Combined effect of abutment height and restoration emergence angle on the progression of peri-implant bone loss

Graduate Periodontics
Department of Periodontics and Oral Medicine
University of Michigan School of Dentistry

Candidate

Jonathan Misch, DDS
Resident, Graduate Periodontics

Committee members

Hom-lay Wang DDS, MSD, PhD
Muhammad H. A. Saleh BDS, MSD[1]
Junying Li DDS, MS, PhD[3]

Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Periodontics from the Horace H. Rackham School of Graduate Studies at the University of Michigan, Ann Arbor, 2023

Jonathan Misch

misch@umich.edu

ORCiD
0000-0002-3189-994X

ACKNOWLEDGMENTS

I dedicate my thesis first to my wife, Jaclyn, and my son, Logan, who bring love, entertainment, joy, and happiness to my life. This project could not have been completed without the countless hours of solo-parenting taken on by Jaclyn, and I will forever be thankful to her for her dedication to our family. Being a full-time parent is undoubtedly the hardest job in the world, and her willingness to take on this role so selflessly has allowed me to pursue my dreams. I could never thank her enough for her sacrifices and unwavering support. Her love, patience, and encouragement have been the backbone of my journey, allowing me to focus on my academic and professional pursuits without worry. Jaclyn, your support has meant the world to me, and I am eternally grateful.

To my mother, for always believing in me and supporting me through the many different life paths that I have pursued. Her unwavering faith in my abilities and relentless support have been the foundation upon which I have built my career and personal life. She has worked tirelessly to provide me with the education and opportunities that have shaped who I am today. Her strength, resilience, and dedication to our family have been a constant source of inspiration. From the countless hours she spent helping me with my studies to the wisdom she imparted through her own experiences, she has been my greatest cheerleader and confidant. Thank you, Mom, for your boundless love, for always encouraging me to reach for the stars, and for never letting me settle for anything less than my best. Your sacrifices, hard work, and unwavering belief in me have been the driving force behind my achievements.

To my father, who I miss every day, and who is a constant source of inspiration and encouragement. His passion for dentistry and dedication to his work sparked my own interest in the field. He was always there to guide me, offering invaluable advice and support at every step

of my journey. His belief in my potential and his unwavering encouragement gave me the confidence to pursue my dreams. Thank you, Dad, for opening my eyes to the field of dentistry, for always pushing me to be the best I can be, and for truly believing – and making me believe – that my potential is only limited to what I can dream is possible. Your legacy continues to inspire me every day.

Dr. Homlay Wang, my program director and the primary investigator of this study, has been a pillar of strength and guidance throughout my residency. His strict yet supportive approach has made me a stronger student of periodontics and implants than I ever thought possible. His high standards and rigorous expectations pushed me to achieve excellence, while his unwavering belief in my abilities and his commitment to my academic and personal growth have been invaluable. I owe so much to him not only from an academic perspective but also for the person he has helped me become. Dr. Wang, your mentorship has been a transformative experience, and I am deeply grateful for your guidance, support, and the countless hours you have invested in my development.

Dr. Muhammad Saleh has been more than a mentor; he has become a cherished friend. From the first time we worked together in surgery, his dedication to my development as a surgeon was evident. He coached me through every step, highlighting what I did right and wrong, and I learned more from him in the clinic than from any other faculty member. His incredible clinical skills, hard work, and moral and ethical standards have made him a role model for me, both professionally and personally. Dr. Saleh, your mentorship, friendship, and unwavering support have been instrumental in my growth as a clinician and as a person. Your guidance has been a beacon of light throughout my residency.

Dr. Junying Li was someone I admired long before entering my residency, initially for his incredible clinical photography skills. As I got to know him, I was struck by his kindness, humility, and vast knowledge. He taught me so much about prosthodontics, opening my eyes to a new world of dentistry that I needed to explore and understand. His investment in my development has rounded me as a clinician, and I am deeply appreciative of his mentorship. Dr. Li, your dedication to teaching and your genuine care for my growth have left a lasting impact on me. Your expertise and passion for dentistry have inspired me to continually strive for excellence.

Dr. Andrea Ravidà, the person who developed the concept for my study with me, has played a pivotal role in my academic journey. Our lunch breaks during his time as my faculty formed my interest in clinical research and helped create the spark that I have for making a significant impact in the field. His innovative thinking and dedication to advancing the field of periodontics have been a source of inspiration. Dr. Ravidà, your mentorship has not only guided my research but has also ignited a passion within me to contribute meaningfully to the field. Your support and belief in my potential have been instrumental in the development and success of this study.

This thesis represents not just the culmination of years of study and research, but also the collective support, guidance, and inspiration of many remarkable individuals. To my family, mentors, and friends, your unwavering belief in my potential and your encouragement have been the driving forces behind this achievement. Each of you has contributed in unique and meaningful ways, shaping not only my professional path but also my personal growth. I am profoundly grateful for your contributions and hope that this work stands as a testament to the collaborative effort and shared dedication to advancing the field of periodontics and implants. Thank you all for being an integral part of this journey.

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LIST OF ABBREVIATIONS

- Transmucosal Abutment Height (TmAH)
- Restorative Emergence Angle (REA)
- Marginal Bone Loss (MBL)
- Peri-implantitis (PI)
- Supracrestal Tissue Attachment (STA)
- Supracrestal Tissue Height (STH)
- Supracrestal Tissue Attachment (STAd)
- Probing Depth (PD)
- Bleeding on Probing (BOP)
- Generalized Estimating Equations (GEE)
- Odds Ratio (OR)
- Confidence Interval (CI)
- Intraclass Correlation Coefficient (ICC)

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ABSTRACT

Aim & Hypothesis: The objective of the present investigation is to determine the influence of the combined effect of both the transmucosal abutment height (TmAH) and restorative emergence angles (REA) on peri-implant marginal bone loss (MBL) after the first year of remodeling in bone level implants. It was hypothesized that by increasing the TmAH, the known effects of REA on peri-implant bone loss progression could be mitigated.

Materials & Methods: Implants with diagnostic radiographs taken 12-18 months after crown placement (T0) and at least one year later (T1) were included in this retrospective analysis. TmAH and REA were measured. Sites were separated into four groups: Long-Gradual (LG) with TmAH ≥2mm with REA <30˚, Long-Abrupt (LA) with TmAH ≥2mm with REA ≥30˚, Short-Gradual (SG) with TmAH <2mm with REA <30˚, and Short-Abrupt (SA) with TmAH <2mm with REA ≥30˚. MBL was calculated, and multiple linear regression analysis was performed to control for patient-level (age, gender, diabetes, smoking status, maintenance visits, history of periodontitis) and implant/prosthesis level factors (implant site, diameter, length, brand, connection, retention type). Subsequently, a multiple binary logistic regression model was performed to identify what factor (REA or TmAH) had a more significant impact on the probability of MBL.

Results:192 implants pertaining to 119 patients were included. When comparing Mean MBL, Group played a significant role ($p<0.001$), with Group SA experiencing on average 0.48mm (95% CI: 0.25 - 0.71, $p<0.001$), 0.43mm (95% CI: 0.18 - 0.68, $p=0.001$), and 0.25mm (95% CI: 0.00 - 0.45, $p=0.013$) greater MBL compared to Group LG, Group LA, and Group SG respectively. Results also revealed that Group was a significant factor impacting the development of periimplantitis ($p=0.041$), with Group SA displaying a roughly 4x greater

likelihood of having peri-implantitis (PI) diagnosed compared to Group LA (OR: 4.19; p= 0.013) and Group LG (OR: 4.04; p=0.091). Additionally, every 1 mm increase in TmAH decreased the probability of MBL >0mm (pMBL>0) by 51% (OR=0.49; p=0.015). Finally, the influence of REA on pMBL>0 was not found to be significant when adjusted for TmAH.

Conclusions: Abutment height greater than 2mm may play a role in reducing the experience of PI and MBL related to abrupt REA around bone-level implants. REA was only a significant factor when TmAH was less than 2mm. The probability of MBL was found to have an inverse relationship with TmAH and have no significant relationship with REA.

Keywords: dental implant; dental prosthesis; peri-implantitis; prevalence; risk factors; abutment height; marginal bone loss; emergence angle.

I. INTRODUCTION

1. Background – Understanding how characteristics of prosthetic components can impact physiologic remodeling and disease susceptibility

1.1 THE IMPACT OF ABUTMENT HEIGHT ON PERI-IMPLANT BONE REMODELING

As it pertains to root form implants, currently there are two categories of implants that are commonly used in practices: tissue level implants, and bone level implants. Tissue level implants have a rough surface which is ideal for the apposition of new bone onto the implant surface for osseointegration, and a smooth surface which is positioned above the bone crest and is ideal for soft tissue adhesion. Bone level implants are placed at the level of the bone crest (or slightly submerged) and require a transmucosal abutment to extend from the level of the implant platform to the implant crown.

Crestal bone loss has been categorized as either physiological, or pathological, based on its timing and etiology. According to the most recent World Workshop on the Classification of Periodontal and Periimplant Diseases, crestal bone changes can be attributed to physiologic remodeling when they occur within the first year of function, and thereafter should be considered as evidence of pathologic progression, or periimplantitis.[1]

Investigations into characteristics of the transmucosal abutment have revealed that, among others, the transmucosal abutment height plays a key role in both physiologic and pathologic bone loss around bone level implants. In particular, a longer transmucosal abutment has been found to result in less bone loss.[2,3,4]

Regarding physiologic remodeling, there are two biologic reasons that could explain why bone level implants experience this phenomenon. First, a taller implant allows for sufficient space for the formation of the supracrestal tissue adhesion (STAd) at the abutment-crown level

rather than at the level of the implant platform.[1,5,6] Second, a longer abutment allows for the separation of the inflammatory zone from the abutment/crown connection and the alveolar crest.[7]

The role of a transmucosal abutment in limiting MBL was first evaluated when Galindo-Moreno and colleagues published their retrospective radiographic study evaluating 308 bone level implants with either a long abutment (≥2mm) or a short abutment (<2mm). Their study revealed, "MBL rates were higher for prosthetic abutment <2 mm vs. ≥ 2 mm."[8] However, prior to this study other groups had performed prospective trials that either directly or indirectly evaluated the impact of varying TmAH.

In 1998, Kastenbaum and colleagues evaluated the impact of either 1mm, 2mm, and 3mm TmAH during 3 years of loading on external hex implants. This study found that abutment height did not play a role in MBL with all implants experiencing a maximum of 1mm MBL after 3 years. This result is not surprising, as the implant-to-abutment margin on an external hex implant is known to create an inflammatory zone[9] which will overshadow the impact of a varying TmAH.

When Collaert and colleagues (2002) later evaluated varying TmAH on internal connection implants, they found that, "the height of the abutment appeared to play a more significant role in the amount of bone remodeling to be expected."[10] Their study saw that as abutment height increased, MBL was predictably decreased.

However, while this study may have brought the concept of abutment height into the conversation, it wasn't until Galindo-Moreno and colleagues published their 2014 retrospective study that the field began to deeply investigate the topic with controlled studies.

One of the factors that is commonly discussed and had to be controlled for was the influence of mucosal thickness on MBL. It had been suggested that soft tissue can act as a

protective barrier against inflammatory infiltration towards the underlying alveolar bone.[11] Studies, such as those by Linkevicius et al. (2009) and Suárez-López Del Amo et al. (2016), reinforced this notion indicating that the vertical mucosal thickness necessary for the establishment of biological width around two-piece dental implants should be at least 2 mm to prevent MBL.[12,13]

Other studies indicated that varying amounts of MBL may occur to accommodate the biological width. Studies by Berglundh, Abrahamsson, and Lindhe (2005), as well as Hermann et al. (2001), revealed that the body might resorb bone to establish adequate biological width.[14,15] Linkevicius et al. (2010) expanded on this by highlighting that vertical keratinized mucosal thickness plays a crucial role in controlling peri-implant MBL around platform-switched implants placed at the crestal level.[16] Their findings demonstrated that, one year post-loading, implants with an initial mucosal thickness exceeding 2 mm preserved marginal bone levels more effectively compared to those with 2 mm or less of mucosal thickness.

Keeping this factor in mind, in 2017 Blanco and colleagues performed a randomized control trial evaluating the impact of an either 1mm or 3mm TmAH. To control for the possible confounding factor of vertical mucosal thickness (VMT), a minimum of 3mm VMT was required in order to be included in the study[5]. After 6 months of loading, there was greater MBL in the 1mm TmAH group vs the 3mm TmAH group (0.91 ± 0.19 vs. 0.11 ± 0.09 mm).

While this study gave a strong voice to TmAH being a significant factor effecting MBL for patient with thick VMT, thin VMT had yet to be evaluated. Patients with thin VMT present a difficult clinical scenario. If an implant is placed equicrestally in a patient with 1mm VMT, using a TmAH of >1mm would be an esthetic failure due to the visible abutment-to-crown margin. However, the previous studies have alluded to a shorter abutment resulting in increased MBL. In

this clinical scenario, Pico and colleagues (2019) presented a plausible solution: sub-crestal platform positioning in patients with thin VMT[17].

Their randomized controlled trial included only patients with ≤2mm VMT, and randomized them into either 2mm sub-crestal or equi-crestal groups. In the sub-crestal group, a 3mm TmAH was used, while equi-crestal implants were restored with a 1mm TmAH. In this way, the abutment-to-crown margin was always placed 1mm above the bone crest, and the impact of the variable abutment height could be evaluated without causing esthetic failure. Their results also indicated that a longer abutment resulted in less MBL with mean MBL of 0.95mm ± 0.88mm at 12 months in the 1mm group, and 0.12 ± 0.33mm in the 3mm group.

While the randomized controlled trials by Pico et al. (2019) and Blanco et al. (2017) evaluated both thick and thin VMT, they both chose abutment height based on the VMT that was presented by the patient cohort that they were evaluating. To control for this possible confounding factor, Spinato and colleagues performed a randomized controlled trial with two groups of patients who presented with thin (≤2.0 mm) and thick (>2.0 mm) VMT[18]. These patients were randomly assigned to receive either a 1mm (short) or 3mm (long) transmucosal abutment after 3 months of submerged healing and followed for 12 months. Their findings revealed that mean MBL at 12 months "ranged between 0.59 and 0.80mm in short abutment groups, and between 0.28 and 0.37mm in long abutment groups," with significant differences between groups irrespective of VMT.[18] This drove the authors to conclude that VMT does not influence the impact of abutment height on remodeling in the first year of loading.

While these trials would seem to thoroughly answer the question of whether VMT impacts remodeling associated with abutment height, a recent RCT by Linkevicius and colleagues (2022) creates a layer of confusion in the literature. Their results concluded that the

height of a titanium base abutment is not a relevant factor when VMT is $\geq$ 3mm[19]. However, their study presented with some significant design issues which would impact the results of their study.

One of the first design flaws in this study is how the radiographic measurements were standardized. The authors calibrated the measurements using the diameter of the implant. Meaning, they used a defined horizontal measurement to calibrate their ruler for vertical measurements. While the impact may be small, this would not allow for any discrepancies due to vertical beam angulation[20]. Since the authors also did not use standardized radiographs, this may be a factor that needed significant calibration.

Furthermore, and perhaps even more significant, implants were placed with a single stage approach, provided with, "standard healing abutments" of an undisclosed height, and evaluated for final restorations at 2mo for the maxilla and 4mo for the mandible. This means that for 2-4mo, the implants had healing abutments that were of an unknown height, potentially impacting the final result. All previous RCTs were either performed by delivering definitive abutments at the time of surgery[5,21,22,17], 2mm healing abutments at the time of surgery[21], or followed a two-stage approach followed by a 3mm healing abutment that was only in place for 3 weeks[18]. Having a 2-4mo period during which there was an unknown sized healing abutment is a very significant factor. Previous studies have indicated that the most significant time for physiologic remodeling to occur is during the first 6 months[18]. In this study, 43/54 implants that are included were placed in the mandible. This means that for the vast majority of implants included in the study, 4mo of healing time may have been with a longer abutment, presenting a significant confounding factor especially for the short abutment group.

While it is true that the mean MBL rates between the short and long group were not significant, the authors also did not disclose if there were significant differences between the ranges of MBL experienced. In Table Ia which was presented in their article, the authors present the ranges. It can be observed that 70% of implants restored with long abutments experienced only 0-0.5mm or MBL, compared to only 44% of implants restored with short abutments. Also, 95% of the long abutment group experienced ≤1mm of MBL with only 1 implant experiencing greater than 1mm and this implant lies in the range of 2.51-3mm of MBL, while 88% of the short abutment group experienced ≤1mm with 4 implants in groups >1mm.

Due to the incomplete reporting, it can't be surmised as to whether these numbers are significant, however it would appear as though there is a strong trend toward a longer abutment experiencing less MBL, which would agree with all preceding RCTs on the topic.

Despite the evidence highlighting the impact of abutment height and supracrestal tissue height on marginal bone loss, there is limited long-term data on how effective this approach is in lowering the risk of peri-implantitis. A crucial factor to consider is the depth at which the crown-abutment margin is placed, as deeper placements increase the likelihood of undetected cement remnants[23]. Research indicates that the most substantial amount of cement residue occurs when margins are positioned 2 to 3 mm below the gumline. Therefore, it is essential to carefully balance vertical implant placement and abutment height to reduce the risk of retained cement following crown placement.

This consideration falls in line with previous findings of a long term retrospective study evaluating the prevalence of peri-implantitis in a Swedish population[4]. The authors found that in the cohort of implants which presented with ≤1.5mm from prosthetic margin to bone crest (ie. the TmAH) there was a 2.3x greater likelihood of a diagnosis of moderate-severe periimplantitis.

Findings such as this are a prime example of why a distance of ≤1.5mm from margin to bone crest is considered as a risk factor for periimplantitis in the Implant Disease Risk Assessment presented by Heitz-Mayfield and colleagues[24], and as a predisposing factor for peri-implantitis according to Monje and colleagues[25].

Considering all of these findings, the role of abutment height is pivotal in influencing MBL around dental implants. Studies consistently show that longer transmucosal abutments are associated with reduced MBL, regardless of vertical mucosal thickness. This underscores the importance of considering abutment height in implant treatment planning, especially in patients with varying mucosal thickness. Future research should continue to explore the interplay between these factors to enhance implant success and longevity.

1.2 THE IMPACT OF RESTORATIVE EMERGENCE ANGLE ON PERI-IMPLANT BONE REMODELING

Following the detailed exploration of abutment height and its influence on physiologic and pathologic bone loss, it is essential to consider another critical factor: the restorative emergence angle (REA). The REA is defined as the angle between the implant long axis and a line tangent to the restoration[26], and has been theorized to have a significant impact on plaque accumulation and oral hygiene measures. Overcontoured restorations may lead to hindering hygienic efforts and more plaque accumulation[27]. While limited studies have been performed evaluating the impact of this restorative characteristic, within the limitations of that research an REA of >30˚ appears to be a factor in increasing MBL and rates of periimplantitis.

Prior to 2018, most studies concerning the contour of implant-supported prostheses had primarily focused on gingival aesthetics, with little attention given to its potential role in peri-implantitis. In contrast, the impact of restoration contour on the periodontium of natural teeth has

been well-documented since the early 1970s. Research has shown that overcontoured restorations on natural teeth can lead to gingival erythema due to increased plaque retention, whereas well-contoured restorations support gingival health[28,29]. Further studies have indicated that restorations with more pronounced contours than natural tooth convexities can contribute to problematic plaque accumulation[30]. These original concepts that have been applied to natural teeth appear to also hold true in the case of dental implants.

In a cross sectional study by Serino and Ström[31] 53 of 58 implants diagnosed with periimplantitis were reported to have no access for oral hygiene measures. A similar finding was reported by Monje et al. (2019) who find that 77.2% of the periimplantitis cases presented with inadequate access for hygiene performance[32]. While access for oral hygiene is not a direct association to emergence angle, studies have reported on their association.

In a recent cross sectional study, implant REAs were evaluated by removal of the crown and scanning with an intraoral scanner, and also using periapical radiographs. The authors reported that there was a high degree of correlation between the mesial and distal REAs when comparing the two methods, and also found that with increasing emergence angle there was a significant increase in both plaque accumulation and BOP[33]. These findings strengthen the argument that an increase in REA for dental implant restorations may have similar impacts as those for natural teeth.

Findings such as these are the basis for the initial investigation into an association between REA and peri-implant diseases lead by Katafuchi and colleagues[26]. The results of this cross-sectional radiographic analysis revealed that implants with >30˚ REA presented with 2x greater prevalence of peri-implantitis (31.3% vs 15.1%). This association was specific to bone level implants, as tissue-level implants presented with only 7.5% prevalence of periimplantitis.

While this finding is compelling, the authors caution that these results should be interpreted with caution as only 67 tissue level implants were included in the analysis.

Future studies went on to corroborate these findings. Yi and coworkers performed a cross-sectional analysis of 359 implants and found that, "as dichotomous variables, a significantly higher MBL and the prevalence of peri-implantitis were detected with REA ≥ 30 than < 30 (OR 3.80; 95% CI [1.75, 8.22]; p = .00)."[34]

Additionally, the influence of the REA on the MBL and the prevalence of peri-implantitis was significant in the bone-level group for both external and internal connection types. This was not the case for the tissue-level group, which agrees with the results by Katafuchi et al. (2018). There was, however, a trend toward a greater prevalence of peri-implantitis in the tissue level group with REA ≥30˚ compared to those with <30˚ REA (21.7% vs 4.1% respectively). While the evidence remains unclear as to if tissue-level implants are impacted by emergence angles, there appears to be a clear association with bone-level implants and increased rates of periimplantitis and increased MBL. Since these publications, other investigations have also found an impact of REA on MBL as well[27,35,36]

In conclusion, the REA is a critical factor in influencing MBL and the prevalence of peri-implantitis around dental implants. Research consistently demonstrates that a REA greater than 30 degrees is associated with increased plaque accumulation, bleeding on probing (BOP), and higher rates of peri-implant diseases. While earlier studies primarily focused on gingival aesthetics, recent findings highlight the significant role of REA in peri-implant health, particularly for bone-level implants. This underscores the necessity of meticulous restorative planning to optimize REA and minimize the risks associated with peri-implantitis.

1.3 SUPRACRESTAL TISSUE ADHESION

Dental implants have become the gold standard for the replacement of natural teeth, offering a durable and functional solution for patients. Clinicians often recommend dental implants with a high degree of confidence, assured by the long-term success rates reported in various studies[37,38]. However, the precise aetiologies of certain complications, both biological and biomechanical (including prosthetic and aesthetic issues), remain only partially understood. One of the critical success factors for dental implants is the long-term maintenance of marginal bone levels, ensuring minimal bone loss and the absence of complications[39].

The prosthetic components of dental implants provide clinicians with a vital tool to achieve long-term success. As discussed in the previous sections, the interaction between the prosthetic–implant connection and the peri-implant soft tissues is pivotal in establishing and maintaining stable crestal bone levels. The vertical dimension that describes this interaction is known as Supracrestal Tissue Height (STH), which refers to the dimension of the soft tissue enveloping an implant, extending from the mucosal margin to the crestal bone. However, Supracrestal Tissue Adhesion (STAd) is more precise as it parallels the corresponding dimension around natural teeth, termed supracrestal tissue attachment.

STAd consists of three components: sulcular epithelium, junctional epithelium, and fibrocollagenous connective tissue. Importantly, this connective tissue is typically not attached to the abutment surface. The interaction of STAd with surrounding tissues is essential for achieving predictable and long-term success in dental implant therapy. STAd significantly influences marginal bone loss patterns, particularly following the delivery of the prosthesis.

Understanding and managing STAd in both surgical and prosthetic phases of implant therapy is critical for predicting initial peri-implant bone remodeling, also known as aseptic bone resorption. This knowledge helps clinicians mitigate early bone loss and enhances the overall

success and longevity of dental implants. Therefore, thorough discussions and considerations of STAd are indispensable in planning and executing dental implant treatments to ensure optimal patient outcomes.

Unlike dentogingival fibers around natural teeth, which insert into the cementum and bone, the fibers around dental implants, for the most part, align parallel to the implant surface, creating a cuff-like barrier against bacterial invasion. Early research into the STAd of dental implants revealed the importance of allowing for a minimum width of peri-implant mucosa to create epithelial and connective tissue attachment.

This was initially observed with the use of bone level implants with external connections[9], and since has been found to be attributed to the presence of a microgap which allows for bacterial aggregation followed by an inflammatory infiltrate and subsequent aseptic bone resorption[7]. Since this discovery, similar observations have been made with multi-unit restorations[8,17,5,40], as well as single implant crowns[18,22,41].

In the case of multi-unit restorations, a similar explanation can be made in that a micro-gap presents at the crown-abutment margin in multi-unit abutments (MUAs). When multiple implants are joined in a splinted restoration, it is extremely difficult to place these implants in a way which would allow for no discrepancy between their paths of insertion. MUAs can correct these slight deviations in angulation to provide a common, parallel path of insertion for the prosthesis, making it easier to fit and remove the restoration. However, this connection is only as stable as the screw which retains it, allowing for a similar micro-gap to form.

In the case of single implant crowns, whether screw retained, or cement retained, the crown is cemented to the abutment. In some circumstances this will be done in a lab under a microscope, and others are done chairside at the time of delivery. However, regardless of their

method of cementation, a small cement line will be present at the crown-abutment margin. This may become a site for bacterial aggregation and a similar inflammatory infiltrate which can impact the occurance of MBL.

Regardless of the type of restoration, it has been observed that MBL will occur as needed to create an appropriate STAd dimension. Therefore, the role of STAd in MBL is crucial, as the vertical positioning of the implant platform relative to the alveolar crest can significantly influence post-surgical bone remodeling, especially in bone-level implants.

One important consideration when discussing STAd is the VMT. It's been observed that thin VMT at the time of implant placement has consistently been associated with a greater amount of marginal bone loss[16]. In response to this, some authors have recommended soft tissue grafting procedures to increase vertical mucosal height at sites with a thin phenotype when shallow implant placement is necessary. However, there is only limited evidence to support this recommendation. The more valid and supported recommendation has been to utilize subcrestal implant positioning to compensate for potential reductions in peri-implant marginal bone levels[42]. Anticipating the establishment of STAd by adjusting the apicocoronal implant positioning in relation to mucosal thickness may effectively prevent unwanted exposure of treated implant surfaces.

Avila-Ortiz et al. suggested a threshold for STAd to be utilized in both research and clinical practice. They categorized STAd as either short (< 3 mm) or tall (≥ 3 mm), based on findings that peri-implant STAd dimensions are typically 1.0 to 1.5 mm greater than those surrounding natural teeth. By adhering to these guidelines, clinicians can strategically position the bone-level implant platform to ensure at least 3 mm of STAd.

A review by Saleh et al. suggested different treatment strategies based on the thickness of the vertical mucosa. For thick vertical mucosa (> 2 mm), the level of the implant platform should be set to accommodate an abutment that provides adequate space for 2 to 4 mm of STAd, minimizing the risk of MBL. In the presence of thin vertical mucosa (< 2 mm), subcrestal placement combined with a longer abutment should be considered to avoid abutment exposure and provide sufficient space for STAd.

For tissue-level implants, since the polished collar forms the connective tissue adhesion, the vertical placement of this type of implant often follows the principle of "placed as deep as necessary, but as shallow as possible" to ensure the optimal 3 mm of STAd is established along with additional abutment height. Ideally, these implants should be placed equicrestally, with the rough-smooth margin at the level of the bone crest, as subcrestal placement has been found to cause excessive remodeling with tissue-level implants.

STAd influences bone remodeling regardless of the implant level, design, or prosthetic features. Nevertheless, bone resorption can be mitigated by distancing the implant–abutment junction from the bone, often achieved through the use of a transmucosal abutment or a tissue-level implant. The inflammatory reaction surrounding the microgap between the crown and abutment is spatially related to the peri-implant marginal bone level. Studies have indicated that employing tissue-level implants can effectively address this issue by increasing soft tissue volume and decreasing the microgap's impact on peri-implant bone stability.

Conversely, a reduced distance between the alveolar crest and the implant–abutment junction, resulting from using a short prosthetic abutment, predisposes early MBL regardless of VMT Numerous researchers have observed that marginal bone is preserved not only by having thick mucosa but also by using an abutment taller than 2 to 3 mm. Independent studies by

Spinato et al., Blanco et al., Pico et al., Muñoz et al., and others in randomized controlled trials have demonstrated that MBL is nearly twice as severe when short (< 2 mm) abutments are used compared to taller (> 2 mm) abutments, regardless of VMT. Thus, selecting an appropriate abutment height is crucial to positioning the crown margin in a way that favors adequate STAd and minimizes MBL.

For achieving optimal aesthetics and a design that is easy to clean, abutment height is often chosen so that the prosthetic margin is at or slightly below the level of the peri-implant mucosa. This approach provides accessible margins for cement retrieval, which is critical as deeper crown–abutment margins may increase the prevalence of cement remnants, potentially triggering peri-implantitis. This relationship underscores the importance of considering abutment height well before prosthetic rehabilitation. If abutment height is only addressed at the time of crown fabrication, it often necessitates using a short abutment to avoid exposing the implant-abutment margin, ultimately leading to excessive remodeling.

In clinical scenarios where VMT is minimal and subcrestal placement is contraindicated due to the proximity of anatomical structures, combining implant surgical and prosthetic therapy may be necessary. Some authors have suggested vertical soft tissue augmentation before implant placement when VMT is thin. Although supporting evidence is limited, this approach could theoretically create adequate thickness for STAd and enable the use of a longer abutment, thereby reducing aseptic remodeling. When subcrestal placement is feasible, it is preferable to create adequate distance for optimal STAd, minimizing MBL, and reducing the risk of peri-implantitis.

In conclusion, the meticulous management of STAd is imperative for the long-term success of dental implants. By carefully planning the vertical positioning of implants and

selecting appropriate abutment heights, clinicians can optimize peri-implant tissue health, minimize bone loss, and enhance the overall aesthetic and functional outcomes of implant-supported restorations. Understanding the complex interactions between STAd, implant positioning, and prosthetic components is essential for achieving predictable and sustainable results in dental implant therapy.

1.4 A REVIEW OF PERIIMPLANT DISEASES

One of the key requirements in the treatment of disease lies in the recognition of disease onset. Mombelli first defined peri-implantitis in 1987 as, "a site-specific infection with remarkably similar ecosystems to those encountered in periodontal diseases." While this definition remains true to much of our understanding today, key advancements have allowed us to more accurately identify the condition and its clinical onset signs. Recently, as part of Workgroup 4 on the Classification for Periodontal and Peri-implant Conditions, Schwarz, Derks, Monje, and Wang redefined peri-implantitis as, "a plaque-associated pathological condition occurring in the tissues around dental implants, characterized by inflammation in the peri-implant mucosa and subsequent progressive loss of supporting bone."

This workgroup resulted in 4 categories of peri-implant disease:

- Peri-implant Health[43]
- Peri-implant Mucositis[44]
- Peri-implant Hard and Soft-Tissue Deficiencies[45]
- Peri-implantitis[46]

One issue that was also recognized was that the lack of a definitive case definition resulted in a high degree of variability with respect to clinical recognition of peri-implantitis[47].

Recognizing this issue, Berglundh and colleagues presented our current definition for peri-implant diseases (Table Ib).

There are similarities in considerations for the progression from health to disease in periodontal and peri-implant diseases, namely the presence of BOP and bone loss. However, the inherent differences in peri-implant and periodontal structures and their impact on clinical measurements are important to understand.

The concept of biologic width encompasses the necessary dimensions of soft tissue attachment for the maintenance of periodontal health. In natural teeth, the biologic width – which is now termed the Supracrestal Tissue Attachment (STA) – is typically composed of a junctional epithelium and connective tissue attachment, averaging around 2.04 mm in height[48]. This space is crucial for protecting the underlying alveolar bone from microbial invasion and inflammation.

Conversely, the biologic width around dental implants, referred to as STAd or STH, tends to be slightly different. Histological studies have shown that the peri-implant mucosa includes an epithelial attachment of about 1.5 to 2 mm and a connective tissue component of 1 to 1.5 mm, totaling approximately 3.5 mm[49]. The peri-implant connective tissue differs from the periodontal connective tissue, primarily due to the absence of a periodontal ligament and the unique orientation of collagen fibers, which run parallel or circumferentially around the implant rather than inserting into the cementum as they do with natural teeth.

The lack of fiber insertion in implants significantly affects clinical measurements. In a study by Lang et al. (1994), it was observed that in sites displaying health or peri-implant mucositis, the probe tip reached the apical border of the junctional epithelium. In contrast, in sites with peri-implantitis, the alveolar bone crest was most likely identified[50]. This differs from

studies on natural teeth, where the probe tip only approached connective tissue in the presence of periodontitis[51].

As the connective tissue zone contains much of the tissue's vascularity, BOP in implants has been extensively investigated as a diagnostic indicator. Dukka and colleagues discussed BOP in implants, noting that pathologic BOP is often induced by inflammation and can be considered a disease indicator[52], as the probability of BOP increases with increasing PD in implants[53]. However, traumatic BOP is more common around implants than natural teeth. This occurs due to probing too hard, which is made more difficult by the "tenuous peri-implant mucosa" and prosthetic contours[52]. This underscores the importance of differentiating between bleeding dots, lines, and drops[54,55].

The most widely accepted etiological factor for the development of peri-implant disease is inflammation induced by plaque[46]. Similarly to gingivitis and its progression to periodontitis, multiple studies following the experimental gingivitis model set by Löe and colleagues in 1965[56] have found that experimental mucositis will develop around implants following the same protocol of plaque control cessation[57–59]. Although, there would be ethical issues with inducing peri-implantitis in man, inducing inflammation through ligature models in animal studies[60] have found this eventually progresses to cause peri-implantitis. As the primary accepted etiology for peri-implant disease, much of our treatments of mucositis/peri-implantitis involve the elimination of biofilm from the implant surface.

In the 2017 World Workshop, Schwarz and colleagues aptly stated: "it appears reasonable to suggest that implant position and design of the suprastructure may influence the access for home care and professionally administered plaque removal."[46] Additionally, other iatrogenic factors, such as "surgically triggered factors," have been implicated in the

development of peri-implantitis (PI), as discussed by Canullo et al. in 2016[61]. These factors include the "presence of plaque associated with oro-vestibular and mesio-distal malpositioning" or failed bone reconstruction, such as the resorption of augmented bone exposing the implant surface. However, it is crucial to recognize that surgical factors, such as placement "too buccal," do not directly cause peri-implantitis. Instead, they increase the physiologic remodeling of the buccal plate, leading to dehiscence, plaque colonization, and subsequent peri-implantitis[62].

This study by Canullo et al. (2016) also provides significant insights into other risk factors and predictors for peri-implantitis. The study evaluated 56 patients with 332 implants, finding that 125 implants presented with peri-implantitis while 207 remained healthy. Notably, peri-implantitis was categorized into three "triggering factors": surgically triggered, prosthetically triggered, and plaque-induced. Of the peri-implantitis cases, 40.8% were surgically triggered, 30.4% were prosthetically triggered, and 28.8% were plaque-induced.

The high prevalence of prosthetic factors as a trigger for peri-implantitis underscores the critical role that prosthetic design and execution play in the health of peri-implant tissues. As we have discussed in previous sections, improper prosthetic contours, emergence profiles, and abutment characteristics can hinder effective plaque removal and increase the risk of inflammation and bone loss.

Understanding the etiological factors of disease allows for a more targeted approach in the prevention and treatment of peri-implantitis. Future research should continue to explore the interplay between these various factors, aiming to refine treatment protocols and develop more effective preventive measures.

2. STATEMENT OF THE PROBLEM

2.1 ABUTMENT HEIGHT AND EMERGANCE ANGLE AS A COMBINED FACTOR IMPACTING PERIIMPLANT BONE LOSS

Establishing a stable peri-implant crestal bone level is a requirement to ensure the long-term success of dental implant therapy required to ensure dental implant therapy's long-term success[39,63]. Crestal bone remodeling, which occurs following implant surface exposure to the oral environment, is recognized as a physiological rather than pathological process[46,64,65].The formation of a biologic seal between soft tissues and implant components can be accompanied by MBL distinct from peri-implantitis, an otherwise pathological condition causing progressive bone loss[46].

While these represent distinct processes, the occurrence of exaggerated MBL during the physiologic remodeling stage has been shown to impact the stability of bone levels thereafter[66]. As discussed in the previous sections, investigations into the factors that influence bone loss around dental implants have identified a significant impact from the height of the prosthetic abutment. When Galindo-Moreno and colleagues first reported this, they noted that the TmAH was the variable with the most influence on the marginal bone loss at both 6 and 18 months [post-loading]", with an TmAH of $\geq$2mm resulting in significantly less bone loss[8]. Several clinical studies and randomized control trials have since supported the necessity of selecting an appropriate TmAH to accommodate the crown margin while providing sufficient space for STAd formation[67,5,17,18,21,68,69].

Understanding that the TmAH plays a critical role in establishing high crestal bone levels during the physiologic remodeling stage, it follows that it will also impact the occurrence of disease around dental implants. Clinical studies have found that implants with shorter abutments

have a greater prevalence of periimplantitis[4,70], with a bone crest-to-crown margin distance of <1.5mm being highlighted as significant risk factors[4,24,25]. The use of a short abutment, however, is not the only factor that may be increasing disease susceptibility in these scenarios. TmAH is often chosen in response to the available space from the implant platform to the planned free-gingival margin (FGM). In cases where an implant is placed shallow with respect to the FGM, the restorative dentist is forced to use a short abutment, as well as an exaggerated REA to achieve an ideal esthetic.

A greater REA has been found to play a significant role in the accumulation of plaque, and impairment of oral hygiene access[25,31,33]. Because dental plaque has been identified as the primary etiology of periimplantitis[46], the clinical scenarios necessitating the use of a short abutment with a greater emergence angle may be creating ideal conditions for disease to take place.

This concept may partially explain the findings of Katafuchi et al. (2018) who saw that bone level implants with REA >30˚ presented with 2x greater prevalence of periimplantitis[26], while the tissue-level implants included in their study did not share the same association. A tissue-level implant is not only fabricated with a built in trans-gingival emergence which is <30˚[34] but also has a polished transgingival collar allowing space for the formation of STAd[26] which may be a reason for this finding in the literature.

Due to the relationship between TmAH and REA, it is crucial that these characteristics be evaluated in conjunction with one another, rather than in isolation. The bi-directional impact of these prosthetic components must be acknowledged, as they collectively influence peri-implant bone remodeling. Studies that have focused on either TmAH or REA independently may not fully capture the interplay between these two factors, leading to potentially confounded results.

For instance, an increase in marginal bone loss could be attributed to a steep REA, a short TmAH, or a combination of both. Without considering their combined effect, it becomes difficult to isolate the contribution of each factor to the observed peri-implant bone changes.

MBL around dental implants is a critical concern in implant dentistry, affecting the long-term success and stability of implants. Despite advancements in implant technology and surgical techniques, peri-implant bone loss remains a prevalent issue, often leading to complications such as peri-implantitis, which can compromise the implant's longevity and patient outcomes. Several factors, including the design and placement of abutments, have been identified as potential contributors to MBL.

Understanding the precise relationship between TmAH, REA, and their combined effects on peri-implant MBL is essential for developing evidence-based clinical guidelines to enhance implant success rates. This study aims to fill this gap by analyzing the combined effect of these variables on bone loss and peri-implantitis incidence, ultimately contributing to better clinical practices and patient care.

3. OBJECTIVES

The primary objective of this retrospective study is to evaluate the combined influence of TmAH and REA on peri-implant MBL around bone level implants. Specifically, this research seeks to determine whether increasing the TmAH can mitigate the adverse effects of abrupt REA on peri-implant bone stability.

To achieve this objective, the study will:

1. Measure and categorize the TmAH and REA of implants based on radiographic analysis.
2. Calculate and compare the mean MBL among implants categorized into four groups: Long-Gradual (LG), Long-Abrupt (LA), Short-Gradual (SG), and Short-Abrupt (SA).
3. Control for various patient-level and implant/prosthesis-level factors through multiple linear regression analysis to isolate the impact of TmAH and REA on MBL.
4. Assess the relative significance of TmAH and REA on the probability of MBL through multiple binary logistic regression modeling.
5. Investigate the correlation between TmAH and the incidence of peri-implantitis, evaluating whether increased abutment height can reduce the likelihood of peri-implantitis in implants with abrupt REA.

By accomplishing these objectives, the study aims to provide a comprehensive understanding of how TmAH and REA collectively influence peri-implant bone health, thereby guiding clinicians in optimizing implant design and placement for improved patient outcomes.

4. HYPOTHESIS

This study hypothesizes that the TmAH and the REA collectively influence peri-implant MBL and the incidence of PI. Specifically, it is hypothesized that:

1. Increasing the TmAH will mitigate the adverse effects of abrupt REA on peri-implant bone stability, resulting in reduced MBL and a lower likelihood of peri-implantitis.
2. Implants with a TmAH greater than 2mm will exhibit less MBL compared to those with a TmAH less than 2mm, regardless of the REA.

This hypothesis aims to elucidate the interplay between TmAH and REA in influencing peri-implant bone health, providing insights that could inform clinical decisions and improve the longevity and success of dental implants.

II. MATERIALS & METHODS

This retrospective radiographic study was conducted in alignment with the ethical standards of the Declaration of Helsinki and adhered to local and international regulations concerning the use of human subjects in research. Given its retrospective nature, this study utilized existing data that was anonymized and handled in compliance with the principles of confidentiality and privacy. This study was approved by the University of Michigan, School of Dentistry, Institutional Review Board for Human Studies (HUM00223052), which confirmed that all procedures performed in the study were in accordance with ethical standards.

In the present retrospective analysis, all patients treated with bone-level implants placed and restored at the University of Michigan Periodontics, Oral Surgery, and Prosthodontics dental clinics between January 2012 and December 2020 were screened for inclusion.

1. *Inclusion Criteria*

- Partially edentulous patients receiving one or more bone-level implants.
- Presence of periapical radiographs (with a full view of the implant and crown being evaluated) taken at crown placement, between 12-18 months after crown placement (T0) and at least a one-year follow-up after T0 (T1).
- Implant characteristics related to implant length available in-patient chart (for radiograph measurement calibration).
- Patient undergoing maintenance at the University of Michigan School of Dentistry.
- Presence of patient-related information on the presence of diabetes, smoking habits, and history of periodontitis.
- Presence of opposing dentition

2. Exclusion Criteria

- Implants placed/restored outside the University of Michigan.
- Full arch restorations
- A portion of the implant/abutment/crown not visible in either T0 or T1 radiographs.
- Non-diagnostic/blurry/poorly angulated radiographs.
- Implants or patients with missing data related to implant brand/characteristics/fixture type/medical history/smoking status.
- Implant level fixtures
- Implants that had undergone reconstructive treatments for peri-implantitis
- Tissue level implants

3. Data Collection and Grouping

Four examiners screened and evaluated the physical and digital records that fell under the predetermined eligibility criteria (JM, SA, DL, OM). As part of the data collection process, relevant patient information was collected including age (at the time of implant placement), gender, smoking status, diabetes (validated via the patient's medical records), number of maintenance visits, and history of periodontal disease. A positive history of periodontitis was assigned to patients who met the criteria for moderate ($\geq$2 interproximal sites with attachment loss (AL) $\geq$4 mm [not on same tooth], or $\geq$2 interproximal sites with PD$\geq$5 mm [not on same tooth]) or severe ($\geq$2 interproximal sites with AL$\geq$6 mm [not on same tooth] and $\geq$1 interproximal site with PD$\geq$5mm) disease according to the CDC-AAP case definitions[71] based on each patient's documented periodontal charts. Implant related data including the implant site, jaw, implant characteristics (length, diameter, connection type), type of crown retention (cement or screw retention), and splinted/non-splinted were also collected. Survival rate was calculated

from the date of implant placement to last date seen in clinic. Finally, implant failure was defined as a removed, lost, mobile, or fractured implant[72].

4. Peri-implant Marginal Bone Loss, Peri-implantitis, and Grouping

One calibrated examiner (JM) performed all measurements related to peri-implant MBL, and prosthetic characteristics including REA and TmAH. The examiner involved in performing radiographic analysis was calibrated in identifying alveolar bone levels (on both mesial and distal aspect of bone level implants) on digital images and trained to identify the crown-abutment margin and the position of the alveolar crest in relation to the implant platform[73]. The examiner was consistent in his inclusion of radiographs with clearly visible threads and absence of notable horizontal or vertical beam angulation. All measurements were performed using the MiPACS plugin (Medicore Imaging, Nashville, TN, USA) built on axiUm software (Henry Shien Inc. Melveille, NY, USA). The implant length listed in the patient's chart was used to calibrate measurements. Marginal bone levels were measured at two-time points (12-18mo after crown placement (T0), and $\geq$1yr following the T0 radiograph (T1)) on both mesial and distal aspects of the implant. MBL was calculated by taking the difference of these two measurements. MBL measurements were repeated 2 times, at least 30 days apart, by the same examiner blinded to previous measurements to calculate the intra-class correlation coefficient. In case of difference of >0.5 mm between first and second measurements, final decision was taken after discussion with a second examiner (AR). Positive MBL calculations were assumed to be due to radiographic error and these measurements were adjusted to reflect no MBL.

The definition of peri-implantitis (PI) proposed by the 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions[1] where PI is diagnosed when there is progressive bone loss deepening probing depth (PD) in conjunction with clinical

notes of inflammation related to bleeding on probing or suppuration was used to classify implants in to positive or negative for PI.

Included cases were separated into four-study groups based upon the radiographically measured TmAH and REA. Mesial and distal sites were grouped independently as follows[8,26] (Figure 1):

- Long/Gradual (LG): TmAH $\geq$2mm and REA <30º
- Long/Abrupt (LA): TmAH $\geq$2mm and REA $\geq$30º
- Short/Gradual (SG): TmAH <2mm and REA <30º
- Short/Abrupt (SA): TmAH <2mm and REA $\geq$30º

5. Statistical Analysis

The study's primary outcomes were mesial and distal MBL, assessed independently. Secondary outcomes included implant failure and periimplantitis rates. Statistical analysis began with a descriptive assessment of variables, including absolute and relative frequencies for categorical and central tendency measures for continuous ones, carried out for the total sample and then stratified by group. Confounding variables were controlled by analyzing homogeneity across patient and implant profiles.

MBL changes from baseline to follow-up were analyzed using simple binary linear regression analysis using Generalized Estimating Equations (GEE) to evaluate group influences and other factors, adjusting for confounders. Periimplantitis diagnosis was assessed using simple binary logistic regression with GEE, generating odds ratios and confidence intervals from the Wald's Chi2 statistic. We then performed multi-level models for each analysis to accommodate for potential confounding factors.

Significance for all analyses was set at a 5% level. For power analysis, a post-hoc estimate determined a corrected sample size, accounting for the non-independence of implants due to multiple implants per patient and their moderate correlation, resulting in an adjusted power of 86.2% to detect significant MBL differences between groups with ANOVA.

6. STROBE Statement

We have conducted this study in accordance with the STROBE guidelines for reporting observational studies. A detailed checklist has been completed and is available as Supplementary Material to ensure transparency and reproducibility of our research methods and findings.

III. RESULTS

1. Clinical Characteristics and Demographic Profiles

A total of 192 implants (pertaining to 119 patients, 54 males (45.4%) and 65 females (54.6%) averaging 64.1 ± 11.6 years of age through a range of 33-years to 91-years at baseline) were selected and mesial and distal sites were each subsequently divided into 4 study groups independently (384 sites; 78 in LA, 61 in LG, 83 in SA, and 162 in SG) for analysis (Figure S1). Patient-level variables are outlined in Table IIIa.

2. Measurement Validation

The mean MBL from T0 to T1 for the initial measurement was 0.427 (SD = 1.089), and 0.442 (SD = 1.081) for the second measurement. The intraclass correlation coefficient (ICC) was calculated to assess the reliability of the measurements, with a higher value indicating higher reliability. The total ICC was 0.95, demonstrating high reliability between the two sets of measurements. Furthermore, the 95% confidence interval for the ICC was between 0.94 and 0.96, further emphasizing the robustness and reliability of the measurements.

3. Homogeneity of Groups

An assessment of the homogeneity of the studied groups was conducted, with results presented in Table IIIb. The majority of factors showed no significant differences among the groups (Age, p=0.351; Gender, p=0.370; Smoking, p=0.337; Diabetes, p=0.545; History of Periodontitis, p=0.546; Radiographic Follow-up, p=0.212; Total Follow-up, p=0.651; Diameter, p=0.086; Retention, p=0.347; Splinted, p=0.150; Maintenance/yr during Radiographic Follow-up, p=0.054; Maintenance/yr during Total Follow-up, p=0.083). Sector of implant placement (p=0.049), the arch in which the implant was placed (p=0.034), length of the implants (p=0.014),

and the type of implant connection (p=0.001) varied significantly across the groups, and these variables were controlled for during the multiple analyses.

4. Patient and Implant Level Factors Influencing Marginal Bone Loss

Both a univariate and multivariate analysis were conducted (Tables IIIc and IIId). Factors found to have a significant impact on MBL were radiographic follow-up period, implant length, and study group. In addition, implants that were called in for >3 maintenance visits/year had significantly more MBL.

5. Impact of Group on the Amount of MBL

The mean MBL experienced in each of the four groups is represented in Figure 2. When comparing Mean MBL across the groups, generally implants with Short TmAH had greater mean MBL compared to those with Long TmAH (Group SG and SA > Group LG and LA), and Abrupt REA greater mean MBL compared to those with Gradual REA and similar TmAH (Group SA > SG, and Group LA > LG).

A linear regression using GEE revealed a significant difference among groups in both univariate (p<0.001) and multivariate (p=0.001) models (Tables IIIc and IIId)

To assess the differences between all groups, re-estimation was performed using each group as a reference (Table IIIe). Specifically, Group SA experienced on average 0.48mm (95% CI: 0.25 – 0.71, p<0.001), 0.43mm (95% CI: 0.18 – 0.68, p=0.001), and 0.25mm (95% CI: 0.00 – 0.45, p=0.013) greater MBL compared to Group LG, Group LA, and Group SG respectively. Group SG experienced on average 0.29mm greater MBL compared to Group LG. No significant difference was found between Groups LG and LA.

6. Patient and Implant Level Factors Influencing Failure and Peri-implantitis

The failure rate was very low with only five cases, making inferential statistics inapplicable. All failed implants were associated with Group SA at mesial or distal sites, with 9/10 sites belonging to Group SA. The mean lifespan of failed implants was 7.93 years (Table IIIf), with severe peri-implantitis as the main failure cause. Adjusted analyses identified history of periodontitis, more maintenance visits, and study group as significant peri-implantitis predictors, while internal hex connections were protective compared to external hex (Table IIIg and IIIh).

7. Impact of Study Group on Peri-Implantitis Experience

At the final radiographic record, the prevalence of PI was 19.3% at the patient level (23/119 patients) and 18.8% at the implant level (36/192). Of the total cases of PI, Group LG made up 11.4%, Group LA 8.6%, Group SG 14.3%, and Group SA 65.7% (Figure 3). The intra-group rate of PI was 13.3%, 9.1%, 13.2%, and 25.6% for groups LG, LA, SG, and SA respectively (Figure 4).

Results from the univariate analysis can be found in Table IIIg. Results of the multiple analysis revealed that the study group was a significant factor impacting the development of periimplantitis (p=0.041) (Table IIIh).

To assess the differences between all groups, re-estimation was performed using each group as a reference (Table IIIi). A significant difference was found when comparing LA vs SA with over 4x greater likelihood of Group SA being diagnosed with PI (OR: 4.19; p= 0.013). Group SA also displayed a roughly 4x greater likelihood of having PI diagnosed in comparison to group LG (OR: 4.04; p=0.091).

8. Impact of TmAH vs REA on the Probability of MBL >0 mm

The prevalence of MBL>0 mm by group was 35.1%, 47.5%, 69.9%, and 67.7% in groups LG, LA, SG, and SA, respectively. A multiple binary logistic regression model (Table IIIj) performed to identify what factor (REA or TmAH) had a more significant impact on the probability of MBL >0mm (pMBL>0) found that the TmAH was the only significant covariate (p=0.015) with every 1 mm increase in TmAH reducing the odds of positive MBL by 51% (OR=0.49; p=0.015).

The logistic equation for the current model is: p/(1-p) = 3.947 x (0.99^Angle) x (0.494^Height) x (1.009^Angle x Height) where p = estimated pMBL>0. Graphical representation of p as a function of TmAH and REA is shown in Figure 5. It can be observed that the minimum pMBL$\geq$0 is reached at the largest level of TmAH and the smallest level of REA. The results show that with an increase in TmAH, pMBL>0 decreases with a steep slope. When TmAH is small, there is virtually no influence from REA and pMBL>0 is the worst possible. However, when the TmAH is large, while statistically insignificant, REA appears to influence pMBL>0, and the lowest pMBL>0 is reached when the TmAH is large, and the REA is small.

IV. Discussion

The results of this retrospective radiographic study suggest that in regards to MBL, REA $\geq$30 only becomes a significant factor when TmAH is <2mm in bone-level implants. Additionally, implants with TmAH $\geq$2mm experienced roughly 4x less periimplantitis, regardless of REA with Group SA displaying an OR of 4.19 for PI in comparison to Group LA (p= 0.013), and 4.04 when compared to Group LG (p=0.091). Finally, while REA was not found to have a significant effect on the prevalence of MBL >0mm, for every 1mm increase in TmAH the prevalence of MBL >0mm decreased by 51%. There have been many efforts to evaluate the impact of these prosthetic characteristics on crestal bone levels and disease experience, however

our study has shown that the added subgrouping of TmAH with REA is an important consideration.

Yi and colleagues reported on the significant association between REA with MBL, with significantly higher values of MBL being detected with REA $\geq$30 vs <30[34]. While they did not take into consideration the implant abutment, they did note that tissue-level implants were not impacted by REA with respect to MBL. These findings seem to support our results that REA only plays a significant role in MBL severity when TmAH is <2mm.

Strauss et al. (2022) contribute to this conversation by suggesting that REA may have a time-dependent effect on MBL. Their prospective study indicated a significant correlation between REA and both the severity and probability of MBL within the first-year post-loading ($p<0.05$). However, this relationship was no longer present at the 5-year follow-up[74]. While the results of our study agree that REA does not significantly affect the incidence of MBL after the first year as shown in our logistic models ($p=0.476$), they deviate in our finding a significant impact in the severity of MBL experienced outlined in our linear models. This discrepancy may be due to the subgrouping presented in our study, which allowed for a more nuanced understanding of the impact of REA on the amount of MBL, identifying that the significant impact of REA is only associated with shorter abutments (<2mm) ($p=0.013$).

While REA did not exhibit a significance impact on the presence of MBL when considered alongside TmAH, our further explorations provide deeper insights. The graphical representation of pMBL>0 suggests that the dynamic between TmAH and REA and their impact on MBL probability is complex. For instance, when TmAH is small, the impact of REA is substantially overshadowed by TmAH, leading to the worst recorded pMBL>0. It can be observed that in the short abutment groups, roughly 70% of implants presented with MBL>0mm

regardless of the REA with 69.9% and 67.7% in groups SG and SA respectively (Table IVa). Conversely, with longer TmAH, REA's impact—though not statistically significant—seemed to gain prominence, with 35.1% in Group LG and 47.5% in Group LA encountering MBL >0mm. This highlights that while TmAH typically holds greater significance over the presence of MBL, reducing its likelihood by 51% for every 1mm increase, the role of REA should not be entirely discounted. Even at longer TmAH, the angular aspect does seem to play a role in contributing to the presence of MBL.

This is not the first study to find an increased risk of disease for implants with TmAH <2mm. In a study of a Swedish population, it was noted that a ≤1.5mm distance from the prosthetic margin to crestal bone at baseline resulted in a 2.3x greater prevalence of moderate-to-severe peri-implantitis[4]. The association found in the present study was much more dramatic, with Group SA displaying a 4x greater prevalence of periimplantitis in comparison to both groups with TmAH ≥2mm (Group LG: OR 4.04, p=0.091; Group LA: OR 4.19, p=0.013). Once again, a likely reason for this discrepancy is the added subgrouping based on REA in our study. A possible explanation for this common finding is that the presence of a short abutment does not allow a sufficient space for supracrestal tissue height establishment. This leads to increased MBL[5,17,18,22,68], exposure of the rough surface of the implants[75–77], and possibly exposure of the implant's threads[78], all of which become a local factor for plaque accumulation and place the implant at a greater risk for periimplantitis.

A narrower emergence angle has been postulated to decrease plaque accumulation and the consequent inflammation arising from bacterial aggregation[26,34,35]. In this context, the use of a tissue-level implant or a bone-level implant with a long transmucosal abutment may offer protection through the improved soft tissue adaptation and increasing the distance from the bone

crest to the restorative margin. This additional space is essential in restricting the impact of plaque-associated inflammation, as inflammatory lesions localized to the sub-epithelial space are less likely to cause damage to the crestal bone[79]. This concept aligns with the principles of bone coupling, where the proximity of the inflammatory lesion to bone surface can stimulate the recruitment of osteoclast precursors, osteoclastogenesis, and subsequent bone resorption[79]. Investigations into the implant or restoration transmucosal design, regardless of the level of the abutment-crown junction, have also shed light on plausible explanations for the current study findings. Several studies have identified that less peri-implant bone loss occurs around implants with straight or convergent collars than around those with divergent collars[80,81]. In a study on tissue-level implants comparing convergent and divergent transmucosal morphology, implants with convergent contours had significantly less marginal bone loss after 24mo of loading[80]. As it pertains to the present study, this would indicate that the length of the abutment played a role only in elevating the initial crown emergence from the crestal bone, and the crown-abutment margin was not the primary influence on marginal bone levels.

This would fall under one of the limitations of the present study, as the level of the initial crown emergence was not documented. Future studies should control for this factor and include it in their investigation. Paradoxically, the results of our study indicated that implants that went through >3 maintenance visits per year showed greater MBL ($p=0.011$) and a higher risk of PI ($p=0.002$) compared with those which had <3 visits. We hypothesize that this occurs retrospectively, akin to the situation observed in patients with periodontitis, where individuals with more significant bone loss necessitate a more rigorous maintenance recall during the follow-up period[82]. In simpler terms, excessive bone loss leads to the patient being enrolled in more maintenance visits, not the other way around[83].

The retrospective design of this study is also a limitation that bares acknowledgement. This makes it impossible to control for factors related to implant placement depth, tissue thickness, and other variables that would require a prospective design. This was one of the reasons we decided to evaluate marginal bone level changes that occurred after the first year, as a majority of these factors are shown to impact early bone loss, but not necessarily late bone loss. Future studies should be performed with a prospective design that can take into account these various factors.

In addition, all negative changes in marginal bone level were considered to be MBL; therefore, despite having an excellent intra-class correlation coefficient, MBL due to measurement error cannot be dismissed. This limitation, however, is compensated by strictly selecting only high-quality radiographs, resulting in more reliable and reproducible marginal bone level measurements evidenced by the ICC of 0.95, albeit with a reduced sample size. It should also be noted that this limitation should not be applied to the analysis of PI, as this diagnosis was strictly made based on the recommendations of the World Workshop[1] using radiographic measurements, in conjunction with deepening probing depths and clinical notes of inflammation, and the analysis was performed in a logistic fashion (yes/no) rather than linear.

Finally, this study did not evaluate the impact of abutment height and emergence angles on tissue level implants, and the findings can only be applied to bone level implants. While previous studies have indicated that tissue level implants may not be impacted by emergence angles[26,34], both studies have had a fairly limited number of tissue level implants that were included in their evaluation. Due to this, the effect of emergence angles on tissue level implants is not yet firmly identified and should be evaluated with further research.

V. Conclusion

Within the limitations of the present study, abutment height greater than 2mm plays a significant role in reducing the experience of PI and MBL related to abrupt REA, specifically around bone-level implants. Additionally, REA becomes a significant factor only when TmAH is less than 2mm. The probability of marginal bone loss was found to have an inverse relationship with TmAH and have no significant relationship with REA.

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Tables & Figures

Table Ia. Bone Loss Distribution as Grouped in Categories Between Groups and Time Points - Linkevicius et al. 2023

Table 3 Bone Loss Distribution as Grouped in Categories Between Groups and Time Points

Bone loss categories (mm)	Group 1—Short base		Group 2—High base	
	T1	T2	T1	T2
0–0.5	9 (32.1%)	12 (44.4%)	10 (37%)	19 (70.4%)
0.51–1	13 (46.4%)	11 (40.7%)	6 (22.2%)	7 (25.9%)
1.01–1.5	5 (17.9%)	1 (3.7%)	8 (29.6%)	0 (0%)
1.51–2	0 (0%)	3 (11.1%)	2 (7.4 %)	0 (0%)
2.01–2.5	1 (3.6%)	0 (0%)	1 (3.7%)	0 (0%)
2.51–3	0 (0%)	0 (0%)	0 (0%)	1 (3.7%)

Table Ib Case Definitions for Peri-implant diseases The current case definitions are presented for Health, Mucositis, and Peri-implantitis with or without a history of radiographs.

	Health	Mucositis	Peri-implantitis	Peri-implantitis (no Hx)
Visual Inflammation	N/A	YES	YES	YES
BOP/Exudate	N/A	*Line/Drop*	*Line/Drop/Exudate*	*Line/Drop/Exudate*
PD	No Increase	Increase	Increase	≥6mm
RBL	Only MBL ≤2mm	Only MBL	Increased vs MBL	≥3mm

Lindquest et al. 1996
Cochran et al. 2009
Renvert et al. 2018

(**Berglundh et al. 2018**)

Table IIIa. Demographic and clinical status of patients. Number of patients (%) or mean ± standard deviation.

N	119
AGE (years)	64.1 ± 11.6
GENDER	
Male	54 (45.4)
Female	65 (54.6)
SMOKING	
Non-smoker	66 (55.5)
Former	41 (34.5)
Current	12 (10.0)
DIABETES	
No	99 (83.2)
Yes	20 (16.8)
HISTORY OF PERIODONTITIS	
No	56 (47.1)
Yes	63 (52.9)
FOLLOW UP period (years)	7.43 ± 2.73

Table IIIb. Homogeneity of groups by independent factors: Results of logistic or linear regression using GEE (p-value).

	p-value
AGE	0.351
GENDER	0.370
SMOKING	0.337
DIABETES	0.545
HISTORY OF PD	0.546
RX time period (years)	0.212
FOLLOW UP period (years)	0.651
SECTOR	**0.049***
ARCH	**0.034***
CONNECTION	**0.001****
LENGTH	**0.014***
DIAMETER	0.086
RETENTION	0.347
SPLINTED	0.150
N.MAINTENANCES (RX FU) per year	0.054
N.MAINTENANCES (Total FU) per year	0.083

*p<0.05; **p<0.01; ***p<0.001

Table IIIc. MBL by group and clinical variables related to patient, implant and prosthesis characteristics: Results of simple linear regression using GEE (Beta, 95% confidence interval and p-value of Wald´s test).

	Beta	95%CI	p-value
GROUP			**<0.001*** **
Group 1	0		
Group 2	0.01	-0.24 0.26	0.951
Group 3	0.20	-0.04 0.43	0.101
Group 4	0.52	0.27 0.77	**<0.001*** **
SIDE			
Mesial	0		
Distal	0.03	-0.09 0.15	0.628
AGE (years)	0.00	-0.01 0.01	0.816
GENDER			
Male	0		
Female	-0.26	-0.49 -0.02	**0.034***
SMOKING			0.514
No	0		
Former	-0.07	-0.33 0.19	0.604
Current	0.14	-0.21 0.49	0.430
DIABETES			
No	0		
Yes	-0.18	-0.43 0.07	0.148
HISTORY OF PD			
No	0		
Yes	0.03	-0.22 0.27	0.834
RX time period (years)	0.06	0.03 0.09	**<0.001*** **
SECTOR			
Anterior	0		
Posterior	0.20	-0.06 0.45	0.127
ARCH			
Maxilla	0		
Mandible	0.07	-0.17 0.31	0.550
CONNECTION			0.189
External Hex	0		
Internal Hex	-0.15	-0.37 0.07	0.182
Internal Tri-lobe	0.15	-0.27 0.56	0.482
LENGTH			0.704

Abutment height and restoration emergence combined effect

<11mm	0			
11-12mm	-0.08	-0.35	0.18	0.541
>12mm	0.02	-0.30	0.33	0.919
DIAMETER				0.416
<4mm	0			
4-4.5mm	0.06	-0.30	0.43	0.734
>4.5mm	0.18	-0.09	0.46	0.185
RETENTION				
Cemented	0			
Screwed	0.02	-0.22	0.26	0.848
SPLINTED				
No	0			
yes	-0.07	-0.32	0.18	0.573
MAINTENANCES per year during RX period				0.530
<=1	0			
1-2	0.00	-0.33	0.33	0.984
2-3	0.01	-0.41	0.42	0.965
>3	0.39	-0.19	0.98	0.187

*p<0.05; **p<0.01; ***p<0.001

Table IIId. MBL by group and clinical variables related to patient, implant and prosthesis characteristics: Results of multiple linear regression using GEE (adjusted Beta, 95% confidence interval and p-value of Wald´s test).

	Beta	95%CI	p-value
GROUP			**0.001****
Group 1	0		
Group 2	0.08	-0.13 0.30	0.444
Group 3	0.29	0.09 0.49	**0.004****
Group 4	0.48	0.25 0.71	**<0.001*****
GENDER			
Male	0		
Female	-0.15	-0.33 0.04	0.121
RX time period (years)	0.06	0.03 0.10	**<0.001*****
SECTOR			
Anterior	0		
Posterior	-0.14	-0.45 0.17	0.376
ARCH			
Maxilla	0		
Mandible	-0.01	-0.22 0.20	0.906
CONNECTION			0.831
External Hex	0		
Internal Hex	0.02	-0.36 0.40	0.932
Internal Tri-lobe	0.11	-0.31 0.53	0.600
LENGTH			0.122
<11mm	0		
11-12mm	-0.25	-0.48 -0.01	**0.040***
>12mm	-0.22	-0.51 0.07	0.138
DIAMETER			0.487
<4mm	0		
4-4.5mm	0.00	-0.27 0.27	0.986
>4.5mm	0.13	-0.11 0.36	0.295
MAINTENANCES per year during RX period			0.079
<=1	0		
1-2	0.13	-0.14 0.39	0.356
2-3	0.15	-0.19 0.49	0.390
>3	0.50	0.11 0.88	**0.011***

*p<0.05; **p<0.01; ***p<0.001

Table IIIe. MBL by group and clinical variables related to patient, implant and prosthesis characteristics: Results of multiple linear regression using GEE (adjusted Beta, 95% confidence interval and p-value of Wald´s test) regarding group changing the reference category

	Reference category			
	Group LG	Group LA	Group SG	Group SA
Group LG	1			
Group LA	0.08 (-0.13 0.30) p=0.444	1		
Group SG	0.29 (0.09 0.49) **p=0.004****	0.18 (-0.04 0.39) p=0.108	1	
Group SA	0.48 (0.25 0.71) **p<0.001*****	0.43 (0.18 0.68) **p=0.001****	0.25 (0.00 0.45) **p=0.013***	1

Table IIIf. Failure according to Radiographic and Total Survival

		FAILURE		
		Total	no	yes
RX FU_years	N	192	187	5
	Mean	5.60	5.59	5.81
	Standard Deviation	2.90	2.84	5.15
	Minimum	.64	.64	.64
	Maximum	17.27	17.27	14.05
	Median	5.22	5.25	5.14
TotalSurvivalFU_years	N	192	187	5
	Mean	7.29	7.28	7.93
	Standard Deviation	2.75	2.71	4.15
	Minimum	2.59	2.59	3.97
	Maximum	18.95	18.95	14.57
	Median	7.11	7.14	6.18

Table IIIg. PI by Clinical variables related to patient, implant and prosthesis characteristics: Results of simple binary logistic regression using GEE (OR, 95% confidence interval and p-value of Wald´s test).

	OR	95%CI		p-value
New GROUP				0.206
Group 1	1			
Group 2	0.65	0.09	4.72	0.670
Group 3	0.99	0.19	5.26	0.986
Group 4	2.23	0.61	8.16	0.225
AGE (years)	0.99	0.95	1.03	0.469
GENDER				
Male	1			
Female	0.45	0.16	1.23	0.118
SMOKING				0.626
No	1			
Former	0.81	0.29	2.26	0.688
Current	0.48	0.11	2.12	0.337
DIABETES				
No	1			
Yes	0.96	0.23	3.97	0.950
HISTORY OF PD				
No	1			
Yes	2.67	0.90	7.94	0.078
RX time period (years)	1.09	0.89	1.33	0.394
SECTOR				
Anterior	1			
Posterior	3.72	0.51	27.2	0.195
ARCH				
Maxilla	1			
Mandible	1.12	0.41	3.06	0.822
CONNECTION				0.170
External Hex	1			
Internal Hex	0.31	0.09	1.06	0.061
Internal Tri-lobe	0.40	0.08	2.02	0.268
LENGTH				0.988
<11mm	1			
11-12mm	0.95	0.32	2.83	0.930
>12mm	1.04	0.38	2.85	0.941

Abutment height and restoration emergence combined effect

DIAMETER				0.492
<4mm	1			
4-4.5mm	0.52	0.11	2.59	0.426
>4.5mm	1.21	0.38	3.88	0.752
RETENTION				
Cemented	1			
Screwed	0.71	0.21	2.46	0.591
SPLINTED				
No	1			
yes	1.08	0.40	2.95	0.875
MAINTENANCES per year during RX period				0.138
<=1	1			
1-2	3.86	0.46	32.5	0.214
2-3	8.48	0.92	78.3	0.059
>3	11.7	1.03	133.9	**0.048***

*p<0.05; **p<0.01; ***p<0.001

Table IIIh. PI by Clinical variables related to patient, implant and prosthesis characteristics: Results of multiple binary logistic regression using GEE (adjusted OR, 95% confidence interval and p-value of Wald´s test).

	OR	95%CI		p-value
NEW GROUP				**0.041***
Group 1	1			
Group 2	0.96	0.16	5.81	0.967
Group 3	3.22	0.28	36.5	0.345
Group 4	4.04	0.80	20.3	0.091
HISTORY OF PD				
No	1			
Yes	4.81	1.31	17.7	**0.018***
RX time period (years)	1.21	0.96	1.54	0.110
SECTOR				
Anterior	1			
Posterior	2.23	0.28	17.8	0.450
ARCH				
Maxilla	1			
Mandible	0.63	0.17	2.31	0.487
CONNECTION				0.072
External Hex	1			
Internal Hex	0.17	0.04	0.79	**0.024***
Internal Tri-lobe	0.15	0.02	1.12	0.064
LENGTH				0.825
<11mm	1			
11-12mm	1.25	0.34	4.58	0.734
>12mm	0.81	0.27	2.46	0.711
SPLINTED				
No	1			
yes	1.05	0.33	3.32	0.932
MAINTENANCES per year during RX period	2.64	1.44	4.84	**0.002****

*p<0.05; **p<0.01; ***p<0.001

Table IIIi. PI by Clinical variables related to patient, implant and prosthesis characteristics: Results of multiple binary logistic regression using GEE (adjusted OR, 95% confidence interval and p-value of Wald´s test) regarding new group changing the reference category

	Reference category			
	Group LG	Group LA	Group SG	Group SA
Group LG	1			
Group LA	0.96 (0.16 5.81) p=0.967	1		
Group SG	3.22 (0.28 36.5) p=0.345	3.35 (0.63 17.7) p=0.155	1	
Group SA	4.04 (0.80 20.3) p=0.091	4.19 (1.35 13.0) **p=0.013***	1.25 (0.21 7.43) p=0.804	1

*p<0.05; **p<0.01; ***p<0.001

NOTE: P-values are raw p-values. They have not been corrected by Bonferroni.

Table IIIj. MBL (no/yes) by angle and height: Results of multiple binary logistic regression using GEE (adjusted OR, 95% confidence interval and p-value of Wald´s test).

	OR	95%CI	p-value
constant	3.95	1.07 – 14.5	0.039*
ANGLE	0.99	0.96 – 1.02	0.476
HEIGHT	0.49	0.28 – 0.87	**0.015***
ANGLE x HEIGHT	1.01	0.99 – 1.02	0.276

*p<0.05; **p<0.01; ***p<0.001

Table IVa. MBL T1_T0 (no/yes) by Group

	GROUP									
	TOTAL		LG		LA		SG		SA	
	N	%	N	%	N	%	N	%`	N	%
Total	382	100.0	77	100.0	61	100.0	83	100.0	161	100.0
No	159	41.6	50	64.9	32	52.5	25	30.1	52	32.3
Yes	223	58.4	27	35.1	29	47.5	58	69.9	109	67.7

Figure 1. Visual representation of groups. Groups were separated into: Long/Gradual (LG) (TmAH ≥2mm and REA <30º), Long/Abrupt (LA) (TmAH ≥2mm and REA ≥30º), Short/Gradual (SG) (TmAH <2mm and REA <30º), Short/Abrupt (SA) (TmAH <2mm and REA ≥30º). 1 implant would often present with mesial and distal sites belonging to separate groups.

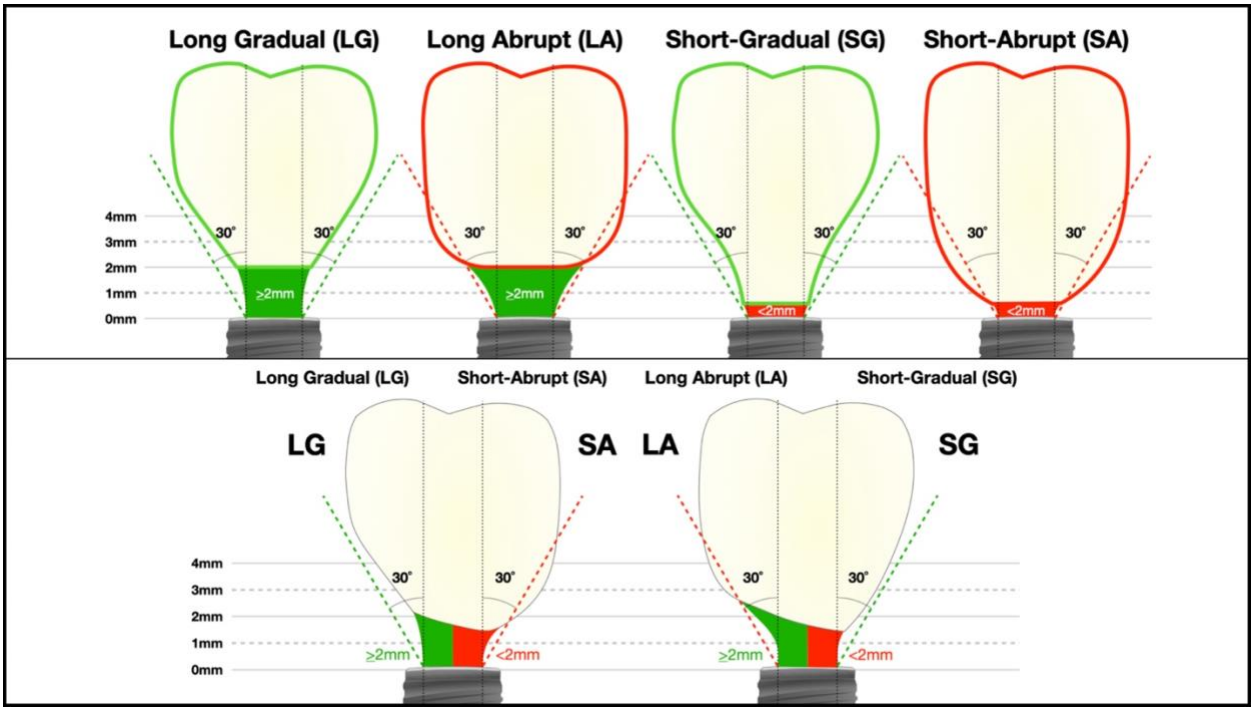


Figure 2. Mean Marginal Bone Loss by Group

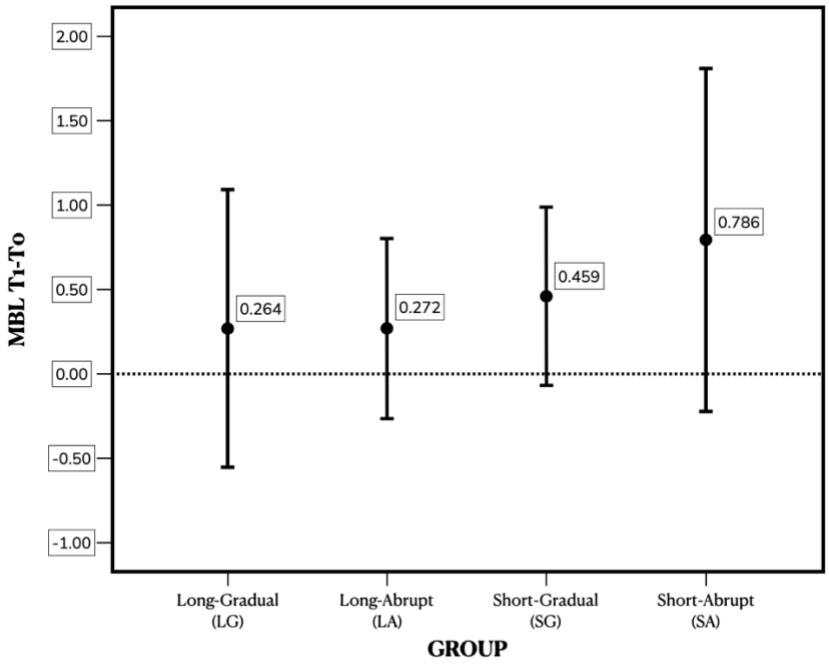
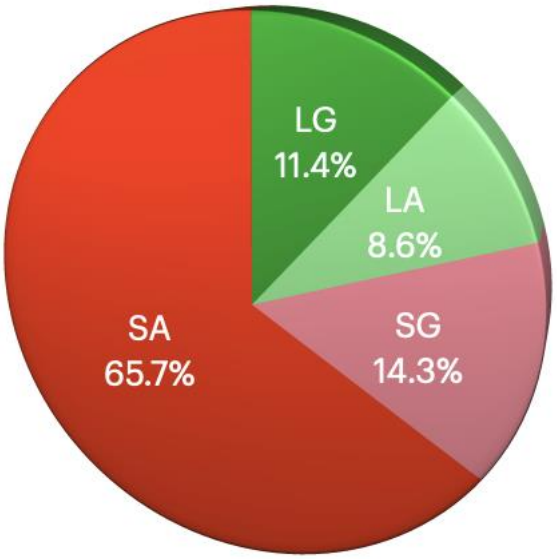


Figure 3. Distribution of Total Peri-implantitis Cases



Abutment height and restoration emergence combined effect

Figure 4. Distribution of PI Cases Per Group and Rate of PI Experience

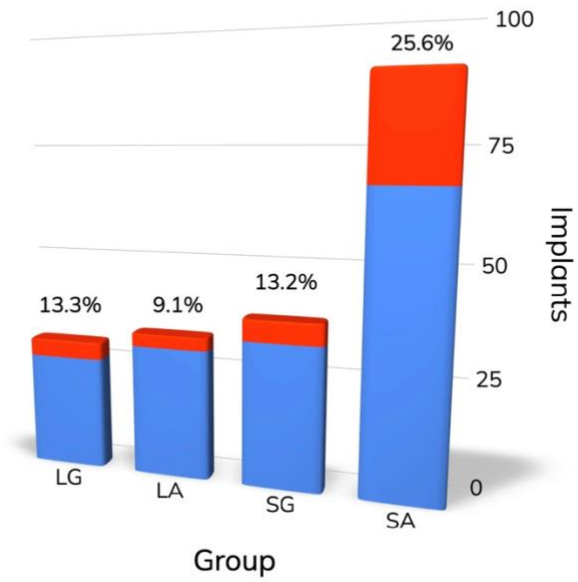


Figure 5 Graphical representation of p as a function of TmAH and REA. In the lateral view of the angle axis, we observe that MBL drops with a high slope through the direction of the angle axis (from left large angles, to right small angles), especially if the height is large: