The Importance of Keratinized Mucosa Around Dental Implants

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Abstract

AIM: The objective of this review is to determine the efficiency of different augmentation materials in increasing the ideal width and thickness of peri-implant keratinized mucosa (PIKM) and thereby achieving stable peri-implant health. To this end, various clinical parameters will be analyzed for the different techniques employed and the initially achieved PIKM width and thickness.

METHODS: An electronic search of the literature from 2009 to 2019 was conducted in PubMed for studies addressing peri-implant keratinized mucosa and peri-implant health, in combination with peri-implant soft tissue augmentation.

RESULTS: The initial search identified 311 studies, of which 28 passed the first review phase, resulting in 19 studies selected based on established criteria. Insufficient peri-implant keratinized mucosa width (< 2 mm) correlates with inflammation. The combination of autogenous grafts (free gingival grafts) and an apically positioned flap is the gold standard for gaining PIKM width, while xenogeneic materials may offer a short-term alternative. For increasing PIKM thickness, Alloderm, Mucoderm, or autogenous grafts used in augmentation procedures significantly reduced marginal bone loss.

CONCLUSION: PIKM width under 2 mm should be avoided due to its association with increased marginal bone loss and inflammation. Autograft augmentation combined with an apically positioned flap is the gold standard, while allogenic and xenogenic materials also yield successful outcomes.

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Accepted: Tuesday 14th October, 2025. **Data availability statement:** All relevant data are within the article or supplement files unless otherwise declared by the author(s).

1 Introduction

The presence of sufficient soft and hard tissue around dental implants is considered one of the key factors for achieving long-term survival and success of both natural teeth and dental implants (Horvath et al., 2014). The soft tissue around teeth and implants, commonly referred to as keratinized mucosa or keratinized gingiva (**Figure 1**), consists of marginal gingiva and attached gingiva. This tissue increases resistance to external injury and contributes to the stabilisation of the gingival margin. It also dissipates physiological forces exerted by the muscular fibres of alveolar mucosa on the gingival tissue (Malathi et al., 2014). It is well documented that a minimum of two millimetres of keratinized gingiva is considered clinically desirable to create a soft tissue seal around natural teeth. However, controversy persists regarding the minimal width of keratinized soft tissue required around dental implants (Lang & Löe, 1972).

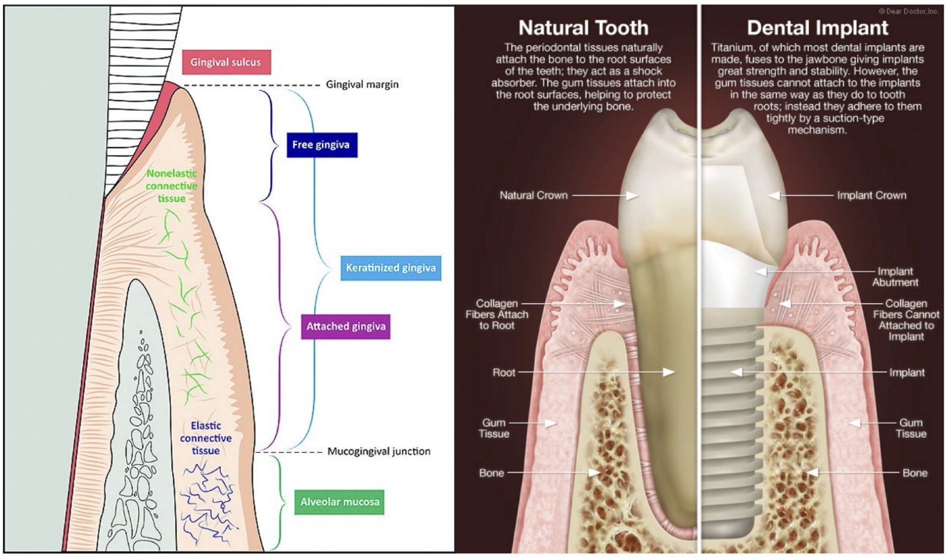

Figure 1. Left: Keratinized mucosa (McGuire 2014). Right: Difference between Periodontal and Peri-implant (Smith, 2025).

Regarding peri-implant tissue, the key differences between peri-implant and periodontal tissues are that peri-implant conditions lack a periodontal ligament and supracrestal fibre attachment around dental implants, as well as the absence of periodontal ligament and cementum (**Table 1**). These factors make peri-implant tissues more susceptible to inflammatory processes caused by plaque accumulation (Dhir et al., 2013). Additionally, insufficient peri-implant keratinized mucosa width (PIKM-W) around dental implants can lead to increased plaque accumulation, a higher incidence of peri-implant mucositis, an increased risk of peri-implant alveolar bone loss (known as peri-implantitis), as well as soft tissue recession and clinical attachment loss (Artzi et al., 2006; Chung et al., 2006; Adibrad et al., 2009; Crespi et al., 2010; Bassetti et al., 2015).

Despite these concerns, the minimal width of keratinized soft tissue needed around dental implants remains a subject of debate (Lang & Löe, 1972). Some studies suggest that gingival inflammation and plaque accumulation are not influenced by peri-implant keratinized mucosa width (Lindhe & Nyman, 1980; Wennström & Lindhe, 1983; Rotundo et al., 2015; Agudio et al., 2016). Others, however, report that PIKM-W does impact soft tissue

Table 1. Difference of periodontal and peri-implant tissue. Adapted from (Dhir et al., 2013).

PERIODONTAL TISSUE	PERI-IMPLANT TISSUE
Free gingival margin with buccal keratinized epithelium	Free gingival margin with buccal keratinized epithelium
Gingival sulcus apically limited by junctional epithelium	Gingival sulcus apically limited by junctional epithelium
Keratinized epithelium at the base of gingival sulcus	No keratinized epithelium at the base of gingival sulcus
Junctional epithelium adherent, less permeable, high regenerative capacity	Junctional epithelium poor adherent, more permeable, low regenerative capacity
cementum	No cementum
Gingival fibers inserting perpendicularly in the cememtum	Gingival fibers inserting parallel in the cememtum
Biological width of at least 2.04mm	Biological width of at least 2.5mm(+/-) 0.5mm
Periodontal ligament	No periodontal ligament
No direct contact between tooth and bone	Direct contact between tooth and bone

inflammation and gingival recession (Rotundo et al., 2015; Agudio et al., 2016). While peri-implant tissues can be maintained in a healthy state with a minimal amount of keratinized tissue when proper plaque control is achieved (Elkhaweldi et al., 2015), insufficient keratinized tissue at implant-supported prostheses can lead to patient discomfort (Dhir et al., 2013). Better outcomes in terms of soft and hard tissue stability and aesthetics are generally observed when there is an adequate width of PIKM (Reddy et al., 2013).

The formation of soft tissue around dental implants is a complex and prolonged process. In one-stage implant procedures, soft tissue formation begins immediately after the placement of a non-submerged implant, as the gingival tissue is sutured. In contrast, for two-stage procedures, the formation of biological width starts upon the connection of the healing screw during implant exposure (**Figure 2**). At this stage, the implant is exposed to the oral environment, increasing the risk of bacterial invasion and subsequent inflammation. To minimise this risk and prevent direct contact between the bone and the oral environment, a protective mechanism must be established. Current recommendations suggest maintaining a minimum vertical height of 3 mm for crestal mucosa to ensure a stable epithelial attachment (Linkevicius et al., 2009b).

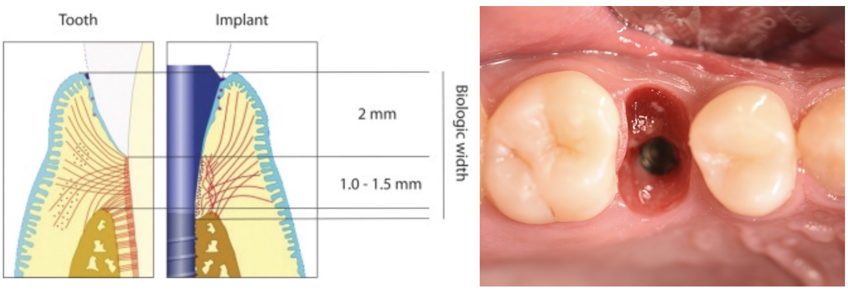

Figure 2. Left: Schematic drawing of biologic width (Albrektsson et al., 1986). Right: Clinical situation of biological width.

The aim of this review is to evaluate the efficiency of different augmentation materials in increasing the ideal width and thickness of peri-implant keratinized mucosa and, consequently, achieving stable peri-implant health. To accomplish this, various clinical parameters will be analysed in relation to the materials used and the initially achieved peri-implant keratinized mucosa (PIKM) width and thickness.

2 Methods

An extensive electronic search was conducted using the MEDLINE (PubMed) database without date restrictions, focusing on randomised controlled clinical trials, as well as prospective and retrospective clinical studies from 2009 to 2019. The search aimed to identify literature addressing peri-implant keratinised mucosa, peri-implant health, and the use of soft tissue augmentation techniques. The key terms included: "dental implant," "grafts," "keratinised mucosa," "attached mucosa," and "peri-implant soft tissue augmentation." A secondary search was performed with terms such as "collagen matrix" and "vestibuloplasty." The final stage involved a manual reference check of relevant articles.

In the course of the review, articles identified from both electronic and manual searches were meticulously examined to ensure adherence to specified criteria. The inclusion criteria focused on the necessity for studies to be randomised controlled clinical trials or clinical studies, either prospective or retrospective in nature. Additionally, it was required that the mean follow-up period for these studies be a minimum of three months, allowing for an adequate assessment of the outcomes related to peri-implant keratinised mucosa and associated measurements.

Conversely, certain studies were systematically excluded from consideration. Specifically, any in vitro or animal studies, as well as case reports, were omitted from the analysis to maintain the focus on human clinical trials. Furthermore, articles published in languages other than English were disregarded, alongside any published prior to 2009, to ensure the relevance and accessibility of the literature examined. This rigorous screening process resulted in the initial identification of 311 studies, from which 28 progressed beyond the initial review phase, ultimately leading to the selection of 19 studies that fulfilled the established criteria.

2.1 Statistics

As this work is a review of existing literature, no original data collection or statistical analysis was conducted. Instead, statistical results from the reviewed studies were extracted and analyzed. The primary focus was on evaluating the reported outcomes related to peri-implant keratinized mucosa width (PIKM-W) and thickness (PIKM-T), as well as clinical parameters like plaque index (PI), bleeding on probing (BOP), gingival index (GI), and probing pocket depth (PPD).

For each study, the statistical methods used were noted, including t-tests, ANOVA, or non-parametric tests such as the Wilcoxon signed-rank test, depending on the data reported. Means, standard deviations, and p-values were extracted to compare the effectiveness of different augmentation techniques, including autografts and xenogeneic materials.

A comparative analysis of the statistical findings across studies was performed to evaluate the efficacy of various peri-implant soft tissue augmentation techniques. Results were summarized to identify trends in the literature.

3 Results

Out of the 19 studies included in this review (**Table 2**), two were retrospective, two were case series, and the remaining were prospective studies. Approximately 11 studies focused primarily on peri-implant keratinized mucosa width (PIKM-W), while 8 studies concentrated on peri-implant keratinized mucosa thickness (PIKM-T). Other parameters assessed in these studies included Plaque Index (PI), Gingival Index (GI), Bleeding on Probing (BOP), and Probing Pocket Depth (PPD).

Most studies employed a range of materials to augment peri-implant soft tissue in cases where PIKM-W and PIKM-T were deemed insufficient. These materials were predominantly autogenous grafts or xenogenic collagen matrices. In addition to the use of different materials, various surgical techniques were applied to increase PIKM-W. Techniques such as different flap designs or the combination of coronally advanced flaps (CAF) with connective tissue grafts (CTG) were commonly employed to achieve this goal.

Table 2. Summary of studies on missing peri-implant keratinize mucosa augmentation techniques. The following abbreviations are employed throughout the table: Pros. - Prospective, Ret. - Retrospective, Ret. Study - Retrospective Study, CS - Case Series, Obs. Period - Observation Period, y - year(s), m - month(s), FD - Flap Design, VP - Various Procedures, AD - Alloderm, CTG - Connective Tissue Graft, MG - Mucograft, FGG - Free Gingival Graft, SCTG - Subepithelial Connective Tissue Graft, GBR - Guided Bone Regeneration, VCMX - Vascularized Connective Graft.

AUTHOR (YEAR)	STUDY TYPE	OBS. PERIOD	SAMPLE SIZE	METHODS	MATERIALS
Todisco (2019)	Pros.	5.0 y	32.0	NK	
Papi (2018)	Pros.	1.0 y	12.0		Mucoderm
Stimmelmayr (2011)	Pros.	1.0 y	29.0		FGG
Zucchelli (2018)	Pros.	5.0 y	20.0	CAF	CTG+CAF
Giovanni (2014)	Pros.	4.0 y	85.0	FD	
Basegmez (2012)	Pros.	1.0 y	64.0	VP	FGG and VP
Basegmez (2013)	Pros.	0.5 y	36.0		FGG and AD
Sanz (2009)	Pros.	0.5 y	20.0		CTG and MG
Lorenzo (2011)	Pros.	0.5 y	24.0		CTG and MG
Schmitt (2016)	Pros.	5.0 y	21.0		FGG and MG
Linkevicius (2013)	Pros.	1.0 y	103.0		
Linkevicius (2009)	Pros.	1.0 y	19.0		
Linkevicius (2009)	Pros.	1.0 y	26.0		
Thoma (2016)	Pros.	0.25 y	20.0		VCMX and SCTG
Delia (2017)	Pros.	1.0 y	32.0		GBR and SCTG
Piusys (2018)	CS		20.0		Mucoderm
Piusys (2014)	CS	0.25 y	40.0		AD
Speroni (2010)	Ret.	3.0 y	14.0		SCTG
Park (2017)	Ret. Study	15.0 y	50.0		ASTG

To augment the missing peri-implant keratinized mucosa, various methods and materials can be applied, such as using autogenous soft tissue grafts (free gingival graft and subepithelial connective tissue graft) or xenogenic materials.

3.1 Autogenous soft tissue grafts

Autogenous soft tissue grafts are commonly used for the augmentation of soft tissue defects. Two types of autogenous grafts are frequently utilized: the free gingival graft (FGG) and the subepithelial connective tissue graft (SCTG).

The FGG technique is widely regarded as the gold standard due to its minimal post-operative soft tissue contraction and its ability to achieve maximal coverage of recession-affected areas. Additionally, it reliably increases the width of peri-implant keratinized mucosa (PIKM), making it an effective and predictable technique (Albrektsson & Branemark, n.d.). However, harvesting graft tissue involves significant drawbacks, including considerable pain and discomfort at donor sites such as the hard palate or maxillary tuberosity. Further limitations include the finite amount of tissue available for harvesting and the potential for colour mismatch between the grafted tissue and the surrounding recipient site (Seibert, 1983; Camargo et al., 2001; Ioannou et al., 2015). These disadvantages have prompted the adoption of SCTG as an alternative for PIKM augmentation.

SCTG offers certain advantages, particularly reduced post-operative morbidity at the donor site. However, the quality and consistency of the newly formed keratinized tissue remain unpredictable and can vary significantly between cases, which poses a challenge in achieving consistently favourable outcomes (Seibert, 1983; Levine et al., 2014).

3.2 Soft tissue substitutes

As a result, soft tissue substitutes are sought as alternatives to overcome these limitations. One such substitute that has shown promise in increasing PIKM is the allograft (Alloderm®). However, the use of Alloderm® is restricted in many European countries due to ethical concerns, leading to the more frequent use of xenogenic materials, particularly those of porcine origin.

A popular xenogenic material on the market is Geistlich Mucograft®, a 3D collagen matrix specifically designed for soft tissue regeneration. It is indicated for acquiring keratinized tissue and covering recession-affected areas, providing a viable alternative to autogenous soft tissue grafts. Mucograft® offers several advantages: it eliminates donor-site morbidity, causes less pain compared to autogenous grafts, reduces surgical chair time, and provides a natural soft tissue colour and structure that matches the patient's tissues. Existing literature shows that Mucograft® yields satisfactory results in enhancing the width of keratinized mucosa and is as effective and predictable as connective tissue grafts (CTG) for gaining a band of keratinized tissue, but with significantly lower patient morbidity. However, Mucograft® is associated with a higher contraction rate, which results in less PIKM compared to the gold standard FGG (Sanz et al., 2009; Lorenzo et al., 2012).

A novel xenogenic soft tissue graft material, Mucoderm® (Botiss, Germany), has recently been developed. It is a cross-linked xenogenic matrix that offers an alternative to autologous soft tissue transplants.

3.3 Efficiency of methods and materials in increasing PIKM-W

In the first part of this study, the effectiveness of various augmentation methods in increasing PIKM width and thickness is analysed. Eleven studies reported on different methods to augment PIKM-W, while eight studies documented techniques for gaining PIKM-T. Various authors applied different methods to achieve adequate PIKM width through the use of biomaterials, flap designs, and autogenous grafts.

Most studies reported gains in PIKM-W over observation periods ranging from 6 months to 5 years, with no apparent influence from the specific methods or materials used (**Table 3**). Across all studies, the increase after 6 months ranged from 0.69 mm to 2.33 mm, after 1 year from 0.6 mm to 4.32 mm, and after 4 years from 3.77 mm. The highest total increase of 4.23 mm was observed for Mucoderm®, a novel xenogenic collagen matrix material, after 1 year (Papi & Pompa, 2018).

Table 3. Different methods and materials to increase PIKM-W.

AUTHOR (YEAR)	OBS. TIME (MO)	AUGMENTATION (ABBR.)	PIKM WIDTH BASELINE (MM)	PIKM WIDTH FOLLOW-UP (MM)
Basegmez (2013)	6.0	FGG	1.0 ± 0.3	2.6 ± 0.5
Basegmez (2013)	6.0	AD	0.9 ± 0.3	1.6 ± 0.4
Sanz (2009)	6.0	CTG	0.2 ± 0.4	2.6
Sanz (2009)	6.0	MG	0.4 ± 0.5	2.5
Lorenzo (2011)	6.0	CTG	0.4 ± 0.5	2.8 ± 1.6
Lorenzo (2011)	6.0	MG	0.5 ± 0.5	2.8 ± 0.4
Papi (2018)	12.0	MD	1.4 ± 0.3	5.7 ± 2.1
Stimmelmayr (2011)	12.0	FGG	2.9	3.5
Basegmez (2012)	12.0	FGG	0.8 ± 0.4	2.4 ± 0.5
Basegmez (2012)	12.0	VP	0.7 ± 0.3	1.8 ± 0.7
Bruschi (2014)	48.0	Flap	2.1 ± 0.1	5.9 ± 0.3
Todisco (2019)	60.0	NK	2.2 ± 1.2	1.9 ± 1.2
Zucchelli (2018)	60.0	CTG+CAF	1.8	3.0
Schmitt (2015)	60.0	FGG	13.1 ± 2.3	8.4 ± 2.4
Schmitt (2015)	60.0	MG	13.0 ± 2.9	6.2 ± 1.2
Park (2017)	180.0	ASTG	4.3 ± 0.9	3.6 ± 1.3

Time converted to months (mo); PIKM width in millimetres (mm); all numeric values rounded to one decimal. '±' = mean ± SD. Abbreviations — FGG: Free gingival graft; CTG: Connective tissue graft; MG: Mucograft; MD: Mucoderm; AD: Alloderm; VP: preserved label from source; ASTG: preserved label from source; NK: preserved label from source; Flap: Flap design; CAF: Coronally advanced flap.

Although no clear dependency on follow-up time was identified, reductions in PIKM-W were seen in studies with longer follow-up periods. After 5 years, the change in PIKM-W ranged from -6.81 mm to +1.25 mm. One study with an even longer follow-up of 15 years reported a reduction of -0.69 mm (Park et al., 2017). No clear effect was found for different materials and methods; for example, both increases and decreases in PIKM-W were reported for FGG and Mucograft®. A reduction was reported only for autogenous soft tissue grafts, which were used exclusively in the 15-year study by Park.

Some studies directly compared different materials and methods, allowing for a more detailed evaluation of the effectiveness of individual techniques. Free Gingival Graft (FGG) outperformed the vestibuloplasty surgical technique after 1 year, with an increase of 2.36 mm compared to 1.15 mm (Basegmez et al., 2012), and Alloderm® after 6 months, with an increase of 2.57 mm compared to 1.58 mm. FGG was also shown to be more stable, as a greater post-operative relapse was observed in the Alloderm® group (Basegmez et al., 2013).

In a 5-year study, FGG was compared to Mucograft®. Both methods showed a reduction in PIKM-W, but the reduction was smaller for FGG (4.66 mm) compared to Mucograft® (6.81 mm), with a much higher contraction rate for the Mucograft® group (Schmitt et al., 2016). Mucograft® was also outperformed by Connective Tissue Graft (CTG) after 6 months, where a significant gain in PIKM-W was observed only in the CTG group (Sanz et al., 2009; Lorenzo et al., 2012).

Autogenous materials (CTG or FGG) consistently produced the best outcomes in all clinical parameters, with greater gains in PIKM-W and lower contraction rates (Lorenzo et al., 2012; Schmitt et al., 2016; Park et al., 2017).

In addition to the clinical parameters of peri-implant keratinized mucosa width (PIKM-W), statistical differences were observed between autogenous and xenogenic groups concerning post-operative morbidity (measured using the Visual Analogue Scale, VAS) and surgical time, as shown in **Table 4**. Only two studies evaluated these parameters. In both studies, the surgical time was shorter for the xenogenic group compared to the autogenous group, with procedures involving autogenous materials taking approximately 15 minutes longer.

Table 4. Surgical Time and Post-operative Pain Control Between Autogenous Grafting Material and Xenogenic Material for Increasing PIKM-W.

		SURGICAL TIME (MIN)	IBUPROFEN TAKEN (MG)	VAS AFTER 10 DAYS
Mariano Sanz 2009	Autogenous graft (FGG/CTG)	47.20	5140 (total dose)	4.01
	Xenogenic (Mucograft)	30.80	720 (total dose)	2.3
Lorenzo et al 2011	Autogenous graft (FGG/CTG)	46.25	< 2000 immediately	< 3
	Xenogenic (Mucograft)	32.50	< 4000 immediately	< 3

Due to secondary wound healing, the VAS scores were lower in the xenogenic group than in the autogenous group after 10 days. However, a statistically significant difference in post-operative ibuprofen consumption was also noted. Despite the different measurement methods used in the two studies, the results clearly showed that, in Mariano Sanz's study, the total amount of ibuprofen taken in the autogenous group was about 7 times higher than in the xenogenic group. Similarly, in Lorenzo's study, immediately following surgery, the consumption of painkillers was twice as high in the autogenous group compared to the xenogenic group (Sanz et al., 2009; Lorenzo et al., 2012).

3.4 Impact of PIKM width and thickness on clinical parameters

Clinical plaque indices are employed to evaluate the level and rate of plaque formation on tooth or implant surfaces. These indices assist in assessing the effectiveness of oral care products in removing and preventing plaque deposits from surfaces (Bosma et al., 2018). The plaque index (PI) reflects oral hygiene status, which, in turn, influences surgical outcomes, particularly during the wound-healing period and the long-term success of implants. Several studies have demonstrated that reduced PIKM-W is significantly associated with increased plaque accumulation, which can result in inflammation around the peri-implant soft tissue, referred to as peri-mucositis (Chung et al., 2006; Bouri et al., 2008; Adibrad et al., 2009; Boynueğri et al., 2013).

Plaque index. **Table 5** provides an overview of four studies that explore the relationship between the plaque index (PI) and changes in PIKM-W following augmentation surgeries. Basegmez (2012) reported the most significant results, with a mean reduction of PI of approximately 1.38 following augmentation with a Free Gingival Graft (FGG). In contrast, the group treated with vestibuloplasty surgery exhibited a significantly inferior PI reduction of 0.97.

Similar findings were reported in two additional studies. A reduction in PI of approxi-

Table 5. Plaque index (PI) value before and after augmentation in relation to PIKM width.

STUDY (YEAR)	OBS TIME	SURGICAL INTERVENTION	BASELINE PIKM WIDTH (MM)	BASELINE PI	FOLLOW-UP PIKM WIDTH (MM)	FOLLOW-UP PI
Basegmez (2013)	6 mo	FGG	1.01 ± 0.34	1.38 ± 0.45	2.57 ± 0.50	0.12 ± 0.16
		Allo	0.89 ± 0.31	1.12 ± 0.15	1.58+0.37	0.35 ± 0.29
Basegmez (2012)	1 yr	FGG	0.75 ± 0.36	1.56 ± 0.67	2.36 ± 0.49	0.18 ± 0.39
		VP	0.67 ± 0.32	1.25 ± 0.62	1.83 ± 0.73	0.28 ± 0.52
Papi (2018)	1 yr	Mucoderm	1.35 ± 0.32	—	5.67 ± 2.12	0.75
Park (2017)	15 yr	ASTG	4.33 ± 0.94	1.20 ± 0.15	3.64 ± 1.27	1.42 ± 0.45
		Non-graft	—	1.31 ± 0.19	—	1.50 ± 0.25

FGG = Free Gingival Graft; Allo = Alloderm; VP = Vestibular Preservation; ASTG = Apically Shifted Tissue Graft; PI = Plaque Index; PIKM = Peri-implant Keratinized Mucosa width; "—" indicates data not reported.

mately 0.75 was observed post-operatively after PIKM-W augmentation in studies conducted by Basegmez (2013) using Alloderm® and by Papi (2018) using Mucoderm®. However, the follow-up period for the Alloderm® group was only 6 months, while the Mucoderm® group was observed for 1 year (Basegmez et al., 2013; Papi & Pompa, 2018). Predictably, Mucoderm® demonstrated more favourable outcomes (Basegmez et al., 2012, 2013).

Autogenous grafts were utilised in two studies, both conducted by Basegmez in 2012 and 2013, respectively. After a 6-month follow-up period, PI reductions of 1.26 and 1.38 were observed in both studies, with no significant differences between the groups. However, autogenous grafts appeared to provide more stable long-term results concerning plaque index reduction.

Gingival health indicator changes following PIKM-W augmentation. Bleeding on probing (BOP) is an indicator of inflammation, suggesting some degree of destruction of the sulcular epithelium surrounding a tooth or implant. Overall, reductions in the Gingival Index (GI) ranged from 0.1 to 1.42 following PIKM-W augmentation surgery.

Table 6 shows that the Gingival Index (GI) in both study groups (Basegmez, 2012, 2013) demonstrated a significant reduction compared to baseline values. There was no significant difference between the two Free Gingival Graft (FGG) groups; however, GI changes exhibited statistically significant differences between the group augmented with Alloderm® and the group treated with vestibuloplasty. The mean reduction in GI for the Alloderm® group was approximately 1.42, while for the vestibuloplasty group it was 1.06. In the 2012 study, after a 1-year follow-up, the mean decrease in GI was 1.06 in both the FGG and vestibuloplasty groups.

In the 15-year retrospective study, a statistically significant difference in GI scores was observed between baseline and the 15-year follow-up in both groups. Interestingly, the study conducted by Mariano (2009) reported controversial results, with GI reduction being greater in the group treated with Mucograft® compared to the group treated with CTG after 6 months. Therefore, combined with the evaluation data after the PIKM-W widening procedure, greater PIKM-W was associated with lower GI and BOP, particularly when autogenous grafts were used in the augmentation surgery (Sanz et al., 2009; Basegmez et al., 2012, 2013; Papi & Pompa, 2018).

Peri-implant probing pocket depth changes after PIKM-W augmentation. Peri-implant probing pocket depth (PPD) was measured from the soft tissue margins to the

Table 6. Gingival index/ Bleeding on Probing (GI/BOP) value before and after augmentation surgery in relation to PIKM width.

STUDY (YEAR)	OBS TIME	SURGICAL INTERVENTION	BASELINE PIKM WIDTH (MM)	BASELINE GI/BOP	FOLLOW-UP PIKM WIDTH (MM)	FOLLOW-UP GI/BOP
Basegmez (2013)	6 mo	FGG	0.89 ± 0.31	1.57 ± 0.32	2.57 ± 0.50	0.19 ± 0.17
		Allo	0.89 ± 0.31	1.71 ± 0.19	1.58 ± 0.37	0.29 ± 0.33
Basegmez (2012)	1 yr	FGG	0.75 ± 0.36	1.34 ± 0.78	2.36 ± 0.49	0.28 ± 0.52
		VP	0.67 ± 0.32	1.43 ± 0.62	1.83 ± 0.73	0.37 ± 0.55
Papi (2018)	1 yr	Mucoderm	1.35 ± 0.32	NK	5.67 ± 2.12	0.08
Park (2017)	15 yr	ASTG	4.33 ± 0.94	0.46 ± 0.16	3.64 ± 1.27	0.71 ± 0.23
		Non-graft		0.65 ± 0.26		0.83 ± 0.16
Sanz (2009)	6 mo	CTG	0.2	0.1	2.6	0.3
		Mucograft	0.40	0.3	2.5	0.2

FGG = Free Gingival Graft; Allo = Alloderm; VP = Vestibular Preservation; ASTG = Apically Shifted Tissue Graft; CTG = Connective Tissue Graft; GI = Gingival Index; BOP = Bleeding on Probing; PIKM = Peri-implant Keratinized Mucosa width; NK = Not Known; " ± " indicates mean ± standard deviation.

bottom of the peri-implant sulcus. Among the selected studies presented in **Table 7**, PPD was examined post-operatively, with overall changes ranging between 0.1 mm and 1.47 mm. Only one study, conducted by Basegmez (2013), reported a significant reduction in PPD. After a 6-month follow-up, PPD in both the FGG and Alloderm® groups was reduced to 3.33 ± 0.37 mm and 3.22 ± 0.15 mm, respectively, compared to the initial PPD values of 4.8 ± 0.58 mm in both groups.

Table 7. Probing Pocket Depth (PPD) Value Differences Before and After Augmentation in Relation to PIKM Width.

STUDY (YEAR)	OBS TIME	SURGICAL INTERVENTION	BASELINE PIKM WIDTH (MM)	BASELINE PI	FOLLOW-UP PIKM WIDTH (MM)	FOLLOW-UP PI
Basegmez (2013)	6 mo	FGG	1.01 ± 0.34	1.38 ± 0.45	2.57 ± 0.50	0.12 ± 0.16
		Allo	0.89 ± 0.31	1.12 ± 0.15	1.58+0.37	0.35 ± 0.29
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		Non-graft	—	1.31 ± 0.19	—	1.50 ± 0.25

FGG = Free Gingival Graft; Allo = Alloderm; VP = Vestibular Preservation; ASTG = Apically Shifted Tissue Graft; PI = Plaque Index; PIKM = Peri-implant Keratinized Mucosa width; "—" indicates data not reported.

However, in Basegmez's 1-year follow-up study, PPD increased by 0.09 mm instead of decreasing. Similarly, a 15-year study reported an elevation of 0.38 mm in PPD when the surgery was augmented with autogenous soft tissue grafts (ATSG). Two studies (Lorenzo, 2011; Zucchelli, 2018) reported no difference in PPD values before and after surgery. In the remaining studies, no significant association was found between PPD and sufficient PIKM-W. For example, studies utilizing Mucograft® conducted by Lorenzo (2011) and Mariano Sanz (2009) demonstrated a reduction in PPD after a 6-month follow-up, but the reduction was not statistically significant.

Based on all the data presented in **Table 7**, PPD values following PIKM-W augmentation, whether with autogenous or xenogenic graft material, showed no statistically significant differences. No clear relationship between PIKM-W and PPD was identified.

Effect of PIKM-T on marginal bone loss. Thin vertical soft tissue has been recognised as a crucial factor contributing to early marginal bone loss around dental implants

(Linkevicius et al., 2010, 2015b; Puisys et al., 2019). As a result, several methods and materials have been developed to increase peri-implant keratinised mucosa thickness (PIKM-T). Eight out of the 19 selected articles (summarised in **Supplemental Table S1**) explored the relationship between mucosal thickness and marginal bone loss. These studies had observation periods ranging from 3 months to 3 years, with most of them being 1-year follow-up studies.

Thin mucosa, defined as a thickness of less than 2 mm, was associated with a higher risk of marginal bone loss, while thick biotypes (wider than 2 mm) demonstrated minimal bone loss. In the two studies by Linkevicius (2009), thick mucosa was correlated with marginal bone loss of less than 0.2 mm postoperatively. In contrast, thin mucosa exhibited significant marginal bone loss of approximately 1.4 mm. In Linkevicius's first study, two groups were compared: the thin biotype group showed nearly 8 times more marginal bone loss in the mesial aspect than in the distal aspect compared to the thick mucosa group. Specifically, thin mucosa showed 6 times more mesial marginal bone loss and 14 times more distal marginal bone loss compared to thick biotypes.

In the second study, similar trends were observed. Thin mucosa had a mean marginal bone loss of 1.35 mm, while thick mucosa showed only 0.12 mm of bone loss, representing an almost 11-fold difference. In another three studies utilising Alloderm® to augment PIKM-T, marginal bone loss following augmentation surgery ranged from 0.19 mm to 0.34 mm. In cases of thin mucosa, marginal bone loss showed statistically significant differences, with approximately 5 times more mesial bone loss compared to sites where thin mucosa was augmented with Alloderm®. At distal sites, marginal bone loss was about 6 times lower when thin mucosa was augmented (Linkevicius et al., 2015a). In both studies that used Alloderm®, no significant difference was found between mesial and distal marginal bone loss. For thick mucosa, marginal bone loss at both mesial and distal sites varied between 0.2 mm and 0.3 mm, with no statistically significant differences (Puisys & Linkevicius, 2015; Linkevicius et al., 2015a).

The remaining four studies explored different methods and materials for augmenting PIKM-T. The initial situation was thin mucosa, which increased by 1.0 mm to 2.21 mm following surgical augmentation across all studies (Speroni et al., 2010; Puisys et al., 2015, 2019; D'Elia et al., 2017). Alloderm® achieved the greatest increase in PIKM-T, with a gain of 2.21 mm after surgery; however, the observation period was only 3 months, and longer-term follow-up is needed to confirm these results. Mucoderm®, a newly developed xenogenic material, showed promising results with a 1.8 mm increase in mucosal thickness after PIKM-T augmentation (Puisys et al., 2019). In a study with a 3-year follow-up (Speroni et al., 2010), autogenous materials were used, and mucosal thickness increased in both thin and thick biotypes. However, thin mucosa exhibited a gain of 2.14 mm, approximately 3 times more than thick mucosa during this procedure.

In conclusion, thin peri-implant mucosa may contribute to early marginal bone loss. If the tissue thickness is ≤ 2 mm, marginal bone loss can reach up to 1.65 mm (Linkevicius et al., 2015). However, thickening thin mucosa using either autogenous or xenogenic materials can significantly reduce bone resorption. Implants with initially thick mucosa tend to experience minimal marginal bone loss (Linkevicius et al., 2009a, 2015a; Puisys & Linkevicius, 2015).

4 Discussion

The aim of this study was to determine the efficiency of different augmentation materials in increasing the width and thickness of peri-implant keratinized mucosa (PIKM) and in achieving stable peri-implant health. To this end, various clinical parameters were analysed for different techniques employed, and the initially achieved PIKM width and thickness were assessed.

Since keratinized mucosa around dental implants is closely correlated with soft tissue health, inadequate PIKM leads to peri-implant soft tissue inflammation. Consequently, various surgical methods and materials (primarily autografts and xenografts) were evaluated in this study to achieve sufficient PIKM width (PIKM-W) and PIKM thickness (PIKM-T). The studies examined focused on allografts (such as Alloderm®), autogenous graft materials (Free Gingival Grafts [FGG] and Connective Tissue Grafts [CTG]), and xenogenic materials (Mucograft® and Mucoderm®).

Autografts generally appeared to be the most reliable method for achieving stable peri-implant keratinized mucosa width. For instance, when combined with an apically positioned flap, the final gain in keratinized mucosa in the autograft group was nearly double that of the vestibuloplasty group. While both methods exhibited a gradual reduction in the width of keratinized mucosa around implants over time due to shrinkage or muscle fibre reattachment, the relapse rate was higher in the vestibuloplasty group (Basegmez, 2012).

Allografts such as Alloderm®, an acellular dermal matrix, also produced favourable results in PIKM-W augmentation surgery. Initially intended to cover burn wounds, Alloderm® is a structurally integrated basement membrane complex containing collagen bundles and elastic fibres as its main components. Over time, this allograft degrades as it is replaced by host tissue. Several clinical studies have demonstrated the efficacy of Alloderm® in increasing the width of keratinized tissue around dental implants (Wei et al., 2000; Yan et al., 2006; Park, 2006; Imberman, 2007).

Park (2006) analysed the clinical efficacy of Alloderm® in increasing peri-implant keratinized mucosa width, reporting satisfactory results, with a mean increase of 2.2 mm after 6 months. However, the gain in keratinized mucosa was significantly higher in the CTG group than in the Alloderm® group (5.5 mm versus 2.5 mm), and the contraction rate for Alloderm® was substantial (71%). Additionally, the use of allografts derived from human cadavers raises ethical concerns and the potential risk of disease transmission (Sanz et al., 2009).

It is important to note that the studies on Alloderm® were not randomised controlled trials, so their results should be interpreted with caution. Moreover, there is a lack of randomised controlled trials comparing the outcomes of acellular dermal matrix allografts with those of free gingival grafts. For this reason, Basegmez (2013) could not directly compare the findings of the current investigation with those of previous studies. In terms of the width of the attached mucosa, the postoperative outcomes extracted 1 month after the procedures were similar across the grafting techniques. However, throughout the entire observation period, the width of the attached mucosa was greater with free gingival grafts, and the final amount of keratinized mucosa was significantly larger at sites treated with free gingival grafts. A stepwise decrease in the width of attached mucosa occurred in both groups until the end of the study period due to shrinkage of the allograft or the autogenous graft. However, this postoperative relapse in the amount of attached mucosa was greater with Alloderm®. Wei et al. (2002) and Park (2006) also reported relapses at 6 months following

ADM application, with a percentage of 71% around natural teeth and 50% around implants. Based on this data, it can be expected that peri-implant keratinized tissue created using free gingival grafts has a higher capacity to maintain stability, whereas Alloderm® appears to be less resistant to shrinkage.

The classic study by Karring et al. (1975) suggested that only connective tissues possess the ability to induce keratinization of the epithelium and that the genetics of the connective tissue determine the characteristics of the epithelium that will form. In the present investigation, Alloderm® was placed onto non-keratinized alveolar mucosa, while free gingival grafts (FGG) originating from the keratinized gingiva in the palate transferred their characteristics to the recipient mucosa. Additionally, it has been reported that the resultant tissue types of acellular dermal matrix (ADM) allografts resemble scar tissue (Wei et al., 2002). This phenomenon may account for the greater contraction observed with ADM allograft application.

Beyond its ability to increase peri-implant keratinized mucosa, the plaque index and gingival indices in both groups decreased significantly in the first six months, according to the literature. However, the Alloderm® group reported higher plaque and local inflammation scores, and the reduction in pocket depth was less after six months, possibly due to compromised oral hygiene following postoperative relapse.

According to the studies mentioned, Alloderm® has certain limitations. First, due to ethical concerns, not all countries have approved this material for use in clinical studies. Furthermore, pain scores (as measured by the Visual Analogue Scale), healing time, and aesthetic outcomes were not statistically measured in the studies reviewed. Another limitation is that relevant clinical parameters, particularly the thickness of the peri-implant keratinized mucosa (PIKM) after augmentation, were not measured. These factors should be included in future investigations to better assess the long-term clinical benefits of Alloderm® as a substitution material.

Xenografts were introduced to the market due to the limitations of autografts and allografts. Collagen devices of xenogenic origin have been widely used in clinical dentistry, primarily as collagen barrier membranes in guided bone regeneration and tissue regeneration procedures (Hammerle & Jung, 2003), and for the management of extraction sockets (Jung et al., 2004).

Mucograft® was mentioned in three papers. In 2009, Mariano conducted a comparative study between connective tissue grafts (CTG) and Mucograft®. The results showed a statistically significant amount of keratinized tissue achieved with both surgical procedures, with mean widths of 2.60 mm and 2.50 mm for CTG and Mucograft®, respectively. These results were more modest compared to those reported by Orsini et al. (2004), which could be attributed to the study sites, as many treated locations were posterior teeth or implant sites with shallow vestibules and high muscle attachments, which make establishing a wide band of keratinized tissue difficult.

A five-year randomised clinical trial reported in 2015 by Schmitt compared the use of the porcine collagen matrix (Mucograft®) to free gingival grafts (FGG) to increase the keratinized mucosa around implants. The primary outcome was the width of keratinized mucosa over time. The study demonstrated that the greatest loss of vestibular depth occurred in the first three months post-surgery (28.7% in the FGG group and 34% in the Mucograft® group), with no statistically significant difference between the two. However, shrinkage continued more in the Mucograft® group compared to the FGG group by the five-year mark. At the five-year point, the FGG group had a remaining mean width of 8.40 mm, compared to 6.15 mm in the Mucograft® group, showing that FGG is more stable over time (Schmitt et al., 2016).

Mucoderm®, a more recent xenogenic material, has demonstrated greater structural stability than Mucograft®. This natural three-dimensional collagen tissue matrix derived from porcine dermis supports revascularization, fast soft tissue integration, and serves as a valid alternative to patient-derived grafts. Mucoderm® has been shown to produce favourable outcomes in PIKM augmentation, with studies reporting a mean gain of 1.8 mm in tissue thickness (Puisys et al., 2019). However, long-term randomised controlled trials are necessary to verify these results.

Conclusions

All three materials—Alloderm®, Mucograft®, and Mucoderm®—have demonstrated efficacy in increasing PIKM width and thickness, reducing marginal bone loss, and improving peri-implant health. Nevertheless, autograft augmentation (FGG) combined with an apically positioned flap remains the gold standard for this surgical procedure despite its drawbacks, such as post-operative morbidity, increased pain, and longer surgical times. Xenogenic materials, particularly Mucograft® and Mucoderm®, offer promising alternatives for short-term use and in cases where autografts cannot be harvested.

The dimensions of peri-implant keratinized mucosa have a direct influence on clinical parameters of inflammation, such as plaque score and bleeding indices. Crestal mucosal thickness also plays a crucial role in maintaining marginal bone around implants. If the mucosal thickness is less than 2 mm, crestal bone loss may occur, while thicker mucosa (greater than 3 mm) contributes to more stable marginal bone conditions. Although the predictive value of PIKM width remains controversial, a minimum of 2 mm is still recommended to maintain the stable peri-implant condition.

Acknowledgements

The authors would like to thank Professor Dr. med. dent. Thomas Stamm, thank you for your assistance in ensuring that the manuscript complies with the journal's format standards. We appreciate commitment and support throughout the submission process. Not applicable.

Ethical approval

No ethical approval was required for this study as it did not involve human participants,animal subjects, or sensitive data. This study falls under the category of data collectionwithout participant identification.No ethical approval was required for this study as it did not involve human participants, animal subjects, or sensitive data. This study falls under the category of data collection without participant identification.

Consent for publication

Not applicable.

Authors' contributions

The author(s) declare that all the criteria for authorship designated by the International Committee of Medical Journal Editors have been met. More specifically, these are: (a)

Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work; AND (b) Drafting the work or revising it critically for important intellectual content; AND (c) Final approval of the version to be published; AND (d) Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Competing interests

The author(s) declare that there are no competing interests related to this work.

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