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Hard tissue dimensional changes following implant removal due to peri-implantitis: A retrospective study

Ramón Pons DDS, MS[1] | **Miguel Carreño DDS, MS[1]** | **Ettore Amerio DDS, MS[1]** | **Jordi Gargallo-Albiol DDS, MS, PhD[2,3]** | **José Nart DDS, MS, PhD[1]** | **Alberto Monje DDS, MS, PhD[1,3]**

[1]Department of Periodontology, Universitat Internacional de Catalunya, Barcelona, Spain

[2]Department of Oral and Maxillofacial Surgery, Universitat Internacional de Catalunya, Barcelona, Spain

[3]Department of Periodontology, School of Dental Medicine, University of Michigan, Ann Arbor, Michigan, USA

Correspondence
Alberto Monje, Department of Periodontics, Universitat Internacional de Catalunya, C/Josep Trueta s/n, 08195 - Sant Cugat del Valles, Barcelona, Spain.
Email: amonjec@umich.edu

Abstract

Background: The current evidence regarding the alterations experienced by the alveolar ridge (hard tissue changes) after implant removal due to peri-implantitis is limited.

Purpose: To assess the hard tissue dimensional changes following implant removal due to peri-implantitis.

Material and methods: Clinical records were examined to identify patients with implants that had to be removed due to a hopeless prognosis secondary to peri-implantitis due to expendability of peri-implantitis implants for functional reasons. Patients with preoperative and postoperative cone-beam computed tomography (CBCT) scans were included. Patient-related, implant-related, and surgery-related factors were assessed based on the clinical records. Linear measurements were made to evaluate the influence of bone plate thickness (BPT), ridge width (RW), and ridge height (RH) at various levels upon the outcome of implant removal. A descriptive statistical analysis of the quantitative and qualitative variables was performed. Correlations of the variables with the primary outcome (dimensional changes) were tested using univariate and multivariate analyses (multinomial random intercept mixed model linear regressions).

Results: A total of 26 patients ($n_{implants} = 79$) met the eligibility criteria. The mean decrease in RW at 1 and 3 mm below the crest was 11.3% and 4.4%, respectively ($P < 0.001$). Buccal and lingual RH was significantly reduced by 2.2% and 6.3%, respectively ($P < 0.001$). Few patient-related, implant-related, and surgery-related factors appeared to have an impact upon the hard tissue dimensional changes. Bone regeneration simultaneous to implant removal minimized the dimensional changes of the ridge both vertically (5% lesser buccal RH reduction) and horizontally (12% lesser RW reduction) when compared with spontaneous healing. The use of a reverse-torque removal kit seemed to be critical in limiting the dimensional changes of the ridge.

Conclusions: Minimal hard tissue changes can be expected following implant removal due to peri-implantitis. Simultaneous bone regeneration procedures and the use of a removal kit may considerably reduce the impact upon the dimensional changes (NCT04534361).

KEYWORDS
alveolar bone, dental implants, peri-implant disease, peri-implantitis

1 | INTRODUCTION

Although the long-term survival rate of dental implants has been shown to be satisfactory,[1-4] peri-implant disorders are a major concern given their nonlinear, accelerating pattern of progression.[5] Once the peri-implantitis lesion becomes established, there is no precise cut-off point regarding the amount of bone loss defining implant failure.[6] Different authors have concluded that when bone loss reaches or exceeds 50% of the total length of the implant, the treatment of choice would be implant removal, in view of the hopeless prognosis.[7,8] Accordingly, other therapeutic options must be proposed for these patients in order to restore chewing function and aesthetics.[7,9,10]

Bone remodeling, as well as the clinical sequelae occurring at the alveolar ridge after tooth extraction, have been extensively described in the literature.[11-17]A major contributing factor in vertical remodeling has been shown to be bundle bone—a tooth-dependent tissue.[14,15] Following tooth extraction, bundle bone loses its function, is gradually remodeled, and the socket becomes filled with immature woven bone. Consequently, a reduction in ridge height is observed, being more pronounced in the buccal (mainly occupied by bundle bone) than in the lingual wall.[15] Likewise, early clinical and preclinical studies have reported that about 50% of the alveolar ridge width is reduced during the first year following tooth extraction, with two-thirds of this reduction occurring within the first 3 months.[18-20]

In contrast, current evidence regarding the alterations experienced by the alveolar ridge after implant removal due to peri-implantitis is limited, and little is known of how the absence of bundle bone can influence the dimensional changes produced in the ridge. Recently, a cross-sectional study has described the clinical sequelae and patient perception following implant removal.[21] However, the hard tissue dimensional changes after implant removal remain unclear. The present study was therefore carried out to assess the hard tissue dimensional changes following implant removal due to peri-implantitis, using cone-beam computed tomography (CBCT), and an evaluation was moreover made of the operator-related, patient-related, and surgery-related factors that may influence alveolar bone changes.

What is known:

- The clinical sequelae and patient perception following implant removal has been recently described.
- However, the current evidence regarding the alterations experienced by the alveolar ridge after implant removal due to peri-implantitis is limited.

What this study adds:

- The present retrospective CBCT study sheds light on the dimensional changes occurring as a consequence of dental implant removal due to peri-implantitis.
- The degree of alveolar bone reduction is associated to certain patient-related, implant-related, and surgery-related factors.

2 | MATERIAL AND METHODS

The protocol of this retrospective study was approved by the Ethics Committee of the University of Extremadura (Badajoz, Spain; Ref. SES-CEI-120820), and followed the Declaration of Helsinki on human studies. Each patient was informed about the details of the study and signed an informed consent before data extraction was performed. In addition, the study was reported following the checklist items in accordance with the STROBE statement and was registered and approved by www.clinicaltrials.gov (NCT04534361).

2.1 | Study population

Patient recruitment was from a private practice exclusively dedicated to periodontics and implantology (Clinica CICOM, Badajoz, Spain). Completely and partially edentulous patients previously subjected to implant removal due to severe peri-implantitis (implants with >50% of bone loss, bleeding on probing, and/or suppuration) or due to expendability of peri-implantitis implants for functional reasons and seeking to have the lost implant replaced, were consecutively included in the study.

2.2 | Eligibility criteria

A prerequisite for being eligible for the study was to have a CBCT scan taken before and after implant removal: the first scan as a diagnostic tool in the diagnosis of peri-implantitis (severity, morphology, and type of peri-implant defect) and the second scan (≥3 months following implant removal) for treatment planning to restore function. Patients aged 18–80 years who had lost implants at least 36 months following final prosthesis delivery were included. Subjects were excluded from the study if they presented the following conditions: pregnancy or breastfeeding, zygomatic or pterygoid implants, use of drugs known to modify bone metabolism, uncontrolled systemic diseases (e.g., diabetes mellitus), and uncontrolled or active periodontal disease requiring treatment.

2.3 | Peri-implantitis case definition

The peri-implantitis case definition was based on the consensus report of Workgroup 4 of the 2017 World Workshop on the Classification of Periodontal and Peri-implant Diseases and Conditions.[10] In the absence of baseline information, the diagnosis of peri-implantitis required the presence of bleeding and/or suppuration on gentle probing, a probing depth of ≥6 mm, and a bone level of ≥3 mm apical to the most coronal portion of the implant or at the rough–smooth interface in transmucosal implants.

2.4 | Patient-related, implant-related, and surgery-related variables

- Patient-related variables: Age, gender, type of edentulism (complete/partial), severity of periodontal disease (mild, moderate or severe), smoking (heavy smoker >10 cigarettes/day [HS], light smoker <10 cigarettes/day [LS], former smoker 0 cigarettes/day [FS], or non-smoker [NS]), number of implants per patient, and site-specific keratinized mucosa (0, <2, or ≥2 mm, as assessed clinically by an experienced periodontist [AM]).
- Implant-related variables: Implant position (mandible/maxilla/anterior/posterior), implant system (brand, diameter, length, and type of connection), implant macrodesign (transmucosal/bone level), and type of prosthesis (single/multiple, screw/cement-retained).
- Surgery-related variables: Implant removal method (trephine[1], forceps[2], or implant removal kit[3]—as a first option and whenever possible) and the application or not of bone regeneration interventions (performed in those cases in which the presence of anatomical structures such as maxillary sinus or dental nerve could limit the implant placement at a later stage), as well as the material used for regeneration.

2.5 | Radiographic assessment

Images from patients included in the study were acquired using a CBCT i-CAT Model 17-19 system (Imaging Sciences International LLC, Hatfield, Pennsylvania) by an experienced radiologist (VC). The imaging parameters were set at a width and depth of 16 × 13 mm, 120 kVp, 20.27 mAs, with a scan time of 14.7 s, resolution 0.25 voxel, and a field of view (FOV) that varied based on the scanned region. Files were exported in DICOM format and entered in the OnDemand3D application (Cybermed, Seoul, South Korea) for superimposition analysis, using the Fusion module, previously validated in another study.[22]

Two reference lines were established for the radiological analysis: the longitudinal axis of the implant and a line perpendicular to this axis and tangential to a reference point (sinus floor in the maxilla and mandibular base in the mandible; Figure 1).

The following parameters were assessed before and after implant removal:

- First bone-to-implant contact (BIC) assessed at four sites (mesial, distal, buccal, and lingual) and defined as the first contact between the bone and the implant surface, assessed from the most coronal part of the intraosseous component of the implant (Figure 1(A)).
- Ridge height (RH) in mm, defined as the distance between the tangential reference line and the most coronal point of the bone crest, assessed buccal (B-RH) and lingual (L-RH) (Figure 1(B)).
- Bone plate thickness (BPT) in mm, assessed at 1, 3, 5, and 7 mm below the crest and measured buccal and lingual. Bone thickness was recorded at these four levels using the previously mentioned reference line (Figure 1(C)).
- Ridge width (RW) in mm, recorded at 1, 3, 5, and 7 mm from the bone crest. In the event of discrepancy between the buccal and lingual bone crests, the most apical one was chosen as reference. In order to evaluate BPT and RW at the same point before and after implant removal, baseline RH was extrapolated onto the post-implant removal CBCT scan (Figure 1(D)).

Additionally, characterization of the peri-implant defect (morphology and severity) was made based on a previous classification.[23]

These assessments were made by a previously calibrated examiner (MC). For calibration, 10% of the total sample of implants was randomly selected from patients not included in the study, and measurements as well as defect configuration were assessed spaced 24 h apart. The examiner yielded an intra-class correlation coefficient (ICC) of >0.85.

2.6 | Statistical analysis

The SPSS version 26.0 statistical package (IBM Corp., Armonk, New York) was used for the statistical analysis. Primary outcome was defined as horizontal and vertical dimensional changes of the alveolar crest. Secondary outcomes included BIC, BPT, patient-related, implant-related, and surgery-related variables. Descriptive statistical analyses were made for both quantitative (mean, standard deviation [SD]) and qualitative variables (absolute and relative frequencies). The Shapiro–Wilk test was used to assess normal data distribution, and parametric (Student *t*-test) and nonparametric tests (Mann–Whitney *U*-test, Wilcoxon test) were used as applicable.

Possible relationships between dimensional changes (dependent variables) and patient-related, implant-related, and surgery-related variables were tested using univariate multinomial random intercept mixed model linear regression analyses (patients and implant level [lower level]). The variables that showed $P < 0.10$ were entered in the subsequent analysis. The multivariate analysis consisted of backward stepwise multinomial random intercept mixed model linear regression analyses, and only variables showing $P < 0.05$ were retained in the final model. The Akaike information criterion and Bayesian information criterion were used to compare the multivariate models. The level of significance set in the analyses was 5% (alpha = 0.05).

3 | RESULTS

3.1 | Demographic data

Of the 31 patients ($n_{implants} = 100$) initially considered for the study, 26 subjects ($n_{implants}=79$) were found to be eligible. The main reason for exclusion was the lack of a CBCT scan following implant removal. The final sample comprised 21 females and 5 males, with a mean age

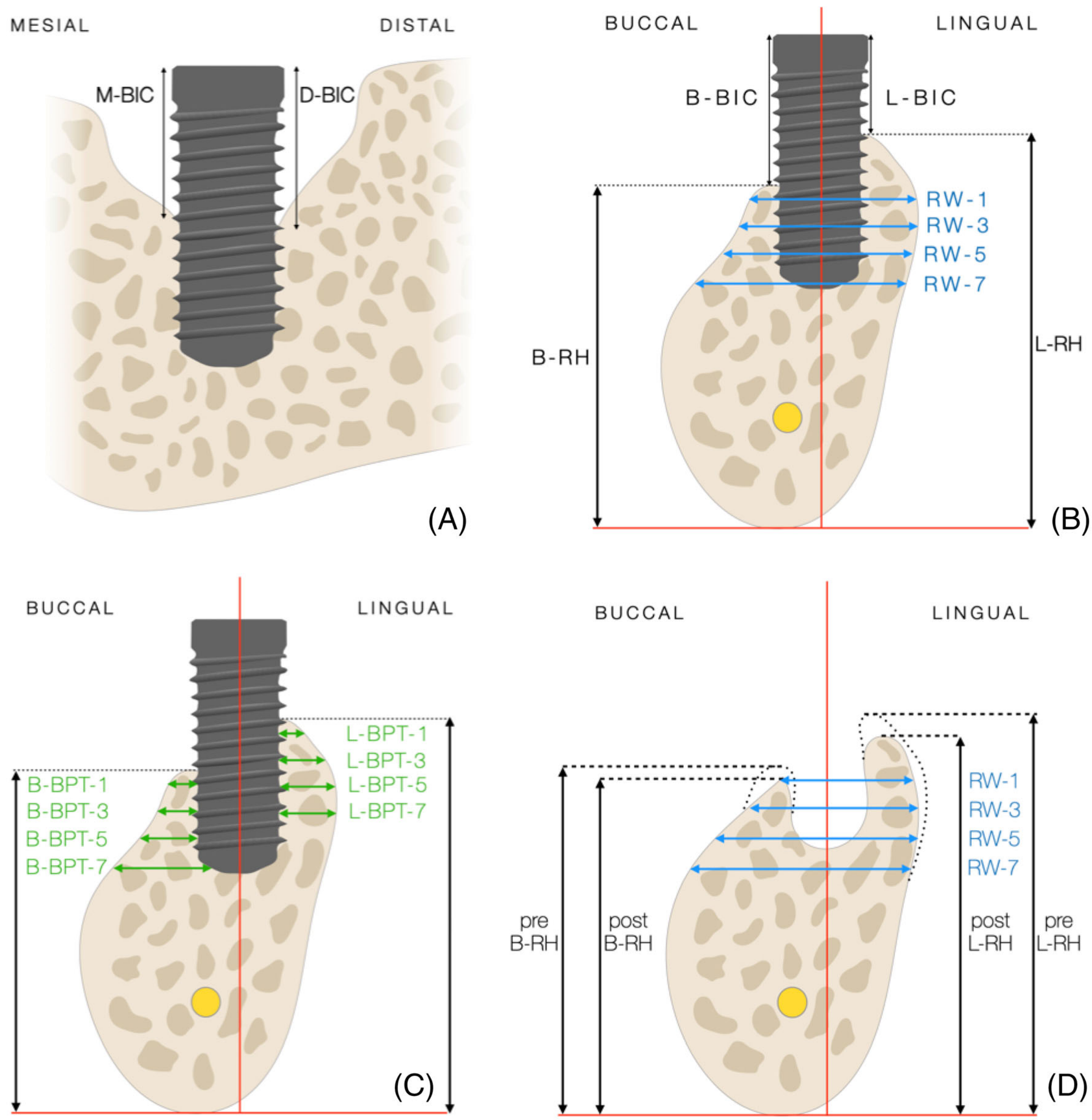

FIGURE 1 Baseline (A–C) and post-implant removal measurements after healing (D). RW-1 (ridge width at 1 mm), RW-3 (at 3 mm), RW-5 (at 5 mm), and RW-7 (at 7 mm) represent baseline measurements performed at different levels from the bone crest. Similarly, buccal (B-BPT) and lingual bone plate thickness (L-BPT) was also measured at 1, 3, 5, and 7 mm from the bone crest. In the vertical dimension, the most coronal aspect of the buccal and lingual bone crests was measured in relation to the reference line (B-RH and L-RH)

of 61.1 ± 8.8 years. One-half of the subjects had a history of severe periodontitis, 10 patients (38%) were non-smokers, 8 patients (31%) were former smokers, 3 patients (12%) were light-smokers, and 5 (19%) were heavy smokers. Each patient contributed with a variable number of implants, ranging from 1 to 14. The majority of them were placed in the posterior maxilla (45.6%). According to the time in function, 54.4% of the implants were loaded more than 10 years before implant removal. The rest of the demographic characteristics of the study sample are summarized in Table 1.

A total of 60.8% of the implants were removed using the implant removal kit, 34.2% using forceps, and 5% using a trephine. At 65.8% of the implant sites, no regeneration material was applied, while the combination of an allograft with a resorbable membrane was used in 11.4% of the implants. In 61% of the removed implant sites, new implants were placed to restore oral function and/or esthetics. Simultaneous bone regeneration at the time of implant removal prevented from future augmentation procedures in 92.4% of the sites where new implants were placed.

With regard to peri-implant defect morphology, the most frequently found defects were type IIIb (36.7%) and Ib defects (24.1%). In relation to peri-implant defect severity, 97.5% were classified as severe (>6 mm or >50% of the implant length).

3.2 | Ridge width and height changes

Representative CBCTs are presented in Figure 2, either applying simultaneous bone regeneration or spontaneous healing after implant

TABLE 1 Descriptive statistic at patient and implant level regarding patient-related, implant-related, and intervention-related factors

	Patient level (n = 26)		Implant level (n = 79)			Implant level (n = 79)			Patient level (n = 26)		Implant level (n = 79)	
Patient-related factors					Implant-related factors			Surgery-related factors				
	Mean	*SD*	*Mean*	*SD*		*Mean*	*SD*		*Mean*	*SD*	*Mean*	*SD*
Age	61.5	8.78	57.11	11.92	Diameter	3.83	0.52	Months between implant removal and re-evaluation	–	–	5.68	2.98
	n	%	*n*	%	Length	11.42	2.25		*n*	%	*n*	%
Gender								Implant removal method				
Female	21	81%	72	91.1%		*n*	%	Implant removal kit	18	69%	48	60.8%
Male	5	19%	7	8.9%	Implant position			Trephine	3	12%	4	5%
					Posterior maxilla	36	45.6%	Forceps	8	31%	27	34.2%
Type of edentulism					Posterior mandible	21	26.6%					
Partial	21	81%	69	87.3%	Anterior maxilla	13	16.4%					
Total	5	19%	10	12.7%	Anterior mandible	9	11.4%	Regeneration material				
								No regeneration	15	58%	52	65.8%
Periodontal disease severity					Keratinized mucosa[a]			PRGF + xenograft	1	4%	1	1.3%
Mild	2	8%	4	5.1%	No KM	24	30.4%	Xenograft + autologous bone	1	4%	2	2.5%
Moderate	11	42%	35	44.3%	KM <2 mm	19	24.1%	Allograft + autologous bone	1	4%	4	5.1%
Severe	13	50%	40	50.6%	KM ≥×2mm	22	27.8%	Xenograft-collagen	1	4%	2	2.5%
								Allograft + resorbable membrane	6	23%	9	11.4%
Smoking					Time in function			Xenograft + resorbable membrane	2	8%	4	5.1%
Non-smoker	10	38%	33	41.8%	<5 year	24	30.4%	Xenograft-collagen + autologous bone	2	8%	3	3.8%
Former smoker	8	31%	31	39.2%	5–10 year	12	15.2%	PRP	1	4%	2	2.5%
Light smoker	3	12%	6	7.6%	>10 year	43	54.4%					
Heavy smoker	5	19%	9	11.4%				Type of defect				
					Bone augmentation at implant placement[b]			Ia	2	8%	2	2.5%
					No	23	29.1%	Ib	12	46%	19	24.1%
					Yes	27	34.2%	Ic	3	12%	5	6.3%
								II	5	19%	9	11.4%
					Implant brand			IIIa	3	12%	3	3.8%
					Nobel Biocare	46	58.2%	IIIb	14	54%	29	36.7%
					NGC	8	10.1%	IIIc	7	27%	12	15.2%
					Machined Brånemark system	2	2.6%					
					AstraTech implant system	6	7.6%	Severity of the defect				

TABLE 1 (Continued)

	Patient level ($n = 26$)		Implant level ($n = 79$)			Implant level ($n = 79$)			Patient level ($n = 26$)		Implant level ($n = 79$)	
					Straumann dental implant system	3	3.8%	Slight				
					Dentium implant system	14	17.7%	Moderate	2	7.7%	2	2.5%
								Advanced	24	92.3%	77	97.5%
					Connection							
					Internal	21	26.6%					
					External	58	73.4%					
					Implant design							
					Tissue level	14	17.7%					
					Bone level	65	82.3%					
					Type of prosthesis Single/multiple							
					Single	8	10.1%					
					Multiple	71	89.9%					
					Type of prosthesis screw-retained/ cemented							
					Cemented	25	31.6%					
					Screw-retained	54	68.4%					

[a]Data available for 25 patients and 65 implants.
[b]Data available for 20 patients and 50 implants.

removal. The ridge width changes (RWC) were characterized by a significant decrease in the distance between the buccal and lingual plate at 1 and 3 mm. In this regard, the mean RW reduction at 1 and 3 mm was 11.3% ($P < 0.001$) and 4.4% ($P < 0.001$), respectively. This reduction was also observed—though to a lesser extent—at 5 (2.5%, $P = 0.11$) and 7 mm (2.1%, $P = 0.137$) from the bone crest (Table 2). However, when sites subjected to regeneration were excluded, the observed changes were even greater (Table 3).

Similarly, the height of the alveolar crest also showed substantial variations after implant removal. Height reduction was more evident in the lingual (6.3%, $P < 0.001$) than in the buccal aspect (2.2%, $P = 0.005$).

3.3 | Relationship between patient-related, implant-related, and surgery-related factors and hard tissue changes

3.3.1 | Patient-related factors

The univariate analysis showed the type of edentulism, gender, age, smoking status and history of periodontitis to exert an influence upon RWC at 1 and 3 mm. For ridge height changes (RHC), time in function was detected as a possible influencing factor. However, the multivariate analysis only confirmed that female gender (1.06, $P < 0.001$) and light smoking (0.61, $P = 0.003$) were associated with increased RWC at 1 and 3 mm, respectively. In turn, implants in function for less than 5 years showed significantly less reduction in B-RH (0.97, $P < 0.001$) and L-RH (0.77, $P = 0.001$) (Table 4).

3.3.2 | Implant-related factors

Implant position, implant system and macrodesign appeared to influence RWC and RHC. For RHC, buccal BPT at 1 and 5 mm negatively influenced the magnitude of the decrease in B-RH.

According to the multivariate analysis, implants placed in the anterior mandibular region were significantly associated to reduced RWC at 1 mm (1.44, $P < 0.001$), and to decreased B-RH (0.97, $P < 0.001$) and L-RH (0.48, $P = 0.007$). On the other hand, greater RWC at 3 mm were observed when implants were placed in the posterior maxilla (-0.88, $P = 0.001$).

The association between certain implant systems and macro designs with a greater horizontal bone remodeling and vertical reduction of the lingual crest is depicted in Table 4.

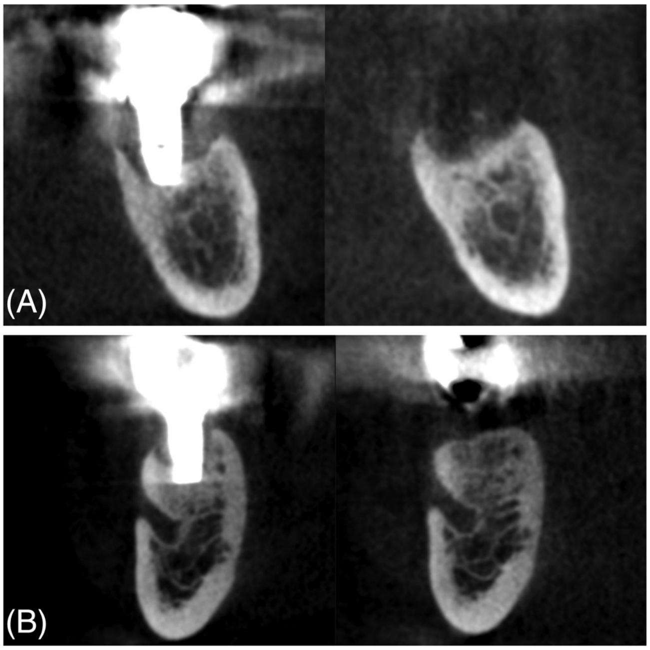

FIGURE 2 Representative CBCT of two different cases: (A) Implant with peri-implantitis in which no regeneration was performed. (B) Implant with peri-implantitis where simultaneous regenerative procedures were applied

3.3.3 | Surgery-related factors

Based on the univariate analysis, the longer the time elapsed between the two CBCT scans, the increased RWC and RHC. Furthermore, both the univariate and the multivariate analyses showed that the use of the implant removal kit prevented L-RH reduction (0.87, $P = 0.002$) compared with other methods.

Regarding the surgical procedure applied at the time of implant removal, the univariate and multivariate analyses showed bone regeneration to be associated with reduced RWC at 1 mm and B-RHC.

As seen in Figure 3 and Table 3, the use of regenerative procedures had a positive effect in preserving the alveolar ridge dimensions. Significantly lesser RWC at 1 mm (3% regeneration vs 15% no regeneration, $P = 0.01$) was observed. In addition, significantly lesser B-RH reduction was detected (3% regeneration vs 8% no regeneration, $P = 0.03$). Besides that, two outliers were identified in different implants but sharing similar characteristics: both were removed by means of implant removal kit and spontaneous healing occurred without additional regenerative procedures (Figure 3).

4 | DISCUSSION

4.1 | Principal findings

The present retrospective CBCT study sheds light on the dimensional changes occurring as a consequence of dental implant removal due to peri-implantitis. We found that minimal hard tissue changes occur associated to remodeling after implant removal. Likewise, it was noticed that the degree of alveolar bone reduction is associated to certain patient-related, implant-related, and surgery-related factors. All this information is of relevance for anticipating hard tissue changes at the sites of implants removed due to peri-implantitis, in particular in those cases where staged implant placement is part of the treatment plan to restore oral function and aesthetics.

4.2 | Agreements and disagreements with previous studies

The dimensional changes that occur at the peri-implant defect following implant removal share a number of similarities with the changes that occur in the post-extraction alveolus. In our study, there was a significant reduction in B-RH (5%) and L-RH (8%). This is consistent with previous observations in post-extraction sockets of natural teeth. In a randomized controlled trial, Jung and colleagues compared different ridge preservation techniques versus spontaneous healing in 40 patients. At 6 months, the buccal and lingual plates were reduced by 5.5% and 10.2%, respectively.[24] In the present study, although the reduction in RH around implants was relatively similar to the observed around natural teeth, it seems to be more contained.

RW also showed significant changes at 1 and 3 mm below the crest, with the observation of a bone reduction of 15% and 6%, respectively. This finding differs widely from the horizontal changes seen at post-extraction sockets. The previous study showed the corresponding values to be 3.3 and 1.7 mm, representing a reduction of 43% and 21%, respectively. These observations were further confirmed in a systematic review and meta-analysis based on 20 studies, in which the amount of horizontal bone reduction was 3.79 ± 0.23 mm and 1.24 ± 0.11 mm in the vertical dimension.[25] In other words, the percentage reduction in vertical dimension ranged between 11% and 22% at 6 months, and the percentage reduction in horizontal dimension ranged between 29% and 63%. These marked differences between the results of our study and those of other investigations at horizontal level may possibly be explained by the influence of bundle bone upon the resorption process taking place around teeth.[14] Another possible explanation for this phenomenon could be the reduced vascular supply around implants as these are devoid of periodontal ligament.[26] In addition, in most of the cases the buccal bone plate was severely damaged or almost missing due to advanced peri-implantitis as opposed to the lingual plate. Therefore, it can be hypothesized that when performing implant removal, the lingual aspect was subjected to more trauma compared with the buccal counterpart that might result in an increased RH reduction.

Due to the hard tissue dimensional changes that occur in the alveolus following tooth extraction, numerous investigations have focused on how to counteract such bone resorption by seeking to minimize it as much as possible. In this regard, a wide variety of alveolar ridge preservation procedures have been described over the last decades, such as socket grafting alone using biomaterials[27]; socket grafting with interpositioning of a barrier membrane[28]; or a

TABLE 2 Horizontal and vertical changes of peri-implant defects, before and after implant removal based on CBCT measurements, expressed in mm and %

		Pre-implant removal (T0)				Post-implant removal (T1)				Ridge changes					
	N	Mean (mm)	*SD*	Min	Max	Mean (mm)	*SD*	Min	Max	Δ (mm)	*SD*	Δ %	*SD*	*P*-value	Test
RW															
1 mm	70	9.18	2.66	4.70	14.30	8.24	3.16	0.00	14.00	−0.95	1.70	−11.30%	21.05%	**<0.001**	Wilcoxon
3 mm	64	10.22	2.88	5.00	16.10	9.78	2.96	4.20	15.80	−0.44	0.94	−4.45%	10.11%	**<0.001**	*T*-test
5 mm	53	10.90	3.50	5.40	22.10	10.59	3.39	4.90	21.30	−0.31	1.41	−2.57%	9.01%	0.11	Wilcoxon
7 mm	33	11.05	3.28	6.00	20.60	10.81	3.34	5.90	20.10	−0.24	0.91	−2.12%	8.22%	0.137	*T*-test
B-RH	79	11.56	5.77	2.30	26.60	11.35	5.74	1.90	25.00	−0.21	0.92	−2.19%	12.43%	**0.005**	Wilcoxon
L-RH	79	14.01	5.90	1.90	28.50	13.26	5.93	1.50	26.40	−0.75	1.13	−6.27%	10.89%	**<0.001**	*T*-test

Abbreviations: Δ, mean change; B-RH, buccal ridge height; L-RH, lingual ridge height; RW, ridge width; *SD*, standard deviation.

Note: The *P* values in **bold** mean $P < 0.05$.

combination of techniques.[29] A recent systematic review based on 22 articles concluded that alveolar ridge preservation procedures involving socket grafting, when compared with unassisted socket healing, significantly prevent bone resorption in the horizontal (mean difference 1.99 mm), vertical mid-buccal (mean difference 1.72 mm), and vertical mid-lingual dimension (mean difference 1.16 mm).[30]

As demonstrated at extracted teeth sites, when performing regenerative procedures simultaneous to implant removal, a significant decrease in the dimensional changes was yielded. In this study, it was hypothesized that initial buccal bone thickness could have an influence upon final bone loss after implant removal comparing spontaneous healing and simultaneous bone regeneration. In this respect, a recent randomized clinical trial on alveolar ridge preservation procedures found a threshold buccal bone thickness of 1 mm (spontaneous healing group) and 0.6 mm (alveolar ridge preservation group) associated to a maximum bone volume loss of 10%.[31] However, our study failed to demonstrate such finding at implant sites, probably due to the severity of bone loss observed in the peri-implant defects.

Furthermore, the present study showed that filling the peri-implant defect resulted in a 5-fold decrease in the magnitude of RWC at 1 mm (3% vs 15%) and 3 mm (1% vs 6%), when compared with spontaneous healing. In the vertical dimension, bone regeneration was associated to reduced RHC (3% vs 8%). Similar findings were obtained in a randomized controlled trial conducted by Jung and colleagues, in which RW was reduced by around 17% when applying demineralized bovine bone mineral into the socket, compared with 43% in the control group. In the vertical dimension, significantly less reduction of the lingual plate was observed (2.6% vs 10%).[24] Regarding surgery, it should be underscored that great caution is required when the implant is removed, since the buccal or lingual plate could be damaged, given the uneven bone-to-implant contact. Different implant removal systems have been analyzed in the literature in terms of the amount of remaining bone and defect morphology or severity.[32] Interestingly, this study demonstrated that the use of an implant removal kit able to generate a controlled reverse torque could benefit the preservation of the lingual plate—this being in accordance with a recent systematic review in which reverse torque seemed to be the most conservative procedure.[33] This might be useful in those cases in need of future implant placement where minimal dimensional changes are desired.

4.3 | Reliability of cone-beam computed tomography in assessing hard tissue dimensional changes

The use of three-dimensional CBCT facilitates imaging of all implant sides, avoiding two-dimensional overlap[34] and providing bone images at lesser cost and with less patient radiation exposure when compared with conventional computed tomography. Hence, the use of CBCT imaging to evaluate peri-implant bone defects[35,36] as well as bone wall configuration or morphology has been described in a number of studies.[23,37,38]

On the other hand, the accuracy of CBCT may be impaired by artifacts caused by the metal components of the implant-supported prosthesis or even by the metal of the implant itself—leading to

TABLE 3 Dimensional changes in ridge height and width according to the use or not of simultaneous bone regeneration

	No regeneration (NR)						Regeneration (R)							
	N	Mean (mm)	*SD*	Min	Max	Mean change %	*N*	Mean (mm)	*SD*	Min	Max	Mean change %	*P*-value	Test
RW														
1 mm	47	−1.22	1.8	−10.3	0.3	−15%	23	−0.40	1.4	−4.7	2.4	−3%	**0.012**	Mann–Whitney *U*-test
3 mm	43	−0.56	1	−4.9	0.8	−6%	21	−0.58	0.8	−2.5	1.7	1%	0.078	Mann–Whitney *U*-test
5 mm	35	−0.18	0.5	−1.5	1	−2%	18	−0.56	2.3	−9.3	1.3	−3%	0.829	Mann–Whitney *U*-test
7 mm	27	−0.26	0.8	−3	1.6	3%	6	−0.15	1.3	−2.2	1.6	0%	0.874	Mann–Whitney *U*-test
B-RH	52	−0.45	0.8	−2.1	1.8	−5%	27	0.24	1.1	−1.3	3.1	3%	0.118	T-test
L-RH	52	−0.89	1.1	−5.1	0.8	−8%	27	−0.47	1.2	−3.2	1.6	−3%	**0.038**	T-test

Abbreviations: B-RH, buccal ridge height; L-RH, lingual ridge height; RW, ridge width; *SD*, standard deviation.
Note: The *P* values in **bold** mean $P < 0.05$.

TABLE 4 Multivariate analysis for dimensional-changes-related factors

Predictors of horizontal change at 1 mm (*N* = 24 subjects/70 implants)	**Coefficient**	***P*-value**
Gender (male = 0; female = 1)	1.064	<0.001
Implant position (anterior mandibular = 1 vs all = 0)	1.446	<0.001
Brand (NGC = 1 vs all = 0)	0.499	0.027
Implant removal method (trephine = 1 vs all = 0)	0.984	<0.001
Regeneration (Yes = 1 vs No = 0)	0.792	<0.001
Intercept	−1.578	<0.001
Predictors of horizontal change at 3 mm (*N* = 24 subjects/64 implants)		
Implant position (posterior maxilla = 1 vs all = 0)	−0.881	0.001
Smoking (LS vs NS)	0.614	0.003
Brand (NGC = 1 vs all = 0)	0.741	0.000
Implant removal method (Forceps = 1 vs all = 0)	0.799	0.002
Intercept	−0.371	0.006
Predictors of vertical change at the buccal plate (*N* = 26 subjects/79 implants)		
Implant position (anterior mandibular = 1 vs all = 0)	0.967	<0.001
Loading time (5–10 year vs <5 year)	−0.97	<0.001
Regeneration (Yes = 1 vs No = 0)	0.797	<0.001
Intercept	−0.204	0.389
Predictors of vertical change at the lingual plate (*N* = 26 subjects/79 implants)		
Implant position (anterior mandibular = 1 vs all = 0)	0.482	0.007
Loading time (>10 years vs <5 years)	−0.773	0.001
Brand (Straumann Dental Implant System = 1 vs all = 0)	−1.286	<0.001
Brand (Machined Brånemark System = 1 vs all = 0)	1.824	<0.001
Implant removal method (Implant removal kit = 1 vs. all = 0)	0.876	0.002
Intercept	−0.851	<0.001

radiolucent shadow effects surrounding the implants[39] and therefore jeopardizing image quality.[40] Additionally, it has been suggested that the dimension of bone structures measuring less than 1 mm might be underestimated when using CBCT,[36] due to the fact that an accuracy of greater than 0.5 mm cannot be expected.[38] More recently, Domic and colleagues concluded that detection of the buccal bone level around implants is largely inaccurate in cases where the buccal bone is ≤1 mm thick.[41]

Nevertheless, CBCT as a radiographic technique allows examination of the bone structures from a three-dimensional perspective in those cases in which the prognosis of the implant is hopeless, and hence in those cases where further treatment is needed.

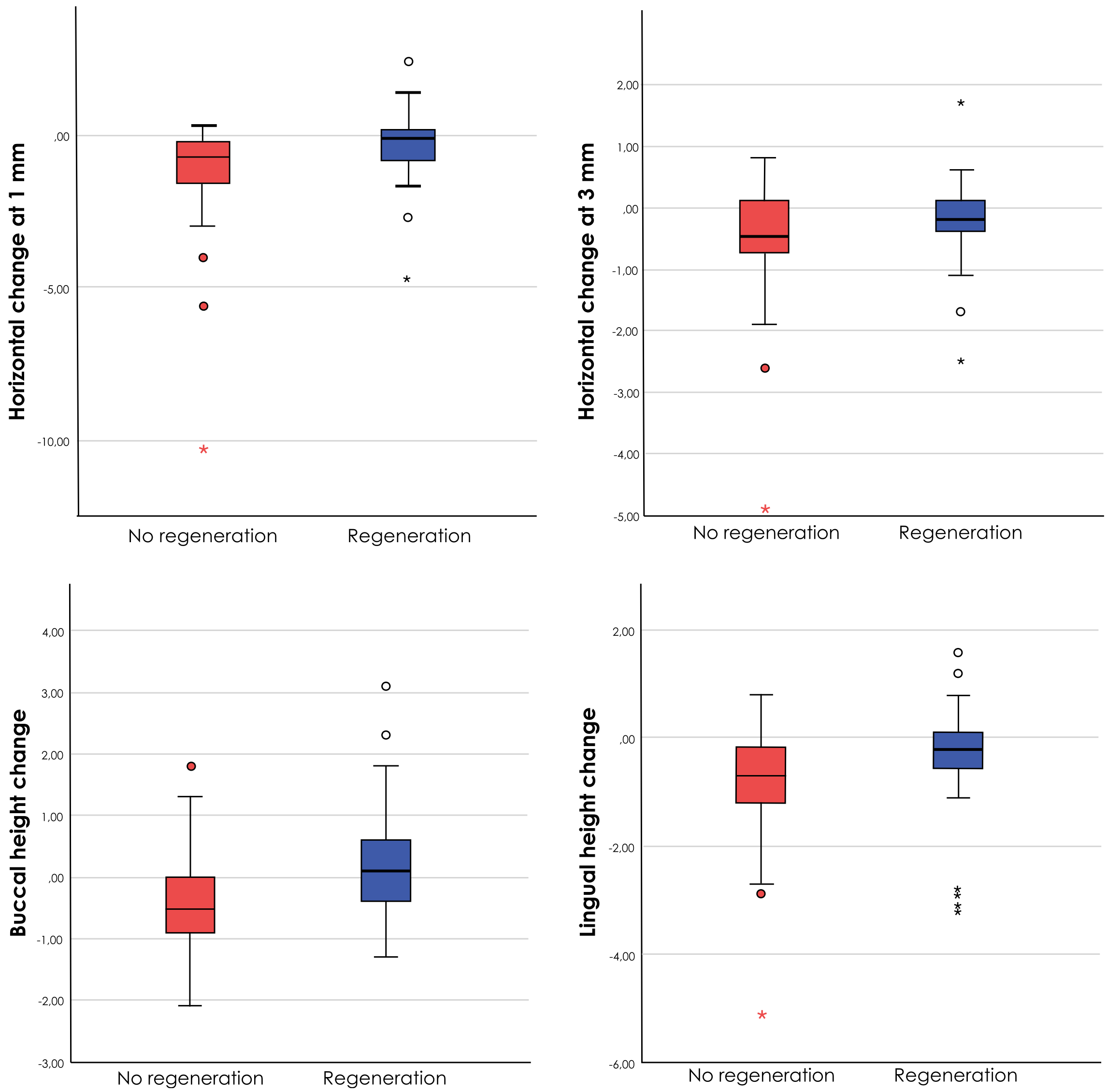

FIGURE 3 Boxplots representing the effect of applying simultaneous regenerative procedures after implant removal on horizontal changes at 1 and 3 mm, and on vertical changes both lingual and buccal

4.4 | Limitations of the study and future recommendations

One possible limitations of our study include its limited sample size, though the sample was representative and significant for the type of study conducted. In addition, several patients were excluded due to the lack of a post-implant removal CBCT scan, thus further reducing the final sample size. In the same context, it should be highlighted that certain radiographic measurements were impossible to be carried out due to the severity of the peri-implant bone loss, the presence of nearby anatomical structures that made superimposition impossible, or the presence of metallic devices that generated artifacts in the radiographic images. Hence, the final number of measurements of RWC decreased progressively as we moved away from the bone crest at 1, 3, 5, and 7 mm.

On the other hand, since this was a non-controlled and non-randomized study, confounder factors could be explored. In line with this, the great disparity between the different surgical procedures carried out during implant removal (different regeneration materials, implant removal methods, and follow-up times) implies that the results obtained must be interpreted with caution. Therefore, the present study should be viewed as a proof-of-concept study and not as an attempt to establish solid bases or guidelines.

In relation to future investigations, animal research would be necessary to describe the healing process that occurs in the peri-implant defect. In this way, it would be possible to describe the dimensional changes produced at histological and histomorphometric level. It is advisable to further investigate the dimensional changes occurring at soft tissue level after implant removal, in addition to those occurring in the hard tissues, as done in our study.

4.5 | Clinical implications

A number of recommendations and clinical implications can be drawn from this study. Contrary to the vast evidence supporting major dimensional changes after teeth extraction, hard tissue changes at removed implant sites seems to be minor. Anyways, simultaneous regeneration of the removed implant site seems to help in limiting the dimensional bone changes. If this is indeed so, then bone regeneration is encouraged, in particular in those scenarios in need of future implant placement and limited alveolar bone availability and in those anatomical sites where more marked dimensional changes have been observed (i.e., posterior maxillary sites). Another significant but less recurrent finding is that use of a removal kit could benefit preservation of the lingual plate, and, therefore it could be considered as a suitable method for implant removal. Nevertheless, due to the nature and the limited sample size of the present study, cautiousness should be exercised when interpreting this data. Moreover, the evidence available up to date on this topic is scarce and thus, preclinical and prospective controlled studies should be performed to validate the effectiveness of this approach.

5 | CONCLUSIONS

Minimal hard tissue changes are anticipated from implant removal due to peri-implantitis. Few patient-related, implant-related, and surgery-related factors are suggested to influence the hard tissue dimensional changes. Simultaneous bone regeneration procedures and the use of a removal kit may considerably reduce the impact upon the dimensional changes (NCT0453436).

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AUTHOR CONTRIBUTIONS

Alberto Monje: Designed the study protocol, obtained the sample data and wrote the manuscript. **Miguel Carreño:** Designed the study protocol, obtained the sample data and wrote the manuscript. **Ramón Pons:** Designed the study protocol, obtained the sample data and wrote the manuscript. **Ettore Amerio:** Contributed to the statistical analysis. **Jordi Gargallo-Albiol:** Interpretation of the data and in the writing of the manuscript. **José Nart:** Interpretation of the data and in the writing of the manuscript.

DATA AVAILABILITY STATEMENT

Data openly available in a public repository that issues datasets with DOIs.

ORCID

Ramón Pons https://orcid.org/0000-0001-7472-7526
Alberto Monje https://orcid.org/0000-0001-8292-1927

ENDNOTES

[1] Komet dental, Gebr. Brasseler GmbH & Co. KG, Lemgo, Germany.

[2] Carl Martin Gmbh, Solingen, Germany.

[3] Implant Retrieval Tool®, Nobel Biocare, Kloten, Switzerland.

REFERENCES

1. Buser D, Mericske-Stern R, Bernard JP, et al. Long-term evaluation of non-submerged ITI implants. Part 1: 8-year life table analysis of a prospective multi-center study with 2359 implants. *Clin Oral Implants Res*. 1997;8(3):161-172. https://doi.org/10.1034/j.1600-0501.1997.080302.x.
2. Buser D, Ingimarsson S, Dula K, Lussi A, Hirt HP, Belser UC. Long-term stability of osseointegrated implants in augmented bone: a 5-year prospective study in partially edentulous patients. *Int J Periodontics Restorative Dent*. 2002;22(2):109-117.
3. Buser D, Janner SF, Wittneben JG, Brägger U, Ramseier CA, Salvi GE. 10-year survival and success rates of 511 titanium implants with a sandblasted and acid-etched surface: a retrospective study in 303 partially edentulous patients. *Clin Implant Dent Relat Res*. 2012;14(6):839-851. https://doi.org/10.1111/j.1708-8208.2012.00456.x.
4. Roos-Jansåker AM, Lindahl C, Renvert H, Renvert S. Nine- to fourteen-year follow-up of implant treatment. Part I: implant loss and associations to various factors. *J Clin Periodontol*. 2006;33(4):283-289. https://doi.org/10.1111/j.1600-051X.2006.00907.x.
5. Derks J, Schaller D, Håkansson J, Wennström JL, Tomasi C, Berglundh T. Peri-implantitis—onset and pattern of progression. *J Clin Periodontol*. 2016;43(4):383-388. https://doi.org/10.1111/jcpe.12535.
6. Greenstein G, Cavallaro J. Failed dental implants: diagnosis, removal and survival of reimplantations. *J Am Dent Assoc*. 2014;145(8):835-842. https://doi.org/10.14219/jada.2014.28.
7. Misch CE, Perel ML, Wang HL, et al. Implant success, survival, and failure: the International Congress of Oral Implantologists (ICOI) Pisa Consensus Conference. *Implant Dent*. 2008;17(1):5-15. https://doi.org/10.1097/ID.0b013e3181676059.
8. Froum SJ, Rosen PS. A proposed classification for peri-implantitis. *Int J Periodontics Restorative Dent*. 2012;32(5):533-540.
9. Decker AM, Sheridan R, Lin GH, Sutthiboonyapan P, Carroll W, Wang HL. A prognosis system for periimplant diseases. *Implant Dent*. 2015;24(4):416-421. https://doi.org/10.1097/ID.0000000000000276.
10. 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 Clin Periodontol*. 2018;45:S286-S291. https://doi.org/10.1111/jcpe.12957.
11. Amler MH, Johnson PL, Salman I. Histological and histochemical investigation of human alveolar socket healing in undisturbed extraction wounds. *J Am Dent Assoc*. 1960;61:32-44. https://doi.org/10.14219/jada.archive.1960.0152.
12. Evian CI, Rosenberg ES, Coslet JG, Corn H. The osteogenic activity of bone removed from healing extraction sockets in humans. *J Periodontol*. 1982;53(2):81-85. https://doi.org/10.1902/jop.1982.53.2.81.
13. Bergman B, Carlsson GE. Clinical long-term study of complete denture wearers. *J Prosthet Dent*. 1985;53(1):56-61. https://doi.org/10.1016/0022-3913(85)90066-6.
14. Cardaropoli G, Araújo M, Lindhe J. Dynamics of bone tissue formation in tooth extraction sites. An experimental study in dogs. *J Clin Periodontol*. 2003;30(9):809-818. https://doi.org/10.1034/j.1600-051x.2003.00366.x.
15. Araújo MG, Lindhe J. Dimensional ridge alterations following tooth extraction. An experimental study in the dog. *J Clin Periodontol*. 2005;32(2):212-218. https://doi.org/10.1111/j.1600-051X.2005.00642.x.
16. Trombelli L, Farina R, Marzola A, Bozzi L, Liljenberg B, Lindhe J. Modeling and remodeling of human extraction sockets. *J Clin*

Periodontol. 2008;35(7):630-639. https://doi.org/10.1111/j.1600-051X.2008.01246.x.
17. Discepoli N, Vignoletti F, Laino L, de Sanctis M, Muñoz F, Sanz M. Early healing of the alveolar process after tooth extraction: an experimental study in the beagle dog. *J Clin Periodontol*. 2013;40(6):638-644. https://doi.org/10.1111/jcpe.12074.
18. Lam RV. Contour changes of the alveolar process following extractions. *J Prosthet Dent*. 1960;10(1):25-32. https://doi.org/10.1016/0022-3913(60)90083-4.
19. Johnson K. A study of the dimensional changes occurring in the maxilla following tooth extraction. *Aust Dent J*. 1969;14(4):241-244. https://doi.org/10.1111/j.1834-7819.1969.tb06001.x.
20. Schropp L, Wenzel A, Kostopoulos L, Karring T. Bone healing and soft tissue contour changes following single-tooth extraction: a clinical and radiographic 12-month prospective study. *Int J Periodontics Restorative Dent*. 2003;23(4):313-323.
21. Gargallo-Albiol J, Tavelli L, Barootchi S, Monje A, Wang HL. Clinical sequelae and patients' perception of dental implant removal: A cross-sectional study. *J Periodontol*. 2020. https://doi.org/10.1002/JPER.20-0259. [Published ahead of print].
22. Meloni SM, Tallarico M, Lolli FM, Deledda A, Pisano M, Jovanovic SA. Postextraction socket preservation using epithelial connective tissue graft vs porcine collagen matrix. 1-year results of a randomised controlled trial. *Eur J Oral Implantol*. 2015;8(1):39-48.
23. Monje A, Pons R, Insua A, Nart J, Wang HL, Schwarz F. Morphology and severity of peri-implantitis bone defects. *Clin Implant Dent Relat Res*. 2019;21(4):635-643. https://doi.org/10.1111/cid.12791.
24. Jung RE, Philipp A, Annen BM, et al. Radiographic evaluation of different techniques for ridge preservation after tooth extraction: a randomized controlled clinical trial. *J Clin Periodontol*. 2013;40(1):90-98. https://doi.org/10.1111/jcpe.12027.
25. Tan WL, Wong TL, Wong MC, Lang NP. A systematic review of post-extractional alveolar hard and soft tissue dimensional changes in humans. *Clin Oral Implants Res*. 2012;23:1-21. https://doi.org/10.1111/j.1600-0501.2011.02375.x.
26. Berglundh T, Lindhe J, Jonsson K, Ericsson I. The topography of the vascular systems in the periodontal and peri-implant tissues in the dog. *J Clin Periodontol*. 1994;21(3):189-193. https://doi.org/10.1111/j.1600-051x.1994.tb00302.x.
27. Artzi Z, Tal H, Dayan D. Porous bovine bone mineral in healing of human extraction sockets. Part 1: histomorphometric evaluations at 9 months. *J Periodontol*. 2000;71(6):1015-1023. https://doi.org/10.1902/jop.2000.71.6.1015.
28. Lekovic V, Camargo PM, Klokkevold PR, et al. Preservation of alveolar bone in extraction sockets using bioabsorbable membranes. *J Periodontol*. 1998;69(9):1044-1049. https://doi.org/10.1902/jop.1998.69.9.1044.
29. Iasella JM, Greenwell H, Miller RL, et al. Ridge preservation with freeze-dried bone allograft and a collagen membrane compared to extraction alone for implant site development: a clinical and histologic study in humans. *J Periodontol*. 2003;74(7):990-999. https://doi.org/10.1902/jop.2003.74.7.990.
30. Avila-Ortiz G, Chambrone L, Vignoletti F. Effect of alveolar ridge preservation interventions following tooth extraction: A systematic review and meta-analysis. *J Clin Periodontol*. 2019;46:195-223. https://doi.org/10.1111/jcpe.13057.
31. Avila-Ortiz G, Gubler M, Romero-Bustillos M, Nicholas CL, Zimmerman MB, Barwacz CA. Efficacy of alveolar ridge preservation: a randomized controlled trial. *J Dent Res*. 2020;99(4):402-409. https://doi.org/10.1177/0022034520905660.
32. Froum S, Yamanaka T, Cho SC, Kelly R, St James S, Elian N. Techniques to remove a failed integrated implant. *Compend Contin Educ Dent*. 2011;32(7):22-32.
33. Roy M, Loutan L, Garavaglia G, Hashim D. Removal of osseointegrated dental implants: a systematic review of explantation techniques. *Clin Oral Investig*. 2020;24(1):47-60. https://doi.org/10.1007/s00784-019-03127-0.
34. Bohner LOL, Mukai E, Oderich E, et al. Comparative analysis of imaging techniques for diagnostic accuracy of peri-implant bone defects: a meta-analysis. *Oral Surg Oral Med Oral Pathol Oral Radiol*. 2017;124(4):432-440. https://doi.org/10.1016/j.oooo.2017.06.119.
35. Pinheiro LR, Gaia BF, Oliveira de Sales MA, Umetsubo OS, Santos Junior O, Cavalcanti MG. Effect of field of view in the detection of chemically created peri-implant bone defects in bovine ribs using cone beam computed tomography: an in vitro study. *Oral Surg Oral Med Oral Pathol Oral Radiol*. 2015;120(1):69-77. https://doi.org/10.1016/j.oooo.2015.04.006.
36. González-Martín O, Oteo C, Ortega R, Alandez J, Sanz M, Veltri M. Evaluation of peri-implant buccal bone by computed tomography: an experimental study. *Clin Oral Implants Res*. 2016;27(8):950-955. https://doi.org/10.1111/clr.12663.
37. Razavi T, Palmer RM, Davies J, Wilson R, Palmer PJ. Accuracy of measuring the cortical bone thickness adjacent to dental implants using cone beam computed tomography. *Clin Oral Implants Res*. 2010;21(7):718-725. https://doi.org/10.1111/j.1600-0501.2009.01905.x.
38. Fienitz T, Schwarz F, Ritter L, Dreiseidler T, Becker J, Rothamel D. Accuracy of cone beam computed tomography in assessing peri-implant bone defect regeneration: a histologically controlled study in dogs. *Clin Oral Implants Res*. 2012;23(7):882-887. https://doi.org/10.1111/j.1600-0501.2011.02232.x.
39. Codari M, de Faria VK, Ferreira Pinheiro Nicolielo L, Haiter Neto F, Jacobs R. Quantitative evaluation of metal artifacts using different CBCT devices, high-density materials and field of views. *Clin Oral Implants Res*. 2017;28(12):1509-1514. https://doi.org/10.1111/clr.13019.
40. Sancho-Puchades M, Hämmerle CH, Benic GI. In vitro assessment of artifacts induced by titanium, titanium-zirconium and zirconium dioxide implants in cone-beam computed tomography. *Clin Oral Implants Res*. 2015;26(10):1222-1228. https://doi.org/10.1111/clr.12438.
41. Domic D, Bertl K, Ahmad S, Schropp L, Hellén-Halme K, Stavropoulos A. Accuracy of cone-beam computed tomography is limited at implant sites with a thin buccal bone: a laboratory study. *J Periodontol*. 2021;92(4):592-601. https://doi.org/10.1002/JPER.20-0222.

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