices. The management of PTFE membrane exposure should, therefore, follow a systematic approach, taking postoperative timing and exposure factors (size of exposure and infectious nature of the area) into consideration. The clinical approaches for treatment of complications proposed in previous studies are based on clinical experience rather than evidence. Furthermore, due to the limited number of patients treated in these studies, and the limited number of recent and available studies, the generalizability of these protocols is limited. Therefore, these protocols should be considered recommendations based on experiential knowledge from clinical practice.

Conclusions

This series of 11 articles was insufficient to draw conclusions regarding good practice recommendations. A larger series is required to validate the specific management approaches. However, based on the available literature, this study presents a management algorithm in the form of a flowchart to address various challenges that currently lack therapeutic consensus.

Furthermore, it is suggested that postoperative complications should be systematically reported in future clinical trials and case reports for research purposes.

Conflict of Interest

The authors declare that they have no conflicts of interest associated with this publication.

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Tables and Figures

Tables

Table N°1 - Postoperative management of polytetrafluoroethylene membranes: a systematic review

	Defect			Exposure		Fontana classification estimation
	Location	Membrane type	Biomaterials	Postoperative delay	Fontana classification	
Fabrizio Belleggia (35) 2021	Posterior maxilla (molar)	TR-dPTFE	Autogenous + Porcine Xenograft	4 months	II	Reader via Text
Abdullah S Almutairi (33) 2018	Posterior mandible (45 / 46)	TR-dPTFE	Allograft (Freeze-Dried Bone Allograft)	4 weeks	II - III	Reader via Text: Exposure Criteria / Inflammation / Infection + Photograph of the exposure
Ghensi P (29) 2017	Posterior maxilla (24 / 26)	TR-dPTFE	Composite graft Autogenous + Bovine Xenograft (BioOss)	14 days	I	Reader via Text: Exposure Criteria / Inflammation / Infection + Photograph of the exposure
Maridati PC (34) 2016	Anterior maxilla (24)	TR-dPTFE	Bovine Xenograft (BioOss)	14 days	II	Reader via Text: Exposure Criteria / Inflammation / Infection + Photograph of the exposure
Veradi Simion (30) 2007	Anterior maxilla (13 / 23)	TR-ePTFE	Autograft	4 weeks	I	Reader via Text: Exposure Criteria / Inflammation / Infection
	Anterior maxilla	TR-ePTFE		3 months	I	

	Maxillary premolar and molar	TR-ePTFE		2 weeks	II	+ Photograph of the exposure
Pier Gallo (31) 2019	Maxilla and Mandible	TR-dPTFE	Autogenous + Xenograft or Allograft 1.1	70% upfront 4 weeks	I – II – III - IV	According to Fontana classification
Valentini Abensur (36) 1992	Maxillary anteriors (11/21)	e-PTFE	Autograft	8 weeks	III	Reader via Text: Exposure Criteria / Inflammation / Infection + Photograph of the exposure
Lindfors (32) 2010	-	TR-ePTFE	Autograft	2 weeks	I – II - III	Reader via Text: Exposure Criteria / Inflammation / Infection
Buser et al. (37) 1990	Posterior mandible	e–PTFE	Autograft	3-4 months	III	Reader via Text: Exposure Criteria / Inflammation / Infection + Photograph of the exposure Note: Other exposures were not quantifiable
Annibali et al. (39) 2012	Posterior mandible (45 / 46)	TR-ePTFE	Autogenous + Allograft (DFDBA)	6 months	IV	Reader via Text: Exposure Criteria / Inflammation / Infection
Heggendorn FL (38) 2022	Middle maxilla (13 / 14 15)	TR-dPTFE	Synthetic porous hydroxyapatite	7 months	III	Reader via Text: Exposure Criteria / Inflammation / Infection +

						Photograph of the exposure

Table N°2 - Postoperative management of polytetrafluoroethylene membranes: Fontana type I

Fontana Classification Type I							
	Membrane type	Exposure time	Management				
			Mouthwash 0.12% Chlorhexidine	Topical application 1% Chlorhexidine gel	Topical application 0.12% Chlorhexidine	Attempted closure	Removal of the membrane
Ghensi P 2017	TR-dPTFE	14 days	X	X	0	0	4 months
Veradi Simion 2007	TR-ePTFE	4 weeks	-	-	X	0	6 months
	TR-ePTFE	3 months	-	-	-	Full-thickness flap for partial removal of the membrane Connective tissue graft	8 months
Pier Gallo 2019	TR-dPTFE	10 days	-	X	X	-	6–8 weeks
		< 4 weeks	-	X	X	-	6–8 weeks
		> 4 weeks	-	X	X	-	9 months
Lindfors 2010	TR-ePTFE	2 weeks	X	X	-	-	3–6 months

Table N°3 - Postoperative management of polytetrafluoroethylene membranes: Fontana type II

Fontana Classification Type II						
	Membrane type	Duration of exposure	Management			
			Mouthwash 0.12% Chlorhexidine	Topical application	Attempted closure	Membrane removal
Abdullah S Almutairi 2018	TR-dPTFE	4 weeks	X	X **Chlorexhydine**	Transected vestibular flap.	Membrane removal at 6 weeks
Veradi Simion 2007	TR-ePTFE	2 weeks	0	0	0	Early — The surgical procedure was resumed after complete tissue healing.
Maridati PC 2016	TR-dPTFE	14 days	-	-	-	Early Membrane removal at 4 weeks + Palatal connective tissue graft.
Fabrizio Belleggia 2021	TR-dPTFE	4 months	X	X **3% hydrogen peroxide**	-	Membrane removal at 5 months.
Pier Gallo 2019	TR-dPTFE	-	-	X **Chlorhexidine**	-	If hygiene is not optimal after 6 weeks.
Lindfors 2010	TR-ePTFE	2 weeks	X	X	-	Only trimming of the exposed parts of the membrane. + Connective tissue graft.

Table N°4 - Postoperative management of polytetrafluoroethylene membranes: Fontana type III

Fontana Classification Type III					
	Type of membrane	Exposure duration	Treatment		
			Mouthwash 0.12% Chlorhexidine	Antibiotic therapy	Removal of the membrane
Abdullah S Almutairi 2018	TR-dPTFE	4 weeks	X	Amoxicilin-clavulanic acid 2 g/day for 7 days	X
Pier Gallo 2019	TR-dPTFE	-	-	Amoxicilin-clavulanic acid 2 g/day for 7 days	X Graft washed with tetracycline Placement of a collagen membrane
Valentini Abensur 1992	e-PTFE	8 weeks	-	-	X
Lindfors 2010	TR-ePTFE	2 weeks	-	-	X
Buser et al. 1990	e-PTFE	3–4 months	-	-	X
Heggendorn FL 2022	TR-dPTFE	7 months	X	Amoxicilin-clavulanic acid 2 g/day for 7 days	X

Table N°5 - Postoperative management of polytetrafluoroethylene membranes: Fontana type IV

Fontana Classification Type IV					
	Membrane type	Duration of exposure	Treatment		
			Mouthwash 0.12% Chlorhexidine	Antibiotic therapy	Removal of the membrane
Pier Gallo 2019	TR-dPTFE	-	-	Amoxicilin-clavulanic acid 2 g/day for 7 days	X Removal of membrane / Soft tissues / Mobile graft particles Placement of a collagen membrane 3 months of healing, followed by surgical revision
Annibali et al. 2012	TR-ePTFE	6 months	-	Amoxicilin-clavulanic acid 2 g/day for 7 days	X Removal of the membrane Irrigation with saline solution and Tetracycline solution Closure of the flap

Table N°6 - Postoperative management of polytetrafluoroethylene membranes:

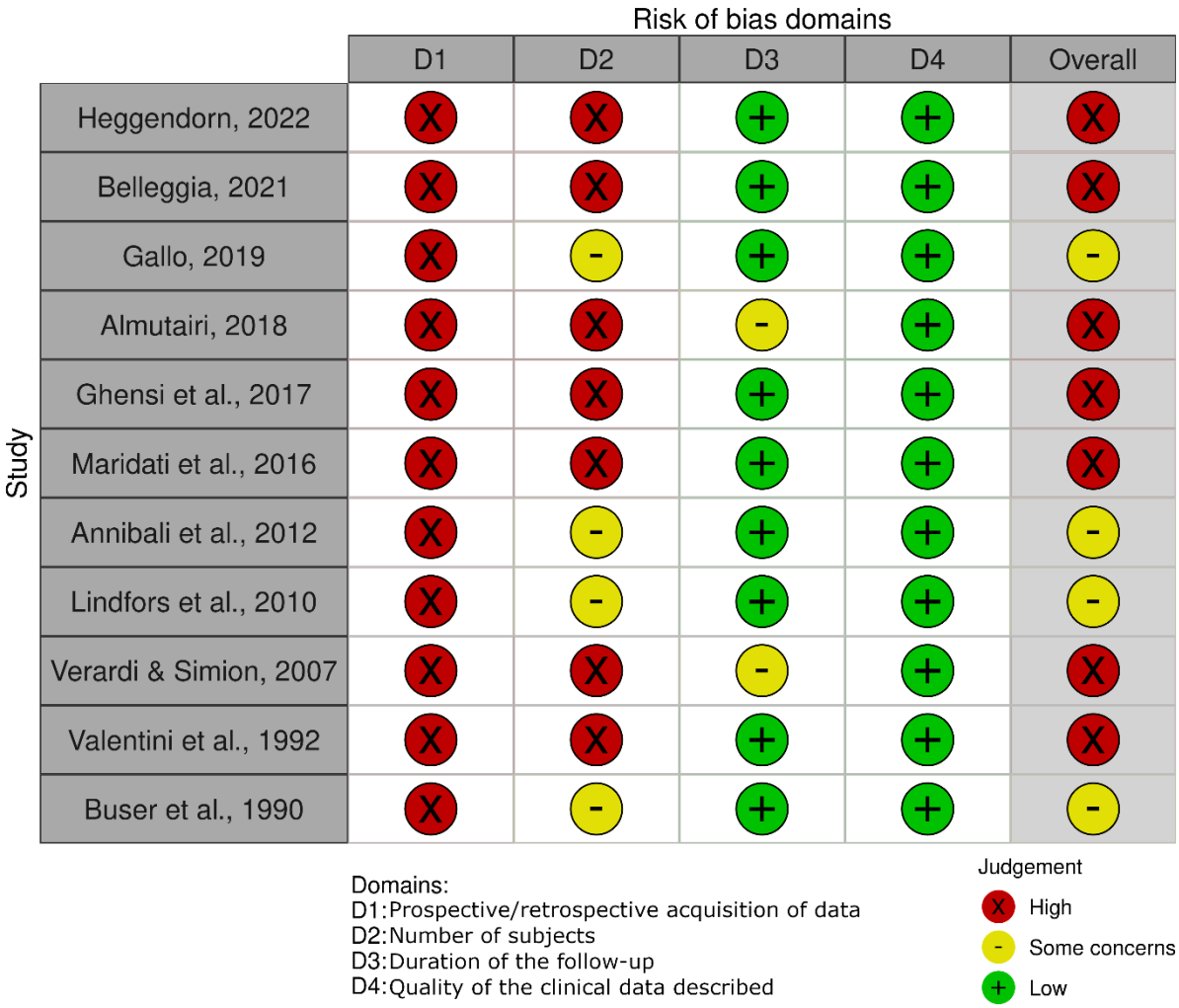
Final clinical outcomes

	Defect			Exposure		Final clinical outcome
	Location	Membrane type	Biomaterials	Delay of Post-operative	Fontana classification	
Fabrizio Belleggia (35) 2021	Posterior maxilla (molar)	TR-dPTFE	Autogenous + Porcine Xenograft	4 months	II	**Success**
Abdullah S Almutairi (33) 2018	Posterior mandible (45 / 46)	TR-dPTFE	Allograft (Freeze-Dried Bone Allograft)	4 weeks	II - III	**Success**
Ghensi P (29) 2017	Posterior maxilla (24 / 26)	TR-dPTFE	Composite graft Autogenous + Bovine Xenograft (BioOss)	14 days	I	**Success**
Maridati PC (34) 2016	Anterior maxilla (24)	TR-dPTFE	Bovine Xenograft (BioOss)	14 days	II	**Success**
Veradi Simion (30) 2007	Anterior maxilla (13 / 23)	TR-ePTFE	Autograft	4 weeks	I	**Success**
	Anterior maxilla	TR-ePTFE		3 months	I	
	Maxillary premolar and molar	TR-ePTFE		2 weeks	II	**Failure of GBR** Renewal of the protocol required
Pier Gallo (31) 2019	Maxilla and Mandible	TR-dPTFE	Autogenous + Xenograft or Allograft 1.1	70% upfront 4 weeks	I – II – III - IV	**Success** 64.29% **Success** Despite the need for additional GBR 12.50%
Valentini Abensur (36) 1992	Maxillary anteriors (11/21)	e-PTFE	Autograft	8 weeks	III	**Success** Despite the need for additional GBR
Lindfors (32) 2010	-	TR-ePTFE	Autograft	2 weeks	I – II - III	**Success**
Buser et al. (37) 1990	Posterior mandible	e-PTFE	Autograft	3–4 months	III	**Failure of GBR**

						Renewal of the protocol required
Annibali et al. (39) 2012	Posterior mandible (45 / 46)	TR-ePTFE	Autogenous + Allograft (DFDBA)	6 months	IV	**Success** Despite peri-implant bone dehiscence
Heggendorn FL(38) 2022	Middle maxilla (13 / 14 15)	TR-dPTFE	Synthetic porous hydroxyapatite	7 months	III	**Success**

Table N°7 - Ronda et al and Urban et al management approaches

Study		Ronda 2014 (57)	Urban 2014 (58)
Defect Type		Vertical defects	Vertical defects
Location		Posterior mandible	Mandible and Maxilla
Average Gain		4.91–5.49 mm	5.45 mm
Patient Characteristics	**Number**	23 patients, 26 operative sites	19 patients, 20 augmentations
	Gender	1 Male and 22 Females	4 Males and 15 Females
	Average Age	49.6 years	43 years
	Tobacco Use	34%	0%
Preoperative Protocol for amoxicilin-clavulanic acid		2 g, 1 hour before surgery + Chlorhexidine 0.2%	2 g, 1 hour before surgery + Chlorhexidine 0.2%
Intraoperative Protocol	**Membrane**	e-PTFE and d-PTFE	d-PTFE
	Incision Type	Tension-free flap management	Tension-free flap management
	Greffons	Grafts 50% autogenous / 50% allogenic	50% autogenous / 50% ABBM
	Associated Implant Placement	Possible	Possible
	Suture Type	Two-layer suturing	Two-layer suturing
Postoperative Protocol	**Antibiotic prophylaxis**	Amoxicilin-clavulanic acid 2 g/day for 7 days	Amoxicillin 500 mg, thrice a day for 7 days
	Suture Removal	14 days	1st layer: 10–14 days 2nd layer: 2–3 weeks



Tables and Figures

Figure 1: Flowchart of the systematic review