The depth of Mucosal tunnel in peri-implant health during 12-month follow-up in patients with controlled periodontitis

Running title: Role of mucosal tunnel in peri-implant health

Authors: Cho-Ying Lin[*,†], Pe-Yi Kuo[*], Meng-Yao Chiu[*], Hom-Lay Wang[‡]

[*]Department of Periodontics, Chang Gung Memorial Hospital, Taipei, Taiwan.

[†] Chang Gung University, Taoyuan city, Taiwan

[‡] Professor and Director of Graduate Periodontics, Department of Periodontics and Oral Medicine, School of Dentistry, University of Michigan, Ann Arbor, MI, USA.

Correspondent author:

Dr. Cho-Ying Lin, Department of Periodontics, Chang Gung Memorial Hospital, Taipei, Taiwan. Chang Gung University, Taoyuan city, Taiwan. TEL: 886-919586178; Email: jessicalin1020@gmail.com

Author contribution:

Cho-Ying Lin: Concept/Design, Data collection/analysis/ interpretation, drafting article, critical revision of article; Pe-Yi Kuo: Data collection and analysis/ interpretation, statistics, drafting article; Meng-Yao Chiu: Data collection, data interpretation, drafting article; Hom-Lay Wang: data interpretation, drafting article, critical revision of article

Funding: No funding.

Conflict of interest: The authors do not have any financial interests in the products or information listed in the paper.

Data availability: The data that support the findings of this study are available from the corresponding author upon request.

Abstract

Background: The association between thickness of peri-implant mucosa, known as mucosal tunnel (MT) and related clinical parameters in bone-level implants has not been investigated.

Methods: Posterior implants, in patients with controlled periodontitis, were evaluated at different time intervals: during uncovering surgery(T_0), 2-month after uncovering surgery(T_{2M}) and 12-month after placement (T_{12M}). Clinical parameters including vertical soft tissue height (VSTH), MT, tooth-implant discrepancy of bone level (DBL), pocket depth (PD), peri-implant marginal bone loss (MBL), emergence profile and emergence angle (EA) were collected, and the correlation were assessed at different time points.

Results: Forty-two patients with 60 implants were recruited, and 81.7 % of the patients were stage III-IV, grade B- C generalized periodontitis. MT presented no significant difference in PD, VSTH and MBL. Periodontitis grade C and absence of bone regeneration were significant predictors for deep MT (>3mm), and 5.85^0 less EA at mesial side of implants (p = 0.02).The regression of analysis implied the increase of DBL 1 mm would cause 0.26 mm deeper MT, 1.7 times higher risk of having deep MT (p = 0.041; OR = 1.731; 95% CI:1.02-2.93) and 2.1 times higher risk of having circumferential PD> 4mm (p = 0.019; OR = 2.1; 95% CI:1.13-3.92).

Conclusions: In bone-level implants, a correlation between MT and clinical parameters at 12-month follow-up was not found. However, history of periodontitis grade C, absence of bone regeneration and tooth-implant discrepancy of bone level might define the depth of MT. Additionally, the depth of MT played a critical role in determining restorative design.

Keywords: soft tissue thickness, mucosal tunnel, periodontitis, restoration contour, emergence angle, marginal bone loss

<u>Introduction</u>

The thickness of peri-implant mucosa known as mucosal tunnel (MT) has been regarded as one of the critical factors in influencing peri-implant health [1-3]. Soft tissue thickness around implants comprised vertical and horizontal components of peri-implant mucosa, and the thickness of mucosa could play specific roles in peri-implant tissue health at different time points. As for vertical dimension, soft tissue thickness could determine the bone remodeling process by creating supracrestal tissue height (defined as biological width) following implant placement[2, 4-8]. For horizontal dimension of mucosa, soft tissue thickness has been thought to contribute to the long-term stability of peri-implant bone level[1, 3, 9]. In addition, the mucosal thickness might act as a camouflage to attenuation of discoloration from metal/titanium abutment[10, 11], to improve esthetic appearance by providing better mucosal contour [12], to enhance the presence of interdental papilla[13]. However, their influence on the restorative design remained unclear.

Mucosal thickness could represent different meanings at different stages of healing after implant placement. Most of the articles emphasize on the thickness of soft tissue above implant either before or during surgery[1-7, 9, 14]. However, one case-control study had investigated the impact of MT on experimental peri-implant mucositis and found deeper MT had higher concentrations of pro-inflammatory cytokines during the induction of peri-implant mucositis, and the effect could last longer before the resolution of inflammation [15]. Similarly, one cross-sectional study identified that subcrestally-placed bone implants resulted in a deeper MT which linked to more implant marginal bone loss (MBL)and higher incidence of peri-implantitis[16].

To promote long-term peri-implant health, a strict supportive post-implant treatment is often needed [17, 18]. Not surprising, history of periodontitis remained a negative indicator for implant survival and success rate even under routine maintenance care[19]. However, the impact of new classification of periodontitis in stage and grade system [20] on peri-implant health remains inconclusive.

Hence, the primary outcome of this retrospective cohort study was to investigate how MT influence on bone level change at different time points and pocket depths at 12-month follow-up. The secondary outcome was to find out the factors influence MT and its correlation to other related clinical parameters (e.g., history of periodontitis with stage/ grade rated system, history of bone regeneration, implant position to adjacent tooth and restorative design of prosthesis).

Materials and Methods

2.1 Patient selection and study design

The study protocol was following the Declaration of Helsinki (revised in October 2018) and was approved by Chang Gung Memorial hospital, Institutional Review Board for Human Studies (IRB approval no.202100964A3). The present retrospective study was conducted by following the guidelines of STROBE (The Strengthening the Reporting of Observational Studies in Epidemiology)[21]. From 2019 to 2021, patients treated at the Department of Periodontics, Chang Gung Memorial hospital in Taipei with partially edentulous ridge were enrolled. All subjects had gone through active periodontal treatment before implant placement. Two experienced surgeons (CYL, PYK) performed all surgical treatments, with the assistance of cone-bean computed tomography (CBCT) and implant surgical stent, including ridge augmentation prior to implant placement, implant surgery with simultaneous guided bone regeneration (GBR) and uncovering implant surgery with minor soft tissue phenotype modification if needed 4 to 6 months after implant placement. All patients involved had provided inform consents prior to all surgeries.

For patient selection, the inclusion criteria were defined as follow:

(1) Patients were more than 20 years old and systemically healthy
(2) Subjects had at least one missing posterior tooth (from premolar to molar) and agreed to have implant supported prostheses

(3) Patients had well-controlled periodontitis with no residual pockets (≥4mm), and had less than 20% full mouth plaque index or full- mouth bleeding on probing (BOP)

(4) Dimensional deficiency had been augmented with GBR for implant placement (3.25, 4, 5 mm in diameters, 8.5 and 10, 11.5 mm in length), and same design and brand of implants*

(5) Patients with good compliance during non-surgical, surgical treatment and maintenance phases

The exclusion criteria include:

(1) Heavy smokers (self-reported more than 10 cigarettes daily)
(2) History of head and neck radiation therapy
(3) Pregnant or breastfeeding women
(4) Took medications that had effects on bone turnover and mucosal healing, such as steroids, antiresorptive therapy
(5) More GBR is required at the uncovering surgery

2.2 Clinical parameters

The classification of periodontitis was diagnosed based upon the proposed staging and grading framework in 2018[20]. In addition, demographic data (age, gender, frequency of maintenance visits) and implant characteristics, including implant size and surgical approaches for soft tissue modifications, were documented. Subsequently, the following clinical and radiographic parameters were collected at different time points for further assessment (Figure1):

(1) Vertical soft tissue height (VSTH): vertical mucosal thickness indicated the distance from soft tissue edge to alveolar ridge by means of probe sounding during implant uncovering surgery.
(2) Mucosal tunnel (MT): the depth of mucosal tissue was measured from implant shoulder to mucosal margin, and the value was confirmed with the reference of abutment (4 mm or 6 mm) at six aspects of each implant 2 months after uncovering surgery[22]: mesiobuccal (mb), mid-buccal

(mid-b), distobuccal (db), mesiolingual (ml), mid-lingual (mid-l), and distolingual (dl). Depth of MT was defined as: deep MT: ≥ 3 mm and shallow MT: <3mm [15].

(3) Classification of distribution of pocket depth (PD)> 4mm around implants:

PD was measure at six aspects (mb, mid-b, db, ml, mid-l, dl) of each implant, and classification of distribution of PD >4 mm was defined as site-specific (one to two points) and circumferential (more than three points) type[23]. Besides, PD at the 12-month follow-up was recorded.

(4) Keratinized mucosa width: the value has been measured with roll technique at a 12-month follow-up period.

2.3 Radiographic parameters

Vertical bitewings were taken with long-cone paralleling techniques at implant uncovering surgery, 2-month following uncovering, 12-month after placement (T_0, T_{2M}, T_{12M}). All measurements were performed by one calibrated blinded examiner (MYC). To assess the intra-examiner reliability, all cases were scored twice with a 10 minutes interval, and good level of agreement (>0.75) was obtained. The following radiographic parameters were collected using digital caliper (Figure2):

(1) Implant - tooth discrepancy of bone level (DBL): vertical distance from mesial or. distal side of bone crest around implants to adjacent tooth or the rising point of ascending ramus for distal-free end cases, and the mean value would be calculated from mesial and distal values.
(2) Horizontal distance (HD): the distance from platform of implant to adjacent tooth. No measurement was performed in distal-free end condition
(3) Emergence angle (EA) and emergence profile (EP): the angle at mesial (EAm) or distal (EAd) side was measured between a line parallel to long axis of implant and the line tangent to the most prominent point of the proximal contour following prosthesis placement. At the same

time, the profile of the proximal contour at mesial and distal sides were assessed into three different categories: straight, convex and concave [24, 25].

(4) Marginal bone level (MBL): the distance was measured from implant platform to the most coronal point of implant contact with bone, and the change of MBL was calculated between each time points (T_0, T_{2M}, T_{12M}) at mesial (MBLm) and distal (MBLd) sides.

2.3 Statistical analysis

SPSS version 25[†] was used for statistical analysis. Descriptive statistics are reported as means ± standard deviations. One-way ANOVA was used to compare the mean differences of MT between groups, including the classification of grade, stage, PD, and emergency profiles. The homogeneity of the variances was checked by Levene's test. Mean values of VSTH, DBL, HD, EA, MBL between shallow and deep MT groups and between different types of PD classification were compared using independent Student's t test and one-way ANOVA, respectively. If an ANOVA resulted in a significant F-statistic, post hoc testing with Tukey's honestly significant difference (HSD) was applied for multiple comparisons. The Chi-square association test (X2) was used to compare categorical variables with MT and PD classifications. Univariate linear regression methods were performed to investigate factors to MT, and logistic regression and Polynomial logistic regression were used to evaluate the associated factors to deep MT and PD>4mm with circumferential type. A $p < .05$ was accepted for the significance level of the tests.

3. Results

The demographic data and implant characteristics of the present study was summarized and presented in Table 1(a). All 42 patients (20 males and 22 females) with 60 implants who met the inclusion criteria were recruited from 2019 to 2021. The mean age of included subjects was 55.15±

10.05. Overall, 81.7 % of enrolled patients were stage III-IV and Grade B- C, 11.7% for stage II and 6.7 % for stage III periodontitis. Thirty-nine patients were fair to good compliers under strict maintenance care every 3 to 6 months while the remaining 3 missed one maintenance appointment during 6- month interval (defined as erratic compliers) due to the outbreak of Covid-19 and work-related issues. As for history of surgical treatment at implant sites, 17 had periodontal surgery, 9 had ridge preservation after extraction, and 5 received vertical ridge augmentation prior to implant placement at implant level. Among all, 49 (81%) were placed in molars with 17 of them were at tooth sites with distal free ends. During uncovering surgery, free gingival grafting procedure was carried out in 20 implants, and soft tissue modifications with modified roll technique and pouch roll technique were performed in 9 and 15 implants, respectively (Table 1(a)).

3.2 Clinical and radiographic measurement

Based on clinical documentation and radiographic measurements, mean value of all parameters at implant level were presented in Table 1(b). All implants possessed more than 2 mm keratinized mucosa at 2-month follow-up, and none of included cases was diagnosed as either peri-implant mucositis or peri-implantitis. Mean value of DBL was 2.11± 1.81 mm with the distance to adjacent tooth was 3.95± 1.34 mm. The mean value of VSTH at implant uncovering surgery was 2.59± 0.61 mm, while the mean MT was 3.23± 0.96 mm with 34 of 60 (56.7%) belonged to deep MT. Table 2 also presents the data of PD, EP distributions and MBL at different time points (T_0~T_{2M}, T_{2M}~T_{3ML}, T_0~T_{3ML}). In addition, the mean value of EA showed $25.61^0 \pm 9.77^0$ (range: 8.3^0~53.1^0) at mesial side and $23.72^0 \pm 9.23^0$ (range: 3.8^0~43.3^0) at distal side.

3.3 Factors associated with MT

Tables 2 and 3(a), (b) reported the statistical outcomes and the differences between mean value or classification of MT (deep and shallow) and each parameter. When history of periodontitis was considered, grade B and C showed significant difference in classification (p=0.006) (Table 3(b)) and mean MT(p=0.004). Furthermore, the logistic regression analysis illustrated grade B was a significant predictor for shallow MT compared to grade C (p = 0.012; OR = 0.217; 95% CI:0.066-0.718) (See Table S1 in online Journal of Periodontology, Supplementary table 1). Implants that had history of ridge preservation or vertical ridge augmentation or no GBR prior to implant surgery correlated significantly to deep MT (p = 0.041; OR = 3.971; 95% CI:1.06-14.86) (See Table S1 in online Journal of Periodontology, Supplementary table 1). Neither history of periodontitis nor history of ridge augmentation/ preservation was relevant with circumferential type of PD (Table 3(b)). Significantly higher DBL was found in deep MT group and circumferential PD defects (Table 3(a)) (Figure3 (a)(b)). A statistically association between DBL and MT was noted (p=0.012, r= 0.324) (Figure3 (c)) (See Table S2 in online Journal of Periodontology, Supplementary table 2). Moreover, the regression of analysis implied the increase 1mm of mean DBL might account for 0.26 mm deeper MT, 1.7 times higher of risk (a raised risk of 1.7 times) to be in the deep MT group (p = 0.041; OR = 1.731; 95% CI:1.02-2.93) and for 2.1 times of likelihood to become circumferential deep PD (p = 0.019; OR = 2.1; 95% CI:1.13-3.92) (See Table S1,S2 in online Journal of Periodontology, Supplementary table 1, 2). The additional soft tissue phenotype modifications in each group (modified roll technique, n=9; pouch roll technique, n=15; free gingival graft, n=21) did not influence the amount of MT when compared to no soft tissue phenotype modifications treatment sites (p=0.972) (Table 2). As for the correlation between MT and peri-implant condition, there is no statistical difference between mean MT and PD classification (Table 2). Similarly, no statistically difference was found between the deep and shallow MT with regards to the change of MBL and mean VSTH (Table 3(a)). Interestingly, a negative correlation was found between EAm and classification of MT: MT≥ 3mm had 5.85^{0} less angle than MT<3mm at mesial side of implants ($p = 0.02$) (Figure3(d)) (See Table S2 in online Journal of Periodontology, Supplementary table 2).

4. Discussion

This study is the first cohort study investigating the depth of MT around bone-level implant and its correlation to other clinical parameters (value and classification of PD and change of MBL) through regular maintenance care. Data from this study showed MT presented borderline significant difference in PD but not in VSTH and MBL. In addition, periodontitis grade C and absence of bone regeneration were significant predictors for deep MT(>3mm). Furthermore, an increase of DBL 1 mm would contribute 0.26 mm deeper MT, 1.7 times higher risk of having deep MT and 2.1 times higher risk of having circumferential PD> 4mm.

4.1 Observation of clinical parameters

In spite of the retained implant prosthesis during clinical measurement, a $p=0.051$ between MT and PD was observed. This might suggest a longer follow-up may be required to see if there is any significant difference. On the other hand, all implants in present study were free of peri-implantitis under regular implant maintenance. It supports the need for the regular supportive treatment [18, 26], which could be more crucial in peri-implant health than MT.

From a biological point of view, MBL from physiologic bone remodeling or pathologic bone loss should be carefully distinguished by tracing the occurrence at different time periods[27]. In this study, the MBL had been documented at T_0, T_{2M}, T_{12M}. During early healing phase, the mean change of MBL was within 0.4 mm. Considering MBL changes from T_{2M} to T_{12M}, only limited bone loss was noted, and some have even showed bone gain especially in the well-maintained implants.

4.2 Factors influencing MT

Based on the results obtained, the depth of MT is associated with grade C periodontitis, discrepancy of bone level from implant to adjacent tooth and history of GBR. Schwarz et al., (2018) showed history of periodontitis is one of the critical risk indicators/ factors for peri-implantitis [27] and it could occur even on routine supportive treatment[19]. Obreja and Schwarz reported synergetic impact of history of periodontitis and deep MT in subcrestally positioned implants[16]. However, results obtained from the present study showed grade C was related to deeper MT, but no relationship between periodontitis stage and MT was found. The "stage" of periodontitis could represent the severity and complexity of periodontitis and the grade of periodontitis had been regarded as the scale of disease progression and presence of risk modifier, thereby often representing the susceptibility of the disease. Hence, the correlation found here might imply a more rigid supportive treatment is required in patients with grade C periodontitis.

In agreement with a recent study, our result showed the MT is highly related to the implant-tooth discrepancy of bone level (DBL), which supported that DBL provides a good depth prediction of MT[15]. This assertion might be even evident for subcrestally placed tissue- or bone-level implants [15, 16, 28]. In addition, mucosal thickness is defined as VSTH at initial phase during implant surgery, and most of the studies had emphasized the importance of VSTH to maintain the stability of marginal bone level[2, 4, 7]. To prevent early bone loss, soft tissue enhancement or subcrestally placed implants have been suggested as means to prevent MBL implants, since it can facilitate the establishment of supracrestal tissue height. However, conflicting reports were noted to question the effectiveness of subcrestal placement to increase mucosa thickness [29] or some even reported higher risk of developing peri-implant disease [16]. Likewise, abutment height has also been linked to mucosal thickness, and is thought to be a critical element in early bone remodeling, especially for rough surfaced implants[30]. Interestingly, mucosal thickness has been constantly associated to VSTH, MT and abutment height. Yet, the actual relationship between MT and abutment height remained unclear due to the heterogeneity of the definition. In present study, the correlation between VSTH and MT was not found, and this may be attributed to the history of soft tissue modification and the discrepancy of bone crests between tooth and implants. In line with the observation in previous studies, large discrepancy of bone crest between implant and adjacent tooth might create deep MT[15, 16], which would be caused by subcrestally placed implants or vertically deficient ridge. As a result, history of vertical ridge augmentation or ridge preservation might diminish the vertical distance of bone crests, and shallower MT could be more likely obtained. In this study, the decrease of DBL is associated with shallower MT and PD, which makes it easier for maintenance care.

It is intriguing to find that the additional soft tissue phenotype modifications did not significantly enhance the depth of MT in this study. This could be due to many reasons such as small sample size in each group, short follow-up time or others. Future studies with a larger sample size and longer follow-up may be needed to verify the true impact of soft tissue phenotype modifications therapy on MT.

MT was found significantly associated with the emergence angle of restorative design. The EA could be determined by the depth of MT, and consequently deep MT might cause smaller EA regardless of implant- tooth distance. It was worth noting that this theory was confirmed only at mesial side, which could be explained by the bias of steep EA from distal free end cases. In line with published studies, EA> 30° had been regarded as a local confounder for peri-implant disease and peri-implant bone loss, due to limited access for oral hygiene maintenance [24, 25, 31-33]. Even though MT in the present study did not directly correlate to proximal MBL, shallow MT with concomitant large EA might cause a hazard to the peri-implant health. This is because the above condition makes it hard for patients to perform proper hygiene, which in turn could lead to peri-implant disease as noted in the current study.

4.3 Limitation and design of future research

The limitations of this study include as below: the retrospective nature of the study might compromise the strength of the results obtained compared with prospective ones; a short follow-up period (12 months); heterogeneity in tooth sites, the history of periodontal treatment and surgical approaches; no customized individual bite block for taking the radiographs to ensure the standardization of all images at each time point. To optimize the radiographic protocol, taking all radiographs digitally with a paralleling technique and a customized film holder should minimize the concern. In addition, digital landmarks were used to further correct and account for angle issue during measurements. Other areas can be better improved in future studies including the document of plaque and bleeding indices to verify the effectiveness of home care as well as supportive treatments. Hence, a well-designed longitudinal cohort study in the future will be required to further confirm the findings noted in this study.

Conclusions

This 12- month retrospective cohort study did not find the correlation between mucosal tunnel and clinical parameters, including PD and MBL, in the bone-level implants under routine supportive maintenance program. However, the results indicated that implant-tooth discrepancy of bone crest, history of periodontitis grade C and history of ridge preservation/ augmentation might define the depth of MT. The result obtained from this study suggested the depth of MT played a critical role in determining emergence angle of the restorative crown contour.

Footnotes:

* BIOMET 3i, Implant Innovations Inc., Palm Beach Gardens, FL, USA

† IBM Corp. Released 2017. IBM SPSS Statistics for Mac, Version 25.0

Funding: No funding.

REFERENCE

1. Thoma DS, Naenni N, Figuero E, et al. Effects of soft tissue augmentation procedures on peri-implant health or disease: A systematic review and meta-analysis. *Clin Oral Implants Res* 2018;29 Suppl 15:32-49.

2. Suarez-Lopez Del Amo F, Lin GH, Monje A, Galindo-Moreno P, Wang HL. Influence of Soft Tissue Thickness on Peri-Implant Marginal Bone Loss: A Systematic Review and Meta-Analysis. *J Periodontol* 2016;87:690-699.

3. Giannobile WV, Jung RE, Schwarz F, Groups of the 2nd Osteology Foundation Consensus M. Evidence-based knowledge on the aesthetics and maintenance of peri-implant soft tissues: Osteology Foundation Consensus Report Part 1-Effects of soft tissue augmentation procedures on the maintenance of peri-implant soft tissue health. *Clin Oral Implants Res* 2018;29 Suppl 15:7-10.

4. Linkevicius T, Puisys A, Steigmann M, Vindasiute E, Linkeviciene L. Influence of Vertical Soft Tissue Thickness on Crestal Bone Changes Around Implants with Platform Switching: A Comparative Clinical Study. *Clin Implant Dent Relat Res* 2015;17:1228-1236.

5. Puisys A, Linkevicius T. The influence of mucosal tissue thickening on crestal bone stability around bone-level implants. A prospective controlled clinical trial. *Clin Oral Implants Res* 2015;26:123-129.

6. Berglundh T, Lindhe J. Dimension of the periimplant mucosa. Biological width revisited. *J Clin Periodontol* 1996;23:971-973.

7. Vervaeke S, Dierens M, Besseler J, De Bruyn H. The influence of initial soft tissue thickness on peri-implant bone remodeling. *Clin Implant Dent Relat Res* 2014;16:238-247.

8. Avila-Ortiz G, Gonzalez-Martin O, Couso-Queiruga E, Wang HL. The peri-implant phenotype. *J Periodontol* 2020;91:283-288.

9. Tavelli L, Barootchi S, Avila-Ortiz G, Urban IA, Giannobile WV, Wang HL. Peri-implant soft tissue phenotype modification and its impact on peri-implant health: A systematic review and network meta-analysis. *J Periodontol* 2021;92:21-44.

10. Jung R, Sailer I, Hämmerle C, Attin T, Schmidlin P. In vitro color changes of soft tissues caused by restorative materials. *Int J Periodontics Restorative Dent* 2007;27:251-257.

11. Lops D, Stellini E, Sbricoli L, Cea N, Romeo E, Bressan E. Influence of abutment material on peri-implant soft tissues in anterior areas with thin gingival biotype: a multicentric prospective study. *Clin Oral Implants Res* 2017;28:1263-1268.

12. Bienz S, Jung R, Sapata V, Hämmerle C, Hüsler J, Thoma D. Volumetric changes and peri-implant health at implant sites with or without soft tissue grafting in the esthetic zone, a retrospective case-control study with a 5-year follow-up. *Clin Oral Implants Res* 2017;28:1459-1465.

13. Ahmed AJ, Nichani AS, Venugopal R. An Evaluation of the Effect of Periodontal Biotype on Inter-Dental Papilla Proportions, Distances Between Facial and Palatal Papillae in the Maxillary Anterior Dentition. *J Prosthodont* 2018;27:517-522.

14. Munoz M, Busoms E, Vilarrasa J, Albertini M, Ruiz-Magaz V, Nart J. Bone-level changes around implants with 1- or 3-mm-high abutments and their relation to crestal mucosal thickness: A 1-year randomized clinical trial. *J Clin Periodontol* 2021;48:1302-1311.

15. Chan D, Pelekos G, Ho D, Cortellini P, Tonetti MS. The depth of the implant mucosal tunnel modifies the development and resolution of experimental peri-implant mucositis: A case-control study. *J Clin Periodontol* 2019;46:248-255.

16. Obreja K, Ramanauskaite A, Begic A, et al. The prevalence of peri-implant diseases around subcrestally placed implants: A cross-sectional study. *Clin Oral Implants Res* 2021;32:702-710.

17. Monje A, Wang HL, Nart J. Association of Preventive Maintenance Therapy Compliance and Peri-Implant Diseases: A Cross-Sectional Study. *J Periodontol* 2017;88:1030-1041.

18. Lin CY, Chen Z, Pan WL, Wang HL. The effect of supportive care in preventing peri-implant diseases and implant loss: A systematic review and meta-analysis. *Clin Oral Implants Res* 2019;30:714-724.

19. Lin CY, Chen Z, Pan WL, Wang HL. Is History of Periodontal Disease Still a Negative Risk Indicator for Peri-implant Health Under Supportive Post-implant Treatment Coverage? A Systematic Review and Meta-analysis. *Int J Oral Maxillofac Implants* 2020;35:52-62.

20. Tonetti MS, Greenwell H, Kornman KS. Staging and grading of periodontitis: Framework and proposal of a new classification and case definition. *J Periodontol* 2018;89 Suppl 1:S159-S172.

21. von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *The Lancet* 2007;370:1453-1457.

22. Sculean A, Gruber R, Bosshardt DD. Soft tissue wound healing around teeth and dental implants. *J Clin Periodontol* 2014;41 Suppl 15:S6-22.

23. Salvi GE, Aglietta M, Eick S, Sculean A, Lang NP, Ramseier CA. Reversibility of experimental peri-implant mucositis compared with experimental gingivitis in humans. *Clin Oral Implants Res* 2012;23:182-190.

24. Katafuchi M, Weinstein BF, Leroux BG, Chen YW, Daubert DM. Restoration contour is a risk indicator for peri-implantitis: A cross-sectional radiographic analysis. *J Clin Periodontol* 2018;45:225-232.

25. Majzoub J, Chen Z, Saleh I, Askar H, Wang HL. Influence of restorative design on the progression of peri-implant bone loss: A retrospective study. *J Periodontol* 2021;92:536-546.

26. Monje A, Aranda L, Diaz KT, et al. Impact of Maintenance Therapy for the Prevention of Peri-implant Diseases: A Systematic Review and Meta-analysis. *J Dent Res* 2016;95:372-379.

27. Schwarz F, Derks J, Monje A, Wang HL. Peri-implantitis. *J Periodontol* 2018;89 Suppl 1:S267-S290.

28. Chappuis V, Bornstein MM, Buser D, Belser U. Influence of implant neck design on facial bone crest dimensions in the esthetic zone analyzed by cone beam CT: a comparative study with a 5-to-9-year follow-up. *Clin Oral Implants Res* 2016;27:1055-1064.

29. de Siqueira RAC, Savaget Goncalves Junior R, Dos Santos PGF, de Mattias Sartori IA, Wang HL, Fontao F. Effect of different implant placement depths on crestal bone levels and soft tissue behavior: A 5-year randomized clinical trial. *Clin Oral Implants Res* 2020;31:282-293.

30. Chen Z, Lin CY, Li J, Wang HL, Yu H. Influence of abutment height on peri-implant marginal bone loss: A systematic review and meta-analysis. *J Prosthet Dent* 2019;122:14-21 e12.

31. Delgado-Ruiz RA, Calvo-Guirado JL, Romanos GE. Effects of occlusal forces on the peri-implant-bone interface stability. *Periodontol 2000* 2019;81:179-193.

32. Dixon DR, London RM. Restorative design and associated risks for peri-implant diseases. *Periodontol 2000* 2019;81:167-178.

33. Yi Y, Koo KT, Schwarz F, Ben Amara H, Heo SJ. Association of prosthetic features and peri-implantitis: A cross-sectional study. *J Clin Periodontol* 2020;47:392-403.

Figure Legends

Figure 1. The schematic illustration of study design and measuring items at different time points (T_0, T_{2M}, T_{12M}). M: months; VSTH: vertical soft tissue height; MT: mucosal tunnel; PD: pocket depth; DBL: discrepancy of bone level from implant to adjacent tooth; HD: horizontal distance from implant to adjacent tooth; MBL: marginal bone loss; VRA: vertical ridge augmentation; RP: ridge preservation.

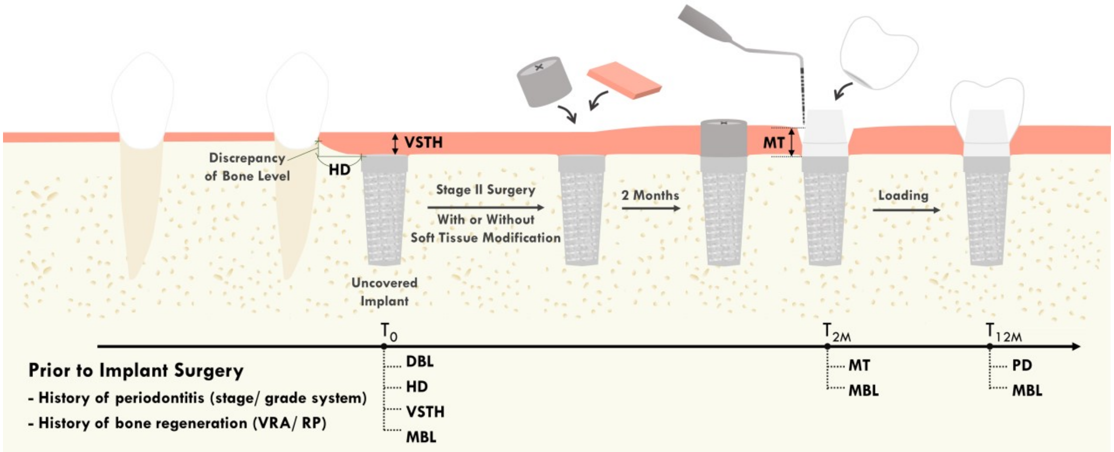

Figure 2. Example of the assessment of marginal bone level (MBL) at T_{2M}, T_{12M}, emergence angle (EA) in upper left and right radiographic images, and emergence profile (EP) was evaluated (Lower left: concave and straight; lower right: convex). M: months; DBL: discrepancy of bone level from implant to adjacent tooth; HD: horizontal distance from implant to adjacent tooth.

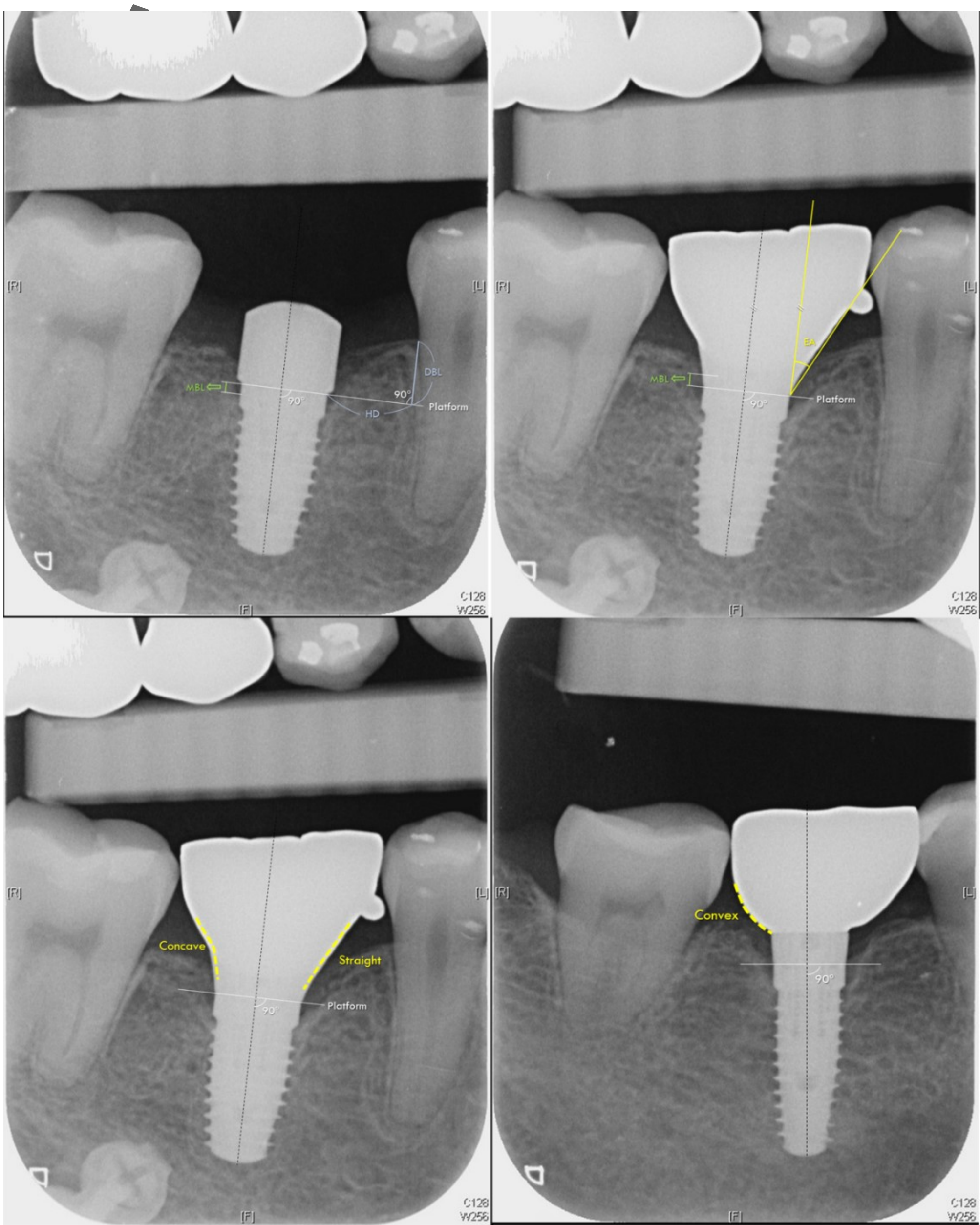

Figure 3. The correlation between mucosal tunnel (MT) and associated parameter: classification of pocket depth (PD), discrepancy of bone level from implant to adjacent tooth (DBL) and emergence angle at mesial side (EAm).

3(a) Higher DBL was significantly related to deep MT group (p=0.033).

3(b) Higher DBL was significantly related to circumferential PD> 4mm compared with PD< 4mm (p=0.023).

3(c) The mean value of DBL and MT was positively correlated (p=0.012, r= 0.324).

3(d) Negative correlation was found between EAm and MT classification (p = 0.02).

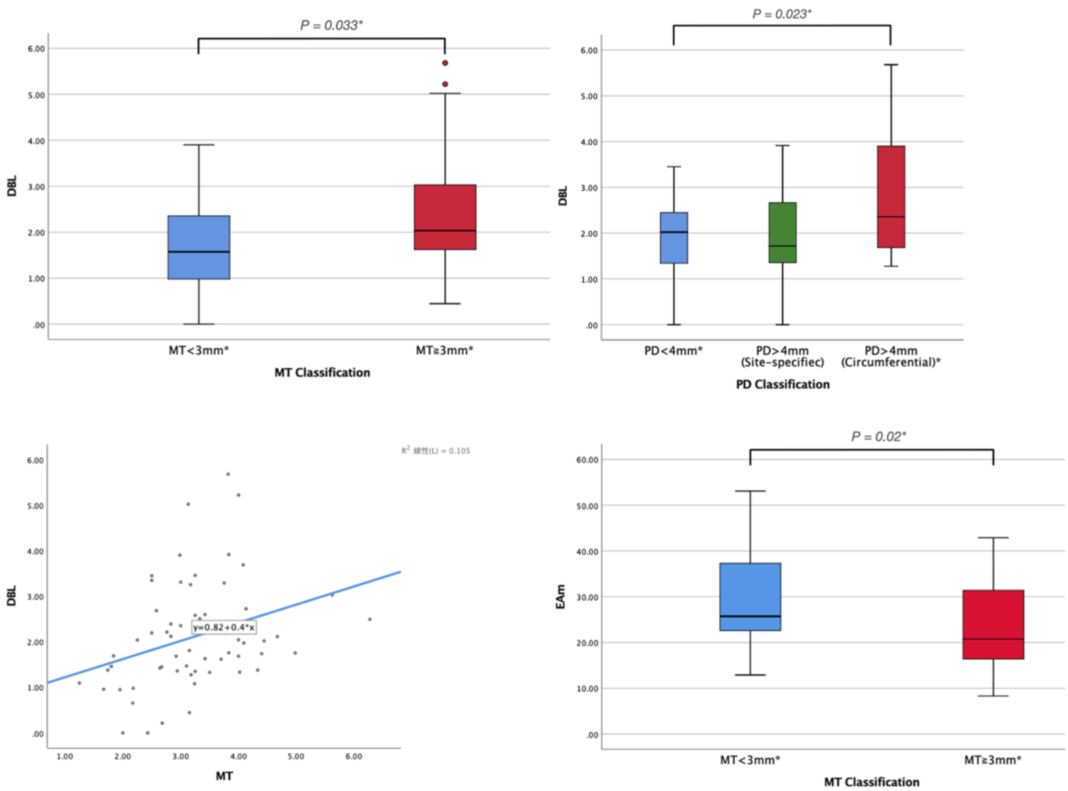

Table 1 Demographic data and implant characteristics at patient and implant levels. (a) Demographic data and implant characteristics

Demographic data and implant characteristics	Mean± SD
Age	55.15±10.05
Gender	Male: 20; Female: 22 (patient level)
Stage of periodontitis	I:4; II:7; III:24; IV:25 (implant level) I:4; II:7; III:18; IV:13 (patient level)
Grade of periodontitis	A:8; B:31; C:23 (implant level) A:8; B:20; C:14 (patient level)
Implant sites	Premolar:11; molar:49 Distal free end: 17
Frequency of maintenance visit	Good:15; Fair compliance:42; Erratic compliance: 3 (implant level) Good:10; Fair compliance:29; Erratic compliance: 3 (patient level)
Previous guided bone regeneration (implant level)	Ridge preservation (RP): 9 Vertical ridge augmentation (VRA): 5 RP or VRA: 13
Soft tissue modification (implant level)	Free gingiva graft: 20 Pouch roll technique: 15 Modified roll technique: 9

SD: standard difference

Table 1(b) Clinical and radiographic measurements at implant level

Clinical and radiographic measurements at implant level	Mean± SD (minimum-maximum)
VSTH	2.59±0.61mm (2-4.67)
MT	3.23±0.96mm (1.25-6.27)
MT classification	Shallow (MT<3mm): 26; Deep (MT≧3mm):34
PD classification	PD<4mm: 27 PD>4mm with site-specific: 20 PD>4mm with circumferential: 13
DBL	2.11±1.81mm (0-5.68)
HD	3.95±1.34mm (2.09-8.66)
EPm	Concave:12; Straight:24; Convex:24
EPd	Concave:15; Straight:28; Convex:17
EAm	$25.61^0 \pm 9.77^0$ (8.3^0-53.1^0)
EAd	$23.72^0 \pm 9.23^0$ (3.8^0-43.4^0)
MBL T_{2M-0}	Mesial: 0.21±0.5mm (-1.42-1.76) Distal: 0.28±0.49mm (-1.62-1.82)
MBL T_{12M-2M}	Mesial: 0.15±0.58mm (-1.23-2.93) Distal: 0.05±0.44mm (-1.12-1.51)
MBL T_{12M-0}	Mesial: 0.37±0.62mm (-1.42-2.9) Distal: 0.32±0.56mm (-1.62-1.68)

SD: standard difference; VSTH: vertical soft tissue height; MT: mucosal tunnel; PD: pocket depth; DBL: discrepancy of bone level from implant to adjacent tooth or ascending ramus in distal-free ended cases; HD: horizontal distance from implant to adjacent tooth; EPm,d: emergence profile at mesial or distal side; EAm,d: emergence angle at mesial or distal side; MBL: marginal bone loss; T_{2M-0}: from implant uncovering surgery to 2 months after that; T_{12M-2M} :from 2 months after uncovering surgery to 12-month follow-up; T_{12M-0} :from implant uncovering surgery to 12-month follow-up.

Table 2 The mean values of mucosal tunnel (MT) in the following categorical variables: pocket depth (PD), history of periodontitis (grade, stage) and emergence profile (EP).

Categorical variables	MT	*P*
Stage		0.86
I	3.58±1.29mm	
II	3.19±1.00mm	
III	3.27±1.06mm	
IV	2.15±0.94mm	
*Grade		0.004*
A	3.62±0.73mm	
B	**2.82±0.75mm***	
C	**3.65±1.07mm***	
Soft tissue modifications		0.972
None	3.31 ± 1.25mm	
Modified roll	3.26 ± 0.57mm	
Pouch roll	3.14 ± 0.81mm	
Free gingiva graft	3.22 ± 1mm	
PD classification		0.051
PD<4mm	2.94±0.78mm	
PD>4mm site-specific	3.31±0.9mm	
PD>4mm circumferential	3.71±1.21mm	
EPm		0.937
Concave	3.22±1.24mm	
Straight	3.1±0.92mm	
Convex	3.29±0.89mm	
EPd		0.908
Concave	3.16±1.02mm	
Straight	3.22±1.05mm	

Convex	3.31±0.79mm

**One-way ANOVA followed by Tukey's test ($p < 0.05$)*

MT: mucosal tunnel; PD: pocket depth; EPm,d: emergence profile at mesial or distal side.

Table 3 The correlation between mucosal tunnel(MT), pocket depth(PD) and other clinical parameters. (a)The mean values of clinical parameters in each classification of mucosal

Clinical parameters	MT			PD			
	Shallow (n=26)	Deep (n=34)	*p*	PD<4mm (n=27)	PD>4mm site specific (n=20)	PD>4mm circumferential (n=13)	*p*
STT	2.55±0.56mm	2.63±0.67mm	0.691	2.46±0.48mm	2.7±0.72mm	2.8±0.77mm	0.371
DBL	**1.74±1.05mm** †	**2.4±1.22mm** †	0.033	**1.86±0.93mm***	1.94±1.05mm	**2.9±1.55mm***	0.023
HD	4.24±1.46mm	3.74±1.23mm	0.154	3.94±1.43mm	3.74±0.99mm	4.32±1.65mm	0.495
EAm	28.93±10$^{0\,\dagger}$	23.08±8.93$^{0\,\dagger}$	0.02	25.3±9.65^{0}	24.96±9.19^{0}	27.28±9.98^{0}	0.787
EAd	24.25±7.26^{0}	23.32±10.58^{0}	0.69	26±9.25^{0}	22.09±9.67^{0}	21.49±7.98^{0}	0.223
$MBLT_{2M-0}$	M: 0.34±0.42mm	M: 0.11±0.54mm	0.079	M: 0.2±0.46mm	M: 0.35±0.52mm	M: 0.02±0.53mm	0.188
	D: 0.36±0.48mm	D: 0.22±0.49mm	0.268	D: 0.28±0.49mm	D: 0.39±0.39mm	D: 0.59±0.16mm	0.253
$MBLT_{3ML-2M}$	M: 0.03±0.41mm	M: 0.25±0.68mm	0.157	M: 0.16±0.54mm	M: 0.16±0.75mm	M: 0.12±0.39mm	0.975
	D: 0.06±0.47mm	D: 0.04±0.43mm	0.87	D: 0.06±0.52mm	D: 0.08±0.45mm	D: -0.03±0.22mm	0.803
$MBLT_{3ML-0}$	M: 0.38±0.45mm	M: 0.36±0.73mm	0.933	M: 0.37±0.55mm	M: 0.51±0.66mm	M: 0.14±0.69mm	0.26
	D: 0.42±0.56mm	D: 0.25±0.57mm	0.276	D: 0.35±0.59mm	D: 0.46±0.49mm	D: 0.07±0.58mm	0.147

**One-way ANOVA followed by Tukey's test ($p < 0.05$); †independent Student's t test ($p < 0.05$). MT: mucosal tunnel; PD: pocket depth; STT: soft tissue thickness measured during uncovering surgery; DBL: discrepancy of bone level; HD: horizontal distance; EAm: emergency angle at mesial site; EAd: emergency angle at distal site; $MBLT_{2M-0}$: the change of marginal bone level 2 months* *after uncovering surgery; $MBLT_{3ML-2M}$: the change of marginal bone level between 3 months post-loading and 2 months after uncovering surgery; $MBLT_{3ML-0}$: the change of marginal bone level between uncovering surgery and 3 months post-loading; m: mesial; d: distal.*

tunnel (MT) and pocket depth (PD).

Table 3(b). Implant level (*n* = 60) cross-tabulations between classification of mucosal tunnel (MT), pocket depth (PD) and the variations: history of periodontitis (stage, grade), history of ridge augmentation/ preservation and emergence profile (EP).

Categorical variables	**MT**			**PD**			
	Shallow	Deep	*p*	PD<4mm	PD>4mm site specific	PD>4mm circumferential	*p*
Stage			0.3				0.407
I	0	4		1	3	0	
II	4	3		4	2	1	
III	11	13		12	5	7	
IV	11	14		10	10	5	
Grade			**0.006***				0.256
A	1	7		3	4	1	
B	19	11		15	11	4	
C	6	16		9	5	8	
VRA or RP			**0.033***				0.123
No	17	30		18	17	12	
Yes	9	4		9	3	1	
EPm			0.873				0.499
Concave	6	6		7	3	2	
Straight	10	14		9	11	4	
Convex	10	14		11	6	7	
EPd			0.732				0.17

Concave	7	8	8	6	1
Straight	13	15	11	7	10
Convex	6	11	8	7	2

*** Statistically significant difference (*p* < .05), chi-square association test (X^2).**

MT: mucosal tunnel; PD: pocket depth; VRA: vertical ridge augmentation; RP: ridge preservation; EPm,d: emergence profile at mesial or distal side.