Lin Guo-Hao (Orcid ID: 0000-0003-1290-9994)
Wang Hom-Lay (Orcid ID: 0000-0003-4238-1799)

The significance of vertical platform discrepancies and splinting on marginal bone levels for adjacent dental implants

Running title: Splinting adjacent implants on marginal bone level

Guo-Hao Lin[#1], Christine Tran[#1], Karolina Brzyska[1], Joseph Y. Kan[2], Hom-Lay Wang[3], Donald A. Curtis[4], Richard T. Kao[1]

1 Division of Periodontology, Department of Orofacial Sciences, School of Dentistry, University of California San Francisco, San Francisco, CA, USA

2 Department of Restorative Dentistry, School of Dentistry, Loma Linda University, Loma Linda, CA, USA

3 Postgraduate Periodontics, Department of Periodontics & Oral Medicine, School of Dentistry, University of Michigan, Ann Arbor, MI, USA

4 Division of Prosthodontics, Department of Preventive and Restorative Dental Sciences, School of Dentistry, University of California San Francisco, San Francisco, CA, USA

# equal contribution

Corresponding author:
Guo-Hao Lin, DDS, MS
Associate Professor & Program Director
Division of Periodontology
University of California, San Francisco
707 Parnassus Ave
San Francisco, CA 94143
Phone: 415-476-1731
Fax: 415-476-1563
E-mail address: guo-hao.lin@ucsf.edu

Tables and figures: 3 tables and 3 figures
Summary: Splinting implants and having adjacent implant platforms at varying vertical heights is associated with a higher risk of peri-implant bone loss.
Conflict of interest statement: The authors declare no conflict of interest.
Author contribution statement: Concept/Design: Guo-Hao Lin, Christine Tran and Hom-Lay Wang. Data collection: Christine Tran and Karolina Brzyska. Data analysis/interpretation: Guo-Hao Lin, Christine Tran and Karolina Brzyska. Drafting article:

Guo-Hao Lin, Christine Tran, Donald A. Curtis and Richard T. Kao. Critical revision of article: Joseph Y. Kan, Hom-Lay Wang, Donald A. Curtis and Richard T. Kao. All authors approved the final version of the manuscript.

Acknowledgments: The authors do not have any financial interests, either directly or indirectly, in the products or information listed in the paper.

Data availability statement: The data sets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Abstract

Objective

The aim of this retrospective study was to investigate the influence of vertical platform discrepancies for splinted and non-splinted adjacent implants on radiographic marginal bone loss (RMBL).

Methods

Data from January 2000 to February 2021 were collected from the electronic charts of 156 patients with 337 implants at the UCSF School of Dentistry. Five different implant restoration categories were evaluated for radiographic evidence of proximal RMBL. Patients with 1) two adjacent single crowns, 2) two adjacent splinted crowns, 3) three-unit bridges supported by two implants, 4) three adjacent single crowns, and 5) three adjacent splinted crowns. Inclusion required baseline radiograph taken at the time of prosthesis delivery or final impression, and follow-up radiographs at least twelve months after restorations have been in function. Measurements assessed included vertical distance between adjacent implant platforms and proximal RMBL around implants. Odds ratios (ORs) and 95% confidence interval (95% CI) of implants with ≥ 1 mm RMBL between different type of restorations were calculated.

Results

In general, prostheses supported by splinted adjacent implants demonstrated a significant association with the presence of ≥1 mm RMBL (OR= 2.55, 95% CI= 1.17 to 5.17, p= 0.018) when compared to prostheses supported by non-splinted adjacent implants. In addition, prostheses with a vertical platform discrepancy ≥ 0.5 mm demonstrated a significant

association with the presence of ≥1 mm RMBL (OR= 4.30, 95% CI= 1.85 to 10.01, p= 0.007) when compared to prostheses with a vertical platform discrepancy < 0.5 mm. When adjacent implants had ≥ 0.5 mm vertical platform discrepancy, the majority (66.67%) of three splinted adjacent crowns had at least one implant with ≥ 1 mm RMBL. This was followed by two splinted adjacent crowns (58.97%), three-unit bridge (25.93%), two single adjacent crowns (24.24%), and three single adjacent crowns (18.18%). When adjacent implants had ≥ 1 mm vertical platform discrepancy, there was an increased percentage of implants with ≥ 1 mm RMBL. The restorative design associated with the highest percent of implants with bone loss was three splinted adjacent crowns (70%), two splinted adjacent crowns (61.11%), three single adjacent crowns (40%), and three-unit bridge and two single adjacent implants (21.05%). Three splinted adjacent crowns were significantly associated with ≥ 1 mm RMBL when compared to three-unit bridge (OR 6.56, 95% CI 1.59 to 27.07). Similarly, two splinted crowns were significantly associated with ≥ 1 mm RMBL when compared to two single crowns (OR= 2.50, 95% CI= 1.08 to 5.79).

Conclusion

Two or three adjacent implants placed with a vertical platform discrepancy, when splinted together, are associated with higher incidence of ≥ 1 mm RMBL than non-splinted restorations.

Key words: dental implants, peri-implantitis, implant-supported dental prosthesis, risk factors, retrospective study

What is known:

- The influence of vertical platform discrepancies of splinted and non-splinted adjacent implants on marginal bone level in partially edentulous patients has not been fully understood, and requires better understanding.

What this study adds:

- This retrospective study found adjacent implants placed at different vertical platform levels had higher incidence of peri-implant bone loss.
- In addition, three splinted adjacent crowns had a higher risk of bone loss than three-unit bridges. Similarly, two splinted crowns had a higher risk of bone loss than two single crowns.

Introduction

Dental implants have become an effective treatment modality for replacing missing teeth. A 2005-2006 survey conducted by the American Dental Association found that more than two million dental implants were placed in the United States.[1] Associated with this increased implant utilization is the concurrent increased prevalence of patients with implant restorations, from 0.7% in 1999 to 2000 to 5.7% in 2015 to 2016. It is anticipated that this prevalence of patients with implant restorations will approach 23% by 2026.[2] With the increased use of dental implants in varying clinical applications, an increasing awareness of peri-implantitis has been recognized.[3,4]

Peri-implant diseases are complex and multifactorial. Peri-implantitis is a plaque-associated pathological condition characterized by inflammation in the peri-implant mucosa which results in pathologic bone loss.[5] There is an increased risk of developing peri-implantitis in patients with a history of chronic periodontitis, poor plaque control capability, or irregular maintenance care after implant therapy.[6] Iatrogenic factors that can contribute to an increased risk of peri-implant disease include poor implant positioning and inadequate hygiene access due to unfavorable prosthetic design.[7] A study done by Serino and Strom[8] concluded that local factors such as inadequate access for oral hygiene at the implant sites are related to the presence of peri-implantitis. In their study, 48% of the implants developing peri-implantitis were those with limited accessibility for proper oral hygiene, while only 4% had peri-implantitis with adequate hygiene access. Less documented are the reasons for difficulty in access such as discrepancies in platform height, splinting or restoration contours.

The design of implant restorations such as splinting the implants or not can impact on patient's access to hygiene and therefore become a risk for developing peri-implantitis.[9,10] The impact of splinting adjacent implants on proximal bone levels remain controversial.[11,12] Although a 10-year prospective study reported statistically significantly less bone loss in the splinted group, the difference of bone loss between the splinted and non-splinted groups was only 0.1 mm, which is not clinically significant. This lack of difference in marginal bone loss has been supported by others.[11,13-16] While some studies have reported a lower success rate for non-splinted implants than splinted implants, [11,17] on the contrary, a recent study reported that splinted implants result in a higher risk of peri-implantitis than non-splinted implants.[10]

The clinician's decision to splint or not splint implants requires additional investigations to assess if splinting is associated with peri-implantitis. Additionally, the clinician is often faced with patient anatomy that includes alveolar height discrepancies. The impact of placing multiple adjacent implants at varying bone level heights has not yet been fully explored. The aim of this study was to investigate the association between splinted versus non-splinted implant-supported restorations and impact of vertical platform discrepancies on radiographic marginal bone loss (RMBL) of adjacent implants.

Materials and Methods

Patient records with implant-supported prostheses from January 2000 to February 2021 were searched from the electronic health records at the University of California San Francisco (UCSF) School of Dentistry. Inclusion criteria were patients with two or three adjacent implants placed and restored at the UCSF School of Dentistry, with at least baseline periapical or bitewing radiographs taken at the time of prosthesis delivery or final impression, and at least one follow-up radiograph taken more than twelve months after prosthesis delivery. Exclusion criteria included implant-supported dental prostheses with more than three units, multi-unit splinted implant-supported prostheses with cantilevers, short dental implants (< 8 mm long), narrow dental implants (< 3 mm diameter), or lack of baseline or follow-up radiographs. Patient information was protected according to the privacy regulations of the Federal Health Insurance Portability and Accountability Act of 1996 (HIPAA). All procedures performed are following Helsinki Declaration and good clinical practice guidelines for research on human beings. The study protocol was approved by the UCSF Institutional Review Board (IRB number: 21-33265).

Five types of implant-supported restorations were included: 1) two single adjacent crowns, 2) two splinted adjacent crowns, 3) three-unit bridges, 4) three single adjacent crowns, and 5) three splinted adjacent crowns. Vertical platform discrepancies between the adjacent implant platforms (Figure 1) and proximal RMBL from the bone crest to the implant platform (for bone-level implants) or to the most coronal portion of the intraosseous part of the implant (for tissue-level implants) were measured (Figure 2) using a computer software (MiPACS, Medicor Imaging, Charlotte, NC, USA) by two examiners (CT and KB). Only

the RMBL between two adjacent implants were recorded and included in data analyses. The RMBL between an implant and a natural tooth was not included. The images were all calibrated with the length (when the full length could be seen) or the diameter (when the full length could not be seen) of the dental implants placed. After data collection, the inter-implant platform discrepancies were averaged for patients who had three adjacent implants. Similarly, the amount of RMBL between adjacent implants was averaged for the adjacent implants. The two examiners (CT and KB) were calibrated for intra-examiner and inter-examiner error. The intra- and inter-examiner agreement was > 90% within 0.2 mm by repeating measurement two times using 10 representative radiographs.

Other implant-related data collected included the implant with the most apically placed platform, type of implant platform (bone- vs. tissue-level), presence of platform-switched abutment, and type of restorations (cement- vs. screw-retained). In addition to these implant-related factors, the patient's demographic data, including gender, age, diabetes status, history of smoking, use of anti-depressants, and history of periodontal disease, were also recorded as potential confounders. The current study is fully compliant with the STROBE checklist guidelines.[18]

Statistical Analysis

The RMBL of individual implant was recorded, and the average RMBL for different types of the prostheses was calculated based on the mean of each patient's implants. Since every patient only had one type of implant-supported prosthesis included, patient-level analyses were performed to demonstrate the percentage of different type of prostheses with RMBL

of ≥ 1 mm when there was a vertical platform discrepancy of ≥ 0.5 mm between the adjacent implant platforms. The association of vertical platform discrepancies and splinting with RMBL for adjacent dental implants were analyzed using logistic regression. The vertical distance between adjacent implant platforms was further analyzed with two subgroups, ≥ 0.5 mm discrepancy and ≥ 1 mm discrepancy. Odds ratios (ORs) and the 95% confidence intervals (CIs) of the vertical distance between adjacent implant platforms for RMBL among different types of the restorations were calculated. Statistical analyses were performed using a computer program (SAS Institute Inc. 2011. Base SAS® 9.3 Procedures Guide, Cary, NC, USA).

Results

Patient and Implant Demographics

After screening the 475 consecutive electronic dental records, 156 patients with 337 implants met the inclusion criteria for this study. Of these 156 patients (age 21-86), 52% were male and 48% were female. In addition, 29% of the patients were smokers, 13% had diabetes, 18% used anti-depressants, and 47% had a history of periodontitis. Each patient only had one out of five implant-supported restoration types qualified for inclusion. Included were 260 bone level implants were and 77 tissue-level implants. Fifty-one bone-level implants had cement-retained restorations and 209 screw-retained restorations. Among the bone-level implants, 209 of them had platform-switched abutments and 51 of them had straight abutments. For the tissue-level implants, 38 of them were cement-retained and 39 of them were screw-retained. All the tissue-level implants had a straight abutment. The mean follow-up period was 43.2 months, ranging from 13 months to 179 months. The demographic data are presented in Table 1.

Radiographic Bone Loss

The average RMBL for adjacent implants restored with two single crowns (Figures 3A to 3C), two splinted crowns (Figures 3D to 3F), three-unit bridges (Figures 3G to 3I), three single crowns (Figures 3J to 3L), and three splinted crowns (Figures 3M to 3O) was 0.9 ± 1.4 mm, 1.1 ± 1.3 mm, 0.8 ± 1.2 mm, 0.7 ± 1.0 mm, and 1.2 ± 1.3 mm, respectively (Table 2). When there was a vertical platform discrepancy of ≥ 0.5 mm, the majority (66.67%) of patients with three splinted crowns had at least one implant with ≥ 1 mm RMBL, followed by patients with two splinted crowns (58.97%), three-unit bridges (25.93%), two single

crowns (24.24%), and three single crowns (18.18%). When the vertical distance between adjacent implant platforms was ≥ 1 mm, there was overall a greater percentage of implant-supported prostheses with ≥ 1mm RMBL. The restoration type with the highest percentage of implants with RMBL was the three splinted adjacent crowns (70.00%), followed by two splinted crowns (61.11%), three single crowns (22.22%), three-unit bridges (21.05%), and two single crowns (21.05%).

When analyzing the pattern of RMBL for adjacent implants placed at different platform levels, there is a trend that the most apically positioned implants had less bone loss than more coronally placed implants. This was true for three splinted adjacent crowns (90.91%) and two splinted crowns (81.82%). However, this finding was not seen for three single crowns (57.14%), three-unit bridges (64.29%), or two single crowns (61.90%).

In general, prostheses supported by splinted adjacent implants demonstrated a significant association with the presence of ≥1 mm RMBL (OR= 2.55, 95% CI= 1.17 to 5.17, p= 0.018) when compared to prostheses supported by non-splinted adjacent implants. When investigating the impact of different types of prosthetic design on RMBL, a significantly higher OR for ≥1 mm RMBL for three splinted crowns was found when compared to three single crowns (OR= 6.67, 95% CI= 1.14 to 38.83, p= 0.013, Table 3). Three splinted crowns also had a significantly higher OR for ≥ 1mm RMBL when compared to three-unit bridges (OR= 6.56, 95% CI= 1.59 to 27.07, p= 0.009). Similarly, a significantly higher OR for ≥ 1mm RMBL was found for two splinted crowns when compared to two single crowns (OR= 2.50, 95% CI= 1.08 to 5.79, p= 0.032).

In addition, prostheses with a vertical platform discrepancy ≥ 0.5 mm demonstrated a significant association with the presence of ≥1 mm RMBL (OR= 4.30, 95% CI= 1.85 to 10.01, p= 0.007) when compared to prostheses with a vertical platform discrepancy < 0.5 mm. When taking different types of prosthetic design into account, a significantly higher OR for ≥ 1 mm RMBL was found for three splinted crowns compared to three single crowns (OR= 9.00, 95% CI= 1.29 to 63.02, p= 0.026), three splinted crowns compared to three-unit bridges (OR= 5.71, 95% CI= 1.30 to 25.03, p= 0.021), and two splinted crowns compared to two single crowns (OR= 4.49, 95% CI= 1.62 to 12.46, p= 0.004). If the vertical platform level ≥ 1 mm between the adjacent implants was detected, a significantly higher OR for ≥ 1 mm RMBL was found for three splinted crowns compared to three single crowns (OR= 8.17, 95% CI= 1.03 to 64.94, p= 0.042), three splinted crowns compared to three-unit bridges (OR= 8.75, 95% CI= 1.53 to 50.11, p= 0.015), and two splinted crowns compared to two single crowns (OR= 5.89, 95% CI= 1.38 to 25.22, p= 0.016). The statistical model did not find the association of the type of implant platform (bone- vs. tissue-level), use of platform-switched abutment, and type of restorations (cement- vs. screw-retained) with RMBL.

Discussion

Our study investigated the impact of splinted implant-supported prostheses on the proximal peri-implant bone level and found that splinted adjacent implants are associated with higher incidence of RMBL ≥ 1 mm than non-splinted implant restorations. When comparing the bone level with the baseline radiographs, these implants were considered to have had a history of peri-implantitis due to presence of bone loss beyond crestal bone level changes resulting from initial bone remodeling.[5] One possible explanation for the increased incidence of peri-implantitis around splinted implants, especially implants placed at different platform levels, is compromised oral hygiene access resulting in increased plaque accumulation.[8,10]

A previous study comparing single and splinted implants found that local factors such as accessibility for oral hygiene at the implant sites seems to be related to the presence or absence of peri-implantitis.[8] In their study, 48% of the implants presenting peri-implantitis were the implants without accessibility for proper oral hygiene. The authors also found that peri-implantitis was a rare finding around implants when proper access for plaque control was allowed. These results highlight the importance of proper prosthetic designs that allow accessibility for oral hygiene around implants, as well as giving proper oral hygiene instructions to patients who are rehabilitated with dental implants. When treatment planning splinted implants, it is important to consider fabricating a provisional restoration to ensure a patient can maintain tissue health before fabrication of the definitive restoration, often by copy milling to ensure matching the provisional contours.

Once implants are uncovered, the implant-abutment interface is established and the bone typically resorbs 1.5-2.0 mm apically.[19] This process is often considered "initial bone remodeling" that is an inevitable process.[19] This process is now being recognized as reformation of supracrestal tissue height/adhesion.[20,21] Tarnow et al. proposed an inter-implant distance of at least 3 mm to minimize further crestal bone loss.[19] However, this "3 mm rule" was observed when the adjacent implants were placed at similar vertical heights. The second finding of the current study suggest that the crestal bone loss beyond the initial bone remodeling could occur when the adjacent implant platforms are at different vertical levels. In several patients participating in the current study, this pattern of bone loss occurred even when the inter-implant distance is more than 3 mm. Future studies should investigate if the minimal inter-implant horizontal distance may need to be greater if the adjacent implant platforms are placed at different vertical levels.

Whether the restoration of adjacent implants should be splinted together is controversial. A recent systematic review[15] analyzed 19 studies and concluded that significant higher survival rates for splinted than for non-splinted restorations. However, both groups achieved a high survival rate (99.1% for splinted and 96.5% for non-splinted restorations) over the follow-up period. The authors also found that no significant differences between splinted and non-splinted restorations for RMBL, which is not in agreement with the findings of the current study. This discrepancy could be explained by the different inclusion criteria between the studies since the systematic review[15] pooled the outcomes of several papers using short dental implants. In addition, the systematic review did not analyze the impact of vertical platform levels of the adjacent implants on RMBL.

To the best of the authors' knowledge, our study is the first article investigating the influence of the vertical platform levels of the adjacent implants on RMBL. Our study demonstrated that when the adjacent implants are splinted together, the risk of having RMBL is much higher than non-splinted adjacent implant crowns. Furthermore, if these splinted implants were placed at different platform levels, RMBL was usually seen at more coronally placed implants. A tendency of bone loss toward the platform level of the most apically positioned implant (Figures 3F and 3O) was seen. On the contrary, this tendency was not detected for non-splinted adjacent crowns or three-unit bridges. The cause of this finding is unclear; however, the strain generated in the neck area of the splinted implants may play a role in this pattern of bone loss.[22]

A previous study compared the effects of simulated occlusal loading of three implants restored with splinted and non-splinted crowns[22] and reported that single non-splinted restorations transfer significantly less strain in the implant neck. The authors further pointed out that each single restoration has inherent inaccuracies and preload stresses because of component misfit (crown-abutment interface and abutment-implant interface). Therefore, when these adjacent implant crowns are splinted, there is a summation of inherent misfit inaccuracies, resulting in transfer of increased loads to the implants and supporting structures.[22] The higher stress transfer associated with splinted implants may contribute to RMBL, and the combination of stress and compromised access for oral hygiene may help explain our findings.

Our study supports the findings of a previous study which observed the prevalence of peri-implantitis for the splinted implant-supported restorations was significantly higher than the implants restored as single crowns.[10] In addition, we found that the risk of RMBL is significantly increased when these splinted implants were placed at different platform levels. Therefore, clinicians are recommended to restore these implants with single crowns when the platforms are placed at different vertical levels to minimize the risk of RMBL and provide better access for hygiene.[23] However, it is worth noting that higher incidence of biomechanical complications such as screw loosening has been reported in the literature when implants are not splinted.[14,24] In a three-year split-mouth study, Clelland et al.[14] reported most of the screw loosening occurred on the non-splinted side. The authors speculated that the greater inter-arch distance, increased crown-to-implant ratio, and increased clinical crown height could contribute to screw loosening on the non-splinted side since most of the study participants had short implants due to severely resorbed alveolar ridge. In this scenario, splinted restorations may be preferred to minimize the biomechanical complications.

There are several limitations for the current study. First, due to the retrospective nature of the study, some clinical parameters, i.e., oral hygiene status and occlusion, could not be assessed. Second, the implants and restorations were completed in a university setting; therefore, the experience of the providers might have an impact on clinical outcomes. Third, the lack of standardized radiographs taken at the time of prosthesis delivery is another study limitation. Last, a limited number of implants and restoration types were identified. Future studies should include a larger sample size for a more robust data

analysis.

Conclusion

Within the limitations of this study, two or three adjacent implants, when splinted together, are associated with higher incidence of marginal bone loss ≥ 1 mm than non-splinted implant restorations. Additionally, when there is a vertical distance of ≥ 0.5 mm between adjacent implant platforms, a significant increased risk for peri-implant bone loss is identified.

References

1. American Dental Association. 2005-2006 Survey of Dental Services Rendered. In. Chicago, Illinois: ADA; 2007.
2. Elani HW, Starr JR, Da Silva JD, Gallucci GO. Trends in Dental Implant Use in the U.S., 1999-2016, and Projections to 2026. *J Dent Res.* 2018;97(13):1424-1430.
3. Moraschini V, Poubel LA, Ferreira VF, Barboza Edos S. Evaluation of survival and success rates of dental implants reported in longitudinal studies with a follow-up period of at least 10 years: a systematic review. *Int J Oral Maxillofac Surg.* 2015;44(3):377-388.
4. Roos-Jansaker AM, Lindahl C, Renvert H, Renvert S. Nine- to fourteen-year follow-up of implant treatment. Part II: presence of peri-implant lesions. *Journal of clinical periodontology.* 2006;33(4):290-295.
5. Berglundh T, Armitage G, Araujo MG, et al. Peri-implant diseases and conditions: Consensus report of workgroup 4 of the 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions. *J Periodontol.* 2018;89 Suppl 1:S313-S318.
6. Schwarz F, Derks J, Monje A, Wang HL. Peri-implantitis. *Journal of periodontology.* 2018;89 Suppl 1:S267-S290.
7. Jepsen S, Berglundh T, Genco R, et al. Primary prevention of peri-implantitis: managing peri-implant mucositis. *Journal of clinical periodontology.* 2015;42 Suppl 16:S152-157.
8. Serino G, Strom C. Peri-implantitis in partially edentulous patients: association with inadequate plaque control. *Clin Oral Implants Res.* 2009;20(2):169-174.
9. 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(2):225-232.
10. 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(3):392-403.
11. Mendonca JA, Francischone CE, Senna PM, Matos de Oliveira AE, Sotto-Maior BS. A retrospective evaluation of the survival rates of splinted and non-splinted short dental implants in posterior partially edentulous jaws. *J Periodontol.* 2014;85(6):787-794.
12. Vigolo P, Mutinelli S, Zaccaria M, Stellini E. Clinical evaluation of marginal bone level change around multiple adjacent implants restored with splinted and nonsplinted restorations: a 10-year randomized controlled trial. *Int J Oral Maxillofac Implants.* 2015;30(2):411-418.
13. Al Amri MD, Kellesarian SV. Crestal Bone Loss Around Adjacent Dental Implants Restored with Splinted and Nonsplinted Fixed Restorations: A Systematic Literature Review. *J Prosthodont.* 2017;26(6):495-501.
14. Clelland N, Chaudhry J, Rashid RG, McGlumphy E. Split-Mouth Comparison of Splinted and Nonsplinted Prostheses on Short Implants: 3-Year Results. *Int J Oral Maxillofac Implants.* 2016;31(5):1135-1141.
15. de Souza Batista VE, Verri FR, Lemos CAA, et al. Should the restoration of adjacent implants be splinted or nonsplinted? A systematic review and meta-analysis. *J Prosthet Dent.* 2019;121(1):41-51.

16. Vigolo P, Zaccaria M. Clinical evaluation of marginal bone level change of multiple adjacent implants restored with splinted and nonsplinted restorations: a 5-year prospective study. *Int J Oral Maxillofac Implants.* 2010;25(6):1189-1194.
17. Lemos CAA, Verri FR, Santiago Junior JF, et al. Splinted and Nonsplinted Crowns with Different Implant Lengths in the Posterior Maxilla by Three-Dimensional Finite Element Analysis. *J Healthc Eng.* 2018;2018:3163096.
18. von Elm E, Altman DG, Egger M, et al. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *Lancet.* 2007;370(9596):1453-1457.
19. Tarnow DP, Cho SC, Wallace SS. The effect of inter-implant distance on the height of inter-implant bone crest. *Journal of periodontology.* 2000;71(4):546-549.
20. Avila-Ortiz G, Gonzalez-Martin O, Couso-Queiruga E, Wang HL. The peri-implant phenotype. *J Periodontol.* 2020;91(3):283-288.
21. Saleh MH, Galli M, Siqueira R, Vera M, Wang HL, Ravida A. The Prosthetic-Biologic Connection and Its Influence on Peri-implant Health: An Overview of the Current Evidence. *Int J Oral Maxillofac Implants.* 2022;37(4):690-699.
22. Nissan J, Ghelfan O, Gross M, Chaushu G. Analysis of load transfer and stress distribution by splinted and unsplinted implant-supported fixed cemented restorations. *J Oral Rehabil.* 2010;37(9):658-662.
23. Kao RT, Lin GH, Kapila Y, Sadowsky S, Curtis DA. A commentary on strategic extraction. *J Periodontol.* 2022;93(1):11-19.
24. Ravida A, Saleh MHA, Muriel MC, Maska B, Wang HL. Biological and Technical Complications of Splinted or Nonsplinted Dental Implants: A Decision Tree for Selection. *Implant Dent.* 2018;27(1):89-94.

Table 1: Demographic data of the participants

	Two single crowns, adjacent	Two splinted crowns, adjacent	Three-unit bridges	Three single crowns, adjacent	Three splinted crowns, adjacent
Bone-level implants					
Number of patients	28	49	23	8	12
Number of implants	56	98	46	24	36
Male/Female	10/18	23/26	14/9	3/5	6/6
Mean age (range)	58.75 (37-79)	62.59 (21-84)	64.35 (45-83)	68.75 (52-82)	66.17 (47-84)
Smoking history	7	19	3	2	4
Diabetes history	3	5	4	1	2
Anti-depressant use	3	11	5	1	2
Patient(s) with history of periodontitis	11	28	8	5	4
Cement-retained (number of implants)	12	18	8	4	9
Screw-retained (number of implants)	44	80	38	20	27
Platform-switched design (number of implants)	50	64	44	24	27
Straight abutment design (number of implants)	6	34	2	0	9
Tissue-level implants					
Number of patients	14	11	6	3	2
Number of implants	28	22	12	9	6
Male/Female	8/6	9/2	5/1	2/1	1/1
Mean age (range)	59.86 (37-74)	59.27 (38-86)	61.17 (55-66)	65.67 (62-68)	73.5 (70-77)
Smoking history	4	5	1	1	0
Diabetes history	2	1	1	1	1
Anti-depressant use	3	0	2	0	1
Patient(s) with history of periodontitis	7	6	3	0	1
Cement-retained (number of implants)	8	10	8	9	3
Screw-retained (number of implants)	20	12	4	0	3
Straight abutment design (number of implants)	28	22	12	9	6

Table 2: Average radiographic bone loss and the incidence of at least one implant with bone loss ≥1 mm for different type of restorations

	Two single crowns, adjacent	Two splinted crowns, adjacent	Three-unit bridges	Three single crowns, adjacent	Three splinted crowns, adjacent
Average radiographic bone loss	0.9 ± 1.4 mm	1.1 ± 1.3 mm	0.8 ± 1.2 mm	0.7 ± 1.0 mm	1.2 ± 1.3 mm
Incidence of at least one implant with bone loss ≥ 1 mm					
Vertical platform discrepancy ≥ 0.5 mm between the adjacent implants	24.24%	58.97%	25.93%	18.18%	66.67%
Vertical platform discrepancy ≥ 1 mm between the adjacent implants	21.05%	61.11%	21.05%	22.22%	70.00%

Table 3: Adjusted ORs and 95% CI of peri-implant bone loss ≥1mm on the adjacent implant between different types of restorations using logistic regression

	Three-unit bridge (control) vs. Three splinted crowns	Three-unit bridge (control) vs. Three single crowns	Three single crowns (control) vs. Three splinted crowns	Two single crowns (control) vs. Two splinted crowns
Overall	6.56 95% CI: 1.59 to 27.07	1.71 95% CI: 0.30 to 9.72	6.67 95% CI: 1.14 to 38.83	2.50 95% CI: 1.08 to 5.79
P value	0.009*	0.554	0.013*	0.032*
Vertical platform discrepancy ≥ 0.5 mm	5.71 95% CI: 1.30 to 25.03	1.58 95% CI: 0.27 to 9.13	9.00 95% CI: 1.29 to 63.02	4.49 95% CI: 1.62 to 12.46
P value	0.021*	0.618	0.026*	0.004*
Vertical platform discrepancy ≥ 1 mm	8.75 95% CI: 1.53 to 50.11	1.07 95% CI: 0.16 to 7.31	8.17 95% CI: 1.03 to 64.94	5.89 95% CI: 1.38 to 25.22
P value	0.015*	0.400	0.042*	0.016*

* Statistically significant; degree of freedom= 9

Figure 1: A diagram illustrating the discrepancy of the vertical platform level between the two adjacent implants.

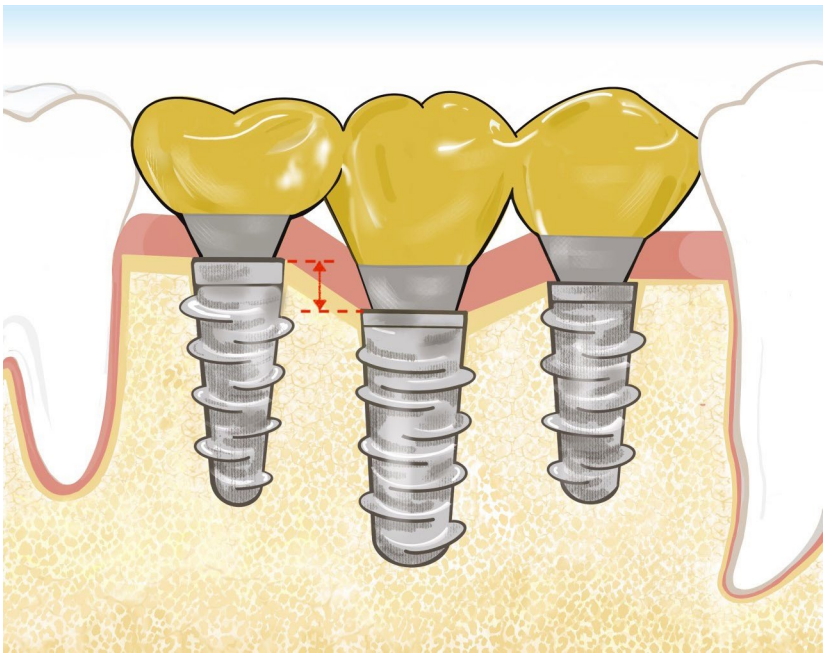
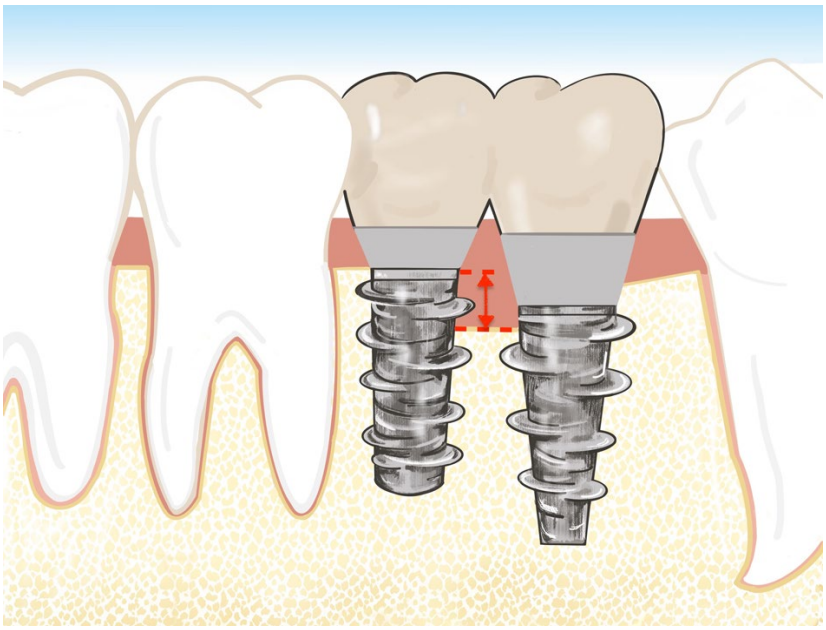
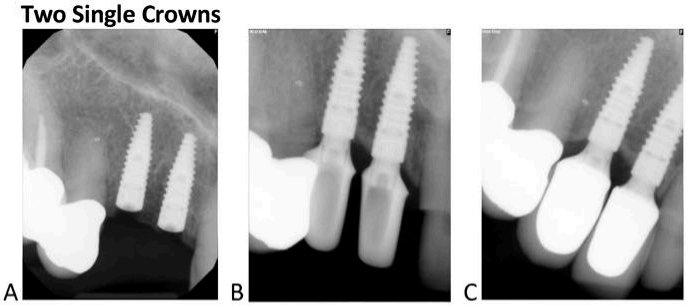


Figure 2: A diagram illustrating the measurement of the radiographic marginal bone loss (RMBL) of a bone-level implant splinted with an adjacent implant. The RMBL was measured from the bone crest to the implant platform following the long axis of the implant.

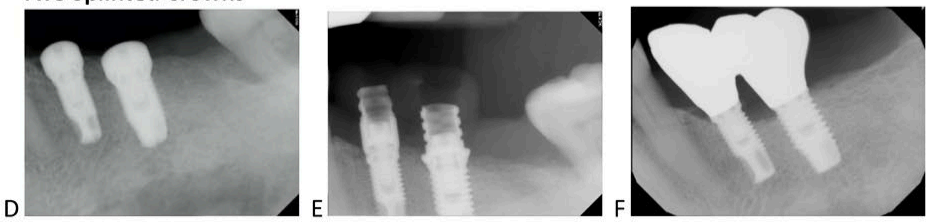


Figures 3A-3J: Representative radiographs showing the baseline radiographic bone level and the pattern of bone loss detected at the last follow-up appointment when the adjacent implants were placed at different vertical platform levels. **Figure 3A:** Radiograph taken at the time of the implant placement for two adjacent implants (#8 and #9) planned to be restored as two single crowns. **Figure 3B:** Baseline radiograph taken at the time of prosthesis delivery. **Figure 3C:** Follow-up radiograph for the two implant-supported single crowns. Both implants showed no radiographic bone loss at the crestal level. **Figure 3D:** Radiograph taken at the time of implant placement for two adjacent implants (#19 and #20) planned to be restored as two splinted crowns. **Figure 3E:** Baseline radiograph taken at the time of final impression. There was still not bone loss present at #20 distal. **Figure 3F:** Follow-up radiograph for the two implant-supported splinted crowns. The #20 implant showed radiographic bone loss on the distal side; the bone loss could be seen toward the platform level of the #19 implant, which was the most apically positioned implant. **Figure 3G:** Radiograph for implants (#3 and #5) planned to be restored as a three-unit bridge. **Figure 3H:** Baseline radiograph taken at the time of final impression. **Figure 3I:** Follow-up radiograph for the implant-supported three-unit bridge. Both implants showed no radiographic bone loss at the crestal level. **Figure 3J:** Radiograph taken at the time of implant placement for three adjacent implants (#12, #13 and #14) planned to be restored as three single crowns. **Figure 3K:** Baseline radiograph taken at the time of final impression. **Figure 3L:** Follow-up radiograph for the three implant-supported single crowns. All three implants showed no radiographic bone loss at the crestal level. **Figure 3M:** Radiograph for three adjacent implants (#3, #4 and #5) planned to be restored as three splinted crowns. **Figure 3N:** Baseline radiograph taken at the time right before the final impression. **Figure 3O:** Follow-up radiograph for the three implant-supported splinted crowns. The #4 and #5 implants showed radiographic bone loss on the distal side; the bone loss could be seen toward the platform level of the #3 implant, which was the most apically positioned implant.

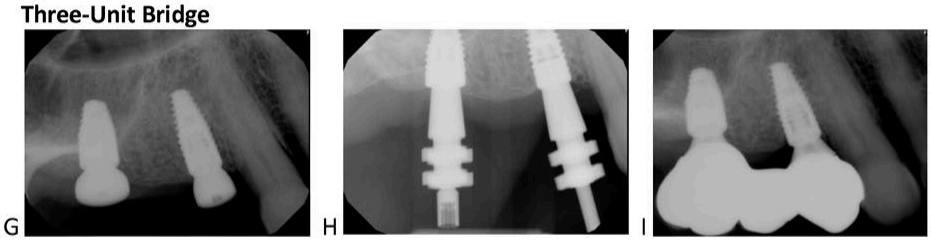
Two Single Crowns



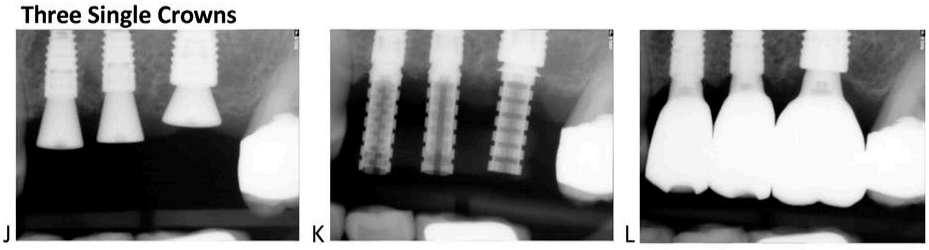
Two Splinted Crowns



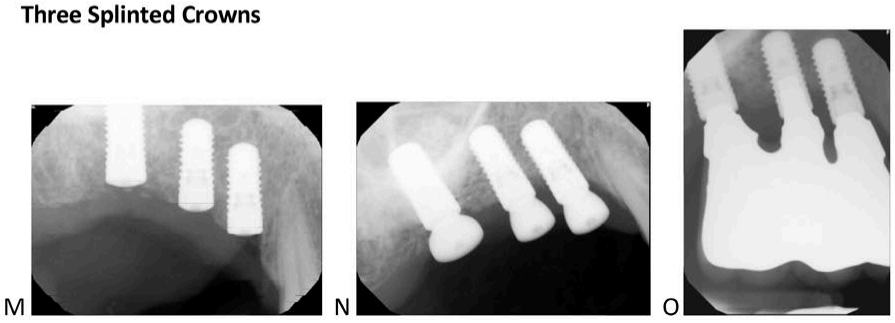
Three-Unit Bridge

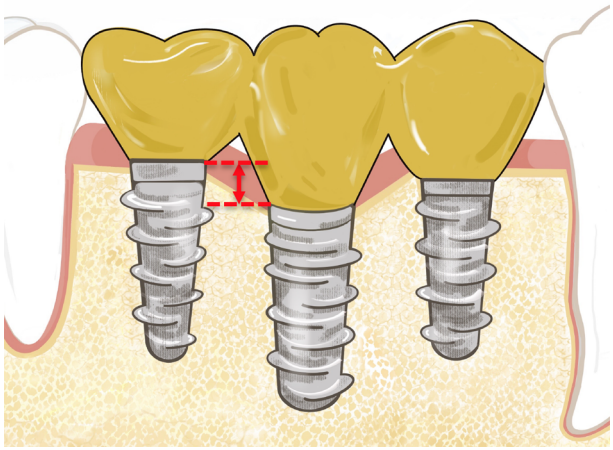


Three Single Crowns

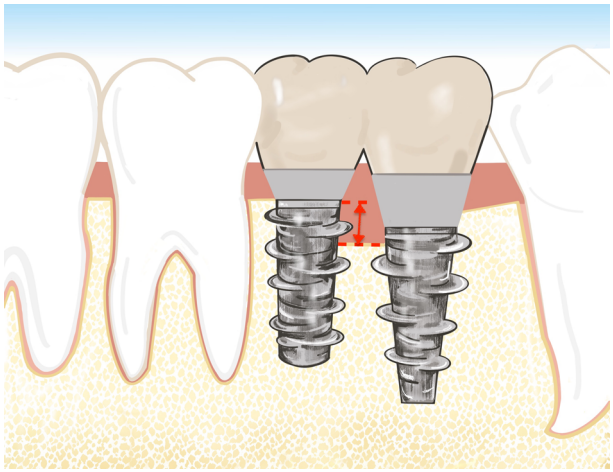


Three Splinted Crowns

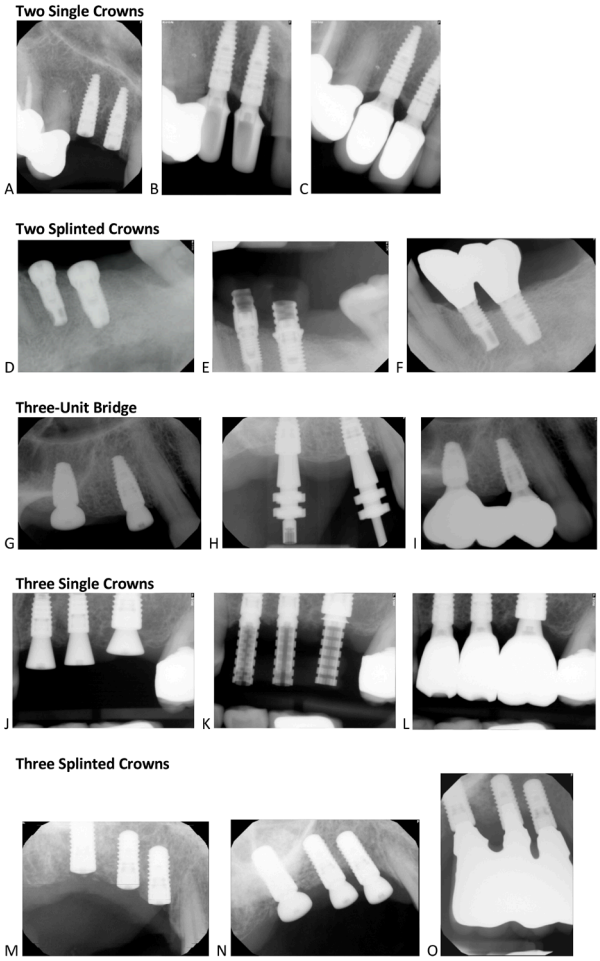




CID_13176_Figure 1.tif



CID_13176_Figure 2.tiff



CID_13176_Figure 3.tif

Table 1: Demographic data of the participants

	Two single crowns, adjacent	Two splinted crowns, adjacent	Three-unit bridges	Three single crowns, adjacent	Three splinted crowns, adjacent
Bone-level implants					
Number of patients	28	49	23	8	12
Number of implants	56	98	46	24	36
Male/Female	10/18	23/26	14/9	3/5	6/6
Mean age (range)	58.75 (37-79)	62.59 (21-84)	64.35 (45-83)	68.75 (52-82)	66.17 (47-84)
Smoking history	7	19	3	2	4
Diabetes history	3	5	4	1	2
Anti-depressant use	3	11	5	1	2
Patient(s) with history of periodontitis	11	28	8	5	4
Cement-retained (number of implants)	12	18	8	4	9
Screw-retained (number of implants)	44	80	38	20	27
Platform-switched design (number of implants)	50	64	44	24	27
Straight abutment design (number of implants)	6	34	2	0	9
Tissue-level implants					
Number of patients	14	11	6	3	2
Number of implants	28	22	12	9	6
Male/Female	8/6	9/2	5/1	2/1	1/1
Mean age (range)	59.86 (37-74)	59.27 (38-86)	61.17 (55-66)	65.67 (62-68)	73.5 (70-77)
Smoking history	4	5	1	1	0
Diabetes history	2	1	1	1	1
Anti-depressant use	3	0	2	0	1
Patient(s) with history of periodontitis	7	6	3	0	1
Cement-retained (number of implants)	8	10	8	9	3
Screw-retained (number of implants)	20	12	4	0	3
Straight abutment design (number of implants)	28	22	12	9	6

Table 2: Average radiographic bone loss and the incidence of at least one implant with bone loss ≥1 mm for different type of restorations

	Two single crowns, adjacent	Two splinted crowns, adjacent	Three-unit bridges	Three single crowns, adjacent	Three splinted crowns, adjacent
Average radiographic bone loss	0.9 ± 1.4 mm	1.1 ± 1.3 mm	0.8 ± 1.2 mm	0.7 ± 1.0 mm	1.2 ± 1.3 mm
Incidence of at least one implant with bone loss ≥ 1 mm					
Vertical platform discrepancy ≥ 0.5 mm between the adjacent implants	24.24%	58.97%	25.93%	18.18%	66.67%
Vertical platform discrepancy ≥ 1 mm between the adjacent implants	21.05%	61.11%	21.05%	22.22%	70.00%

Table 3: Adjusted ORs and 95% CI of peri-implant bone loss ≥1mm on the adjacent implant between different types of restorations using logistic regression

	Three-unit bridge (control) vs. Three splinted crowns	Three-unit bridge (control) vs. Three single crowns	Three single crowns (control) vs. Three splinted crowns	Two single crowns (control) vs. Two splinted crowns
Overall	6.56 95% CI: 1.59 to 27.07	1.71 95% CI: 0.30 to 9.72	6.67 95% CI: 1.14 to 38.83	2.50 95% CI: 1.08 to 5.79
P value	0.009*	0.554	0.013*	0.032*
Vertical platform discrepancy ≥ 0.5 mm	5.71 95% CI: 1.30 to 25.03	1.58 95% CI: 0.27 to 9.13	9.00 95% CI: 1.29 to 63.02	4.49 95% CI: 1.62 to 12.46
P value	0.021*	0.618	0.026*	0.004*
Vertical platform discrepancy ≥ 1 mm	8.75 95% CI: 1.53 to 50.11	1.07 95% CI: 0.16 to 7.31	8.17 95% CI: 1.03 to 64.94	5.89 95% CI: 1.38 to 25.22
P value	0.015*	0.400	0.042*	0.016*

* Statistically significant; degree of freedom= 9

Table 2: Average radiographic bone loss and the incidence of at least one implant with bone loss ≥1 mm for different type of restorations

	Two single crowns, adjacent	Two splinted crowns, adjacent	Three-unit bridges	Three single crowns, adjacent	Three splinted crowns, adjacent
Average radiographic bone loss	0.9 ± 1.4 mm	1.1 ± 1.3 mm	0.8 ± 1.2 mm	0.7 ± 1.0 mm	1.2 ± 1.3 mm
Incidence of at least one implant with bone loss ≥ 1 mm					
Vertical platform discrepancy ≥ 0.5 mm between the adjacent implants	24.24%	58.97%	25.93%	18.18%	66.67%
Vertical platform discrepancy ≥ 1 mm between the adjacent implants	21.05%	61.11%	21.05%	22.22%	70.00%

Table 3: Adjusted ORs and 95% CI of peri-implant bone loss ≥1mm on the adjacent implant between different types of restorations using logistic regression

	Three-unit bridge (control) vs. Three splinted crowns	Three-unit bridge (control) vs. Three single crowns	Three single crowns (control) vs. Three splinted crowns	Two single crowns (control) vs. Two splinted crowns
Overall	6.56 95% CI: 1.59 to 27.07	1.71 95% CI: 0.30 to 9.72	6.67 95% CI: 1.14 to 38.83	2.50 95% CI: 1.08 to 5.79
P value	0.009*	0.554	0.013*	0.032*
Vertical platform discrepancy ≥ 0.5 mm	5.71 95% CI: 1.30 to 25.03	1.58 95% CI: 0.27 to 9.13	9.00 95% CI: 1.29 to 63.02	4.49 95% CI: 1.62 to 12.46
P value	0.021*	0.618	0.026*	0.004*
Vertical platform discrepancy ≥ 1 mm	8.75 95% CI: 1.53 to 50.11	1.07 95% CI: 0.16 to 7.31	8.17 95% CI: 1.03 to 64.94	5.89 95% CI: 1.38 to 25.22
P value	0.015*	0.400	0.042*	0.016*

* Statistically significant; degree of freedom= 9