

**ORIGINAL ARTICLE**

# Characteristics and frequency distribution of bone defect configurations in peri-implantitis lesions—A series of 193 cases

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**Abstract**

**Background:** Knowledge on peri-implantitis bone defect characteristics and predictors is still limited.

**Purpose:** To describe peri-implantitis bone defect characteristics and identify possible predictors.

**Methods:** Various parameters at patient- (age, gender, smoking, and supra-structure), implant- (surface, type, connection, platform, and misfit), and site level (region, alveolar ridge position, defect characteristics, neighboring structure) were recorded retrospectively.

**Results:** Among 193 implants, the most prevalent defects were class Ic (25.4%), and Id (23.8%); a previously non-described category “class Id with only one bone wall” was frequently observed (11.9%). Mean intrabony defect depth and width ranged from 4.5 to 6.2 mm and from 2.7 to 2.9 mm, respectively; mean dehiscence extent ranged from 2.8 to 7.0 mm. A total of 37.8% of the defects presented horizontal bone loss and an intrabony component; in 52.7% of the implants, total defect extent was >6 mm. Jaw region, implant position within the alveolar ridge, and implant/abutment misfit showed significant associations either to defect configuration and/or defect extent.

**Conclusion:** (a) Most common peri-implantitis defects exhibited a combination of intrabony component and a buccal/oral dehiscence, while purely circumferential defects were relatively seldom; (b) implants with defects with bone dehiscence were placed more frequently closer to the lateral aspect of the ridge harboring the dehiscence; (c) implants placed in the lower anterior region had the highest risk for more severe peri-implant bone loss; and (d) peri-implant bone defects with only a single bone wall appropriate for regenerative procedure were relatively frequent.

**KEYWORDS**

bone defects, clinical study, peri-implant defect, peri-implantitis

## 1 | INTRODUCTION

Peri-implantitis is a site-specific pathological condition characterized by inflammation of the peri-implant soft connective tissue and progressive loss of implant-supporting bone.<sup>1,2</sup> With a weighted mean prevalence of 22% and an increasing number of annually placed dental implants, peri-implantitis represents a growing problem.<sup>3,4</sup> In moderate and advanced peri-implantitis cases, non-surgical therapy often does not achieve complete disease resolution and surgical treatment is required.<sup>5,6</sup>

Schwarz et al. established in 2007 a classification for peri-implant bone defects, based on the pattern of bone loss around 40 implants. Specifically, a class I defect is defined by a buccal dehiscence and/or the presence of an intrabony defect, and a class II defect is characterized by horizontal bone loss. Class I defects are further subclassified (i.e., class Ia to Ie) based on the presence/absence of supporting bone walls and/or of intrabony defects at the four implant aspects (buccal-mesial-oral-distal).<sup>9</sup> In this study, most intrabony defects (55.3%) had a circumferential configuration (i.e., class Ie).<sup>9</sup> In another study, based on 46 implants in total and 37 implants with an intrabony component, 40.5% of the intrabony defects presented with class Ie.<sup>10</sup> More recently, based on cone-beam computed tomography (CBCT) analysis of peri-implantitis lesions in a larger patient cohort with 158 implants, a class III configuration was added to the classification scheme, to describe defects with both intrabony and horizontal bone loss (i.e., combination of classes I and II).<sup>11</sup> Interestingly, circumferential defects were much more rare (i.e., only in 8.4% of the defects with an intrabony component)<sup>11</sup> compared to what was reported in the previous studies.<sup>9,10</sup> This difference among the later study and the former ones may be due to either the small patient cohorts (i.e.,  $\leq 40$  implants) in the former studies<sup>9,10</sup> or due to the assessment method in the latter study,<sup>11</sup> which appears to be more prone to bias, especially in cases with thin alveolar bone. It has recently been shown, that in cases with a thin buccal bone (i.e.,  $\leq 1$  mm thickness), detection of the buccal bone level at dental implants is largely inaccurate in CBCT images.<sup>12</sup>

In this context, peri-implant bone defect configuration is considered crucial, affecting treatment choice (i.e., resective, regenerative, or combined surgical approach) and the outcome of surgical treatment.<sup>7,17,8,18</sup> Specifically, class Ie defects have shown a better response comparing to class Ib and Ic, after a regenerative approach including grafting plus a collagen membrane; that is, after 6 and 12 months of healing, mean probing pocket depth reduction and clinical attachment level gain was up to 1 to 1.5 mm higher in class Ie compared to other defect classes, while the worst outcome was observed at implants with class Ib and Ic defects at the lateral aspect of the alveolar ridge harboring the bone dehiscence<sup>7</sup>; similar findings were reported in other recent studies.<sup>8,17</sup> Considering the importance of defect configuration for the outcome of surgical peri-implantitis treatment, it is interesting to know the prevalence of the various defect configurations and of any factors possibly contributing to the one or other configuration. The aim of the present study was (a) to assess characteristics and frequency distribution of peri-implant bone defects (i.e., configuration and extent) in a large patient sample, based on intra-operative recordings, and (b) to

### What is known:

- Peri-implant bone defect configuration is considered crucial for treatment choice and outcome. However, knowledge on bone defect characteristics and predictors is still limited.

### What this study adds:

- Implants with peri-implantitis mostly exhibit a combination of intrabony and buccal/oral dehiscence defect rather than purely circumferential defect, in contrast to what previously reported.
- Implants placed closer to the lateral aspect of the alveolar ridge develop frequently bone dehiscences.
- Peri-implant bone defects presenting only a single bone wall appropriate for regenerative procedure are not uncommon.

investigate a possible association of peri-implant bone defect characteristics to patient-, implant-, and site-related variables.

## 2 | MATERIALS AND METHODS

### 2.1 | Patient population and eligibility criteria

A retrospective case-series was conducted in two centers (Faculty of Odontology, University of Malmö, Malmö, Sweden, and University Clinic of Dentistry, Medical University of Vienna, Vienna, Austria). The dental journals of patients, who had received surgical intervention due to peri-implantitis, were screened backward from March 2020 until a convenience sample of 100 patients was achieved based on the following eligibility criteria: (a) detailed intra-operative documentation of the peri-implant bone defect configuration and extent; (b) availability of radiographs prior to surgical intervention allowing judgment of presence of and distance to neighboring structures. Ethical approval was obtained from the Ethical committee of the Medical University of Vienna (Vienna, Austria; EK-Nr. 1276/2018) and from the Swedish Ethical Review Authority (Lund, Sweden; Dnr. 2020-01019); reporting complies with the STROBE guidelines (Appendix 1).

### 2.2 | Patient-, implant-, and site-related parameters

Various parameters were extracted and calculated from the patients' dental records and radiographs. The following parameters were recorded:

At the patient level:

- Age at time-point of surgical treatment for peri-implantitis (in years)

- Gender
- Smoking status at time-point of surgical treatment for peri-implantitis (i.e., smoker; non-smoker)
- Number of implants included herein per patient

**TABLE 1** Patient and implant characteristics (n = 100)

Age (mean ± SD [min; max])	64.8 ± 13.7 (28.5; 88.4)
Gender (female; n [%])	57 (57)
Smoking status (smoker; n [%]) <sup>a</sup>	40 (41.2)
Number of implants included per patient (mean ± SD)	1.9 ± 1.3
Number of implants included per patient (n [%])	193 (100)
1	47 (24.4)
2	64 (33.2)
3	33 (17.1)
4	24 (12.3)
5	15 (7.8)
10	10 (5.2)
Supra-structure (n [%])	193 (100)
Single implant	35 (18.1)
Multiple implants	70 (36.3)
Teeth and implants combined	0 (0)
Cross-arch restoration	88 (45.6)
Number of implants splinted (mean ± SD [min; max])	3.5 ± 1.9 (1; 6)

Note: max, maximum value; min, minimum value; n, number.

<sup>a</sup>Three missing values.

- Type of supra-structure (i.e., single implant; multiple implants; teeth and implants combined; cross-arch restoration)
- Number of implants splinted in the supra-structure

At the implant level:

- Implant surface (i.e., modified; smooth)
- Implant type (i.e., bone level; tissue level)
- Connection type (i.e., internal; external)
- Platform type (i.e., match; switch)
- Presence of an implant/abutment misfit (i.e., presence or absence of a gap between the implant and abutment/crown)

At the site level:

- Peri-implant bone defect configuration assessed intra-operatively according to Schwarz et al.<sup>9</sup>

Bone defect configurations were intraoperatively recorded as classes I, II, or combinations thereof. Class I defects were further subclassified into class Ia (i.e., presence of a buccal bone dehiscence), class Ib (i.e., buccal bone dehiscence in combination with mesial and distal intrabony defects), class Ic (i.e., buccal bone dehiscence in combination with a circumferential defect), class Id (i.e., buccal and oral bone dehiscences combined with mesial and distal intrabony defects), and class Ie (i.e., circumferential defect). If defects, which fulfilled in general the above-described characteristics for class Ic or Ie but presented with minor additional bone dehiscences buccal and/or oral, they were still classified as Ic or Ie. If defects could not be assigned to one

**TABLE 2** Frequency distribution of peri-implant bone defect configurations in the various jaw regions

Peri-implant bone defect configuration	Total n (%) <sup>a</sup>	Maxilla			Mandible		
		Anterior n (%) <sup>b</sup>	Premolar	Molar	Anterior	Premolar	Molar
<b>Intrabony defect configuration</b>							
Class Ia	2 (1.0)	1 (50.0)	0	0	0	1 (50.0)	0
Class Ib	7 (3.6)	0	1 (14.3)	0	2 (28.6)	1 (14.3)	3 (42.8)
Class Ic	49 (25.4)	19 (38.8)	3 (6.2)	1 (2.1)	11 (22.3)	9 (18.4)	6 (12.2)
Class Id	46 (23.8)	23 (50.0)	9 (19.6)	1 (2.2)	6 (13.0)	3 (6.5)	4 (8.7)
Class Ie	20 (10.4)	2 (10.0)	6 (30.0)	1 (5.0)	3 (15.0)	1 (5.0)	7 (35.0)
Class Id with only 1 wall	23 (11.9)	6 (26.1)	9 (39.1)	2 (8.7)	4 (17.4)	2 (8.7)	0
Others	13 (6.8)	3 (23.1)	5 (38.5)	0	4 (30.7)	1 (7.7)	0
<b>Horizontal bone loss configuration</b>							
Class II	33 (17.1)	6 (18.2)	11 (33.3)	3 (9.1)	7 (21.2)	5 (15.2)	1 (3.0)
Total	193	60 (31.1)	44 (22.8)	8 (4.1)	37 (19.2)	23 (11.9)	21 (10.9)

Note: The following bone defect configurations are summarized among "Others": class Ic but one wall missing (n = 3), inverted class Ic (n = 4), intrabony defect at a single aspect (n = 2), class Ia with the bone defect/dehiscence at another aspect (n = 2), class Ia with a second bone dehiscence at another aspect (n = 1), and class Ia with an intrabony component at a single aspect (n = 1). n indicates number.

<sup>a</sup>Percentages represent the percentages of the total number of implants included (n = 193).

<sup>b</sup>Percentages represent the percentages per peri-implant bone defect configuration.

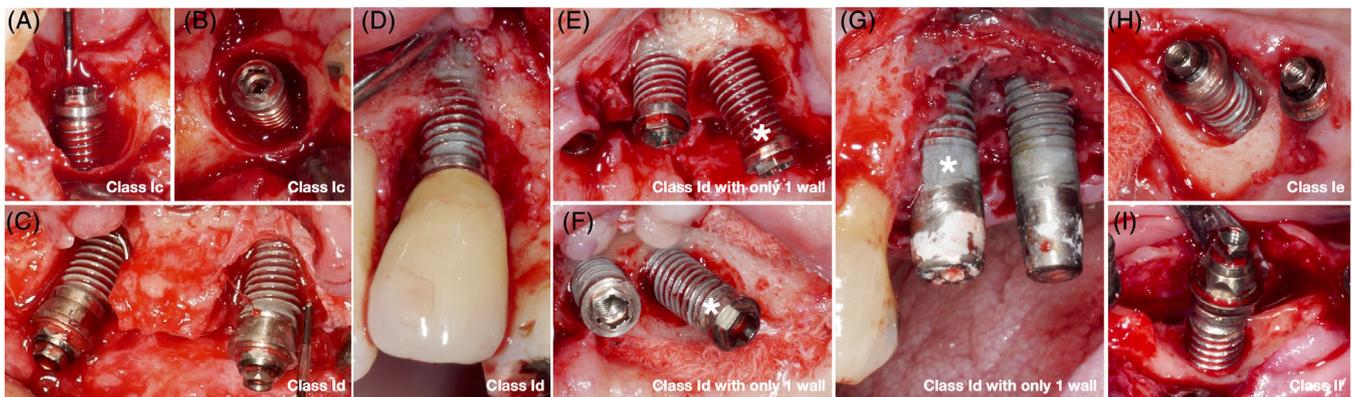
of the above-mentioned classes, new classes were considered later on in the analysis.

- Jaw region (i.e., anterior [incisors and canines], premolars, and molars in the upper or lower jaw)
- Intrabony defect depth (mm) measured from the marginal bone to the bottom of the deepest defect aspect
- Horizontal bone loss height (mm) measured from the implant neck to the marginal bone
- Total defect extent (mm) measured from the implant neck to the bottom of the deepest defect aspect (i.e., sum of horizontal bone loss height and intrabony defect depth, but not taking any buccal or oral bone dehiscence into account)

This parameter was further classified according to its extent into the following categories: (a) slight (i.e., 2 to 3 mm), (b) moderate (i.e., >3 to ≤6 mm), (c) advanced (i.e., >6 to ≤9 mm), and (d) severe (i.e., >9 mm).

- Intrabony defect width (mm) measured from the implant surface to the bone at the height of the marginal bone level
- Extent of the buccal and oral bone dehiscence (mm) measured from the implant neck to the most apical extent of the dehiscence
- Presence of and distance to neighboring structures (i.e., teeth or implants) at the mesial and distal aspect of the implant

This parameter was defined as (a) “nothing” if no neighboring structure was within 5 mm, as (b) “tooth or implant too close” if the



**FIGURE 1** Clinical examples of the most frequent peri-implant bone defect configurations (\* indicates the corresponding implant in case of several implants with different bone defect configurations); A, buccal and, B, occlusal view of class Ic; C and D, buccal view of two cases with class Id; E and G, buccal and, F, occlusal view of two cases with class Id with only one wall; H, buccal-occlusal view of class Ic; and, I, buccal view of class II

**TABLE 3** Characteristics of the most prevalent peri-implant bone defect configurations (ie, peri-implant bone defect configurations with a frequency >10 implants)

Peri-implant bone defect configuration	Intrabony defect (mm)		Extent of the bone dehiscence (mm)		Combined with a class II defect Yes n (%) <sup>a</sup>	Horizontal bone loss (mm) Height Mean ± SD (min; max)	Total defect extent (mm) (2; 15)
	Depth Mean ± SD (min; max)	Width (2; 4.5)	Buccal (2; 12)	Oral (1.5; 8)			
<b>Intrabony defect configuration</b>							
Class Ic	6.2 ± 2.4 (2; 11)	2.9 ± 0.7 (2; 4.5)	7.0 ± 1.9 (2; 12)	4.5 ± 1.8 (1.5; 8)	21 (42.9)	3.6 ± 2.0 (1; 7)	7.7 ± 3.0 (2; 15)
Class Id	6.1 ± 2.1 (1.5; 10.5)	2.9 ± 0.6 (2; 4.5)	6.7 ± 2.3 (2; 12.5)	6 ± 2.2 (2; 12)	13 (28.3)	3 ± 1.4 (1; 6)	6.8 ± 2.4 (3; 13)
Class Id with only 1 wall	5.6 ± 2 (2; 9)	2.7 ± 1.4 (0; 5)	6.9 ± 2.4 (2; 12)	6.3 ± 1.9 (2; 10)	9 (39.1)	2.3 ± 1.8 (1; 6)	6.5 ± 2.6 (2; 12)
Class Ie	4.5 ± 2.4 (1; 10)	2.7 ± 0.9 (1; 5)	3.3 ± 2.1 (1; 6)	2.8 ± 1.3 (1; 4)	17 (85.0)	3.1 ± 2.2 (1; 9)	7.2 ± 2.8 (2; 12)
<b>Horizontal bone loss configuration</b>							
Class II	-	-	-	-	-	5.9 ± 2.5 (2; 12)	5.9 ± 2.5 (2; 12)

Note: max, maximum value; min, minimum value; n, number.

<sup>a</sup>Percentages are within each peri-implant bone defect configuration.

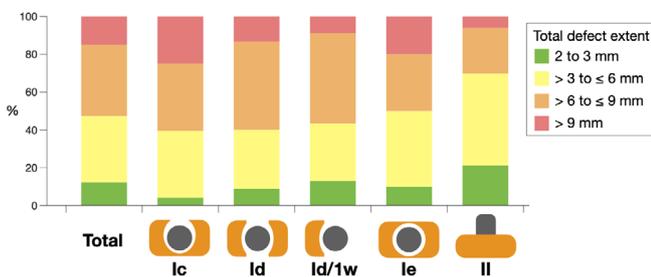
distance to the neighboring tooth or implant was <1.5 or <3 mm, respectively, or as (c) "neighboring tooth" or (d) "neighboring implant" if the tooth or implant was in a distance of 1.5 to 5 or 3 to 5 mm, respectively. A digital radiography software (Sidexis version XG 2.52, Sirona, Bensheim, Germany) was used for the measurements on peri-apical radiographs taken with the parallel technique. All radiographs in each center were measured by a single examiner (Vienna: C. W., Malmö: K. B.) and a calibration based on the known size of the digital sensor was performed. The above-mentioned classes were used instead of the actual distance to minimize the effect of a measurement error due to non-standardized radiographs.

- Position of the implant in the alveolar ridge assessed at the buccal and oral aspect

Three categories applied for this parameter depending on the distance of the implant surface to the lateral aspect of the alveolar ridge; that is, as (a) "outside" if the implant surface was more buccally or orally than the lateral aspect of the alveolar ridge, as (b) "≤1 mm" if the implant surface was within 1 mm to the lateral aspect of the alveolar ridge, and as (c) ">1 mm" if the implant surface was >1 mm to lateral aspect of the alveolar ridge.

### 3 | STATISTICAL ANALYSIS

Descriptive statistics were used and means, SD, and frequency distributions were calculated. Univariate mixed-effects ordered logistic regression analyses were applied with total defect extent categories as ordinal primary outcome parameter and the following parameters as predictors: age, gender, smoking status, number of implants included per patient, jaw region, alveolar ridge position (buccal and oral), implant surface, implant type, connection type, platform type, implant/abutment misfit, supra-structure, and mesial and distal aspect of the implant. Furthermore, all peri-implant bone defect configurations, which were present more than 10-times, were considered separately for univariate random-effects logistic regressions analyses. The specific bone defect configuration was defined as binary primary outcome parameter and the same predictors used as listed earlier. For both approaches, a multivariate analysis was additionally performed including all parameters presenting with a *P*-value <0.2 in the



**FIGURE 2** Frequency distribution of the total defect extent in total and among the most prevalent peri-implant bone defect configurations; Id/1w, class Id with only 1 wall

univariate analysis. Statistical analysis was performed with STATA/IC 16.0 for Mac and a *P*-value of ≤.05 was considered as statistically significant.

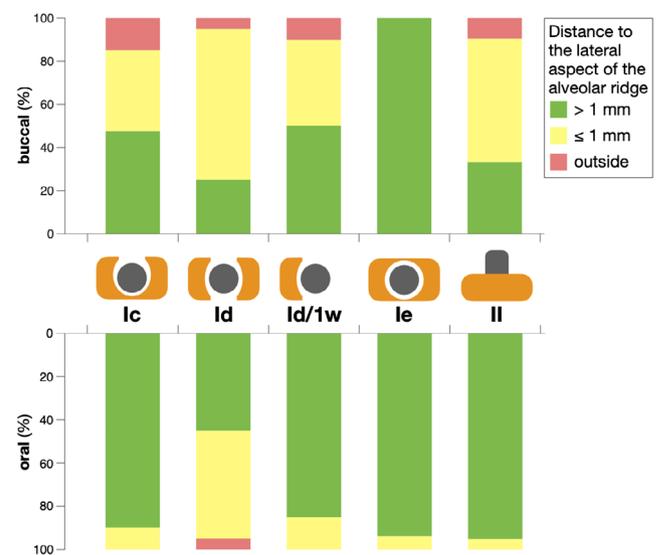
## 4 | RESULTS

### 4.1 | Patient characteristics

Per protocol 100 patients (57 female; mean age: 64.8 years; 41% smokers) contributed with 193 implants (Table 1). In most of the cases, patients presented with a single or two implants with peri-implantitis (i.e., in 24.4% and 33.2% of the implants, respectively), while a single patient contributed with 10 implants. Most of the implants affected by peri-implantitis were part of a cross-arch restorations (i.e., 45.6%; Table 1) and installed in the upper anterior and premolar region (i.e., in 31.1% and 22.8% of the implants, respectively; Table 2).

### 4.2 | Peri-implant bone defect configuration

Peri-implant bone defects were most often class Ic (25.4%), followed by class Id (23.8%), and pure class II defects (17.1%), while 36 defects (18.7%) did not fit the Schwarz et al<sup>9</sup> classification. Of those, only one specific bone defect configuration appeared frequently (i.e., 23-times or in 11.9% of all defects): "class Id with only 1 wall", which fulfills in general the criteria of class Id but is lacking additionally either the mesial or distal bone wall. Clinical examples of the most frequent peri-implant bone defect configurations are presented in Figure 1. Among the remaining 13 defects (6.8%), no specific defect configuration appeared more often than four-times: "class Ic but one wall missing" (*n* = 3), "inverted class Ic" (i.e., with the dehiscence at the oral aspect) (*n* = 4), "intraony defect at a single aspect" (*n* = 2), "class Ia with the bone dehiscence at another



**FIGURE 3** Frequency distribution of the distance of the implant surface to the lateral aspect of the alveolar ridge among the most prevalent peri-implant bone defect configurations; Id/1w, class Id with only 1 wall

**TABLE 4** Implant characteristics of the most prevalent peri-implant bone defect configurations (i.e., peri-implant bone defect configurations with a frequency >10 implants)

Peri-implant bone defect configuration	Implant surface		Connection type	Platform type	Implant/abutment misfit
	Modified/Smooth n (%) <sup>a</sup>	Implant type Bone level/Tissue level			
<b>Intrabony defect configuration</b>					
Class Ic	47/2 (95.9/4.1)	42/7 (85.7/14.3)	29/20 (59.2/40.8)	38/11 (77.5/22.5)	6/43 (12.2/87.8)
Class Id	36/10 (78.3/21.7)	42/4 (91.3/8.7)	27/19 (58.7/41.3)	28/18 (60.9/39.1)	7/39 (15.2/84.8)
Class Id with only 1 wall	23/0 (100.0/0.0)	23/0 (100.0/0.0)	19/4 (82.6/17.4)	12/11 (52.2/47.8)	6 /17 (26.1/73.9)
Class Ie	18/2 (90.0/10.0)	16/4 (80.0/20.0)	14/6 (70.0/30.0)	11/9 (55.0/45.0)	2/18 (10.0/90.0)
<b>Horizontal bone loss configuration</b>					
Class II	24/9 (72.7/27.3)	29/4 (87.9/12.1)	19/14 (57.6/42.4)	24/9 (72.7/27.3)	4/29 (12.1/87.9)
Total (n = 193)	168/25 (87.1/12.9)	169/24 (87.6/12.4)	121/72 (62.7/37.3)	130/63 (67.4/32.6)	29/164 (15.0/85.0)

Note: n indicates number.

<sup>a</sup>Percentages are within each peri-implant bone defect configuration and parameter.

**TABLE 5** Neighboring structure mesial and distal of the diseased implant in relation to the most prevalent peri-implant bone defect configurations (i.e., peri-implant bone defect configurations with a frequency >10 implants)

Peri-implant bone defect configuration	Mesial aspect of the implant <sup>a</sup>				Distal aspect of the implant <sup>a</sup>			
	Nothing n (%) <sup>b</sup>	T/I too close	Neighboring T	Neighboring I	Nothing	T/I too close	Neighboring T	Neighboring I
<b>Intrabony defect configuration</b>								
Class Ic	26 (53.1)	2 (4.1)	7 (14.2)	14 (28.6)	28 (57.2)	3 (6.1)	5 (10.2)	13 (26.5)
Class Id	27 (58.7)	1 (2.2)	6 (13.0)	12 (26.1)	29 (63.0)	3 (6.5)	5 (10.9)	9 (19.6)
Class Id with only 1 wall	10 (43.5)	6 (26.1)	4 (17.4)	3 (13)	12 (52.2)	4 (17.4)	6 (26.1)	1 (4.4)
Class Ie	10 (50.0)	1 (5.0)	5 (25.0)	4 (20.0)	13 (65.0)	0 (0.0)	1 (5.0)	6 (30.0)
<b>Horizontal bone loss configuration</b>								
Class II	14 (42.4)	4 (12.1)	3 (9.1)	12 (36.4)	18 (54.6)	3 (9.1)	2 (6.1)	10 (30.3)
Total (n = 193)	95 (49.2)	16 (8.3)	33 (17.1)	49 (25.4)	113 (58.6)	17 (8.8)	22 (11.4)	41 (21.2)

Abbreviations: I, implant; n, number; T, tooth.

<sup>a</sup>"Nothing" is defined as no neighboring structure within 5 mm; <1.5 mm is the cut-off value for a tooth being too close and <3 mm is the cut-off value for an implant being too close.

<sup>b</sup>Percentages are within each peri-implant bone defect configuration and parameter.

aspect" (n = 2), "class Ia with a second bone dehiscence at another aspect" (n = 1), and "class Ia with an intrabony component at a single aspect" (n = 1). These defects configurations are summarized later on as "others". Frequency distribution of the various peri-implant bone defect configurations according to the jaw region is displayed in Table 2.

### 4.3 | Extent and characteristics of peri-implant bone defects

Defect extent and characteristics of the most prevalent peri-implant bone defect configurations (i.e., peri-implant bone defect

configurations with a frequency >10 implants) are summarized in Table 3. Intrabony defect depth ranged from  $4.5 \pm 2.4$  to  $6.2 \pm 2.4$  mm, and defect width ranged from  $2.7 \pm 1.4$  to  $2.9 \pm 0.7$  mm. The range of the extent of the buccal bone dehiscence was from  $3.3 \pm 2.1$  to  $7.0 \pm 1.9$  mm, and of the oral bone dehiscence from  $2.8 \pm 1.3$  to  $6.3 \pm 1.9$  mm. Class Ie was most frequently combined with a class II defect (i.e., in 85% of the cases) and among the combined defects (i.e., class I and II) the horizontal bone loss height ranged from  $2.3 \pm 1.8$  to  $3.6 \pm 2.0$  mm, while for those defects with only class II the horizontal bone loss height averaged at  $5.9 \pm 2.5$  mm. The total defect extent ranged from  $5.9 \pm 2.5$  to  $7.7 \pm 3.0$  and more than half of the implants (i.e., 52.7%) presented with advanced bone

**TABLE 6** Univariate and multivariate mixed-effects ordered logistic regression analyses with total defect extent as ordinal primary outcome parameter

Predictors		Univariate model				Multivariate model			
		OR	95% CI		P value	OR	95% CI		P value
			Lower	Upper			Lower	Upper	
Age	Years	<b>1.036</b>	<b>1.008</b>	<b>1.064</b>	<b>.010</b>	1.032	0.997	1.067	.070
Gender	Male								
	Female	1.877	0.929	3.792	.079	1.990	0.959	4.131	.065
Smoking status	Non-smoker								
	Smoker	0.982	0.473	2.038	.961				
Implants included per patient	Count	0.898	0.719	1.121	.340				
Jaw region <sup>a</sup>	Upper posterior								
	Upper anterior	1.671	0.722	3.870	.231	2.063	0.809	5.262	.129
	Lower posterior	0.723	0.286	1.825	.492	0.949	0.373	2.414	.912
	Lower anterior	<b>3.407</b>	<b>1.226</b>	<b>9.466</b>	<b>.019</b>	<b>3.557</b>	<b>1.211</b>	<b>10.448</b>	<b>.021</b>
Alveolar ridge position (buccal)	Outside								
	≤1 mm	1.142	0.268	4.864	.857				
	>1 mm	1.379	0.304	6.241	.677				
Alveolar ridge position (oral)	Outside								
	≤1 mm	1.887	0.017	214.644	.793				
	>1 mm	6.437	0.061	684.793	.434				
Implant surface	Smooth								
	Modified	1.034	0.357	2.991	.952				
Implant type	Bone level								
	Tissue level	<b>0.321</b>	<b>0.117</b>	<b>0.881</b>	<b>.027</b>	0.402	0.140	1.150	.089
Connection type	Internal								
	External	1.542	0.723	3.289	.263				
Platform type	Match								
	Switch	1.336	0.632	2.827	.448				
Implant/abutment misfit	No								
	Yes	<b>0.358</b>	<b>0.142</b>	<b>0.904</b>	<b>.030</b>	<b>0.265</b>	<b>0.102</b>	<b>0.685</b>	<b>.006</b>
Supra-structure <sup>b</sup>	Single implant								
	Multiple implants	1.613	0.632	4.116	.317	0.664	0.211	2.087	.483
	Cross-arch restoration	<b>2.789</b>	<b>1.102</b>	<b>7.058</b>	<b>.030</b>	0.776	0.244	2.464	.667
Mesial aspect of the implant <sup>c</sup>	Nothing								
	T/I too close	1.302	0.393	4.318	.666				
	Neighboring T	0.555	0.225	1.368	.201				
	Neighboring I	0.818	0.391	1.712	.594				
Distal aspect of the implant <sup>c</sup>	Nothing								
	T/I too close	0.929	0.292	2.961	.901				
	Neighboring T	0.674	0.237	1.918	.460				
	Neighboring I	0.952	0.443	2.047	.900				

Note: Bold values indicate significance.

Abbreviations: CI, confidence interval; I, implant; OR, odds ratio; T, tooth.

<sup>a</sup>Due to the low number of cases the premolar and molar region was pooled as "posterior" for the regression analysis.

<sup>b</sup>No case with "multiple teeth + implants."

<sup>c</sup>"Nothing" is defined as no neighboring structure within 5 mm; <1.5 mm is the cut-off value for a tooth being too close and <3 mm is the cut-off value for an implant being too close.

loss (i.e., with a total defect extent >6 mm). Class Ic and Ie presented the highest percentage of severe bone loss (i.e., >9 mm total defect extent; in 25% and 20% of the implants, respectively), while the total defect extent of class II defects remained ≤6 mm in about 70% of the implants (Figure 2). Furthermore, implants installed in the lower anterior followed by the upper anterior presented the highest percentage of advanced and severe peri-implant bone loss (i.e., about 60% each of the implants with advanced or severe bone loss were installed in the anterior region; Appendix 2a).

Figure 3 illustrates the frequency distribution of the position of the implants in the alveolar ridge from the buccal and oral aspect. It becomes evident, that implants with circumferential defects (i.e., class Ie) were located more centrally within the alveolar ridge and had almost in 100% of the cases a distance >1 mm to the lateral aspect of the alveolar ridge, while defects with a buccal and/or oral bone dehiscence (i.e., class Ic, class Id, class Id with only 1 wall) were more often located closer to the lateral aspect of the alveolar ridge.

#### 4.4 | Implant characteristics

Implant characteristics of the most prevalent peri-implant bone defect configurations are summarized in Table 4. Overall, the implants presented primarily (i.e., ≥ 85% of the cases) with modified implant surface, were bone level implants, and showed no misfit; furthermore, about 2/3 of the implants had an internal connection and showed platform match. All implants with class Id with only 1 wall defects had modified surface and were bone level type implants, while pure class II defects presented more often at smooth implants (i.e., in 27.3% of the cases). Interestingly, implants with class Id with only one wall defects, when compared to all other bone defect configurations, presented a slightly higher frequency for internal connection, platform switch, and misfit.

Implant characteristics in relation to the total defect extent are displayed in Appendix 2b. Briefly, a somewhat larger variation (i.e., >15%) regarding the distribution of implant type and implant/abutment misfit in the four total defect extent categories was observed; that is, tissue level implants and implants with a misfit presented more often a slight peri-implant bone loss (i.e., 2 to 3 mm).

#### 4.5 | Neighboring structure mesial and distal of the diseased implant

The data regarding the neighboring structure at the mesial and distal aspect of the implants in relation to defect configuration and the total defect extent is presented in Table 5 and Appendix 2c, respectively. Overall, ≥49% of the implants had either mesially or distally no neighboring structure within a distance of 5 mm, while it appeared only seldom that the diseased implant had been placed too close to the neighboring tooth or implant (i.e., only in about 8% to 9% of the cases each for the mesial and distal aspect). Interestingly, implants with class Id with only 1 wall defects presented a higher frequency for a tooth

or implant being too close (i.e., mesial and distal in 26.1% and 17.4% of the cases, respectively) compared to all other bone defect configurations. At the same time, implants with class Id with only one wall defects had less often an implant as neighboring structure within a correct distance; regarding implants with class Ie defects, it was only once that the diseased implant was placed too close to the neighboring structure.

#### 4.6 | Association of peri-implant bone defect configuration and extent to patient-, implant-, and site-related variables

Detailed data on the association between the potential predictors and peri-implant bone defect configuration are presented in Appendices 3a to 3f. However, only few statistically significant results were found by the univariate and multivariate regression analyses. More specifically, the jaw region showed for class Ic and class Ie, and class II defects a significant effect; class Ic defects appeared significantly less often in the upper posterior compared to all other regions and class Ie defects appeared more often in the posterior regions. Otherwise, two already above-described tendencies showed statistical significance in the univariate regression analyses: (a) the implant surface of class Id defects was more often closer to or outside of the lateral aspect of the alveolar ridge (and this effect remained significant in the multivariate model); and (b) implants with class Id with only one wall defects were placed more often too close to the neighboring structure.

Table 6 displays the associations between the potential predictors and total defect extent. In the univariate regression analyses age, jaw region, implant type, implant/abutment misfit, and supra-structure showed significant results. More specifically, a higher age, implants placed in the lower anterior, bone level type implants, lack of a misfit, and implants of a cross-arch restoration showed an increased risk for presenting with more severe peri-implant bone defects (i.e., an increased total defect extent). After combining these significant predictors together with gender ( $P = .079$ ) in a multivariate regression analysis, only jaw region and implant/abutment misfit remained statistically significant.

## 5 | DISCUSSION

The present study based on intra-operatively assessed characteristics of 193 peri-implantitis defects in 100 patients undergoing surgical treatment, showed that (a) most common peri-implantitis defects exhibited a combination of intrabony component and a buccal/oral dehiscence (i.e., class Ic and Id), while purely circumferential defects (i.e., Ie) were relatively seldom; (b) implants with defects with bone dehiscence were placed more frequently closer to the lateral aspect of the alveolar ridge harboring the dehiscence, whereas implants with circumferential defects (i.e., class Ie) were placed more centrally within the alveolar ridge; (c) implants placed in the lower anterior region had the highest risk to show a class Ic configuration and for more severe

peri-implant bone loss (i.e., 14.5- and 3.5-times higher compared to the upper posterior, respectively); and (d) peri-implant bone defects with only a single bone wall appropriate for regenerative procedure were relatively frequent (i.e., 12% of all defects).

When introducing the classification for peri-implant bone defects, Schwarz et al<sup>9</sup> reported circumferential defects (class le) as the most frequent bone defect configuration, occurring in more than half of the cases (i.e., 55%); the remaining defects showed a configuration comprising an intrabony component and a bone dehiscence (i.e., class Ia: 5.5%, Ib: 15%, Ic: 13%, and Id: 10%). Similarly, García-García et al<sup>10</sup> reported that class le was the most frequent configuration among the defects exhibiting an intrabony component (i.e., in 40.5%), while about 33% were class Ic. Both of those reports, however, included a relatively low number of implants (i.e.,  $\leq 40$  implants with intrabony defects).<sup>9,10</sup> In a more recent study<sup>11</sup> including a larger number of implants (i.e., 158 implants in 47 patients), purely circumferential defects (i.e., class le) were observed in only about 8% of the defects with an intrabony component, while the majority of the defects exhibited an intrabony component and a bone dehiscence, similarly to the present study. Specifically, if one considers only those defects herein with an intrabony component that could be classified according to the Schwarz et al<sup>9</sup> as Ia, Ib, Ic, Id, or le—to allow for a direct comparison to the above studies<sup>9,10</sup>—only 16.1% of the cases were class le, while class Ic and Id defects were the most frequent ones (i.e., in 39.5% and 37.1% of the cases, respectively), and class Ia and Ib were the most seldom ones (i.e., in  $< 6\%$  of the cases). Importantly, 36 of the 193 evaluated peri-implant bone defects herein, did not fit in any of the Schwarz et al<sup>9</sup> classes. While some of those “non-classifiable” defects had a quite unique configuration and could not be grouped in a reasonable way as a “new” class, one specific defect type was present more often (i.e., 23-times or in 11.9% of all cases). These defects were related to class Id but were lacking one additional bone wall either mesially or distally (Figure 1E-G); therefore, a new class is suggested: “class Id with only 1 wall” (i.e., Id-m and Id-d, when the mesial or distal bone wall is present, respectively). It appears thus important, for treatment planning or within the context of clinical studies, to have the possibility of a peri-implant bone defect configuration presenting only a single bone wall appropriate for regenerative procedure in mind.

As outlined in the introduction, studies have indicated that peri-implant bone defect configuration and extent influence the outcome of reconstructive therapy of peri-implantitis,<sup>7,17,8,18</sup> although this has not been a consistent observation.<sup>19</sup> This may indicate that other factors, such as the difficulty to achieve effective debridement of the contaminated implant surface in deep circumferential defects can be challenging and thereby potentially limiting the outcome. Furthermore, it has been demonstrated that peri-implantitis lesions with limited to moderate bone loss (i.e., 2 to 4 mm prior to treatment) achieve a better clinical outcome 2 years after surgical therapy compared to implants with more severe bone loss (i.e.,  $\geq 5$  mm).<sup>18</sup> In perspective, presence of sufficient buccal and oral bone wall thickness at the timepoint of implant installation (either pristine bone or after bone augmentation) appears advantageous, not only because it shows reduced bone remodeling over time<sup>20,21</sup> and results in a stable aesthetic

outcome,<sup>22,23</sup> but also in the context of peri-implantitis by increasing the chances for a peri-implant bone defect configuration with more favorable treatment outcomes after reconstructive interventions (i.e., class le).<sup>7,8,17</sup> Since delayed adequate therapeutic intervention most likely results in more advanced/complex peri-implant bone defect configurations and less chances for a good treatment outcome, a timely diagnosis and treatment of peri-implantitis lesions are imperative.

In this context, differences in the frequency distribution of purely circumferential defects and defects with an intrabony component and a bone dehiscence among studies may be explained by differences in the jaw region/anatomy in which the implants were placed and/or by the stage of disease progression. For example Schwarz et al<sup>9</sup> reported primarily on posterior implants (i.e., 77.5% of the included implants in that study where from the premolar or molar region), while in the present study only about 50% of the implants were posterior ones. Indeed, in the present study, le defects were more likely associated with posterior implants compared to anterior ones; implants harboring class le defects also had almost in 100% of the cases a distance  $> 1$  mm to the lateral aspect of the alveolar ridge, while implants with defects with bone dehiscence appeared placed more often closer to or beyond the lateral aspect of the alveolar ridge harboring the dehiscence. Truly, the residual alveolar ridge is wider more posteriorly comparing to more anteriorly, and this usually allows for a more central implant placement—in relation to the bucco-oral width of the ridge—and for sufficient bone wall thickness buccally and orally to the implant after installation. It is reasonable to assume that implants placed in wider/wide ridges are more likely to develop defects with more bone walls at the event of peri-implantitis, compared with implants placed in narrower/narrow ridges. This notion is supported by the results of a recent study, showing that implants harboring “4-wall defects” had a wider bucco-oral width distally and mesially to the implant, compared with implants with “2- and 3-wall” defects.<sup>8</sup> Furthermore, it is also reasonable to assume that implants placed in “narrower/narrow” ridges will present with fewer bone walls at a “later” stage of disease, where the disease has resulted in complete resorption of the bone wall, than at an “earlier” stage of disease. Indeed, horizontal bone loss height and intrabony defect depth herein, ranged from  $2.3 \pm 1.8$  to  $5.9 \pm 2.5$  mm and from  $4.5 \pm 2.4$  to  $6.2 \pm 2.4$  mm, respectively, in the various defect classes, which indicates a rather advanced disease stage at the timepoint of treatment in this specific population. In comparison, the average horizontal bone loss height and intrabony defect depth in the Schwarz et al<sup>9</sup> was  $1.9 \pm 1.3$  and  $2.9 \pm 1.5$  mm, respectively.

It is of interest whether specific patient-, implant-, and/or site-related parameters predispose to a specific peri-implant bone defect configuration and/or a more advanced lesion. Indeed, in a previous study,<sup>11</sup> a significant association between the defect configuration and patient age and between the amount of vertical bone loss and smoking status, type of supra-structure, and proximity to the neighboring structures has been described. Specifically, peri-implant bone defects with intrabony components and a bone dehiscence but without horizontal bone loss were observed more often with higher age,

while heavy smoking, fixed restorations, and implant proximity were significantly associated with a larger total defect extent.<sup>11</sup> Herein, the only predictor that appeared somehow consistently having a relevant effect on both defect configuration and extent was jaw region. Thus, implants placed in the lower anterior region had the highest risk to show a class Ic defect and the highest risk for more severe peri-implant bone loss, for example, 14.5- and 3.5-times higher, respectively compared to the upper posterior. Although the width of keratinized mucosa was not registered in this study, the finding that implants in the lower anterior developed a more complex defect configuration and more severe disease may be, at least partly, also related to the frequent lack of adequate width or total lack of keratinized mucosa - i.e. in addition to the impact of the narrow alveolar ridge, discussed above. It has indeed been shown previously<sup>11</sup> that only a limited number of implants (i.e., <15%) with peri-implantitis lesions in the lower anterior presented  $\geq 2$  mm of keratinized mucosa. Lack of keratinized mucosa has been discussed as risk factor for peri-implant biological complications, because it is associated with plaque accumulation, and it appears more relevant for patients with a low compliance.<sup>13-16</sup>

Surprisingly, presence of an implant/abutment misfit was associated herein with a reduced total defect extent. It can only be hypothesized that although the presence of a misfit may initiate a biological complication and result in some extent of peri-implant marginal bone loss, once a certain distance between the prosthetic gap and the marginal bone has been established, the misfit per se does not necessarily further drive disease progression, and other factors are probably more important. Indeed, a relatively recent review<sup>24</sup> concluded that the notion that prosthetic misfit leads to a higher rate of biological complications cannot be confirmed due to currently scarce information on this topic.

In perspective, this is a retrospective study with inherent limitations, which in turn may have compromised parts of the analysis. For example, despite that this study included 193 implants—the largest sample reported upon until now on this topic—some of the groups presented relatively small numbers; for example, implants with a machined surface or tissue level type implants were <15% of the total sample. Thus, lack of significance of tissue level implants to present a reduced risk for more severe peri-implant bone defects may, at least partly, be due to the low sample size of this type of implants. Furthermore, the peri-apical radiographs used herein for measuring the distance to the neighboring structures have not been taken under standardized conditions. Thus, classes of distances between the implant and the neighboring structures were used instead of the actual distance to minimize the effect of a measurement error due to non-standardized radiographs. Lastly, the majority of included implants has been placed elsewhere and there was no information on aspects related to the surgical procedure, for example, implant installation in connection with bone augmentation, type of augmentation material, immediate implant installation, implant misplacement, overheating during implant site preparation, overcompression of the (thick) cortical crestal bone, and so forth, which have been suggested to

possibly affect the incidence and/or progression of peri-implantitis.<sup>25</sup> Therefore, no assessment of an association of these factors with defect configuration and extent was possible herein.

In conclusion, based on the current analysis, implants with peri-implantitis exhibited a combination of intrabony and buccal/oral dehiscence defects rather than purely circumferential defects, in contrast to what reported previously. Furthermore, implants placed closer to the lateral aspect of the alveolar ridge developed frequently bone dehiscences, and implants placed in the lower anterior region had the highest risk for more severe peri-implant bone loss. Finally, the possibility of having a peri-implant bone defect configuration presenting only a single bone wall appropriate for regenerative procedure should be considered.

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## CONFLICT OF INTEREST

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## DATA AVAILABILITY STATEMENT

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

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#### SUPPORTING INFORMATION

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

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