Received: 12 February 2023 | Revised: 10 June 2023 | Accepted: 18 June 2023

DOI: 10.1111/cid.13244

ORIGINAL ARTICLE

WILEY

Defect angle as prognostic indicator in the reconstructive therapy of peri-implantitis

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Abstract

Objective: To analyze the influence of the characteristics of bone defects caused by peri-implantitis on the clinical resolution and radiographic bone gain following reconstructive surgery.

Methods: This is a secondary analysis of a randomized clinical trial. Periapical x-rays of bone defects, caused by peri-implantitis exhibiting intrabony component, were analyzed at baseline and 12-month follow-up after reconstructive surgery. Therapy consisted of anti-infective therapy along with a mixture of allografts with or without a collagen barrier membrane. The association of defect configuration, defect angle (DA), defect width (DW), and baseline marginal bone level (MBL) with clinical resolution (based on a prior defined composite criteria) and radiographic bone gain was correlated by means of generalized estimating equations.

Results: Overall, 33 patients with a total of 48 implants exhibiting peri-implantitis were included. None of the evaluated variables yielded statistical significance with disease resolution. Defect configuration demonstrated statistical significance when compared to class 1B and 3B, favoring radiographic bone gain for the former ($p = 0.005$). DW and MBL did not demonstrate statistical significance with radiographic bone gain. On the contrary, DA exhibited strong statistical significance with bone gain ($p < 0.001$) in the simple and multiple logistic regression analyses. Mean DA reported in this study was 40°, and this resulted in 1.85 mm radiographic bone gain. To achieve ≥1 mm of bone gain, DA must be <57°, while to attain ≥2 mm of bone gain, DA must be <30°.

Conclusion: Baseline DA of peri-implantitis intrabony components predicts radiographic bone gain in reconstructive therapy (NCT05282667—this clinical trial was not registered prior to participant recruitment and randomization).

KEYWORDS
biocompatible materials, dental implants, jaw, peri-implantitis, regeneration, wound healing

Summary Box

What is known?

- Surgical therapy of peri-implantitis is safe and effective.

- Reconstructive therapy of peri-implantitis is safe and effective.
- Defect configuration dictates the therapuetic modality.

What this study adds?

- Defect angle is key to foresee effective reconstructive outcomes in the management of peri-implantitis.
- Narrow defect angles (<40°) result in consistent radiographic outcomes in the management of peri-implantitis.
- The narrower the defect angle is, the greater bone gain occurs.

1 | INTRODUCTION

Peri-implantitis represents a biofilm-mediated inflammatory condition featured by progressive bone loss and clinical signs of inflammation, which, if not arrested, may lead to implant failure.[1] Therefore, the primary end point in managing it is to restitute a condition of health characterized by shallow probing depths with a dominant population of aerobic bacteria.[2] To obtain this goal, various nonsurgical and surgical therapeutic modalities have been proposed. Nonsurgical measures were revealed to be unsatisfactory in terms of disease resolution.[3] Thus, surgical strategies are often necessary to efficiently manage the disorder.[4]

Among the surgical options, open flap debridement,[5] reconstructive,[6] and resective approaches,[7] with or without simultaneous soft tissue conditioning/grafting, have been advocated. The suitability of the modality is dominantly dictated by defect configuration.[2,8] In general lines, peri-implantitis bone defects exhibiting contained defects are prone to show favorable reconstructive outcomes together with a consistent pocket depth reduction.[9,10] On the other side, non-contained defects are discouraged to apply the principles of bone regeneration. In this sense, defect configuration has been shown to play a critical role in the reconstructive outcomes. Schwarz and colleagues[9] tested the effectiveness of reconstructive therapy by means of anorganic bovine bone and collagen membrane in three different scenarios. At 6-month follow-up, statistically significant differences were noted in pocket depth and clinical attachment level, favoring the defects exhibiting pure circumferential configuration. Alike, Aghazadeh and colleagues[10] showed that circumferential and deeper defects were subjected to show more defect fill at 12-month follow-up when compared to partially contained defects (two- to three-wall defects).

Periodontal regenerative procedures have been shown to be effective and predictable in the long term.[11–13] Interestingly, data suggested that deeper defects with narrower baseline radiographic defect angles (DAs) exhibit more favorable reconstructive outcomes.[14] This is consistent with data derived from guided bone regeneration in alveolar deficiencies, where individual phenotypic dimensions and the buccal DA are key to understand the predictability of regenerative procedures.[15,16] In the arena of reconstructive therapy for the management of peri-implantitis, however, the influence of the DA upon the outcomes is yet unexplored. Accordingly, the aim of this study was to analyze the influence of peri-implantitis bone defect-related features on the clinical resolution and radiographic bone gain of reconstructive therapy.

2 | MATERIALS AND METHODS

A prospective randomized controlled two-arm study was conducted in accordance with the Declaration of Helsinki on human studies, following approval from the Ethics Committee of the University of Extremadura (Badajoz). Patients were collected at CICOM-MONJE Institute (Badajoz, Spain). Patients received and signed a written informed consent. Patient data were anonymized. The study was registered and approved by www.clinicaltrials.gov (NCT05282667). This clinical trial was not registered prior to participant recruitment and randomization. The study is reported according to the CONSORT statement.[17] Data used for subset analyses are derived from a study published elsewhere.[6]

2.1 | Study sample

As described elsewhere,[6] consecutive patients exhibiting peri-implantitis were recruited from April 2019 up to June 2021. An a priori sample size was calculated considering 37% as the difference in disease resolution between the study groups.[18] Using this estimation with an alpha risk of 0.05% and a statistical power of 80% led to a sample size of 31 patients. Considering a potential dropout rate of 15%, a total of 36 patients (18 per group) were recruited. Each patient contributed with 1.5 ± 0.6 implants (overall = 48 implants). The following criteria were applied: all patients in the age of 18–80, non-smokers, with no presence of infectious diseases at the time of implant placement or during the maintenance program, and with no presence of systemic disease or medication known to alter bone metabolism; and partial/complete edentulous patients who had no active periodontal disease. Moreover, peri-implantitis bone defects, where reconstructive therapy was indicated due to contained defect configuration combined or not with supracrestal defect configuration, were included (ie, type Ib, Ic, IIIb, and IIIc).[8] Subjects were excluded due to pregnancy or lactation, former (<10 years) or current smoking, and uncontrolled medical conditions. Uncontained defects (ie, supracrestal bone defects—type II or implants outside of the bony envelope—type Ia or IIIa)[8] where reconstructive therapy was not indicated, sites with <2 mm of keratinized mucosa at the buccal aspect, or implants outside of the bony housing based upon intraoperative visualization[19] were excluded.

2.2 | Case definition of peri-implantitis

Peri-implantitis was defined according to the 2017 Word Workshop of Periodontal and Peri-implant diseases.[20] Hence, the case definition applied was as follows: presence of bleeding and/or suppuration on gentle probing (~0.2 N), probing pocket depths of ≥6 mm, and bone levels ≥3 mm apical of the most coronal portion of the intraosseous part of the implant based on periapical x-ray. If the examiner deemed unsuitable access, the prosthesis was retrieved for accurate diagnosis.

2.3 | Definition of disease resolution

Successful treatment was evaluated at the latest evaluation. Peri-implantitis was considered "resolved" if the following case definition was met at 12-month follow-up:

- Lack or 1 spot (not profuse) of bleeding and/or suppuration on gentle probing (~0.2 N)
- Probing pocket depths of ≤5 mm
- No radiographic progressive bone loss within the standard error ≥1 mm[21]

2.4 | Radiographic assessment

Periapical x-rays were taken applying the long cone paralleling technique assisted by the intraoral radiographic positioning system. For the reproducibility of the x-rays, the blinded examiner reached an intraoperative *k*-value >85% based on a previous examination of 15% of the overall sample. The following radiographic variables were recorded at baseline and at the latest follow-up examination (12 months) and were determined by a masked examiner (Figure 1):

- *Marginal bone level (MBL)*: Distance determined by taking linear measurements from the most mesial and distal points of the implant platform to the crestal bone on each peri-apical x-ray and corrected according to the known implant pitch. Regarding severity, implants were graded as follows—slight (S): <25% of the implant length, moderate (M): 25%–50% of the implant length, and advanced (A): >50% of the implant length.
- *Intrabony defect width (DW)*: Distance (mm) between the distal and mesial interproximal bone crests and the implant surface.
- *Angulation of the intrabony defect (DA)*: Angle resulted from a vertical line along the outer implant surface and a line extending along the peri-implant bone defect.

2.5 | Surgical reconstructive therapy phase

Oral hygiene instructions were instructed as part of the diagnostic phase. All eligible patients diagnosed with peri-implantitis underwent nonsurgical therapy at least 5–6 weeks prior to the surgical reconstructive phase by one operator (AM). A full-thickness flap was raised to have sufficient access. Debridement of granulation tissue was conducted subsequently using a "mini-five" curette,[*] site-specific Gracey curettes,[†] and NiTi brushes.[‡] The surgical approach was tailored to the scenario. Implantoplasty was performed whenever uncontained components were present (supracrestal or one- to two-wall defects with a tungsten carbide bur).[§] Surface decontamination was performed by means of NiTi brushes[¶] for about 2–3 min at 600 rpm followed by hydrogen peroxide (3%) for 2 min and irrigation with saline. The intrabony compartments were grafted using a demineralized (fibers) and mineralized (particulated) cortical allograft[**] up to the adjacent bony peaks. The test group received a cross-linked collagen membrane[††] on the top of the stratified grafting material, whereas in the control group, no membrane was used, and the demineralized fibers were left in contact with the soft tissues. Nylon 5.0[‡‡] was used for suturing. All the sites were left for transmucosal (nonsubmerged) healing. Thereafter, patients were prescribed to apply three times a day chlorhexidine and chitosan gel in the area for 2 weeks,[§§] and systemic amoxicillin 750 mg of two tablets a day for 7 days was also prescribed. Moreover, anti-inflammatory medication (ibuprofen 600 mg 1 tablet every 5–6 h for 5 days) was prescribed. In addition, patients were adhered to a 3-/4-month recall peri-implant maintenance therapy program supervised by the principal investigator during the first year after surgery (T_2).

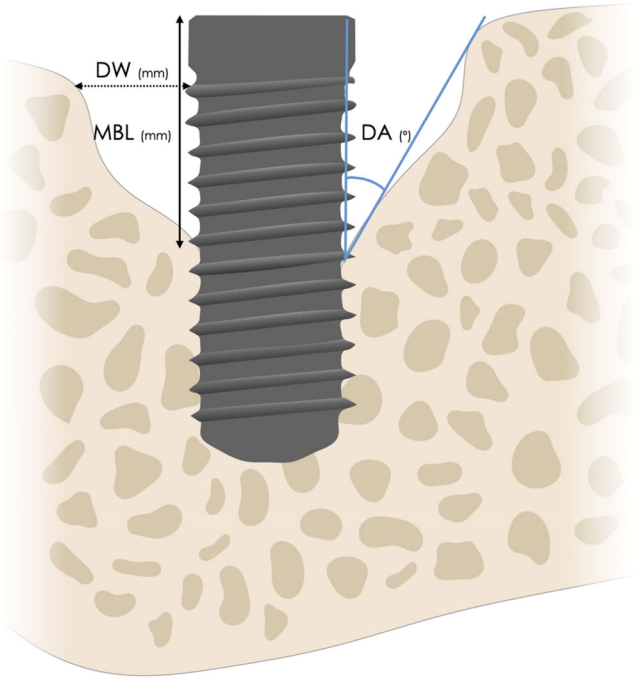

FIGURE 1 Radiographic morphological variables analyzed. DA, defect angle; DW, defect width; MBL, marginal bone loss.

2.6 | Statistical analysis

Absolute and relative frequencies, and means and standard deviation (SD) were used to describe the categorical and continuous variables, respectively. The homogeneous distribution of variables between study groups was analyzed through Pearson and Mann-Whitney tests for patient-level variables and using generalized estimating equations (GEEs) for implant-level variables. Binary logistic regressions were carried out through GEE to test the effectiveness of the therapy on the resolution according to the independent variables (DA, DW, and MBL). Nonadjusted odds ratios (OR) and 95% confidence intervals were obtained. For the dependent variable (radiographic bone gain), linear regression models were performed through GEE. The analysis was performed with SPSS 15.0 (SPPS Inc., Chicago, IL). The significance level used was 5% ($\alpha = 0.05$).

3 | RESULTS

3.1 | Study population

Among the 36 enrolled patients with a total of 51 implants, half of them were randomly allocated in the test group ($n = 18$), and the other half were in the control group ($n = 18$). At T_2, a total of 33 ($n_{implants} = 48$) patients (test = 17; control = 16) completed the study ($n_{DA} = 96$).

3.2 | Demographics

Mean age of the participants was 64 ± 9.3 years. Overall, 60.6% were female. The average of implants treated per patient was 1.5 ± 0.6. More than half of the surgical reconstructive procedures were performed in the posterior upper arch (54.2%). Most of the treated implants in the control group had an anodized surface (75%), whereas 41.7% of the implants in the test group included an acid-etched surface. Homogeneous distribution among the study groups was noted. In particular, 31.3%, 29.2%, 29.2%, and 10.4% exhibited defect types 1B, 1C, 3B, and 3C ($p = 0.8$) (Figure S1).

3.3 | Impact of bone defect characteristics on disease resolution

Most of the implants exhibited M severity of peri-implantitis (58.3%) followed by S severity (27%). Disease resolution was noted in 84.6% S, 75% M, and 71.4% A cases. The ORs for S, M, and A were 1, 0.55, and 0.46, respectively. Statistical significance was not reached. Mean DW was 2.11 ± 0.56 mm. It was noted that the mean DW of sites, where disease was resolved, was 2.07 ± 0.55 mm, whereas for nonresolved sites, it was slightly greater 2.25 ± 0.61 mm ($p = 0.38$). Mean DA was 43.44 ± 13.92%. Disease resolution was reported in wider DA (45.1 ± 13.9°) when compared with nonresolved sites that exhibited persistent disease (37.8 ± 13.2°; $p = 0.16$). These variables did not show statistically significant changes in any of the GEE. Additionally, the variable "bone defect configuration" did not yield statistical significance. In particular, the ORs for 1B, 1C, 3B, and 3C were 1, 3, 6.5, and 0.33, respectively.

TABLE 1 Multiple logistic regression for the tested morphological variables.

	Beta	IC 95%	*p*-value
DW	0.19	−0.05–0.44	0.126
DA	−0.04	−0.05–0.02	**<0.001*****
Severity (MBL)			0.671
Slight	0		
Moderate	−0.08	−0.58–0.41	0.745
Advanced	−0.18	−0.65–0.28	0.441

Abbreviations: DA, defect angle; DW, defect width; MBL, marginal bone loss.
***Strong statistical significance.

3.4 | Impact of bone defect characteristics on bone gain

DW and baseline MBL (severity) did not demonstrate statistical significance with bone gain. On the contrary, DA exhibited strong statistical significance with bone gain ($p < 0.001$) in the simple and multiple logistic regression analyses (Table 1). In particular, +1° baseline DA has a negative impact on the bone gain of 0.04 mm. Accordingly, the regression equation was 3.26–0.03 × DA (mm). The mean DA reported in this study was 40°, and this resulted in 1.85 mm of bone gain. To bypass the mean bone gain reported across the sample (1.72 mm), the DA was noted to be <45°. If a bone gain of ≥1 mm is the desired outcome, the DA must be <57°. If a bone gain of ≥2 mm is required to meet the outcome, the DA must be <30° (Figures 2 and 3). Moreover, bone defects classified as class 3B showed statistically less bone gain when compared with class 1B ($p = 0.005$). No other associations between defect configurations were noted. Intraclass correlation coefficient (ICC) was calculated to assess the dependence of MBL bone gain between the defects of the same patient, obtaining a poor value (ICC = −0.05; 95% CI: −0.56, 0.49).

4 | DISCUSSION

4.1 | Main findings

The present study demonstrated that the effectiveness and magnitude of radiographic bone gain in the reconstructive therapy of peri-implantitis fall on baseline DA. In order to achieve a consistent bone gain within a range of 1.7–2 mm, the DA must be <40° (Figure 4). However, DW and MBL (defect severity) did not yield statistical significance. These findings are, therefore, partially in line with

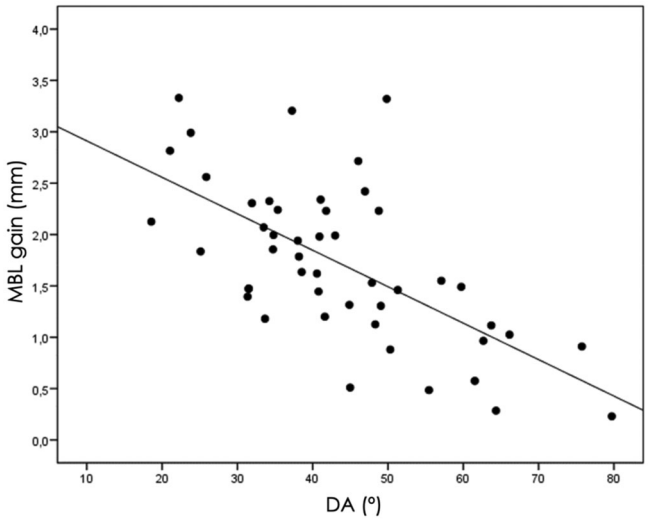

FIGURE 2 Diagram showing the positive correlation between the defect angle (DA) and radiographic marginal bone level (MBL) gain (raw values, no statistical model involved).

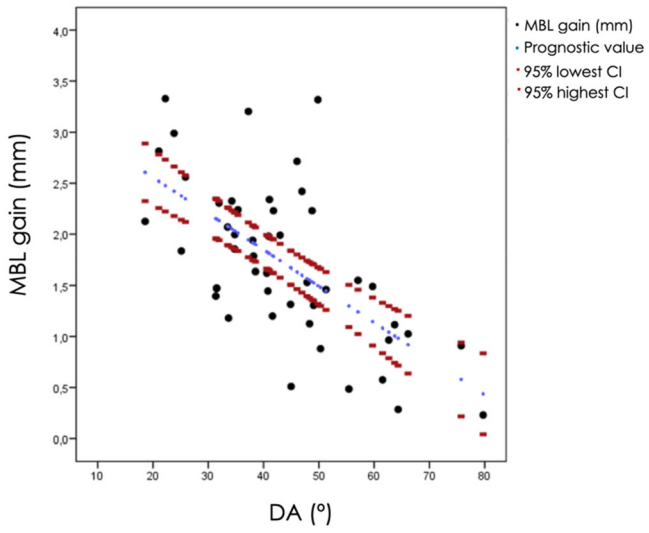

FIGURE 3 Diagram showing the prognostic value of defect angle (DA) to gain radiographic bone level. Predicted marginal bone level (MBL) gain, from linear regression models using generalized estimating equation (GEE), was represented as blue dots and 95% CI as red dots.

previous reports on periodontal regenerative therapy[14] and data on horizontal alveolar bone regeneration in deficient ridges.[15]

4.2 | Agreements and disagreements with previous findings

The characteristics of bone defect in peri-implantitis and their influence on reconstructive outcomes are not well understood. The configuration of the defect has been identified as a key factor in determining both clinical and radiographic outcomes of reconstructive therapy.[9,10] In a study conducted by Schwarz and colleagues,[9] the effectiveness of reconstructive therapy using anorganic bovine bone and a collagen membrane was tested in three different scenarios. At 6-month follow-up, statistically significant differences were noted in probing pocket depth and clinical attachment level, favoring the defects exhibiting four walls when compared with two- to three-wall defects. Alike, Aghazadeh and colleagues[10] showed that circumferential and deeper defects were subjected to show more defect fill at 12-month follow-up when compared with partially contained defects (two- to three-wall defects). However, the findings of Roccuzzo and colleagues[22] were different as they showed that defect configuration was not associated with either implant survival or clinical resolution after managing peri-implantitis by reconstructive means at 60-month follow-up. In addition, Aghazadeh and colleagues[10] evaluated the effect of baseline MBL on the radiographic bone fill. The results indicated that the deeper the defects at baseline examination, the greater the radiographic bone gain. Our findings provide evidence that, in fact, intrabony defects (class 1B) showed better radiographic bone gain when compared with combined defects (class 3B). Nonetheless, to the best of the authors' knowledge, DW and DA have not been previously studied as prognostic indicators in reconstructive therapy of peri-implantitis. Results from this study suggested that narrow defects (<40°) are more prone to exhibit favorable reconstructive outcomes in terms of radiographic bone gain (Figures 5 and 6). However, DW and MBL were not shown to impact on the outcomes.

These findings are consistent with the literature on periodontal therapy on the management of intrabony defects. Steffensen and Weber[23] suggested that a DA <45° was more conducive to radiographic bone gain when compared with wider DA in open flap debridement procedures. Tonetti and colleagues[24] assessed the influence of DA on regenerative surgery, which included the use of a nonresorbable membrane without a bone substitute. They found that the wider the radiographic DA, the lower the regenerated probing attachment level in intrabony defects. Tonetti and colleagues[25] demonstrated that narrow DA (<25°) tended to show more favorable outcomes in terms of clinical attachment level when compared with wide DA (>37°). Alike, Tsitoura and colleagues[26] noted statistical significance for DA in periodontal regeneration by means of enamel matrix derivative. In particular, it was shown that in DA ≤22°, the odds to achieve clinical attachment level gain ≥4 mm were 2.5× higher when compared with baseline DA ≥36°. Eickholz and colleagues[27] showed that, applying guided tissue regeneration, narrow DA (<37°) and deeper (≥4 mm) responded more favorably to therapy when compared with wide and shallow defects. The above-mentioned findings are, hence, in agreement with ours. It was elucidated that this finding might be explained by an insufficient support of the bone substitute and/or barrier membrane in wider DA[24] or by the lower distance for osteoprogenitor cell migration necessary to repopulate the wound of narrow DA.[23] It is important to note that, however, on average, regenerative procedures for the management of peri-implantitis caused defects

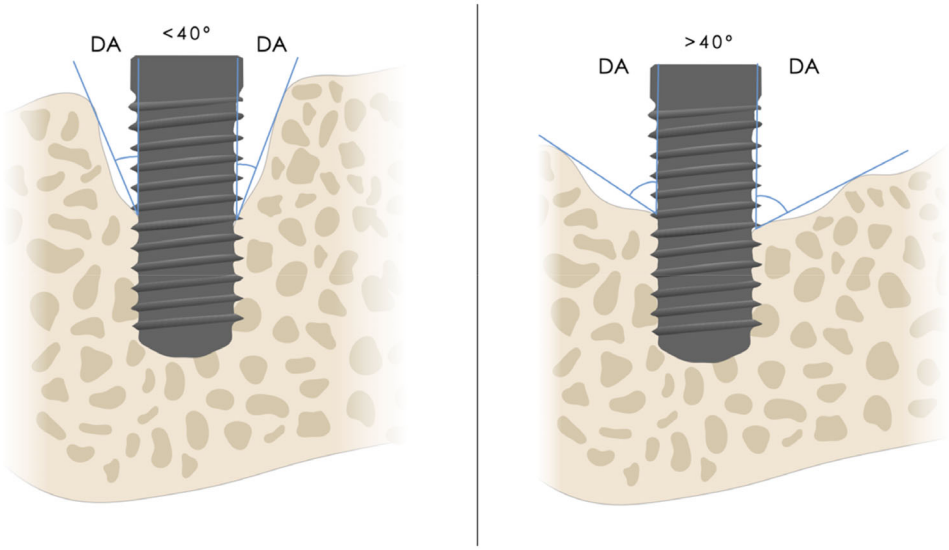

FIGURE 4 Defect angle (DA) demonstrated predicting radiographic bone gain. Narrow DA (<40°) was more prone to achieve greater bone level gain.

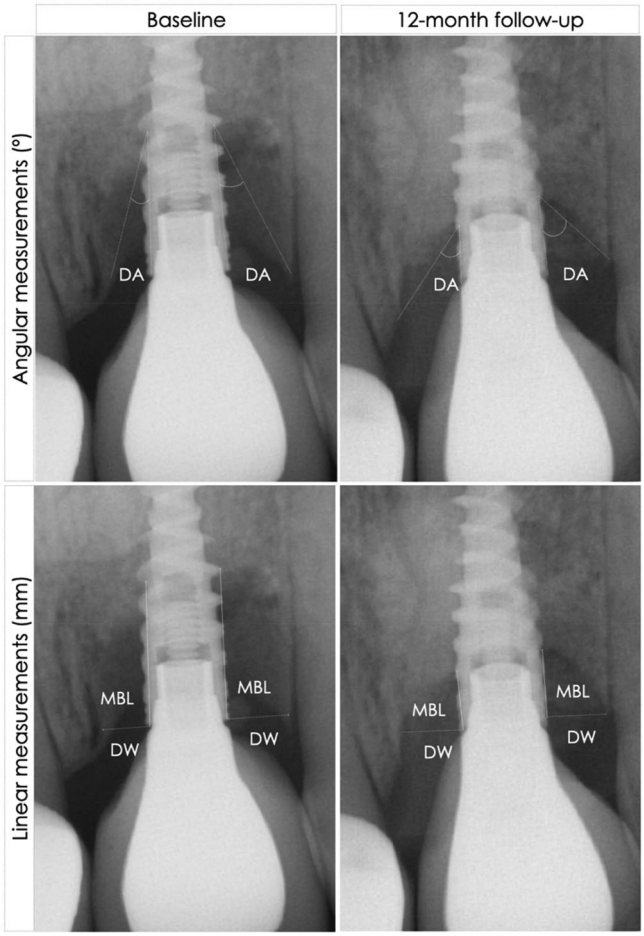

FIGURE 5 Scenario at baseline and 12-month follow-up exhibiting a narrow defect angle (DA <40°). DW, defect width; MBL, marginal bone loss.

yielded less bone gain when compared to regenerative periodontal procedures.[6,10,22,24,28–35] This discrepancy may be due, in part, to the substantial differences existing between the bone defect configurations and between the periodontal and peri-implant defects, or the arduousness to decontaminate the infected implant surface.

Moreover, in the arena of alveolar bone regeneration for implant site development, narrower defects have also been advocated for predictable bone regeneration. Garaicoa and colleagues,[15] in a radiographic study using cone-beam computed tomography (CBCT), showed that the crest angulation was 150° at 9 mm apical to the crest. In fact, it was found that in cases of a crest angulation of <150°, the horizontal bone gain was ~4, whereas in scenarios presenting crest angulation >150°, the gain was ~3 mm lesser. More recently, Quirynen and colleagues[16] demonstrated the existence of individual alveolar phenotypes to predict horizontal ridge augmentation using 3-dimensional virtual reconstruction and superimposition of CBCT data, with the contralateral ridge dimensions as reference. One possible explanation for this finding is the stability of the coagulum and the material that provides the barrier membrane in a contained defect in contrast to a flat architecture. Again, our findings support this hypothesis as DA reached strong statistical significance with radiographic bone gain.

4.3 | Limitations and recommendations for future research

This is a subset analysis of an randomized controlled clinical trial. Hence, this observation was derived from a study published elsewhere[6] subjected to an eligibility criteria to test the significance of barrier membrane on reconstructive therapy. Although this was found not to impact on the reconstructive outcomes, it would be interesting in future studies to analyze reconstructive therapy using the same biomaterials in a larger sample size. Moreover, in the pursuit to enhance accuracy, the use of three-dimensional technologies to analyze the features that define bone defects.

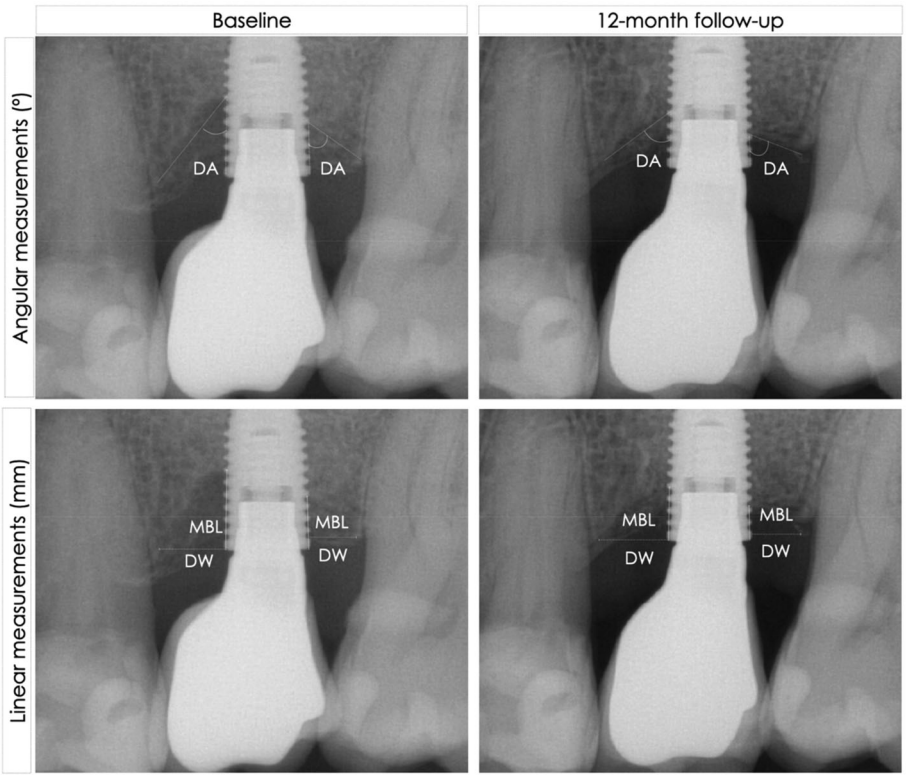

FIGURE 6 Scenario at baseline and 12-month follow-up exhibiting a wide defect angle (DA >40°). DW, defect width; MBL, marginal bone loss.

5 | CONCLUSION

Baseline DA of peri-implantitis intrabony components predicts radiographic bone gain in surgical reconstructive therapy. As such, narrow DA (<40°) results in more consistent and effective radiographic bone gain. DW and MBL, however, do not seem to influence the radiographic outcome.

AUTHOR CONTRIBUTIONS

All authors have made substantial contributions to conception and design of the study. Alberto Monje has been involved in data collection, conception, design of this study, and drafting the manuscript. Ramón Pons has been involved in data analysis and data interpretation. José Nart, Anton Sculean, and Hom-Lay Wang have been involved in the critical review of the manuscript and have given final approval of the version to be published.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Monje A, Pons R, Sculean A, Nart J, Wang H-L. Defect angle as prognostic indicator in the reconstructive therapy of peri-implantitis. *Clin Implant Dent Relat Res*. 2023;1-8. doi:10.1111/cid.13244