Current Oral Health Reports (2020) 7:283–303
https://doi.org/10.1007/s40496-020-00278-y

PERI-IMPLANTITIS (I DARBY, SECTION EDITOR)

Surgical Management of Peri-implantitis

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Published online: 1 August 2020

Abstract

Purpose of Review To provide an overview of current surgical peri-implantitis treatment options.

Recent Findings Surgical procedures for peri-implantitis treatment include two main approaches: non-augmentative and augmentative therapy. Open flap debridement (OFD) and resective treatment are non-augmentative techniques that are indicated in the presence of horizontal bone loss in aesthetically nondemanding areas. Implantoplasty performed adjunctively at supracrestally and buccally exposed rough implant surfaces has been shown to efficiently attenuate soft tissue inflammation compared to control sites. However, this was followed by more pronounced soft tissue recession. Adjunctive augmentative measures are recommended at peri-implantitis sites exhibiting intrabony defects with a minimum depth of 3 mm and in the presence of keratinized mucosa. In more advanced cases with combined defect configurations, a combination of augmentative therapy and implantoplasty at exposed rough implant surfaces beyond the bony envelope is feasible.

Summary For the time being, no particular surgical protocol or material can be considered as superior in terms of long-term peri-implant tissue stability.

Keywords Peri-implantitis · Treatment · Surgical therapy

Introduction

Peri-implantitis is a plaque-associated pathological condition occurring around dental implants that results in a breakdown of the supporting tissues [1•, 2••]. Clinically, peri-implantitis-affected sites exhibit bleeding on probing (BOP) and/or suppuration (Supp), increased probing depths (PDs), and/or recession of the peri-implant mucosal margin in addition to radiographic bone loss compared to previous examination [1•]. Untreated disease progresses in nonlinear accelerating pattern and finally leads to a loss of the implant [3••, 4]. As the number of patients undergoing restorative therapy through dental implants increases, peri-implantitis is considered to be a major and growing problem in dentistry [4].

The primary goal of peri-implantitis treatment has been established as a resolution of the inflammation and a prevention of further bone loss [5]. To achieve these treatment endpoints, it is currently accepted that surgical approaches that allow adequate access to the contaminated implant surface are required [6–8]. Indeed, numerous peri-implantitis surgical treatment protocols have been proposed, which basically can be categorized into two main modalities: non-augmentative and augmentative.

The aim of this narrative review is to provide an overview of various peri-implantitis surgical treatment strategies with regard to their indications, performance, and efficacy.

Non-augmentative Approaches

Open Flap Debridement

In order to achieve the resolution of inflammation and arrest further bone loss, decontamination of the implant's surface is of critical importance [9]. Open flap debridement (OFD) is a surgical technique aimed at gaining access to the implant surfaces to facilitate decontamination.

This article is part of the Topical Collection on *Peri-implantitis*

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Procedure

The surgery consists of the following steps:

- Access to the lesion
- Removal of granulation tissues
- Decontamination of the implant surface
- Suturing with or without apical flap positioning

During OFD surgery, implant surface is mechanically debrided with titanium or plastic curettes or titanium brushes, with or without the adjunctive application of antimicrobials (Table 1) [8, 11,12, 13, 15]. The effectiveness of different decontamination approaches has been assessed in randomized clinical investigations (RCTs) [10••, 13, 14]. Particularly, significantly greater reductions of initial PD values as well as stable bone levels were obtained at implant sites debrided with titanium brushes compared with those cleaned with plastic curettes or an air-abrasive device [13]. Repeated applications of local antibiotics (minocycline) led to superior therapeutic outcomes (i.e., greater PD reductions and increased marginal bone levels) compared with those in the placebo group [14]. In contrast to the abovementioned decontamination approaches, the additional use of a diode laser provided comparable treatment outcomes to those of mechanical debridement alone (i.e., plastic curettes and cotton pellets soaked in sterile saline) [10••]. It should, however, be noted that all of the abovementioned controlled clinical investigations involved a follow-up period limited to 6 months and thus do not permit an assessment of the long-term impacts of the implant surface decontamination method on the treatment outcomes following OFD. Regarding the rationale for adjunctive systemic antibiotic therapy, as demonstrated by a 1-year follow-up controlled clinical investigation, prescribing systemic antibiotics did not lead to improved therapeutic outcomes, as compared with those in the control group [12].

Outcomes of the Therapy

Peri-implantitis management with the OFD approach significantly reduced inflammation signs (BOP, PD values, and Supp) compared with the baseline situation [8, 10••, 11, 12, 13]. However, a postoperative soft tissue recession of 1.9 to 1.8 mm occurred after 1 year and 5 years, respectively [8, 11].

Treatment success, defined as PD $\leq$ 5 mm, no BOP, no Supp, and no bone loss $\geq$ 0.5 mm, after 6 months was achieved in 33% of the implants mechanically treated with titanium brushes, whereas lower values were noted for the sites where debridement was performed with plastic curettes or an air-abrasive device (22% and 27%, respectively; $p < 0.05$) [13]. According to the same definition, success was obtained in 47% of patients with postoperative antibiotics and 25% without systemic antibiotic prescription after 1 year; however, no significant difference was found between the groups ($p = 0.2$) [12]. Contrarily, disease resolution (defined as PD < 5 mm, no BOP/Supp, and no bone loss) was more frequently noted at the sites treated with locally repeated minocycline applications (intraoperatively, after 1 month, 3 months, and 6 months) compared to the controls (test 66.7%, control 36.3% of the implants) [14]. Over a 5-year follow-up, treatment success (the absence of PD $\geq$ 5 mm with concomitant BOP and Supp and the absence of additional bone loss) was yielded in 63% of the patients that adhered to a regular supportive therapy [11].

Resective Therapy

Resective peri-implantitis therapy involves reducing or eliminating pathological peri-implant pockets, apical positioning of the mucosal flap, or recontouring of the bone with or without implantoplasty [16]. The indication of this surgical approach includes the presence of horizontal bone loss with exposed implant threads in non-aesthetic areas [16].

Procedure

The following steps should be followed during resective peri-implantitis therapy (Fig. 1):

- Access to the defect
- Removal of inflamed tissues
- Decontamination of the implant surface
- Performance of resective therapy by means of osseous recontouring with or without implantoplasty
- Apical positioning of the mucosal flap

Mechanical debridement combined with antibacterial agent application (e.g., chlorhexidine gluconate (CHX), hydrogen peroxide, sterile saline, phosphoric acid, or antibiotic gel) is the most common method for decontaminating implant surfaces [15, 17–25] (Table 2). Clinical comparative studies have shown that the adjunctive use of phosphoric acid or CHX application with or without cetylpyridinium chloride was not superior to control methods (e.g., sterile saline alone) [17–20, 22]. Adjunctive systemic antibiotics regimens had no impact on disease resolution (i.e., PD $\leq$ 5 mm, no BOP/Supp, bone loss $\leq$ 0.5 mm) in implants with nonmodified surfaces, whereas they had a positive effect on treatment success on implants with modified surfaces [20]. Over a 3-year period, however, the increased treatment success by systemic antibiotics at nonmodified surfaces was not sustained [19].

Implant surface modification, or implantoplasty, was suggested to be used as an adjunct to the resective therapy of peri-implantitis [24, 25]. Implantoplasty is aimed at removing

Table 1 Studies reporting on open flap debridement therapy

Author (study type)	General information		Treatment procedure		
	Follow-up period	Number of implants/patients	Decontamination of implant surface	Submerged/ nonsubmerged healing	Systemic antibiotics
Papadopoulos et al. [10••] (2015) (RCT)	6 months	16/16 Test, 8/8 Control, 8/8	Test: mechanical debridement with plastic curettes + use of cotton swabs soaked in saline solution + use of a diode laser (low-power 980 nm) Control: mechanical debridement with plastic curettes + use of cotton pellets soaked in saline solution	Nonsubmerged	No
Heitz-Mayfield et al. [11] (2018) (prospective cohort study)	5 years	24/36	Mechanical debridement with titanium-coated Gracey curettes or carbon fiber curettes + irrigation with sterile saline and rubbing of the implant surface with cotton pellets soaked in sterile saline	Nonsubmerged	Amoxicillin (500 mg) + metronidazole (400 mg), 3 times/day, 7 days
Hallström et al. [12] (2017) (RCT)	1 year	31/31 Test, 15/15 Control, 16/16	Mechanical debridement with curettes and cotton pellets soaked in saline	Nonsubmerged	Test group: postoperative systemic antibiotics —Zithromax (Sandoz AS, Copenhagen, Denmark) 250 mg × 2 at the day of surgery and 250 mg × 1 per day for 4 days Control group: no systemic antibiotics
Toma et al. [13] (2019) (RCT)	6 months	47/70 Group 1, 15/25 Group 2, 16/22 Titanium brush group, 16/23	Group 1: debridement with plastic curettes + irrigation with sterile saline Group 2: debridement with air-abrasive device + irrigation with sterile saline Group 3: debridement with titanium brush + irrigation with sterile saline	Nonsubmerged	No
Cha et al. [14] (2019) (RCT)	6 months	46/46 Test, 24/24 Control, 22/22	Mechanical debridement with titanium-coated curettes, metallic copper-alloy scaler tip, titanium brush, and air-powder abrasive device Test: adjunctive minocycline ointment (+ repeated after 1 month, 3 months, and 6 months) Control: placebo ointment	Nonsubmerged	Combination of amoxicillin (500 mg) 3 times for 3 days

Author (study type)	Treatment outcomes					
	PD changes (mm) (SD; range)	BOP changes (%) (SD; range)	Supp changes (%) (SD; range)	Soft tissue recession (mm)/ clinical attachment changes (mm)	Radiographic outcomes	Treatment success, definition, and outcome
Papadopoulos et al. [10••] (2015) (RCT)	Implant level Baseline: control, 5.52 mm; test, 5.92	BOP changes Baseline: control, 93.8%; test, 81.2%	% of implants with suppuration	Clinical attachment level changes (mm)	NR	NR

Table 1 (continued)

	6 months: control, 4.31; test, 4.44 mm Significant reduction compared to the baseline ($p < 0.05$) No significant difference between the groups ($p > 0.05$)	6 months: control, 31.3%; test, 23.8% Significant reduction compared to the baseline ($p < 0.05$) No significant difference between the groups ($p > 0.05$)	Baseline: control, 49.2 ± 29%; test, 57.1 ± 28% After 1 year: control, 1.9 ± 1%; test, 10.4 ± 5% No significant difference between the groups ($p = 0.222$)	Baseline: control, 4.94 mm; test, 5.25 mm 6 months: control, 4.11 mm; test, 4.46 mm Statistically significant differences between baseline and 6 months ($p > 0.05$)		
Heitz-Mayfield et al. [11] (2018) (prospective cohort study)	Implant level Baseline, 5.3 ± 1.8 mm 12 months, 2.9 ± 0.8 mm 5 years, 3.2 ± 1.0 mm Significant reduction compared to the baseline ($p < 0.001$)	Number of sites with BOP (mean ± SD) Baseline, 2.5 ± 1 12 months, 1 ± 1.2 5 years, NR Significant reduction compared to the baseline ($p < 0.01$)	Number of implants with suppuration (mean ± SD) (%) Baseline, 21 ± 58% 12 months, 2 ± 5.6% 3 years, 2 ± 6.7% 5 years, 5 ± 21% Significant reduction compared to the baseline ($p < 0.001$)	Facial recession (mean ± SD) (mm) Baseline, no recession 12 months, 1.0 ± 0.9 mm 5 years, 1.8 ± 1.6 mm Significant increase compared to the baseline ($p < 0.001$)	3 implants in 3 patients had 0.6–1.0 mm bone loss. 3 implants in 3 patients showed bone gain, while the rest of the implants had stable marginal bone levels	Absence of PD ≥ 5 mm with concomitant BOP/suppuration, no progression of bone loss Patient level: 1 year, 79% (19/24); 3 years, 75% (18/24); 5 years, 63% (15/24) Implant level: 1 year, 821% (29/36); 3 years, 69% (25/36); 5 years, 53% (19/36)
Hallström et al. [12] (2017) (RCT)	Implant level Mean PD reduction (mean ± SD) (mm) Test, 1.7 ± 1.1 mm, $p < 0.001$ Control, 1.6 ± 1.5 mm, ($p < 0.001$) Significant reduction compared to the baseline ($p < 0.001$) No significant difference between the groups ($p = 0.5$)	BOP changes (mean ± SD) (%) Baseline: test, 100%; control, 100% After 1 year: test, 12.4 ± 9.2%; control, 13.3 ± 11.1% No significant difference between the groups ($p = 0.1$)	NR	NR	Radiographic bone level (mm) Baseline: test, 4.6 ± 1.6 mm; control, 4.9 ± 1.7 mm ($p = 0.6$) After 1 year: test, 4.0 ± 1.6 mm; control, 4.5 ± 1.5 mm No significant difference between the groups ($p = 0.4$)	PD ≤ 5 mm, no BOP, no suppuration, no bone loss ≥ 0.5 mm Total, 35.3% (11/31) of the patients Test, 46.7% (7/15) of the patients Control, 25% (4/16) of the patients No difference between the groups ($p = 0.2$)
Toma et al. [13] (2019) (RCT)	Mean PD changes Group 1: baseline, 7.11 ± 1.15 mm; after 6 months, 5.44 ± 0.67 mm ($p < 0.001$) Group 2: baseline, 6.94 ± 1.29 mm; after	Mean BOP changes Group 1: baseline, 54 ± 4.4 mm; after 6 months, 29 ± 3.4 mm ($p < 0.001$) Group 2: baseline, 59 ± 5.4 mm; after	NR	NR	Bone loss changes Group 1: baseline, 6.49 ± 1.98 mm; after 6 months, 5.99 ± 1.78 mm ($p < 0.001$) Group 2: baseline, 7.34 ± 1.29 mm; after	PD ≤ 5 mm + no BOP/Supp, no bone loss ≥ 0.5 mm Group 1, 22% Group 2, 27% Group 3, 33% Significantly higher in group 3 ($p < 0.05$)

Table 1 (continued)

	6 months, 4.71 ± 1.24 mm ($p < 0.001$)	6 months, 23 ± 2.3 mm ($p < 0.001$)			6 months, 6.44 ± 1.46 mm ($p < 0.001$)	
	Group 3: baseline, 6.45 ± 1.87 mm; after 6 months, 3.98 ± 1.43 mm ($p < 0.001$)	Group 3: baseline, 62 ± 4.7 mm; after 6 months, 16 ± 3.7 mm ($p < 0.001$)			Group 3: baseline, 7.09 ± 1.23 mm; after 6 months, 5.88 ± 1.3 mm ($p < 0.001$)	
	Significantly greater reduction in groups 2 and 3 compared with group 1 ($p < 0.001$				Significantly less bone loss in group 3 ($p < 0.05$)	
Cha et al. [14] (2019) (RCT)	PD changes at the deepest site (mm): test, 3.58 ± 2.32 mm; control, 2.45 ± 2.13 mm ($p = 0.094$)	Gingival index changes at the deepest site: test, 0.96 ± 0.86; control, 0.41 ± 0.85 ($p = 0.035$)	Bleeding/suppuration (%) At the deepest site: test, 0.58 ± 0.50; control, 0.32 ± 0.57 ($p = 0.102$)	NR	NR	PD < 5 mm, without concomitant BOP/suppuration, no further bone loss
	Mean PD changes (mm): test, 2.68 ± 1.73 mm; control, 1.55 ± 1.86 mm ($p = 0.039$)	Mean gingival index changes: test, 0.83 ± 0.60; control, 0.40 ± 0.68 ($p = 0.026$)	Mean bleeding/suppuration changes: test, 0.49 ± 0.35; control, 0.31 ± 0.46 ($p = 0.141$)			Implant level: test, 66.7% (16/24); control, 36.3% (8/22)

SD standard deviation, *NR* not reported, *RCT* randomized controlled clinical study, *BOP* bleeding on probing, *PD* probing pocket depth, *Supp* suppuration

supracrestally exposed rough implant surfaces, which, in turn, would be less prone to plaque accumulation and, ultimately, the recurrence of infection [24, 25, 27–29]. Clinically, the advantage of implantoplasty compared to resective therapy alone in terms of BOP, PD reduction, and marginal bone preservation was demonstrated in a 3-year comparative clinical investigation (Table 2) [24]. Nevertheless, compared to the control sites, adjunctively performed implantoplasty leads to significant postoperative soft tissue recession (1.64 mm vs. 1.94 mm, respectively) [24].

Outcomes of the Therapy

Surgical resective peri-implantitis treatment was found to be effective in reducing signs of peri-implant soft tissue inflammation and decreased probing depths in the short term [16, 30]. According to the similar definitions used by different authors, resective therapy yielded success in 14% of implants after 6 months [21] and in 75% of implants after 3 years [26] (Table 2). Over a 5-year period, healthy conditions (PD < 4 mm and no BOP or Supp) were found in 60% of implants for patients enrolled in a 6-month recall system [15].

The characteristics of implant surfaces were demonstrated to be among the prognostic factors for the successful treatment of peri-implantitis following resective treatment [19, 20]. Over 3 years, treatment success (no bone loss > 0.5 mm, PD ≤ 5 mm, and no BOP or Supp) was more frequently observed for implants with nonmodified surfaces compared to implants with modified surfaces (61% vs. 23%, respectively) [19]. In addition, retrospective data demonstrated significantly higher PD and BOP reduction as well as greater crestal bone preservation for the implants with nonmodified surfaces 2 to 10 years after the resective therapy [31]. Factors, such as the preoperative presence of Supp, bone loss > 7 mm, and PD > 8 mm, as well as residual PDs ≥ 4 mm following resective peri-implantitis therapy, were found to be associated with the reduced therapeutic success and increased the risk of further disease progression [15, 21].

Augmentative Approaches

Augmentative Therapy

In addition to resolving infection, augmentative therapy for peri-implantitis is aimed at (1) regenerating the bone defect, (2) achieving re-osseointegration, and (3) limiting the recession of peri-implant soft tissue [32]. Indications of this surgical approach involve the presence of intrabony defects with a minimum depth of 3 mm, three- or four-wall-contained defects, and the presence of keratinized mucosa [32].

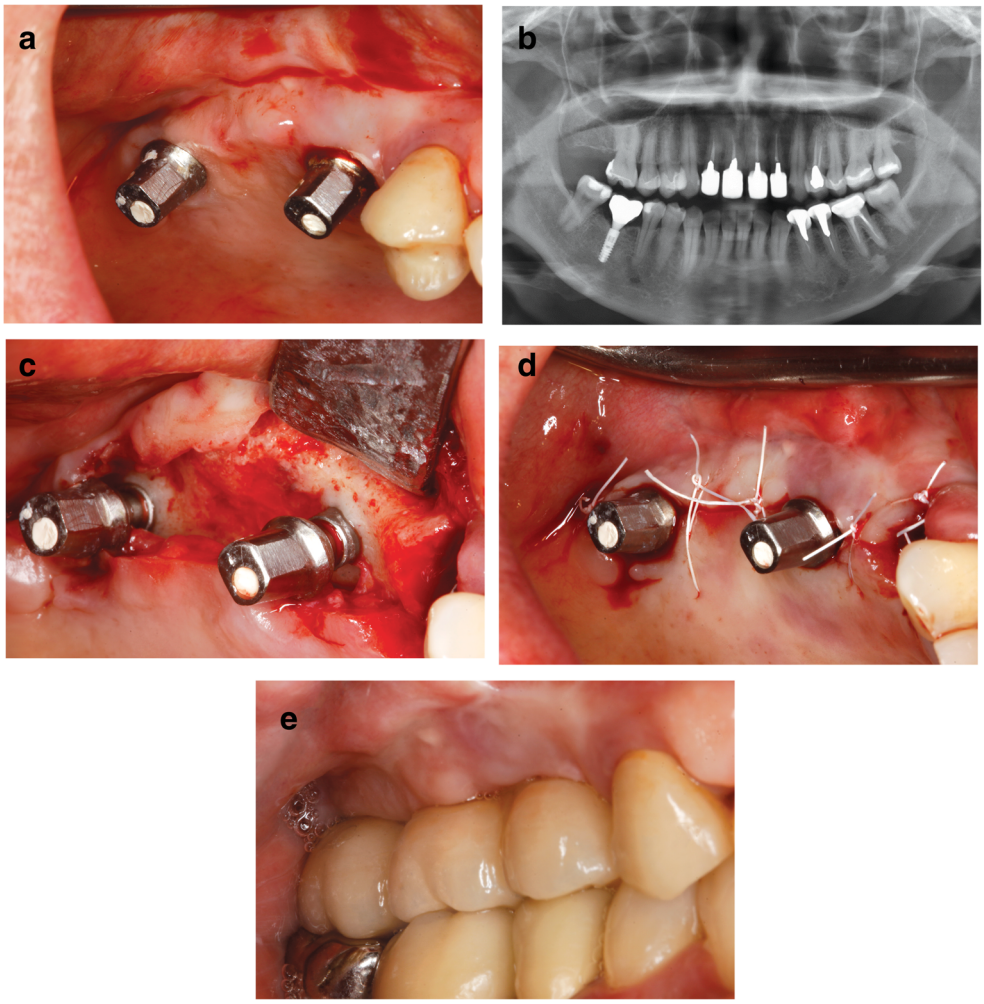

Fig. 1 A clinical case of resective peri-implantitis therapy combined with implantoplasty. **a** Presurgical view following the removal of a suprastructure. **b** Radiographic view. Marginal bone loss present around implants 14 and 16. **c** Implantoplasty performed at supracrestally exposed implant sites. **d** Suturing. **e** Intraoral view after 6 months

Interventions

Augmentative peri-implantitis treatment protocol includes the following steps (Fig. 2):

- Access to the defect
- Removal of inflamed tissues
- Decontamination of the implant surface
- Placement of the graft material (with or without a barrier membrane)
- Adequate flap adaptation

Implant surface decontamination methods applied during augmentative peri-implantitis treatment include mechanical debridement (i.e., plastic, titanium, or carbon curettes; titanium brushes; or air polishing), laser therapy (carbon dioxide and Er:YAG lasers), application of chemical agents (chlorhexidine digluconate, citric acid, minocycline, sterile saline, ethylenediaminetetraacetic acid (EDTA) 24%, or hydrogen peroxide), and their combinations (Table 3) [8, 33–38, 40]. As indicated in a recent systematic review, currently existing clinical, radiographic, and microbiological data do not favor any implant surface decontamination approach and fail to show the influence of a particular decontamination protocol on the long-term outcomes of peri-implantitis surgical therapy [41].

The impact of such factors as the healing pattern (i.e., submerged or nonsubmerged) or additional use of systemic antibiotics for the therapeutic outcomes of augmentative peri-implantitis therapy cannot be investigated because of the absence of comparative studies [42]. Nevertheless, whenever feasible, to facilitate protected physiological healing, clinicians are recommended to choose submerged postoperative wound closure [43].

Grafting Materials

Reconstruction of peri-implant bone defect can be performed by either the use of bone substitute material solely or in combination with a barrier membrane [42]. Bone replacement materials suggested for peri-implant bone defect fill include

Table 2 Studies reporting on the treatment outcomes following resective therapy

Author (study type)	General information		Treatment procedure		
	Follow-up period	Number of implants/patients	Decontamination of implant surface	Osseous recontouring	Submerged/nonsubmerged postoperative healing
Romeo et al. [24, 25] (2005 and 2007, respectively) (RCT)	3 years	17/35 Test, 10/19 Control, 7/16	Metronidazole gel and solution of tetracycline hydrochloride (3 min) + implantoplasty	Test (+) Control (+)	Test (+) Control (−)
de Waal et al. [17] (2013) (RCT)	1 year	30/79 Test, 15/31 Control, 15/48	Test, 0.12% CHX + 0.05% cetylpyridinium chloride (CPC) Control: placebo solution	Test (+) Control (+)	Nonsubmerged
de Waal et al. [18] (2015) (RCT)	1 year	44/108 Test, 22/49 Control, 22/59	Test, 2.0% CHX Control, 0.12% CHX + 0.05% CPC	Test (+) Control (+)	Nonsubmerged
Serino et al. [15] (2015) (prospective clinical study	5 years	27/71	Scaling and polishing with ultrasonic instruments and rotating rubber cups under irrigation with 12% chlorhexidine	+	Nonsubmerged
Carcuac et al. [20] (2016) (RCT)	1 year	100/179	Debridement with titanium-coated curettes Groups 1 and 3: decontamination with 0.2% CHX Groups 2 and 4: decontamination with saline for 2 min	+	Nonsubmerged
Carcuac et al. [19] (2017) (continuum); Carcuac et al. [20] (2016) (RCT)	3 years	67/121	Debridement with titanium-coated curettes Groups 1 and 3: decontamination with 0.2% CHX Groups 2 and 4: decontamination with saline for 2 min	+	Nonsubmerged
Koldsland et al. [21] (2018) (prospective case series)	6 months	45/143	Debridement with titanium curettes + decontamination with cotton pellets soaked in 3% H_2O_2 + irrigation with saline	+	Nonsubmerged
Hentenaar et al. [22] (2017) (RCT)	3 months	28/33 Control group, 14/22 Test group, 14/31	Test: debridement with titanium curettes and cotton pellets soaked in saline + application of 35% phosphoric acid (pH 1, 1 min) Control: debridement with titanium curettes and cotton pellets soaked in saline	Test (+) Control (+)	Nonsubmerged
Sarmiento et al. [23] (2018) (prospective case series)	6 months	14 implants 5 implants were treated with respective therapy, 9 implants with apically positioned flap	Debridement with ultrasonic device and implant protective cap + titanium brush 60 s + 5% H_2O_2 (5%) 60 s + irrigation with 0.9% saline + Er:YAG laser application 60 s	Test (+) Control (−)	Nonsubmerged
Englezos et al. [26] (2018) (prospective case series)	2 years	25/40	Debridement with carbon fiber curettes and ultrasonic implant cleaning scaler + cleaning with cotton pellets soaked in CHX and sterile saline + implantoplasty	+	+

Author (study type)	Treatment procedure	Treatment outcomes				
	Systemic antibiotics	PD changes (mm) (SD; range)	BOP changes (%) (SD; range)	Supp changes (%) (SD; range)	Radiographic outcomes	Treatment success, definition, and outcome
Romeo et al. [24, 25] (2005 and 2007,	Nonsubmerged, apical flap suturing	Amoxicillin 50 mg/kg/day for 8 days	Baseline: test, 5.70 ± 1.69 mm; control, 6.52 ± 1.62 mm	Bleeding index (mBI)	Baseline: test, 0.5 ± 0.91 mm; control, 0.23 ± 0.84 mm	Peri-implant bone resorption mesial and distal

Table 2 (continued)

respectively) (RCT)			After 24 months: test, 3.58 ± 1.06 mm; control, 5.5 ± 1.47 mm Significantly higher PD values in the control group (Student's *t* test value + 5.5) After 36 months: test, 3.21 ± 0.56 mm	Baseline: test, 2.83 ± 0.47; control, 2.86 ± 0.35 After 24 months: control, 2.33 ± 0.74 After 36 months: test, 0.61 ± 0.67 (Student's *t* test value of + 9.61)	After 24 months: control, 1.64 ± 1.29 mm After 36 months: test, 1.96 ± 1.42 mm (Student's *t* test value of + 9.61) Recession index in the control group is significantly lower (Student's *t* test value of − 2.14)	Test: baseline, 3.82 mm and 3.94 mm; after 3 years, 3.81 mm and 3.94 mm Control: baseline, 3.45 mm and 3.49 mm; after 3 years, 5.35 mm and 5.42 mm The mean variation of marginal bone level values (mesial and distal) Test, 0 mm and 0.001 mm ($p > 0.05$) Control, 1.44 mm and 1.54 mm ($p < 0.05$)
de Waal et al. [17] (2013) (RCT)	No	Baseline: control, 5.5 ± 1.4 mm; test, 6.6 ± 1.6 mm After 1 year: control, 3.7 ± 0.8 mm; test, 4.3 ± 2.1 mm No significant difference between the groups ($p = 0.563$)	% of implants with BOP Baseline: control, 95.8 ± 46%; test, 96.8 ± 30% After 1 year: control, 94.7 ± 36%; test, 96.8 ± 30% No significant difference between the groups ($p = 0.965$)	% of implants with suppuration Baseline: control, 31.3 ± 15%; test, 64.5 ± 20% After 1 year: control, 15.8 ± 6%; test, 29.0 ± 9% No significant difference between the groups ($p = 0.977$)	Mean marginal bone loss (mm) Baseline: control, 3.6 ± 1.9 mm; test, 4.3 ± 2.1 mm After 1 year: control, 3.9 ± 2.0; test, 5.0 ± 2.5 No significant difference between the groups ($p = 0.949$)	No progressive bone loss, no suppuration, BOP less than 2 sites or less, PD < 5 mm Patient samples were combined, 43% (81/187) of the implants 33% (26/74) of the patients
de Waal et al. [18] (2015) (RCT)	No	Baseline: control, 5.0 ± 1.2 mm; test, 4.7 ± 1.0 mm After 1 year: control, 2.9 ± 0.7 mm; test, 3.0 ± 0.7 mm No significant difference between the groups	% of implants with BOP Baseline: control, 94.9 ± 56%; test, 98.0 ± 47% After 1 year: control, 68.5 ± 37%; test, 77.1 ± 37% No significant difference between the groups ($p = 0.583$)	% of implants with suppuration Baseline: control, 49.2 ± 29%; test, 57.1 ± 28% After 1 year: control, 1.9 ± 1%; test, 10.4 ± 5% No significant difference between the groups ($p = 0.222$)	Mean marginal bone loss (mm) Baseline: control, 4.1 ± 1.6 mm; test, 4.0 ± 1.5 mm After 1 year: control, 4.1 ± 1.7; test, 4.3 ± 1.7 No significant difference between the groups ($p = 0.950$)	
Serino et al. [15] (2015) (prospective clinical study	No	NR	NR	NR	NR	After 5 years Healthy conditions (i.e., PD < 4 mm + no BOP and Supp) 43 implants

Table 2 (continued)

						Implants with residual pockets of 4–5 mm or ≥ 6 mm, 28 implants
Carcuac et al. [20] (2016) (RCT)	Groups 1 and 2: amoxicillin 2 × 750 mg for 10 days, 3 days prior surgery	Overall PD reduction, 2.58 ± 1.97 mm Group 1, 2.80 ± 1.87 mm Group 2, 3.44 ± 1.66 mm Group 4, 2.16 ± 1.79 mm Group 4, 1.69 ± 2.22 mm Significantly greater in group 2 than in groups 3 and 4 ($p < 0.05$)	Mean reduction, 41.9% Group 1, 39.1% Group 2, 34.8% Group 3, 44.4% Group 4, 51.4% No significant difference among groups ($p < 0.05$)	Presence of suppuration (%) Baseline: mean, 68.7% Group 1, 72.3% Group 2, 65.2% Group 3, 67.3% Group 4, 70.3% After 1 year: mean, 17.4% Group 1, 13% Group 2, 6.5% Group 3, 22.2% Group 4, 31.4%	Mean loss of bone (mm), − 0.21 ± 1.32 mm Groups 1 and 2: bone gain detected Group 1, 0.18 ± 1.15 mm Group 2, 0.51 ± 0.84 mm Groups 3 and 4: bone loss detected Group 4, − 0.69 ± 1.32 mm Group 4, − 0.96 ± 1.42 mm	PD ≤ 5 mm, no BOP, or/and suppuration, bone loss ≤ 0.5 mm 80/178 (44.9%) of the implants 38/99 (38.4%) of the patients
Carcuac et al. [19] (2017) (continuum); Carcuac et al. [20] (2016) (RCT)	Groups 1 and 2: amoxicillin 2 × 750 mg for 10 days, 3 days prior surgery	Overall PD reduction compared to baseline: reduction of 2.73 ± 2.39 mm Group 1, 3.00 ± 2.44 mm Group 2, 2.38 ± 2.55 mm Group 3, 2.67 ± 2.48 mm Group 4, 2.90 ± 2.12 mm PD reduction was more pronounced at nonmodified surface implants	Presence of BOP/suppuration (%) Group 1, 66.2% Group 2, 52.8% Group 3, 70% Group 4, 32.3%	NR	Radiographic bone level changes (mm) mean loss − 0.04 ± 1.14 mm Group 1: gain 0.32 ± 1.64 mm Group 2: loss − 0.51 ± 1.87 mm Group 3: loss − 0.28 ± 1.78 mm Group 4: gain 0.65 ± 0.86 mm	Absence of additional bone loss > 0.5 mm + PD ≤ 5 mm + absence of BOP/suppuration 33.1% (40/121) of the implants
Koldsland et al. [21] (2018) (prospective case series)	Amoxicillin (500 mg × 3) + metronidazole (500 mg × 3), for 10 days starting the day before surgery	Mean baseline deepest PD, 7.6 ± 2.4 mm (range 4–15) After 6 months, 4.9 ± 1.4 mm (range 4–10)	Baseline BOP registered on 76 to 100% of surfaces around the implant, 88% After 6 months, 32%	NR	Mean bone loss (mean ± SD) (mm) Baseline, 4.9 ± 2.6 mm (range 2.0–11.0) After 6 months, 4.6 ± 2.4 mm (range 2.0–10.1)	Level I: no progression of bone loss, PD ≥ 4 mm with BOP 7/143 (5%) of the implants Level II: no progression of bone loss, no PD ≥ 6 mm with BOP 20/143 (14%) of the implants
Hentenaar et al. [22] (2017) (RCT)	No	Baseline: control, 5.3 ± 1.1 mm; test, 5.2 ± 1.1 mm After 3 months: control,	Baseline: control, 100 ± 22%; test, 96.8 ± 30%	Baseline: control, 54.5 ± 12%; test, 80.6 ± 25% After 3 months: control,	NR	NR

Table 2 (continued)

		3.5 ± 1.5 mm; test, 4.1 ± 1.6 mm No significant difference between the groups ($p = 0.205$)	After 3 months: control, 50 ± 10%; test, 76.7 ± 23% No significant difference between the groups ($p = 0.743$)	10.0 ± 2%; test, 20.0 ± 6% No significant difference between the groups ($p = 0.1$)		
Sarmiento et al. [23] (2018) (prospective case series)	Preoperative 2 g amoxicillin 1 h before surgery	Test: baseline, 5.86 ± 0.23 mm; after 6 months, 3.63 ± 0.14 mm Significant reduction ($p < 0.001$) Control: baseline, 6.79 ± 0.27 mm; after 6 months, 4.32 ± 0.16 mm Significant reduction ($p < 0.001$)	Test: baseline, 100%; after 6 months, 0% Significant reduction ($p < 0.001$) Control: baseline, 100%; after 6 months, 14.3% Significant reduction ($p < 0.001$)	NR	NR	NR
Englezos et al. [26] (2018) (prospective case series)	Nonsubmerged	Amoxicillin 3 g per/day for 1 week	Baseline, 8.7 ± 1.6 mm After 2 years, 3.3 ± 1.1 mm Significant reduction ($p \leq 0.001$)	Baseline, 100% After 2 years, 10 out of 40 implants (25%) showed BOP	2.5 ± 0.8 (range 2.0–3.0) (mm)	Baseline mean peri-implant bone resorption, 5.1 ± 1.6 mm After 2 years, 5.3 ± 2.0 mm No significant changes ($p = 0.15$)

SD standard deviation, *NR* not reported, *RCT* randomized controlled clinical study, *BOP* bleeding on probing, *PD* probing pocket depth, *Supp* suppuration, *CHX* chlorhexidine digluconate

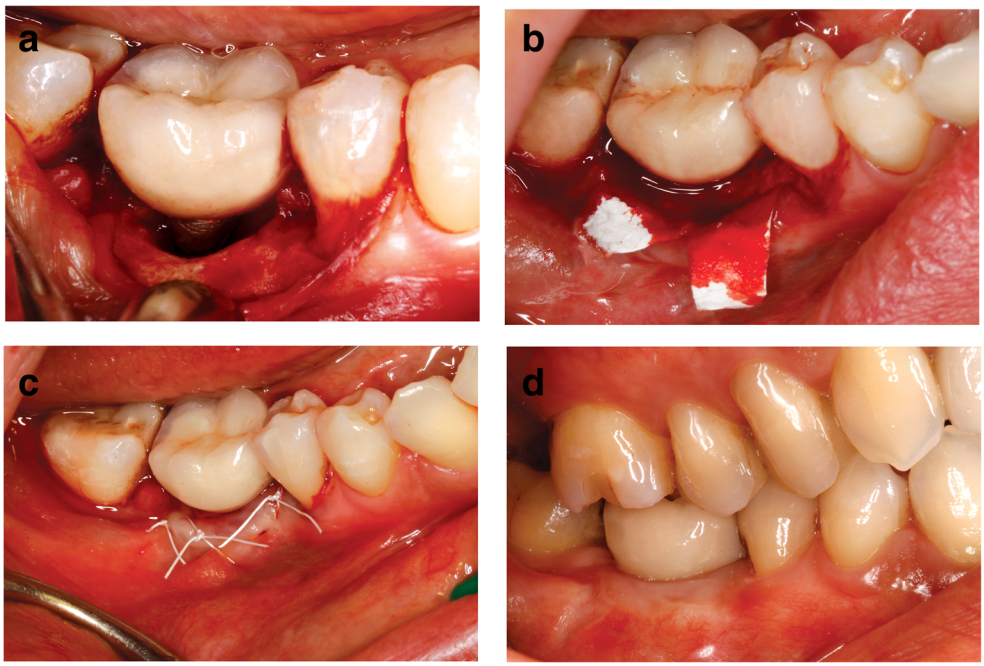

Fig. 2 Peri-implantitis therapy with an augmentative approach. **a** Intrabony circumferential defect at implant 46. **b** Intrabony defect fill with bone substitute and coverage with collagen membrane. **c** Suturing. **d** Intraoral view after 12 months

autogenous bone; alloplastic, xenogenic, and allogenic bone substitutes; and titanium granules [8, 33–35, 37, 38, 40, 44].

Findings of a comparative investigation pointed toward significantly better clinical and radiographic outcomes when using a xenograft over autogenous bone [34]. Superior clinical treatment outcomes were obtained at the implant sites where xenogeneic bone substitute was applied over alloplastic bone particles (i.e., hydroxyapatite) [33]. Furthermore, a significantly higher radiographic fill of peri-implant bone defect resulted was noted at the implant sites treated with titanium particles compared to the xenogenic bone substitute, although the clinical outcomes (i.e., PD and BOP changes) did not differ between the two treatment modalities [40]. It should be, however, elucidated that the findings of the aforementioned comparative investigations should be evaluated with caution since the compared bone fill materials (i.e., autogenous bone vs. xenograft, xenograft vs. titanium granules) exhibit different opacity properties, which may lead to the misinterpretation of the data.

The potential beneficial effect of the application of enamel matrix derivates (EMDs) into intrabony peri-implant defects of ≥ 3 mm depth was investigated over a 5-year period [45, 46]. After 1 year, significantly higher marginal bone levels and an increased prevalence of Gram-positive and Gram-negative aerobic bacteria compared with OFD alone were noted at the implant test sites [45]. However, over the 3-year and 5-year periods, the positive effect associated with the superior marginal bone level was not sustained, as a bone level gain of 1.3 mm was observed in the control group, and a gain of 1.4 mm was noted in the test group, with no significant difference between the two groups ($p = 0.043$) [46].

Conflicting data exist with regard to the rationale for using barrier membranes to improve augmentative treatment outcomes [33, 35, 44]. In particular, two studies did not observe beneficial effects from the adjunctive use of a barrier membrane over autogenous bone or alloplastic bone substitute alone after 3 years and 5 years, respectively [35, 44]. Contrarily, over a 4-year period, the use of a combination of xenogenic bone and a collagen membrane provided better clinical outcomes, in terms of BOP and PD reduction, than hydroxyapatite particles alone [33].

Outcomes of the Therapy

The overall efficacy of augmentative peri-implantitis therapy was assessed in a recent systematic review and meta-analysis [47]. Based on its findings, significant improvement in marginal bone levels (weighted mean difference (WMD) = 2.0 mm), clinical attachment gain (WMD = 1.8 mm), and reduction of the PD values (WMD = 2.8 mm) were obtained at peri-implantitis sites treated with adjunctive-augmentative measures [47]. Assessment of the potential beneficial effects of the augmentative therapy over the controls (i.e., open flap debridement) showed a significantly higher gain in marginal bone levels of 1.7 mm and defect fill (WMD = 57%), favoring augmentative measures [47]. Clinically, augmentative therapy resulted in significant postoperative soft tissue recession (WMD = 0.7 mm), and when compared to the control sites, the therapy failed to produce significant reductions in PD and BOP values [47].

Peri-implant defect morphology has shown to impact upon the augmentative outcomes for the management of peri-implantitis [48]. Specifically, augmentation of

Table 3 Studies reporting on augmentative therapy of peri-implantitis

Author (study type)	General information		Treatment procedure		
	Follow-up period	Number of implants/ patients	Decontamination of implant surface	Augmentation materials	Submerged/ nonsubmerged postoperative healing
Schwarz et al. [33] (2009) (RCT)	4 years	20/21 Test, 9/9 Control, 10/11	Mechanical debridement (plastic curettes) + rinsing with sterile saline	Test: nanocrystalline hydroxyapatite paste Control: bovine-derived xenograft + native collagen barrier membrane	Nonsubmerged
Aghazadeh et al. [34] (2012) (RCT)	12 months	45/71 Test, 23/37 Control, 22/34	Mechanical debridement (titanium instruments) + decontamination using H_2O_2 (1 min)	Test: bovine-derived xenograft + resorbable synthetic barrier membrane Control: autogenous bone chips harvested from the mandibular ramus region + resorbable synthetic barrier membrane	Nonsubmerged
Roos-Jansaker et al. [35] (2014) (controlled clinical study)	5 years	25/45 Test, 13/23 Control, 12/22	Decontamination with H_2O_2 (3 min) + rinsing with sterile saline	Test: algae-derived xenograft + resorbable synthetic membrane Control: algae-derived xenograft	Nonsubmerged
Jepsen et al. [36] (2016) (RCT)	12 months	63/63 Test, 33/33 Control, 30/30	Rotary titanium brush and 3% H_2O_2 (1 min) followed by rinsing with saline (60 s)	Test: titanium granules Control: OFD alone	Nonsubmerged
Roccuzzo et al. [37] (2017) (controlled clinical study)	7 years	26/26 Test, 12/12 Control, 14/14 Test: SLA surface implants Control: TPS surface implants	Mechanical debridement with plastic curettes + decontamination (24% EDTA and 1% CHX gel)	Bovine-derived xenograft	Nonsubmerged
Mercado et al. [38] (2018) (case series)	3 years	30/30	Debridement with ultrasonic scaler + 24% ethylenediaminetetraacetic acid (EDTA) 2 min (PrefGel, Switzerland) + deproteinized	Bovine bone mineral with 10% collagen (DBBMC) mixed with 0.35 ml of enamel matrix derivative (EMD) and 1 capsule of doxycycline 100 mg + in case of no keratinized tissue, connective tissue graft	Nonsubmerged
Renvert et al. [8] (2018) (RCT)	1 year	21/21	Debridement with titanium-coated curettes + decontamination with 3% hydrogen peroxide cotton pellets + rinsing with sterile saline	Test: xenograft particles mixed with subject's blood Control: OFD	Nonsubmerged
Isler et al. [39] (2018) (case series)	12 months	41/60 Test, 20/30 Control, 21/30	Test: mechanical debridement with titanium curettes + irrigation with saline (3 min) + ozone application Control: mechanical debridement with titanium curettes + irrigation with saline (3 min)	Bovine bone mineral mixed with pieces of concentrated growth factors (CGF) + coverage with CGF membranes	Nonsubmerged

Table 3 (continued)

Author (study type)	Treatment procedure	Treatment outcomes				
	Systemic antibiotics	PD changes (mm) (SD; range)	BOP/Supp changes (%) (SD; range)	Soft tissue recession (mm)	Radiographic outcomes	Treatment success, definition, and outcome
Schwarz et al. [33] (2009) (RCT)	No	Subject level Mean PD reduction (mm): test, 1.1 ± 0.3 mm; control, 2.5 ± 0.9 mm	Mean BOP reduction (mean ± SD) (%): test, 32%; control, 51%	Mean gingival recession increase (mm): test, 0.4 ± 0.5 mm; control, 0.5 ± 0.4 mm Mean clinical attachment level changes (mm): test, 0.6 ± 05 mm; control, 2.0 ± 1.0 mm	NR	NR
Aghazadeh et al. [34] (2012) (RCT)	Postoperative antibiotics azithromycin 2 × 250 mg for 1 day, 1 × 250 mg for 2–4 days	Implant level Mean PD decrease (mean ± SD) (mm): test, 3.1 ± 0.2 mm; control, 2.0 ± 0.2 mm Significantly higher in the test group ($p < 0.01$)	Mean BOP reduction (%): test, 50.4 ± 5.3%; control, 44.8 ± 6.3% No significant difference between the groups ($p > 0.05$) Mean suppuration reduction (%): test, 25.2 ± 4.3%; control, 11.5 ± 5.2% Significantly higher in the test group ($p < 0.01$)	NR	Mean radiographic bone defect fill (mean ± SD) (mm): test, 1.1 ± 0.3 mm; control, 0.2 ± 0.3 mm Significantly higher in the test group ($p < 0.05$)	Successful treatment outcome defined by PD ≤ 5 mm, no BOP, no suppuration (at any implant surface), and gain or no loss of alveolar bone Test, 8 implants (20.5%) Control, 4 implants (11.1%)
Roos-Jansaker et al. [35] (2014) (controlled clinical study)	Amoxicillin 375 mg × 3 per day + metronidazole 400 mg × 2 per day, 10 days following the surgery	Implant level PD reduction at the deepest site (mm): test, 3.0 ± 2.4 mm; control, 3.3 ± 2.0 mm No significant difference between the groups ($p = 0.60$)	NR	Mucosal recession changes at the deepest site (mean ± SD) (mm): test, − 1.6 ± 1.5 mm; control, − 1.7 ± 2.1 mm No significant difference between the groups ($p = 0.89$)	Radiographic defect fill (mean ± SD) (mm): test, 1.5 ± 1.2 mm; control, 1.1 ± 1.2 mm No significant difference between the groups ($p = 0.24$)	Radiographic evidence of ≥ 25% bone fill, PD ≤ 5 mm, bleeding of probing score ≤ 1 51.1% (23/45) of the implants
Jepsen et al. [36] (2016) (RCT)	Amoxicillin 500 mg 3 times/day + metronidazole 400 mg 2 times/day, 8 days, starting 1 day before surgery	Implant level PD reduction (mean ± SD) (mm): test, 2.8 ± 1.3 mm; control, 2.6 ± 1.4 mm	BOP reduction (mean ± SD) (%): test, 56.1 ± 30.5%; control, 44.9 ± 38.2%	NR	Radiographic defect height reduction (mean ± SD (mm) Mesial/distal: test, 3.61 ± 1.96/3.56 ± 2.07 mm; control, 1.05 ± 1.42/1.04 ± 1.34 mm	Complete disease resolution: PD ≤ 4 mm, no BOP at 6 implant sites, and no further bone loss 30% (10/33) of the implants

Table 3 (continued)

		Significant reduction compared to baseline ($p < 0.001$) No significant difference between groups ($p > 0.05$)	Significant reduction compared to baseline ($p < 0.001$) No significant difference between groups ($p > 0.05$) Suppuration reduction (mean ± SD) (%): test, 23.2 ± 32.8%; control, 25.6 ± 32.7% Significant reduction compared to baseline ($p < 0.001$) No significant difference between groups ($p > 0.05$)		Significantly higher in the test group ($p < 0.0001$) Mean radiographic intrabony defect fill (mean ± SD) (%) Mesial/distal: test, 79.00 ± 29.85%/74.22 ± 36.33-%; control, 23.11 ± 46.28%/21.89 ± 30.16-% Significantly higher in the test group ($p < 0.0001$)	
Roccuzzo et al. [37] (2017) (controlled clinical study)	1 g of amoxicillin + clavulanic acid 2 times/day, 6 days	Implant level PD changes (mean ± SD) (mm) Baseline: test, 6.6 ± 1.3 mm; control, 7.3 ± 1.5 mm After 7 years: test, 3.2 ± 0.7 mm; control, 3.4 ± 0.6 mm Significantly higher reduction in the test group ($p = 0.01$) Significant improvement compared to baseline ($p < 0.001$)	BOP changes (mean ± SD) (%) Baseline: test, 75.0 ± 31.2%; control, 90.0 ± 12.9% After 7 years: test, 7.5 ± 12.1%; control, 30.0 ± 19.7% Significant improvement compared to baseline ($p < 0.001$) Presence of suppuration, % of implants Baseline: test, 4 (40%); control, 7 (70%) After 7 years: test, 0 (0%); control, 1 (10%)	NR	Mean bone level decrease (mean ± SD) (mm) Baseline: test, 2.9 ± 0.9 mm; control, 3.7 ± 1.6 mm After 7 years: test, 0.8 ± 1.0 mm; control, 1.7 ± 0.9 mm Significantly higher reduction in the control group ($p = 0.03$)	PD < 5 mm, no BOP or suppuration, no further bone loss Test, 7/12 (58.3%) of the implants Control, 2/14 (14.3%) of the implants Significantly higher success in the test group ($p = 0.04$)
Mercado et al. [38] (2018) (case series)	No	Implant level Mean PD changes (mm) Baseline, 8.90 ± 1.9 mm After 3 years, 3.5 ± 0.05	Mean BOP changes (%) Baseline, 100% After 3 years, 20%	Mid-buccal recession changes (mm) Baseline, 0.16 ± 0.14 mm After 3 years, 0.22 ± 0.19 mm No significant increase	Bone loss (mean ± SD) (mm) Baseline, 6.92 ± 1.26 mm After 3 years, 2.60 ± 0.73 mm Significant reduction compared to the baseline ($p < 0.01$) Bone loss (mean ± SD) (%) Baseline, 57 ± 16.5	PD < 5 mm, no further bone loss > 10%, no BOP or suppuration, recession of < 0.5 mm for the anterior implants and < 1.5 mm for posterior implants 57.7% (17/30) of implants

Table 3 (continued)

		Significant reduction compared to the baseline ($p < 0.01$)			After 3 years, 14.5 ± 0.73 Significant reduction compared to the baseline ($p < 0.01$)	
Renvert et al. [8] (2018) (RCT)	Zithromax (Sandoz AS, Copenhagen, Denmark) 500 mg for 1 day and 250 mg for 2–4 days	Mean PD values: Test: baseline, 6.6 ± 1.8 mm; after 1 year, 2.61 ± 1.5 mm Significant reduction ($p < 0.001$) Control: baseline, 6.0 ± 1.7 mm; after 1 year, 3.9 ± 2.7 mm Significant reduction ($p < 0.001$)	Baseline: 100% implants presented BOP After 1 year: test, 11 implants presented with BOP (52.4%); control, 35% of implants No significant difference ($p = 0.41$)	Mean extent of soft tissue recession: test, 1.2 mm; control, 1.9 mm	Bone level changes (mm): test, 0.7 ± 0.9 mm; control, 0.2 ± 0.6 mm	Radiographic defect fill ≥ 1.0 mm + PD ≤ 5 mm + no BOP (1 dot of bleeding out of 4 sites per implant accepted) Test, 9/21 (42.3%) of the patients Control, 1/20 (5%) of the patients
Isler et al. [39] (2018) (case series)	Amoxicillin (500 mg) + metronidazole (500 mg) 3 times/day for 1 week	Baseline: test, 6.27 ± 1.42 mm; control, 5.73 ± 1.11 mm After 12 months: test, 2.75 ± 0.7 mm; control, 3.34 ± 0.85 mm Significant reduction compared to the baseline ($p < 0.001$) No difference between the groups ($p = 0.158$)	Baseline: test, 96.6 ± 10.5; control, 97.5 ± 10.06 After 12 months: test, 15.8 ± 19.1; control, 25 ± 21.7 Significant reduction compared to the baseline ($p < 0.001$) No difference between the groups ($p = 0.575$)	Baseline: test, 0.12 ± 0.14 mm; control, 0.25 ± 0.42 mm After 12 months: test, 0.48 ± 0.75 mm; control, 0.55 ± 0.64 mm Significant reduction compared to the baseline ($p < 0.01$) No difference between the groups ($p = 0.753$)	Bone defect fill(mm): test, 2.32 ± 1.28 mm; control, 1.17 ± 0.77 mm Significantly higher fill in the test group ($p = 0.02$)	PD < 5 mm + no BOP/suppuration + no further bone loss + radiographic defect fill ≥ 1 mm Test, 50% of the implants Control, 36.6% of the implants No difference between the groups ($p = 0.62$)

SD standard deviation, *NR* not reported, *RCT* randomized controlled clinical study, *BOP* bleeding on probing, *PD* probing pocket depth, *Supp* suppuration, *CHX* chlorhexidine digluconate, *OFD* open flap debridement

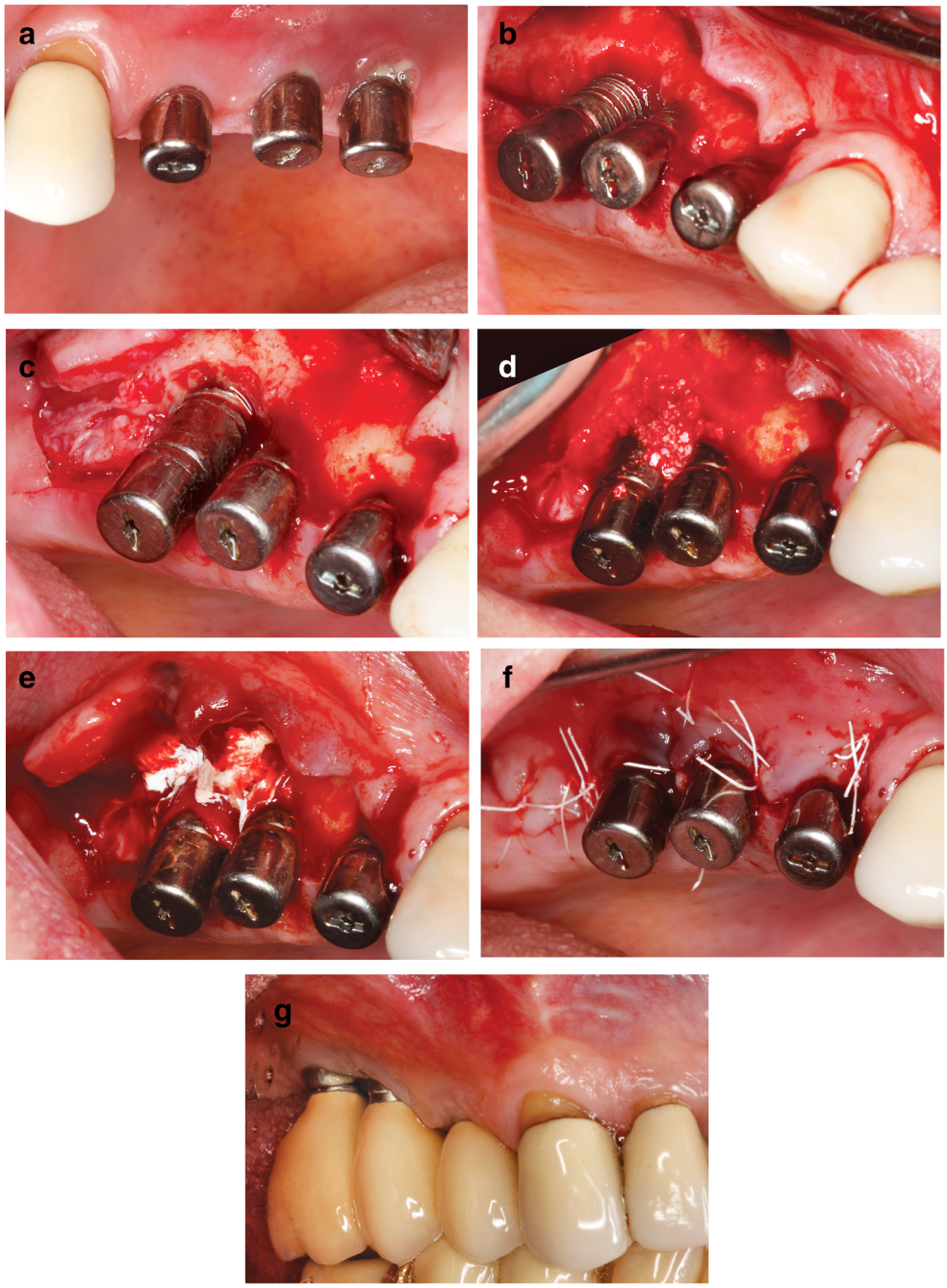

Fig. 3 Combined peri-implantitis therapy. **a** Presurgical view following the removal of a suprastructure. Suppuration detected at implants placed in regions 15 and 16. **b** Raising of full-thickness flap and removal of granulation tissues. **c** Implantoplasty performed at the supracrestally and buccally exposed implant surfaces. **d** Intrabony defect at implant 16 filled with bone substitute. **e** Placement of collagen membrane over the bone substitute. **f** Suturing. **g** Clinical view after 6 months

circumferential peri-implant defects resulted in higher PD reduction and clinical attachment level (CAL) gain at 6 months and 12 months compared with the dehiscence-type defects [48]. Furthermore, treatment success (defined as PD < 5 mm, no BOP or Supp, and no further bone loss) was more frequently achieved for rough-surfaced implants versus moderately rough implants (14% vs. 58%, respectively) [37].

Combined Therapy

Combined peri-implantitis therapy includes implantoplasty (i.e., mechanical modification of the implant surface) performed at implant sites where no bone regeneration is expected (i.e., supracrestally and buccally exposed implant parts) followed by augmentation of the intrabony defect components [48]. This surgical approach might be applicable in the majority of peri-

Table 4 Studies reporting on combined peri-implantitis therapy

Author (study type)	General information		Treatment procedure		
	Follow-up period	Number of implants/patients	Decontamination of implant surface	Augmentation materials	Submerged/nonsubmerged postoperative healing
Matarasso et al. [29] (2014) (prospective case series)	1 year	11/11	Implantoplasty at suprabony exposed implant parts + air-abrasive device with glycine powder for intrabony defect (30 s) + rinsing with saline solution (30 s)	Deproteinized bovine bone mineral + resorbable membrane	Nonsubmerged
Schwarz et al. [50] (2014) (case series)	6 months	10/13	Implantoplasty at buccally and supracrestally exposed implant parts + decontamination of unmodified surface with plastic curettes and cotton pellets soaked in saline	Bovine-derived xenograft + native collagen membrane at intrabony components + connective tissue graft from the palate on the buccal aspect	Nonsubmerged
Schwarz et al. [27] (2017) (RCT)	7 years	15/15 Test, 6/6 Control, 9/9	Test: Er:YAG laser device (cone-shaped glass fiber tip) at 11.4 J/cm^2 + implantoplasty at buccally and supracrestally exposed implant parts Control: mechanical debridement (plastic curette) + decontamination (cotton pellets soaked in saline) implantoplasty at buccally and supracrestally exposed implant parts	Bovine-derived xenograft + native collagen membrane	Nonsubmerged
Nart et al. [51] (2018) (case series)	1 year	13/17	Mechanical debridement with stainless steel curette + implantoplasty supracrestally + intrabony defect debrided with ultrasonic devise + 3% H_2O_2 (1 min) + rinsing with saline	50% particulated mineralized cancellous allograft impregnated with trombomycine and 50% impregnated with vancomycin + collagen membrane	Nonsubmerged
de Tapia et al. [28] (2019) (RCT)	1 year	30/30 Test, 15/15 Control, 15/15	Implantoplasty supracrestally with diamond burs and Arkansas stone Control: mechanical debridement using plastic ultrasonic scalers + rinsing with 3% H_2O_2 Test: + titanium brush with an oscillating low speed	Alloplastic bone substitute (Straumann bone ceramic) + collagen membrane	Nonsubmerged

Author (study type)	Treatment procedure	Treatment outcomes				
	Systemic antibiotics	PD changes (mm) (SD; range)	BOP/Supp changes (%) (SD; range)	Soft tissue recession (mm)	Radiographic outcomes	Treatment success, definition, and outcome
Matarasso et al. [29] (2014) (prospective case series)	Amoxicillin 875 mg + clavulanic acid 125 mg, 5 days	Implant level Mean PD changes (mean ± SD) (mm): baseline, 8.1 ± 1.8 mm; after 12 months, 4.0 ± 1.3 mm Significant reduction compared to the baseline ($p = 0.032$)	BOP changes (mean ± SD) (%): baseline, 19.7 ± 40.1%; after 12 months, 6.1 ± 24.0% Significant reduction compared to baseline ($p = 0.001$)	Clinical attachment level changes (mean ± SD) (mm): baseline, 9.7 ± 2.5 mm; after 12 months, 6.7 ± 2.5 mm Significant reduction ($p < 0.001$) Mucosal recession changes (mean ± SD) (mm): baseline, 1.7 ± 1.5 mm; after 12 months, 3.0 ± 1.8 mm Significant increase ($p < 0.003$)	Radiographic marginal bone level changes (mean ± SD) (mm): baseline, 8.0 ± 3.7; after 12 months, 5.2 ± 3.0 Significant decrease ($p < 0.001$) Radiographic mean bone defect fill (mean ± SD) (%), 93.3 ± 13.0% Radiographic depth of intrabony defect (mean ± SD) (mm): baseline, 3.5 ± 3.5 mm; after 12 months, 0.5 ± 13.0 mm Significant reduction ($p < 0.001$)	NR

Table 4 (continued)

Schwarz et al. [50] (2014) (case series)	Amoxicillin 2 × 1000 mg/day (in case of allergy: clindamycin 2 × 600 mg/day) 1 h before and 5 days postoperatively	Implant level Mean PD reduction (mean ± SD) (mm), 2.53 ± 1.80 mm Significant improvement compared to the baseline ($p = 0.001$)	Mean BOP reduction (mean ± SD) (%), 74.39 ± 28.52% Significant improvement compared to the baseline ($p = 0.001$)	Mucosal recession changes at the buccal aspect (mm), 0.07 ± 0.5 mm No significant increase compared to the baseline ($p = 0.841$) Clinical attachment level changes (mean ± SD) (mm), 2.07 ± 1.93 mm Significant reduction compared to the baseline ($p = 0.003$)	NR	NR
Schwarz et al. [27] (2017) (RCT)	No	Subject level Mean PD reduction (mm): test, 0.74 ± 1.89 mm; control, 2.55 ± 1.67 mm Significant improvement compared to the baseline ($p < 0.001$)	Mean BOP reduction (%): test, 86.66 ± 18.26%; control, 89.99 ± 11.65% Significant improvement compared to baseline ($p < 0.001$)	Mean mucosal recession reduction (mm): test, 1.36 ± 1.04 mm; control, 0.49 ± 0.92 mm Clinical attachment level gain (mean ± SD) (mm): test, 2.06 ± 2.52 mm; control, 2.76 ± 0.92 mm	NR	No BOP Total, 9/15 patients (60%) Test, 4 out of 6 patients Control, 5 out of 9 patients
Nart et al. [51] (2018) (case series)	No	Implant level PD changes (mm): baseline deepest PD, 7.88 ± 1.22 mm; after 12 months, 4.23 ± 1.62 mm Significant reduction compared to the baseline ($p = 0.001$)	Mean BOP reduction (%), 70.6% Significant compared to the baseline ($p = 0.001$) Suppuration on probing (%): baseline, 88.2%; after 12 months, 0% Significant reduction compared to the baseline ($p = 0.001$)	Mucosal recession (mm): baseline, 0.1 ± 0.31 mm; after 12 months, 1.42 ± 0.50 mm Significant increase compared to the baseline ($p = 0.001$)	Mean radiographic intrabony defects (mm): baseline, 4.33 ± 1.62; after 12 months, 0.56 ± 0.88 mm Significant reduction compared to the baseline ($p = 0.001$). Mean bone defect fill (mean ± SD) (mm), 86.99 ± 18.2%	NR
de Tapia et al. [28] (2019) (RCT)	Combination of 500 mg amoxicillin and 500 mg metronidazole 3 times a day, for 7 days	Mean PD changes between baseline and 12 month: test, 2.19 mm ± 1.31 mm; control: 2.84 ± 0.93 mm ($p = 2.04$) PD changes at the deepest site: test, 2.85 ± 1.91 mm; control, 4.87 ± 1.55 mm ($p = 0.009$)	Baseline: test, 100%; control, 100% After 12 months: test, 79%; control, 55% ($p = 0.147$) Supp Baseline: test, 43%; control, 47% After 12 months: test, 0%; control, 23% ($p = 0.053$)	Baseline: test, 100%; control, 100 After 12 months: test, 79%; control, 55% ($p = 0.147$)	Test, 0.4 ± 0.45 mm Control, 0.6 ± 0.62 mm ($p = 0.374$)	Absence of PD ≥ 5 mm, no BOP/suppuration, no additional bone loss Test, 10/15 patients (66.7%) Control, 3/15 patients (23.1%) ($p = 0.021$)

SD standard deviation, *NR* not reported, *RCT* randomized controlled clinical study, *BOP* bleeding on probing, *PD* probing pocket depth, *Supp* suppuration

implantitis cases, as more than half of naturally occurring peri-implantitis sites (79%) have a combined configuration, including intrabony and suprabony components [49].

Procedure

Combined peri-implantitis surgery comprises the following steps (Fig. 3):

- Access to the defect
- Removal of inflamed tissues
- Decontamination of the implant surface
- Implantoplasty performed at buccally and supracrestally exposed implant parts
- Grafting of the intrabony defect (bone substitute + barrier membrane) with or without a connective tissue graft
- Adequate flap adaptation

With respect to the method of implant surface decontamination, over a 12-month period, the use of titanium brushes (i.e., mechanical debridement with an ultrasonic scaler + rinsing with 3% H_2O_2 + titanium brush) led to significantly better PD reduction (4.87 mm vs. 2.85 mm) and bone defect fill (2.61 mm vs. 1.17 mm) compared with the controls (i.e., mechanical debridement with ultrasonic scaler + rinsing with 3% H_2O_2) [28] (Table 4). Contrarily, during a 7-year follow-up period, Er:YAG laser application showed similar treatment outcomes to debridement with plastic curettes and cotton pellets soaked in sterile saline [27].

For the reconstruction of the intrabony defects, xenogenic bone substitute or antibiotic impregnated allograft was used in conjunction with collagen membrane (Table 4) [29, 50, 51]. A concomitant soft tissue augmentation with a concomitant connective tissue graft placed on the buccal aspect performed with a combined peri-implantitis therapy after 6 months led to a mean gain in facial soft tissue height of 0.07 mm around 13 implant sites [50].

Outcomes of the Therapy

Compared with the baseline, combined peri-implantitis therapy significantly reduces BOP, PD, and Supp [27, 29, 51]. A significant reduction in intrabony defects, with a mean radiographic intrabony defect fill of 87 to 93%, was detected after 1 to 7 years [29, 51]. The rate of successful treatment (defined as the absence of PD ≥ 5 mm, no BOP/Supp, and no additional bone loss) was significantly higher for the patients whom titanium brushes were adjunctively used for decontaminating the implant surface (66.7% (10/15) vs. 23.1% (3/15)) [28]. Peri-implant tissue health (i.e., absence of BOP) was detected in 60% (9/15) of the patients 7 years after the combined therapy [27]. As indicated by the retrospective data, disease resolution (i.e., the absence of BOP and PD ≥ 6 mm) was obtained in 28% (11/39) of the patients at 6 months to 10 years following combined peri-implantitis therapy [52].

Summary

The disease severity, the defect's regenerative potential, and patient expectations should be evaluated prior to choosing a surgical technique for peri-implantitis management. OFD with or without adjunctive resective measures may be indicated in the presence of horizontal bone loss. Implantoplasty as a part of peri-implantitis surgical therapy may improve soft tissue inflammatory status; however, it can lead to more extensive mucosal recession. At peri-implantitis sites exhibiting intrabony defects, augmentative measures should be favored. In more advanced cases with combined defect configurations, a combination of augmentative and resective measures may be feasible. Soft tissue volume grafting as an adjunct to surgical peri-implant therapy may be effective to overcome mucosa recession in the aesthetic zone.

Funding Information Open Access funding provided by Projekt DEAL.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:
- • Of importance
- •• Of major importance

1.• Berglundh T, et al. Peri-implant diseases and conditions: consensus report of workgroup 4 of the 2017 world workshop on the classification of periodontal and Peri-implant diseases and conditions. J

Periodontol. 2018;89(Suppl 1):S313–s318 **This manuscript is a part of the World Workshop on the Classification of Periodontal and Peril-Implant Diseases and Conditions (2017), and presents classifications and diagnostic criteria for peri-implant diseases.**

2.•• Schwarz F, et al. Peri-implantitis. J Periodontol. 2018;89(Suppl 1): S267–s290 **This manuscript provides a current update on etiology, clinical characteristics, and risk factors/indicators for peri-implantitis.**

3.•• Derks J, et al. Peri-implantitis - onset and pattern of progression. J Clin Periodontol. 2016;43(4):383–8 **This clinical analysis evaluates the clinical characteristics of peri-implant diseases that are of great relevance in a clinical practice.**

4. Derks J, et al. Effectiveness of implant therapy analyzed in a Swedish population: prevalence of Peri-implantitis. J Dent Res. 2016;95(1):43–9.

5. Sanz M, Chapple IL. Clinical research on peri-implant diseases: consensus report of working group 4. J Clin Periodontol. 2012;39(Suppl 12):202–6.

6. Ramanauskaite A, Daugela P, Juodzbalys G. Treatment of peri-implantitis: meta-analysis of findings in a systematic literature review and novel protocol proposal. Quintessence Int. 2016;47(5): 379–93.

7. Klinge B, et al. Peri-implant diseases. Eur J Oral Sci. 2018;126(Suppl 1):88–94.

8. Renvert S, Roos-Jansaker AM, Persson GR. Surgical treatment of peri-implantitis lesions with or without the use of a bone substitute-a randomized clinical trial. J Clin Periodontol. 2018;45(10):1266–74.

9. Lang NP, Salvi GE, Sculean A. Nonsurgical therapy for teeth and implants-when and why? Periodontol. 2019;79(1):15–21.

10.•• Heitz-Mayfield LJA, et al. Supportive peri-implant therapy following anti-infective surgical peri-implantitis treatment: 5-year survival and success. Clin Oral Implants Res. 2018;29(1):1–6 **This is a clinical study evaluates the mid-term (5-years) peri-implantitis surgical treatment success among the patients enrolled in a regular supportive therapy.**

11. Serino G, Turri A, Lang NP. Maintenance therapy in patients following the surgical treatment of peri-implantitis: a 5-year follow-up study. Clin Oral Implants Res. 2015;26(8):950–6.

12. Hallstrom H, et al. Open flap debridement of peri-implantitis with or without adjunctive systemic antibiotics: a randomized clinical trial. J Clin Periodontol. 2017;44(12):1285–93.

13. Toma S, Brecx MC, Lasserre JF. Clinical evaluation of three surgical modalities in the treatment of Peri-Implantitis: a randomized controlled clinical trial. J Clin Med. 2019;8(7):966.

14. Cha JK, Lee JS, Kim CS. Surgical therapy of Peri-Implantitis with local minocycline: a 6-month randomized controlled clinical trial. J Dent Res. 2019;98(3):288–95.

15. Papadopoulos CA, et al. The utilization of a diode laser in the surgical treatment of peri-implantitis. A randomized clinical trial. Clin Oral Investig. 2015;19(8):1851–60.

16. Keeve PL, et al. Surgical treatment of Periimplantitis with non-augmentative techniques. Implant Dent. 2019;28(2):177–86.

17. de Waal YC, et al. Implant decontamination during surgical peri-implantitis treatment: a randomized, double-blind, placebo-controlled trial. J Clin Periodontol. 2013;40(2):186–95.

18. de Waal YC, et al. Implant decontamination with 2% chlorhexidine during surgical peri-implantitis treatment: a randomized, double-blind, controlled trial. Clin Oral Implants Res. 2015;26(9):1015–23.

19. Carcuac O, et al. Surgical treatment of peri-implantitis: 3-year results from a randomized controlled clinical trial. J Clin Periodontol. 2017;44(12):1294–303.

20. Carcuac O, et al. Adjunctive systemic and local antimicrobial therapy in the surgical treatment of Peri-implantitis: a randomized controlled clinical trial. J Dent Res. 2016;95(1):50–7.

21. Koldsland OC, Wohlfahrt JC, Aass AM. Surgical treatment of peri-implantitis: prognostic indicators of short-term results. J Clin Periodontol. 2018;45(1):100–13.

22. Hentenaar DFM, et al. Implant decontamination with phosphoric acid during surgical peri-implantitis treatment: a RCT. Int J Implant Dent. 2017;3(1):33.

23. Sarmiento HL, et al. Surgical alternatives for treating Peri-implantitis. Int J Periodontics Restorative Dent. 2018;38(5):665–71.

24. Romeo E, et al. Therapy of peri-implantitis with resective surgery. A 3-year clinical trial on rough screw-shaped oral implants. Part I: clinical outcome. Clin Oral Implants Res. 2005;16(1):9–18.

25. Romeo E, et al. Therapy of peri-implantitis with resective surgery. A 3-year clinical trial on rough screw-shaped oral implants. Part II: radiographic outcome. Clin Oral Implants Res. 2007;18(2):179–87.

26. Schwarz F, et al. Combined surgical therapy of advanced peri-implantitis evaluating two methods of surface decontamination: a 7-year follow-up observation. J Clin Periodontol. 2017;44(3):337–42.

27. de Tapia B, et al. The adjunctive effect of a titanium brush in implant surface decontamination at peri-implantitis surgical regenerative interventions: a randomized controlled clinical trial. J Clin Periodontol. 2019;46(5):586–96.

28. Matarasso S, et al. Clinical and radiographic outcomes of a combined resective and regenerative approach in the treatment of peri-implantitis: a prospective case series. Clin Oral Implants Res. 2014;25(7):761–7.

29. Ramanauskaite A, et al. Surgical non-regenerative treatments for peri-implantitis: a systematic review. J Oral Maxillofac Res. 2016;7(3):e14.

30. Englezos E, et al. Resective treatment of Peri-implantitis: clinical and radiographic outcomes after 2 years. Int J Periodontics Restorative Dent. 2018;38(5):729–35.

31. Berglundh T, Wennstrom JL, Lindhe J. Long-term outcome of surgical treatment of peri-implantitis. A 2-11-year retrospective study. Clin Oral Implants Res. 2018;29(4):404–10.

32. Jepsen S, et al. Regeneration of alveolar ridge defects. Consensus report of group 4 of the 15th European workshop on periodontology on bone regeneration. J Clin Periodontol. 2019;46(Suppl 21):277–86.

33. Aghazadeh A, Rutger Persson G, Renvert S. A single-Centre randomized controlled clinical trial on the adjunct treatment of intrabony defects with autogenous bone or a xenograft: results after 12 months. J Clin Periodontol. 2012;39(7):666–73.

34. Roos-Jansaker AM, et al. Surgical treatment of peri-implantitis using a bone substitute with or without a resorbable membrane: a 5-year follow-up. J Clin Periodontol. 2014;41(11):1108–14.

35. Jepsen K, et al. Reconstruction of Peri-implant osseous defects: a Multicenter randomized trial. J Dent Res. 2016;95(1):58–66.

36. Schwarz F, et al. Surgical regenerative treatment of peri-implantitis lesions using a nanocrystalline hydroxyapatite or a natural bone mineral in combination with a collagen membrane: a four-year clinical follow-up report. J Clin Periodontol. 2009;36(9):807–14.

37. Roccuzzo M, et al. Surgical treatment of peri-implantitis intrabony lesions by means of deproteinized bovine bone mineral with 10% collagen: 7-year-results. Clin Oral Implants Res. 2017;28(12): 1577–83.

38. Mercado F, Hamlet S, Ivanovski S. Regenerative surgical therapy for peri-implantitis using deproteinized bovine bone mineral with 10% collagen, enamel matrix derivative and doxycycline-a prospective 3-year cohort study. Clin Oral Implants Res. 2018;29(6): 583–91.

39. Guler B, et al. The comparison of porous titanium granule and xenograft in the surgical treatment of Peri-Implantitis: a prospective clinical study. Clin Implant Dent Relat Res. 2017;19(2):316–27.

40. Koo KT, et al. Implant surface decontamination by surgical treatment of Periimplantitis: a literature review. Implant Dent. 2019;28(2):173–6.
41. Ramanauskaite A, et al. Surgical treatment of Periimplantitis with augmentative techniques. Implant Dent. 2019;28(2):187–209.
42. Khoury F, et al. Surgical treatment of peri-implantitis - consensus report of working group 4. Int Dent J. 2019;69(Suppl 2):18–22.
43. Khoury F, Buchmann R. Surgical therapy of peri-implant disease: a 3-year follow-up study of cases treated with 3 different techniques of bone regeneration. J Periodontol. 2001;72(11):1498–508.
44. Isehed C, et al. Effectiveness of enamel matrix derivative on the clinical and microbiological outcomes following surgical regenerative treatment of peri-implantitis. A randomized controlled trial. J Clin Periodontol. 2016;43(10):863–73.
45. Isehed C, et al. Surgical treatment of peri-implantitis using enamel matrix derivative, an RCT: 3- and 5-year follow-up. J Clin Periodontol. 2018;45(6):744–53.
46. Tomasi C, et al. Efficacy of reconstructive surgical therapy at peri-implantitis-related bone defects. A systematic review and meta-analysis. J Clin Periodontol. 2019;46(Suppl 21):340–56.
47. Schwarz F, et al. Impact of defect configuration on the clinical outcome following surgical regenerative therapy of peri-implantitis. J Clin Periodontol. 2010;37(5):449–55.
48. Schwarz F, et al. Comparison of naturally occurring and ligature-induced peri-implantitis bone defects in humans and dogs. Clin Oral Implants Res. 2007;18(2):161–70.
49. Schwarz F, Sahm N, Becker J. Combined surgical therapy of advanced peri-implantitis lesions with concomitant soft tissue volume augmentation. A case series. Clin Oral Implants Res. 2014;25(1):132–6.
50. Nart J, et al. Vancomycin and tobramycin impregnated mineralized allograft for the surgical regenerative treatment of peri-implantitis: a 1-year follow-up case series. Clin Oral Investig. 2018;22(6):2199–207.
51. Ramanauskaite A, et al. Clinical outcomes following surgical treatment of peri-implantitis at grafted and non-grafted implant sites: a retrospective analysis. Int J Implant Dent. 2018;4(1):27.
52. Isler SC, et al. The effects of ozone therapy as an adjunct to the surgical treatment of peri-implantitis. J Periodontal Implant Sci. 2018;48(3):136–51.