Association between keratinized mucosa width and peri-implant diagnostic parameters in Asian maintenance compliers: A Cross-sectional study.

Sukuma Manopattanasoontorn, Kakanang Supanimitkul, Teerawut Tangsathian, Navawan Sophon, Sirikarn P. Arunyanak and Kajorn Kungsadalpipob

Department of Periodontology, Faculty of Dentistry, Chulalongkorn University, Bangkok, Thailand.

Abstract

Aims: To investigate the association between the keratinized mucosa (KM) width and peri-implant diagnostic parameters in implant maintenance.

Methods: A total of 331 posterior implant-supported fixed prostheses in 165 patients were evaluated. Demographic data were collected from history taking and treatment records. Plaque index, bleeding index, probing depth, mucosal recession, and bone level in relation to buccal keratinized mucosa were examined. The Kruskal-Wallis, Mann-Whitney U, and multivariable models were used as the statistical tests.

Results: The majority of subjects attended implant maintenance at least once a year and demonstrated optimal oral hygiene. keratinized mucosa width ranged from 0–7 mm. Considering the keratinized mucosa widths, a marked recession was determined at < 2 mm keratinized mucosa and less recession was determined at > 2 mm keratinized mucosa. The multivariate model indicated that < 2 mm keratinized mucosa was significantly associated with increased mucosal recession (B = 0.12; CI: 0.01, 0.23). Plaque accumulation, mucosal inflammation, and interproximal bone level were not related to keratinized mucosa width after adjusting for oral hygiene, smoking status, history of chronic periodontitis, and implant prosthesis type.

Conclusion: The presence of < 2 mm of KM width was associated with mucosal recession. However, other peri-implant diagnostic parameters were not associated with the width of keratinized mucosa.

Keywords: Dental implants, keratinized mucosa, peri-implant tissues, implant maintenance

Introduction

Peri-implant diseases are major pathological conditions that occur during the implant maintenance phase, leading to implant failure and potential loss (Pjetursson *et al.*, 2004). Peri-implant mucositis, a subtype of peri-implant diseases, is a reversible inflammatory event that affects the soft tissues adjacent to a dental implant. The diagnosis is mainly based on clinical inflammation such as bleeding on gentle probing, erythema, swelling, or suppuration. The progression of disease can lead to considerable peri-implant tissue destruction, including surrounding bone loss. When this condition involves progressive loss of bone it is classified as peri-implantitis (Berglundh *et al.*, 2018). According to a meta-analysis, the prevalence of peri-implant mucositis is relatively high (ranging from 19–65%) and therefore, this inflammatory process needs to be better controlled to prevent the onset of peri-implantitis during implant maintenance (Derks *et al.*, 2015; Jepsen *et al.*, 2015; Monje *et al.*, 2016).

There is clinical evidence that untreated peri-implant mucositis during implant maintenance is associated with a higher incidence of peri-implantitis after 5 years (Costa *et al.*, 2012). Because the results of peri-implantitis treatment are unpredictable, early detection and management

Correspondence to: Assist. Prof. Kajorn Kungsadalpipob, Department of Periodontology, Faculty of Dentistry, Chulalongkorn University, 34 Henry Dunant Rd., Wangmai, Patumwan, Bangkok, 10330, Thailand. Email: kajornk@gmail.com

of peri-implant mucositis are essential to prevent the development of peri-implantitis (Salvi *et al.*, 2017). After implant placement, regular monitoring of peri-implant diagnostic parameters and pathological peri-implant signs is recommended for long-term peri-implant tissue stability (Heitz-Mayfield *et al.*, 2014).

Many clinicians and researchers suggest that the presence of a band of keratinized mucosa (KM) around dental implants is needed to support peri-implant tissue health and stability. Poorer peri-implant diagnostic parameters are reported at implant sites with inadequate keratinized mucosa (Chung *et al.*, 2006; Bouri *et al.*, 2008; Zigdon *et al.*, 2008; Adibrad *et al.*, 2009; Kim *et al.*, 2009; Crespi *et al.*, 2010; Boynuegri *et al.*, 2013). The lack of keratinized mucosa is associated with PGE_2 upregulation (Zigdon and Machtei, 2008), which may explain the less efficient resolution of experimental mucositis in these situations compared to implants with ≥ 2 mm keratinized mucosa (Schwarz *et al.*, 2018a). The contribution of the keratinized mucosa towards peri-implant health is controversial.

In summary, there are studies supporting the necessity of adequate keratinized mucosa. In contrast, when strict maintenance schedules and oral hygiene are consistently performed by patients, no association between keratinized mucosa width and peri-implant diagnostic parameters is observed (Wennstrom, 1987; Esper *et al.*, 2012; Frisch *et al.*, 2015; Lim *et al.*, 2019).

Based on these disparate findings, this study aimed to investigate the association between the keratinized mucosa width and peri-implant diagnostic parameters in the posterior region during implant maintenance phase, while adjusting for known confounding factors. Secondary to this, a number of peri-implant disease risk factors, including oral hygiene, smoking status, diabetes, history of chronic periodontitis, and implant prosthesis type were taken into consideration in the model analysis (Renvert *et al.*, 2015; Dalago *et al.*, 2017; Schwarz *et al.*, 2018b; Isler *et al.*, 2019).

Materials and methods

Ethics and Study design

The study protocol was approved by the Ethics Committee of the Faculty of Dentistry at Chulalongkorn University (No. 005/2019). This cross-sectional study is part of an implant survey study that began in 2016 and is ongoing. The full study protocol has been previously described (Arunyanak *et al.*, 2019).

Patients who received dental implant(s) from various clinics at the Faculty of Dentistry, Chulalongkorn University from 1996–2014 and who adhered to implant maintenance therapy were recruited. The implants included in the study were (1) placed in the posterior region, (2) supported fixed dental prosthesis, and (3) were in prosthetic function ≥ 1 year. Exclusion criteria comprised implants: (1) placed in the anterior region, or (2) supported removable dental prosthesis. All participating patients received a description of the study objectives and signed an informed consent.

Data collection

The demographic data, e.g. age, gender, medical and dental history, smoking habits, history of periodontal treatment, oral hygiene status, maintenance visits, and implant prosthesis type, were obtained through history taking, chart review, and dental examination.

History taking, clinical examination, and radiographic evaluation were performed at the survey visit. Periodontal care at the implant sites was performed according to the Cumulative Interceptive Supportive Therapy (CIST) protocol (Lang *et al.*, 2004). The patients were subsequently enrolled into individual maintenance schedules.

Keratinized mucosa (KM) and Peri-implant diagnostic parameters

The keratinized mucosa width was measured in millimeters at the narrowest distance between the gingival margin and the mucogingival junction at the buccal aspect using visual and functional methodologies to identify the color, texture, and mobility differences between the keratinized mucosa and non-keratinized oral mucosa (Figure 1).

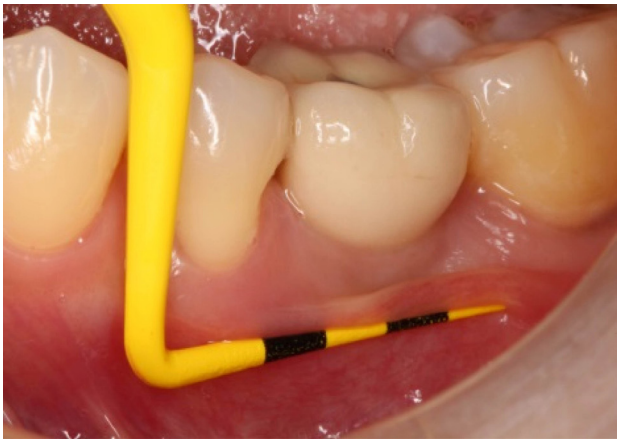

Figure 1. Keratinized mucosa (KM) width measurement using functional method to identify mucogingival junction.

Peri-implant diagnostic parameters were measured at six sites (mesiobuccal, mid-buccal, distobuccal, mesiolingual, mid-lingual, and distolingual) of each implant using a plastic periodontal probe (12-UNC COLORVUE®; Hu-Friedy, Chicago, IL, USA.). The following parameters were assessed:

Modified plaque index (mPLI) (Mombelli *et al.*, 1987) – scored from 0–3: 0 – no plaque detection, 1 – plaque recognized by running a probe across the marginal surface of the implant, 2 – plaque seen with the naked eye, and 3 – abundant soft matter.

Modified bleeding index (mBI) (Mombelli *et al.*, 1987) – scored from 0–3: 0 – no bleeding when a periodontal probe is passed along the gingival margin adjacent to implant, 1 – isolated bleeding spots visible, 2 – blood forms a confluent red line on the margin, 3 – heavy or profuse bleeding.

Probing depth (PD) – measured in millimeters from the mucosal margin to the base of implant sulcus.

Mucosal recession (RE) – measured in millimeters from the restorative margin to the mucosal margin.

Tissue phenotype (Kan *et al.*, 2003) – classified as "thin" or "thick": thin – probe outline could be seen through mucosa, thick – probe outline could not be seen.

Three dentists (TT, KS, and NS) calibrated by an experienced periodontist (KK) performed all of the clinical measurements. Both intra- and inter- were determined by measuring the diagnostic parameters (modified plaque index, modified bleeding index, probing depth, mucosal recession, and keratinized mucosa width) on five volunteer subjects who had at least one dental implant restoration. Cohen's Kappa coefficient was used to determine the average intra- and inter-examiner reliability, which was 0.891 and 0.839, respectively examiner (Appendix Table A1).

Radiographic evaluation and measurements

Standardized periapical radiographs were obtained using a positioning device and the long cone parallel technique. The digital radiographs were imported by Infinitt software (Infinitt version 2: Infinitt Co., Seoul, Korea) and measurements were taken with the software tools. The interproximal bone level (BL) was measured in millimeters at the mesial and distal aspects of each implant from a suitable reference level to the most coronal bone-implant contact point (Figure 2). Because various implant systems were included in the study (Table 1), a suitable reference level at the fixture-abutment or abutment-crown connection was defined for each system (Arunyanak *et al.*, 2019).

Radiographic evaluation was conducted in a blinded manner by one examiner with expertise in periodontology (KK). The intra-examiner reliability for this particular examination was held by measuring peri-implant bone level of 30 randomly selected radiographs on the Faculty's database. Each measurement was performed twice within a 1 week interval, and the intraclass correlation coefficient was 0.86.

Confounding variables and Peri-implant classifications

Oral hygiene status (Lertpimonchai *et al.*, 2017) – classified as "good-to-fair" when modified plaque index < 2, and "poor" when modified plaque index ≥ 2

Smoking status (Rinke *et al.*, 2011) – classified as "non-smoker" in patients without a history of smoking or had quit smoking for ≥ 5 years, and "smoker" in patients who smoked at the time of the survey visit or had quit smoking for < 5 years

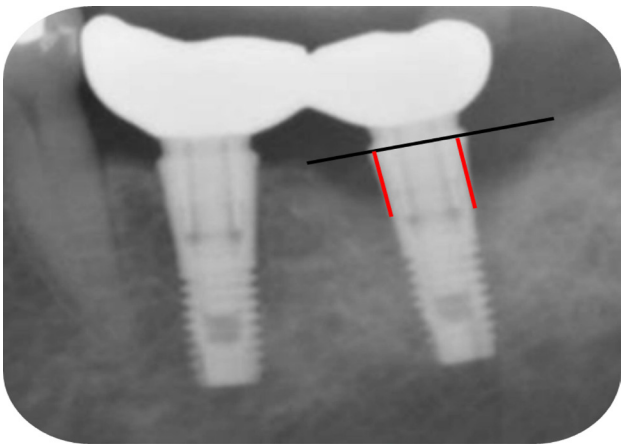

Figure 2. Interproximal bone level (BL), i.e., distance from the implant shoulder to the most coronal bone-implant contact point (mm), represented by red line at mesial and distal sites of implant 37.

Diabetes – classified as "diabetic" in patients with a history of ≥ 126 mg/dL fasting plasma glucose, or ≥ 6.5% A1C, or taking anti-diabetic medicine at the time of the survey visit; "non-diabetic" in patients without the above criteria

History of chronic periodontitis (Armitage, 2004) – classified as "with history" in patients with bleeding on probing + probing depth ≥ 4 mm at ≥ 30% of total sites before implant placement; "without history" in patients without the above criteria

Implant prosthesis type – classified as "screw-retained", or "cement-retained" crown

Implant status based on the absence of baseline data (Renvert *et al.*, 2018) – classified as "peri-implant health" in implants with a lack of profuse bleeding on probing + interproximal bone level < 3 mm, "peri-implant mucositis" in implants with profuse bleeding on probing + interproximal bone level < 3 mm and "peri-implantitis" in implants with profuse bleeding on probing and interproximal bone level ≥ 3 mm.

Statistical analysis

The sample size calculation was conducted with G*Power software version 3.0.10 (Universitat Kiel, Universitat Dusseldorf, Universitat Mannheim, Germany). A total of 165 patients were included in the study which was sufficiently large to have 95% power with α=0.05 in detecting the association between keratinized mucosa width and diagnostic parameters as significant ($p < 0.05$).

The normality of the data variables was confirmed by the Kolmogorov-Smirnov test. Descriptive statistics were used to determine the frequency of each variable. To represent the effect of keratinized mucosa, mean diagnostic parameters (modified plaque index, MBI, probing depth, and mucosal recession) at the buccal

Table 1. Demographic data of study population

Characteristics	Patient (n=165) n (%)	Implant (n=331) n (%)
Age (years)	58.95±11.58 (range 18-79)	
Time after implant placement (months)	62.50±39.56 (range 16-198)	
Time after implant loading (months)	53.91±39.55 (range 12-191)	
Gender		
Male	71 (43.0)	124 (37.5)
Female	94 (57.0)	207 (62.5)
Smoking status		
Non-smoker	144 (87.3)	290 (87.6)
Former or current smoker	21 (12.7)	41 (12.4)
Systemic condition		
Non-diabetes	149 (90.0)	304 (91.8)
Diabetes	16 (10.0)	27 (8.2)
Oral hygiene status		
Good or fair	154 (93.3)	309 (93.4)
Poor	11 (6.7)	22 (6.6)
History of periodontal disease		
Without history of chronic periodontitis	101 (61.2)	188 (56.8)
With history of chronic periodontitis	64 (38.8)	143 (43.2)
Implant status		
Peri-implant health	96 (58.2)	226 (68.3)
Peri-implant mucositis	48 (29.1)	76 (23.0)
Peri-implantitis	21 (12.7)	29 (8.7)
Implant location		
Posterior maxilla		117 (35.3)
Posterior mandible		214 (64.7)
Premolar area		101 (30.5)
Molar area		230 (69.5)
Type of implant prosthesis		
Screw-retained crown		88 (26.6)
Cement-retained crown		243 (73.4)
Implant type		
Bone level		205 (61.9)
Tissue level		126 (38.1)
Implant system		
Straumann		123 (37.2)
AstraTech		105 (31.7)
Zimmer		40 (12.1)
Noble replace		17 (5.1)
Intra-lock		16 (4.8)
Others		30 (9.1)

aspect (mesiobuccal, mid-buccal, and distobuccal) of each implant and mean radiographic bone level (BL) at the mesial and distal sites were calculated and reported based on the different keratinized mucosa widths. To identify the minimum keratinized mucosa width that would negatively contribute to peri-implant pathological conditions, the Kruskal-Wallis test and pairwise comparisons with Dunn-Bonferroni post hoc tests were used to assess the difference in diagnostic parameters between keratinized mucosa widths (median score value was used for an estimation of the number of implants in each width). This minimum keratinized mucosa width was then used as a cut-off point to dichotomize the implants into two groups (keratinized mucosa ≥ 2 mm vs. keratinized mucosa < 2 mm). Statistical differences of mean diagnostic parameters between both groups were analyzed by using Mann-Whitney U test.

Univariate and multivariate regression analysis or a multivariable model were then used to verify the association between keratinized mucosa width (independent variable) and all peri-implant diagnostic parameters (dependent variables). Categorical parameters, modified plaque index and modified bleeding index, were classified into "yes" (modified plaque index ≥ 1, modified bleeding index ≥ 2) or "no" (modified plaque index < 1, modified bleeding index < 2), and were evaluated using binary logistic regression, while multiple linear regression analysis was used to evaluate the continuous parameters (mucosal recession, probing depth, and interproximal bone level). The confounding factors measured were oral hygiene status, smoking status, diabetes, history of chronic periodontitis, and implant prosthesis type. Odds ratios (OR) and unstandardized coefficients (B) with 95% confidence intervals (CI) were represented as the degree of association. All statistical analysis were performed by IBM SPSS Statistics version 22.0 (IBM, Armonk, NY) with the level of significance established at 5%.

Results

Demographic and implant characteristics

The demographic data for our study population are shown in Table 1. This study comprised 331 posterior dental implant-supported fixed prostheses from 165 subjects (71 male and 94 female) with a mean age of 59 ±11 years. Seventy percent of subjects attended implant maintenance at least once a year (≥ 1x per year, 3–12 month interval). Most subjects were non-smokers (87.3%), non-diabetic (90%), and demonstrated good-to-fair oral hygiene status (93.3%). Sixty-four subjects (38.8%) had a history of chronic periodontitis and received completed comprehensive periodontal treatment before implant placement.

In total, 14 implant systems were studied, the majority of implants were Straumann (37.2%) and AstraTech (31.7%). Two-thirds of implants were placed in posterior mandible (64.7%) or molar area (69.5%). The prevalence of peri-implant mucositis (29.1%) and peri-implantitis (12.7%) were present at the patient level with an average of 4.5 years follow up after implant loading.

Keratinized mucosa and peri-implant diagnostic parameters

The keratinized mucosa width ranged from 0–7 mm (mean 2.32±1.38 mm) and the diagnostic parameter values can be seen in Table 3. Negligible plaque accumulation was observed at the implant sites (0.13±0.29). A relatively low modified bleeding index (0.29±0.45), mucosal recession (0.10±0.45 mm), probing depth (2.86±0.78 mm), and interproximal bone level (0.98±1.34 mm) were present.

The mean peri-implant diagnostic parameters (modified plaque index, modified bleeding index, mucosal recession, probing depth, and interproximal bone level) were computed for different keratinized mucosa widths and the outcomes are presented in Table 2. Decreased mucosal recession was observed as keratinized mucosa width increased. A change in mucosal recession primarily occurred at the 2 mm keratinized mucosa cut-off point compared with no keratinized mucosa ($p < 0.06$); however, no clear trend between modified plaque index, modified bleeding index, and interproximal bone level ; and keratinized mucosa width was observed. Therefore, the 2-mm keratinized mucosa width was selected as the cut-off point to dichotomize implants into 2 groups (keratinized mucosa ≥ 2 mm versus keratinized mucosa < 2 mm). Two hundred and forty implants (72.5%) were categorized into the keratinized mucosa ≥ 2 mm group and 91 implants (27.5%) were categorized into the keratinized mucosa < 2 mm group. Mean keratinized mucosa width and diagnostic parameter values of both groups are shown in Table 3. Mean mucosal recession of keratinized

Table 2. Peri-implant diagnostic parameters in relation to the width of keratinized mucosa

KM width (mm)	n	Peri-implant diagnostic parameters				
		mPLI mean±SD	mBI mean±SD	RE mean±SD	PD mean±SD	BL mean±SD
0 mm	31	0.16±0.04	0.26±0.07	0.39±0.17	2.77±0.11	1.36±0.29
1 mm	60	0.07±0.02	0.22±0.04	0.08±0.04	2.65±0.07	0.89±0.18
2 mm	107	0.10±0.03	0.33±0.05	0.12±0.05‡	2.83±0.07	0.99±0.13
3 mm	62	0.16±0.04	0.23±0.04	0.03±0.02*	2.80±0.07	0.93±0.14
4 mm	52	0.20±0.05	0.42±0.07	0.02±0.02*	3.22±0.16†	1.01±0.21
≥5 mm	19	0.23±0.09	0.25±0.10	0.00±0.00	3.08±0.21	0.67±0.19
Total	331	0.13±0.29	0.29±0.45	0.10±0.45	2.86±0.78	0.98±1.34

Kruskal-Wallis test, Pairwise comparisons using Dunn-Bonferroni post hoc tests
‡ Marginally significant difference from KM 0 mm, $p = 0.06$
* Statistically significant difference from KM 0 mm, $p < 0.05$
† Statistically significant difference from KM 1 mm, $p < 0.01$
KM: keratinized mucosa; mPLI: modified plaque index; mBI: modified sulcus bleeding index; RE: mucosal recession; PD: probing depth; BL: interproximal bone level.

Table 3. Peri-implant diagnostic parameters between keratinized mucosa groups

Parameters	Total (n = 331) mean±SD	KM < 2 mm (n = 91) mean±SD	KM ≥ 2 mm (n = 240) mean±SD	Mean difference mean±SD
KM width	2.32±1.38	0.66±0.05	2.95±0.07	-2.29±0.11†
mPLI	0.13±0.29	0.10±0.20	0.15±0.32	-0.05±0.04
mBI	0.29±0.45	0.23±0.35	0.31±0.48	-0.08±0.06
RE	0.10±0.45	0.19±0.60	0.07±0.37	0.12±0.06†
PD	2.86±0.78	2.69±0.58	2.93±0.84	-0.23±0.10*
BL	0.98±1.34	1.05±1.48	0.95±1.28	0.10±0.16

* Statistically significant difference, $p < 0.05$ (Mann-Whitney U test)
† Statistically significant difference, $p < 0.01$ (Mann-Whitney U test)
KM: keratinized mucosa; mPLI: modified plaque index; mBI: modified sulcus bleeding index; RE: mucosal recession; PD: probing depth; BL: interproximal bone level.

mucosa < 2 mm was significantly higher than keratinized mucosa ≥ 2 mm (mean difference 0.12±0.06mm). Conversely, probing depth was significantly lower in keratinized mucosa < 2 mm group (mean difference 0.23±0.10mm).

The univariate linear regression analysis revealed a positive correlation between < 2 mm keratinized mucosa and mucosal recession (B = 0.12; CI: 0.01, 0.23, $p = 0.029$) and a negative correlation between < 2 mm keratinized mucosa and probing depth (B = -0.23; CI: -0.42, -0.04; $p = 0.016$). Both associations (keratinized mucosa with mucosal recession and keratinized mucosa with probing depth) reached the significance level after controlling for oral hygiene status, smoking status, diabetes, history of chronic periodontitis, and implant prosthesis type (Table 4 and 5). keratinized mucosa < 2 mm was associated with increased mucosal recession (B = 0.12; CI: 0.01, 0.23; $p = 0.038$) and decreased probing depth (B = -0.27; CI: -0.45, -0.10, $p = 0.003$). Whereas, there were no associations between keratinized mucosa width and plaque accumulation (modified plaque index ≥ 1), mucosal inflammation (modified bleeding index ≥ 2), or interproximal bone level (BL) ($p > 0.05$).

From multivariate regression analysis for mucosal recession and probing depth, the significant association was also observed in history of chronic periodontitis, probing depth ≥ 4 mm, modified plaque index ≥ 1, and modified bleeding index ≥ 2 at buccal aspect (Tables 4

Table 4. Multivariable model for the association between keratinized mucosa width and peri-implant mucosal recession (RE)

Recession model	Unstandardized coefficients		*p value*
	B	95% CI	
constant	-0.03	-0.15, 0.09	0.630
KM width (KM ≥ 2 mm vs. KM < 2 mm)	0.12	0.01, 0.23	0.038*
Oral hygiene status (good to fair vs. poor)	-0.11	-0.32, 0.09	0.283
Smoking status (non-smoker vs. smoker)	-0.10	-0.25, 0.06	0.221
Diabetes (non-diabetic vs. diabetic)	-0.03	-0.21, 0.15	0.750
History of chronic periodontitis (without vs. with history)	0.09	-0.02, 0.19	0.106
Type of implant prosthesis (screw vs. cement-retained)	0.04	-0.07, 0.16	0.434
PD ≥ 4 mm (no vs. yes)	0.12	0.02, 0.22	0.023*
mPLI ≥ 1 at implant site (no vs. yes)	0.01	-0.12, 0.12	0.977
mBI ≥ 2 at implant site (no vs. yes)	-0.01	-0.16, 0.13	0.863

Model accuracy: Adjusted $R^2 = 0.02$, $p = 0.089$
* Statistically significant, $p < 0.05$, † Statistically significant, $p < 0.01$
KM: keratinized mucosa; PD: probing depth; mPLI: modified plaque index; mBI: modified bleeding index; CI: confidence interval

Table 5. Multivariable model for the association between keratinized mucosa width and peri-implant probing depth (PD)

Probing depth model	Unstandardized coefficients		*p value*
	B	95% CI	
constant	2.68	2.50, 2.85	< 0.001†
KM width (KM ≥ 2 mm vs. KM < 2 mm)	-0.27	-0.45, -0.10	0.003†
Oral hygiene status (good to fair vs. poor)	0.19	-0.14, 0.52	0.268
Smoking status (non-smoker vs. smoker)	-0.04	-0.29, 0.21	0.773
Diabetes (non-diabetic vs. diabetic)	0.03	-0.26, 0.32	0.843
History of chronic periodontitis (without vs. with history)	0.24	0.08, 0.41	0.004†
Type of implant prosthesis (screw vs. cement-retained)	-0.04	-0.22, 0.14	0.681
mPLI ≥ 1 at implant site (no vs. yes)	0.37	0.18, 0.55	< 0.001†
mBI ≥ 2 at implant site (no vs. yes)	0.62	0.39, 0.85	< 0.001†

Model accuracy: Adjusted $R^2 = 0.16$, $p < 0.001$†
* Statistically significant, $p < 0.05$, † Statistically significant, $p < 0.01$
KM: keratinized mucosa; mPLI: modified plaque index; mBI: modified bleeding index; CI: confidence interval

and 5). The other models (Appendix Tables A2 – A4) revealed that poor oral hygiene, smoking, history of chronic periodontitis, cement-retained crown factors and probing depth ≥ 4 mm at buccal aspect had increased odds for modified plaque index ≥ 1, modified bleeding index ≥ 2, or interproximal bone level .

Discussion

Maintaining peri-implant tissue health during implant maintenance phase is important for the long-term success of dental implant restorations. An adequate keratinized mucosa width may be clinically relevant in supporting peri-implant tissue homeostasis. This study reports an association between keratinized mucosa width and buccal mucosal recession in posterior dental implant-supported fixed restorations. However, no association was observed between keratinized mucosa width and plaque accumulation, mucosal inflammation, and interproximal bone level in a population that adhered to implant maintenance therapy and demonstrated optimal oral hygiene.

The presence of < 2 mm keratinized mucosa was associated with increased mucosal recession (B = 0.12; CI: 0.01, 0.23, p = 0.029) in this study. This finding is consistent with other studies, where mucosal recession has been linked with a keratinized mucosa < 2 mm (Zigdon and Machtei, 2008; Adibrad *et al.*, 2009; Kim *et al.,* 2009; Schrott *et al.*, 2009). Zigdon and Machtei (2008) observed a moderate correlation between keratinized mucosa width and mucosal recession during supportive periodontal therapy (r = 0.41, p < 0.001), after loading 63 implants supported fixed prosthesis for 3 years. Conversely, the majority of our study subjects had minimal mucosal recession (0.10±0.45 mm), which may explain the mild association found between keratinized mucosa width and mucosal recession herein. This limited mucosal recession may be strongly related to peri-implant tissue phenotype as previously reported (Nisapakultorn *et al.*, 2010).

In addition, decreased probing depth was associated with keratinized mucosa < 2 mm (B = -0.23; CI: -0.42, -0.04; p= 0.016). This phenomenon had been explained in the study of Zigdon and Machtei (2008) that it might be related to the fact that greater mucosal recession in accordance with less pocket formation was commonly found in narrow keratinized mucosa regions. However, mean probing depth in each keratinized mucosa width group in the study did not exceed 4-5 mm (Table 2) which does not relate with a disease (Renvert *et al.*, 2018). Therefore, shallower probing depth may be a result of a reduced soft tissue height around dental implant with less keratinized mucosa band (Fuchigami *et al.*, 2017).

The analysis of mucosal recession variables indicated that < 2 mm keratinized mucosa remained significantly associated with increased mucosal recession (B = 0.12; CI: 0.01, 0.23; p= 0.038). Thus, 2 mm or more of keratinized mucosa may be important in supporting the existing peri-implant tissue during implant maintenance. Previous studies (Chung *et al.*, 2006; Bouri *et al.*, 2008; Adibrad *et al.*, 2009; Kim *et al.*, 2009; Schrott *et al.*, 2009; Crespi et al., 2010) also indicated that at least 2 mm of keratinized mucosa was required for maintaining a peri-implant health. Our study primarily observed a change in mean mucosal recession at 2-mm cut-off point (p = 0.06). Consequently, this width was used to further categorize implants into keratinized mucosa ≥ 2 mm and keratinized mucosa < 2 mm groups to investigate the association between keratinized mucosa and peri-implant diagnostic parameters. However, no association between keratinized mucosa width and modified plaque index, modified bleeding index, or interproximal bone level was found. A retrospective clinical study by Chung et al. (2006) found no association between < 2 mm keratinized mucosa and annual bone loss in posterior dental implants, however there was an association between keratinized mucosa and modified plaque index, and modified bleeding index. Furthermore, this study did not control for oral hygiene and smoking factors. In another cross-sectional study (Bouri *et al.*, 2008), more than 2-fold more bleeding on probing and increased peri-implant bone loss were detected at implant sites with < 2 mm keratinized mucosa after controlling for smoking status, mucosal thickness, and oral hygiene.

The differences in outcomes compared with previous observational studies might be explained by the following sample population characteristics: 1) Majority of subjects (70%) were implant maintenance compliers and 2) 93.3% of subjects had good-to-fair oral hygiene and negligible plaque deposits were observed at the implant sites (modified plaque index = 0.13±0.29). Implant maintenance has been shown to be a crucial factor for long-term dental implant success rates (Costa *et al.*, 2012, Gay *et al.*, 2016; Monje *et al.*, 2016; Rokn *et al.*, 2017). Although there was no specific recall interval for implant maintenance because it was tailored to the individual's risk profile, many studies suggested a minimum period of 6-12 months (Costa *et al.*, 2012; Gay *et al.*, 2016; Monje *et al.,* 2016). In the present study, 70% of the subjects attended recall for ≥ 1x per year (3–12 month interval). The influence of maintenance compliance on implants with a lack of keratinized mucosa has been addressed in several studies (Romanos *et al.*, 2015; Lim *et al.*, 2019; Monje *et al.*, 2019) . Increased adverse peri-implant conditions and prevalence of peri-implantitis were associated with < 2 mm keratinized mucosa in patients who were not regularly attending a minimum implant maintenance protocol (Monje and Blasi, 2019). Whereas, in a 5-year retrospective study where patients strictly followed maintenance schedules,

an nonsignificant association was found between keratinized mucosa width and peri-implant diagnostic parameters comprising marginal bone change, bleeding on probing, probing depth, and plaque index (Lim *et al.*, 2019). The results from this study are similar with our findings. Thus, keratinized mucosa width might not be a crucial clinical issue when regular implant maintenance therapy is performed. In the multivariate regression models, poor oral hygiene, smoking, history of chronic periodontitis, and cement-retained prosthesis were related to more plaque accumulation, pronounced mucosal inflammation, and increased peri-implant bone level. A review reported an association between poor oral hygiene, history of chronic periodontitis, and irregular maintenance therapy and an increased risk of peri-implantitis, while smoking may also be a potential risk factor (Schwarz *et al.*, 2018b). Therefore, well-performed oral hygiene and perhaps implant maintenance compliance could be protective factors that over-ride the influence of keratinized mucosa width on peri-implant health. Therefore it cannot be definitively concluded that less keratinized mucosa width directly worsens peri-implant diagnostic parameters if the above factors or confounders are present.

There are some potential limitations in this study: 1) The assessment of periodontal disease progression is limited during a cross-sectional study design, because baseline data (mucosal margin, keratinized mucosa width, and radiographic bone level) are not taken into consideration. Causality can only be established from cohort study designs such as that carried out by Perussolo *et al.* (2018) who reported a significant effect between keratinized mucosa width and time in function on peri-implant bone loss. 2) The patient-reported outcome on brushing discomfort was not collected. Thus, the impact of keratinized mucosa width on oral hygiene performance could not be evaluated in the present study. The role of an additive effect of multiple factors on peri-implant tissue homeostasis should be explored in a future study.

In summary, an increased peri-implant mucosal recession in the posterior region was associated with keratinized mucosa less than 2 mm wide. However, greater plaque accumulation, pronounced mucosal inflammation, and increased bone level were not associated with sites with lower keratinized mucosa width in subjects with good-to-fair oral hygiene and were compliant with regular implant maintenance therapy.

Conclusion

The presence of < 2 mm of keratinized mucosa width in posterior dental implant was associated with buccal mucosal recession. However, the other peri-implant diagnostic parameters were not associated with the width of keratinized mucosa.

Acknowledgments and conflict of interest statement

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Appendices

Table A1. Intra- and inter-examiner calibration of all parameters

Parameters	Mean Intra-examiner reliability	Mean Inter- examiner reliability
Keratinized mucosa (KM) width	0.904 (0.714 – 1)	0.850 (0.782 – 0.895)
Probing depth (PD)	0.845 (0.787 - 0.948)	0.756 (0.713 – 0.829)
Mucosal recession (RE)	0.925 (0.917 - 0.934)	0.829 (0.789 – 0.886)
Modified plaque index (mPLI)	-	0.872 (0.836 - 0.927)
Modified sulcus bleeding index (mBI)	-	0.891 (0.847-0.956)
Mean Kappa of all parameters	0.891	0.839

Table A2. Multivariable model for the association between KM width and plaque accumulation (mPLI ≥ 1)

Plaque model	Adjusted odds ratio	95% CI	*p value*
constant	0.22		*<0.001*†
KM width (KM ≥ 2 mm vs. KM < 2 mm)	1.37	0.74, 2.52	*0.316*
Oral hygiene status (good to fair vs. poor)	1.11	0.38, 3.23	*0.854*
Smoking status (non-smoker vs. smoker)	2.44	1.14, 5.21	*0.022**
Diabetes (non-diabetic vs. diabetic)	1.44	0.58, 3.58	*0.435*
History of chronic periodontitis (without vs. with history)	0.70	0.40, 1.25	*0.233*
Type of implant prosthesis (screw vs. cement-retained)	0.74	0.41, 1.34	*0.316*
PD ≥ 4 mm (no vs. yes)	2.19	1.26, 3.82	*0.006**
mBI ≥ 2 at implant site (no vs. yes)	1.19	0.56, 2.52	*0.651*

Model accuracy: Adjusted R^2=0.05, *p = 0.034**
* Statistically significant, *p < 0.05*, † Statistically significant, *p < 0.01*
KM: keratinized mucosa; PD: probing depth; mBI: modified bleeding index; CI: confidence interval

Table A3. Multivariable model for the association between KM width and mucosal inflammation (mBI ≥ 2)

Bleeding model	**Adjusted odds ratio**	**95% CI**	***P value***
constant	0.03		*<0.001†*
KM width (KM ≥ 2 mm vs. KM < 2 mm)	1.37	0.65, 2.87	*0.404*
Oral hygiene status (good to fair vs. poor)	4.19	1.55, 11.31	*0.005†*
Smoking status (non-smoker vs. smoker)	1.71	0.67, 4.37	*0.259*
Diabetes (non-diabetic vs. diabetic)	1.22	0.38, 3.96	*0.738*
History of chronic periodontitis (without vs. with history)	0.76	0.38, 1.54	*0.453*
Type of implant prosthesis (screw vs. cement-retained)	2.89	1.14, 7.31	*0.025**
PD ≥ 4 mm (no vs. yes)	3.05	1.53, 6.09	*0.002†*
mPLI ≥ 1 at implant site (no vs. yes)	1.18	0.56, 2.49	*0.668*

Model accuracy: Adjusted $R^2 = 0.09$, $p < 0.001$†
* Statistically significant, $p < 0.05$, † Statistically significant, $p < 0.01$
KM: keratinized mucosa; PD: probing depth; mPLI: modified plaque index; CI: confidence interval

Table A4. Multivariable model for the association between KM width and peri-implant bone level (BL)

Bone level model	**Unstandardized coefficients**		***p value***
	B	**95% CI**	
constant	0.48	0.13, 0.83	*0.007†*
KM width (KM ≥ 2 mm vs. KM < 2 mm)	0.12	-0.21, 0.44	*0.476*
Oral hygiene status (good to fair vs. poor)	-0.05	-0.65, 0.54	*0.868*
Smoking status (non-smoker vs. smoker)	-0.09	-0.54, 0.36	*0.700*
Diabetes (non-diabetic vs. diabetic)	0.41	-0.11, 0.93	*0.120*
History of chronic periodontitis (without vs. with history)	0.51	0.21, 0.81	*0.001†*
Type of implant prosthesis (screw vs. cement-retained)	-0.01	-0.33, 0.32	*0.973*
PD ≥ 4 mm (no vs. yes)	0.45	0.15, 0.75	*0.003†*
mPLI ≥ 1 at implant site (no vs. yes)	0.03	-0.31, 0.37	*0.857*
mBI ≥ 2 at implant site (no vs. yes)	0.22	-0.20, 0.64	*0.298*

Model accuracy: Adjusted $R^2 = 0.06$, $p = < 0.001$†
* Statistically significant, $p < 0.05$, † Statistically significant, $p < 0.01$
KM: keratinized mucosa; PD: probing depth; mPLI: modified plaque index; mBI: modified bleeding index; CI: confidence interval

Table A5. Multivariable model for the association between KM width and peri-implantitis

Peri-implantitis model	Adjusted odds ratio	95% CI	*P value*
constant	0.01		*<0.001†*
KM width (KM ≥ 2 mm vs. KM < 2 mm)	1.54	0.67, 3.54	*0.315*
Oral hygiene status (good to fair vs. poor)	0.78	0.16, 3.81	*0.757*
Smoking status (non-smoker vs. smoker)	0.75	0.22, 2.48	*0.632*
Diabetes (non-diabetic vs. diabetic)	1.57	0.46, 5.32	*0.471*
History of chronic periodontitis (without vs. with history)	2.93	1.23, 6.95	*0.015**
Maintenance compliance (≥ 1x per year vs. < 1x per year)	2.25	0.99, 5.15	*0.054*
Type of implant prosthesis (screw vs. cement-retained)	2.68	1.87, 8.24	*0.034**
mPLI ≥ 1 at implant site (no vs. yes)	2.56	1.08, 6.12	*<0.001†*

Model accuracy: Adjusted $R^2 = 0.05$, $p = < 0.018^{\dagger}$
* Statistically significant, $p < 0.05$, † Statistically significant, $p < 0.01$
KM: keratinized mucosa; PD: probing depth; mPLI: modified plaque index; CI: confidence interval

Table A6. Peri-implant diagnostic parameters in relation to implant location and tooth type

Clinical parameters	Posterior maxilla (n = 117)	Posterior mandible (n = 214)	Premolar area (n=101)	Molar area (n=230)
KM width	2.93±1.43	1.99±1.23	2.60±1.21	2.20±1.43
mPLI	0.15±0.32	0.12±0.28	0.13±0.30	0.14±0.29
mBI	0.30±0.42	0.29±0.47	0.40±0.48	0.24±0.42
RE	0.14±0.66	0.09±0.25	0.09±0.40	0.10±0.47
PD	2.92±0.66	2.83±0.84	2.80±0.98	2.89±0.68
BL	0.90±1.28	1.02±1.36	1.02±1.50	0.96±1.26

KM: keratinized mucosa; mPLI: modified plaque index; mBI: modified sulcus bleeding index; RE: mucosal recession; PD: probing depth; BL: interproximal bone level.

Table A7. Peri-implant diagnostic parameters in relation to implant maintenance and KM groups

Diagnostic parameters	Regular maintenance (≥ 1x per year)		Erratic maintenance (< 1x per year)	
	KM < 2 mm n=68	KM ≥ 2 mm n=177	KM < 2 mm n=23	KM ≥ 2 mm n=63
mPLI	0.11±0.20	0.18±0.35	0.07±0.17	0.07±0.18
mBI	0.27±0.38	0.30±0.47	0.12±0.24	0.36±0.52
RE	0.19±0.63	0.06±0.39†	0.17±0.49	0.08±0.33*
PD	2.69±0.54	2.92±0.87	2.72±0.66	2.93±0.77
BL	0.95±1.49	0.90±1.30	1.36±1.44	1.10±1.21

* Statistically significant difference, p < 0.05 (Mann-Whitney U test)
† Statistically significant difference, p < 0.01 (Mann-Whitney U test)
mPLI: modified plaque index; mBI: modified sulcus bleeding index; RE: mucosal recession; PD: probing depth; BL: interproximal bone level.