Successful Surgical Protocols in the Treatment of Peri-Implantitis: A Narrative Review of the Literature

Stuart J. Froum, DDS, PC,* Alex S. Dagba, DDS, CES,† Ye Shi, DDS,‡ Alejandro Perez-Asenjo, DDS,§ Paul S. Rosen, DMD, MS,¶ and Wendy C. W. Wang, BDS, MSc‡

Background: *The aim was to identify and evaluate those surgical protocols reporting on positive clinical outcomes for treating peri-implantitis with 12 or more months of follow-up. Method of surface decontamination (SDC) was evaluated for any correlation with outcomes.*

Results: *A literature search was performed of all articles published in English between January 1, 2001 and April 30, 2015. Of the 639 identified, 26 satisfied the inclusion criteria. Outcomes reported on included reductions in bleeding on probing (BoP) and probing depth (PD), mean radiographic bone fill (RBF), and mean change in marginal soft tissue levels (MR±). Methods of SDC included mechanical debridement (MD) with and without saline use, MD plus laser or photodynamic therapy, MD with air powder abrasion, MD with chemotherapeutic implant surface decontamination, and combination approaches. The results suggested that various methods of SDC were effective. Heterogeneity of the studies made it impossible to determine correlations between clinical outcome and SDC method. Most studies over 12 months reporting better treatment outcomes employed a bone replacement. Additionally, studies where patients with periodontitis were treated before their peri-implantitis care also had better outcomes.*

Conclusion: *The current review failed to reveal any correlation between any particular method for SDC or defect treatment protocol and positive clinical outcomes. Further comparative studies are warranted to determine the most appropriate approach for both of these topics. (Implant Dent 2016;25: 1–11)*

Key Words: implant surface decontamination, implant surface detoxification, peri-implantitis, treatment outcomes, re-osseointegration

Peri-implantitis has been defined as an inflammatory disease of the soft tissues surrounding an implant accompanied by bone loss that exceeds normal physiologic remodeling.[1,2] The etiology of this disease has been identified as bacterial biofilm forming on the implant surface, which interacts with the host tissue leading to the destruction of supporting bone.[3–6] Some authors have included "Triggering Factors" that they claim can act synergistically with each of the etiologic agents. The list of the latter includes lesions of peri-implant attachment, presence of aggressive bacterial strains, excessive mechanical stress, and corrosion.[7] However, 6 recently published studies identified bacteria (oral microbiome) as a main etiologic agent in peri-implantitis.[8–13] Treatment of peri-implantitis varies significantly as evidenced by 9 literature reviews on the subject, each describing a variety of techniques with different strategies.[14–22]

However, these classical systematic reviews and meta-analyses and the strength of their conclusions are limited by the strength of the literature upon which they are based. Unfortunately, as noted in 2 of the most recent systematic reviews, the heterogeneity and the many variables in the studies included in the reviews forced the authors to conclude that more well-controlled studies are needed with less heterogeneity, greater sample size, and longer follow-up periods.

*Clinical Professor and Director of Clinical Research, Department of Periodontology and Implant Dentistry, New York University College of Dentistry, New York, NY; Private Practice, New York, NY.
†Former Resident, Department of Periodontology and Implant Dentistry, New York University College of Dentistry, New York, NY; Private Practice, Paris, France.
‡Resident, Department of Periodontology and Implant Dentistry, New York University College of Dentistry, New York, NY.
§Visiting Clinical Instructor, Department of Periodontology and Implant Dentistry, New York University College of Dentistry, New York, NY.
¶Clinical Professor of Periodontics, Department of Periodontology, Baltimore College of Dental Surgery, University of Maryland, Baltimore, MD; Private Practice, Yardley, Pennsylvania.

Reprint requests and correspondence to: Stuart J. Froum, DDS, PC, 17 W. 54th Street, Suite 1C/D, New York, NY 10019, Phone: 212-586-4209, Fax: 212-246-7599, E-mail: dr.froum@verizon.net

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Table 1. Mechanical Debridement (MD) With or Without the Use of Saline

Study	Study Design	N Implant/ N Patient	Disease Definition	SDC	Surgical Method	Frequency of Maintenance (mo)	Time of Follow-up (mo)
Schwarz et al[34,35]	CS	9/9	PD > 6 mm, IBD > 3 mm	P Cu + Sal	FF + SDC + HAG + CRF	6	48
	CS	10/10	PD > 6 mm, IBD > 3 mm	P Cu + Sal	FF + SDC + XG + R Mbn + CRF	6	48
Schwarz et al[36]	CS	9/9	PD > 6 mm, buccal Dehiscence ± semicircumferential defect (IBD 3 mm)	C Cu + Sal	FF + SDC + XG + R Mbn + CRF	3	12
		9/9	PD > 6 mm, buccal dehiscence + circumferential defect (IBD > 3 mm)	C Cu + Sal	FF + SDC + XG + R Mbn + CRF	3	12
		9/9	PD > 6 mm, circular defect (IBD > 3 mm)	C Cu + Sal	FF + SDC + XG + R Mbn + CRF	3	12
Heitz-Mayfield et al[37]	Cohort	36/24	BoP, PD > 5 mm, IBI ≥ 2 mm	Ti Cu/C Cu + Sal	FF + SDC + ATB	3	12
Schwarz et al[38,39]	CS	7/7	BoP, PD > 6 mm, IBD > 3 mm	P Cu + Sal	FF + Imp P + SDC + XG + R Mbn + ATB	6.12	48
Esposito et al[40]	RCT	10/10	BoP, IBL > 5 mm	Cu + Scaler	FF + SDC + (Imp P)*	4	12
Toma et al[41]	CS	12/10	BoP, PD ≥ 5 mm, IBL ≥ 3 mm	P Cu + Sal	FF + SDC	3.6	12

Study	BoPR	IPPD (mm)	PPDR (mm)	PPDR%	IBD (mm)	RBF (mm)	RBF%	CAL Gain	Marginal Recession ± (mm)
Schwarz et al[34,35]	32%	6.9 ± 0.6	1.1 ± 0.3	18	NS	NS	NS	0.6 ± 0.5	MR–: 0.4 ± 0.5
	51%	7.1 ± 0.7	2.5 ± 0.9	35	NS	NS	NS	2.0 ± 1.0	MR–: 0.5 ± 0.4
Schwarz et al[36]	38.9% ± 16.6	6.7 ± 0.7	1.6 ± 0.9	24	NS	NS	NS	1.2 ± 1.1	MR–: 0.4 ± 0.7
	25.9% ± 14.7	7.1 ± 0.6	1.6 ± 0.7	23	NS	NS	NS	1.1 ± 0.9	MR–: 0.5 ± 0.5
	61.1% ± 16.7	7.0 ± 0.5	2.7 ± 0.7	39	NS	NS	NS	2.4 ± 1.0	MR–: 0.3 ± 0.6
Heitz-Mayfield et al[37]	47%	5.3 ± 1.8	2.4	45	NS	NS	NS	NS	MR–: 1
Schwarz et al[38,39]	85.2% ± 16.4	5.5 ± 1.7	1.2 ± 1.9	22	NS	NS	NS	1.5 ± 2.0	MR+: 0.3 ± 0.9
Esposito et al[40]	SBI: 1.4†	6.45 ± 2.15	0.95 ± 1.89†	15	4.90 ± 2.07	–0.13 ± 1.27	–3	NS	NS
Toma et al[41]	SBI: 0.63	4.94 ± 1.29	0.7	14	5.34 ± 1.9	–0.27	–5	NS	NS

Studies in the treatment of peri-implantitis that resulted in positive outcomes and used MD with and without the use of saline to decontaminate the implant surface. The study design, number of patients/implants, specific method of SDC, surgical protocol, and frequency of postsurgical maintenance are also included. The reduction in BoP, initial PD, and probing depth reduction (mm and %) are included. Initial bone defect depth, RBF in millimeters and %, clinical attachment level gain, and marginal recession or growth are listed for each study.

*Need for implantoplasty based on clinical decision.

†Outcomes were reported as control and test group, but no differentiation was made between surgical and nonsurgical group.

AG indicates Allograft; APA, Air powder abrasive; ARF, Apically repositioned flap; ATB, Antibiotics; Au Cu, Gold curette; Auto, Autogenous graft; BC, Bicarbonate; BoP, Bleeding on Probing; BoPR, Bleeding on Probing reduction; BR, Bone recontouring; BTCP, Beta Tricalcium Phosphate; CAL, clinical attachment level; C Cu, Carbon curette; CHX, chlorhexidine; CO_2 L, CO_2 Laser; CTG, Connective tissue graft; CPC, cetylpyridinium chloride; CRF, Coronally repositioned flap; EMD, Emdogain; ETCH, Etching gel; ETH Ac, ethylenediaminetetraacetic acid gel; ErL, Er:YAG lasers; FF, full thickness Flap; G Cu, Graphite Curette; GF, Growth factor; HAG, Hydroxyapatite graft; IBD, Initial bone defect; IBL, Initial bone level; Imp P, Implantoplasty; IPPD, initial pocket probing depth; LATB, Local antibiotic; LAD, Light activated disinfection; Nr Mbn, Nonresorbable membrane; NS, Not Specify; P Cu, Plastic curettes; PCC, Phytogenic carbonate calcium; PD, Probing depth; PPDR, Probing pocket depth reduction; PTFE Cu, PTFE curette; PTG, porous titanium granule; QE, Quasi-experimental design; R mbn, Resorbable membrane; RBF, radiographic bone fill; Sal, Saline; SBI, Sulcus bleeding index; SR, Soft tissue resection; SDC, Surface decontamination; SS, Stainless steel; SSG, Saline Soaked Gauze; Ti Cu, Titanium curettes; US, Ultra sonic; XG, xenograft.

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Table 2. Mechanical Debridement, Lasers or Use of Photodynamic Therapy

Study	Study Design	N Implant/N Patient	Disease Definition	SDC	Surgical Method	Frequency of Maintenance (mo)	Time of Follow-up (mo)
Romanos et al[42]	CS	19/15	Initial BL, N = 8: 1/3 of implant length; N = 7: 2/3 of implant length; N = 4: To apical area	Ti Cu + CO_2 L	FF + SDC + XG/Auto + R Mbn	NS	27.1
Schwarz et al[38,39]	CS	7/7	BoP, PD > 6 mm, IBD > 3 mm	ErL	FF + Imp P + SDC + XG + R Mbn	6.12	48
Esposito et al[40]	RCT	19/10	BoP, IBL > 5 mm	Cu + scaler + LAD	FF + SDC + (imp P)*	4	12

Study	BoPR	IPPD (mm)	PPDR (mm)	PPDR%	IBD (mm)	RBF (mm)	RBF%	CAL Gain	Marginal Recession ± (mm)
Romanos et al[42]	SBI: 1.73	6 ± 2.03	3.52	59	6.95 ± 1.84	N = 13: 0–2 mm; N = 6: 1/3 of implant length	NS	NS	NS
Schwarz et al[38,39]	71.6% ± 24.9	5.1 ± 1.5	1.3 ± 1.8	25	NS	NS	NS	1.2 ± 2.0	MR–: 0.1 ± 0.3
Esposito et al[40]	SBI: 1.6	6.23 ± 1.62	1.14 ± 2.00†	18	4.5 ± 1.75	0.00 ± 1.33	0	NS	NS
Deppe et al[43]	SBI: 1.0	5.7 ± 1.4	2.3	40	7.4 ± 1.1	0.6	8	0.6	MR–: 1.7
	SBI: 1.4	5.7 ± 1.4	3.2	56	7.6 ± 1.1	3.1	40	3.6	MR±: 0.4

Studies in the treatment of peri-implantitis that resulted in positive clinical outcomes and used laser or light-activated disinfection to decontaminate the implant surface. The study design, number of patients/implants, specific method of SDC, surgical protocol, and frequency of postsurgical maintenance are included. The reduction in BoP, initial PD, probing depth reduction (mm and %) are also included. Initial bone defect depth, RBF in millimeters and %, clinical attachment level gain and marginal recession or growth are listed for each study.
Need for implantoplasty based on clinical decision.
†No differentiation was made between surgical and non-surgical group.

Examples of These Include:

> "The reported outcomes must be viewed in the context of the varied peri-implantitis case definitions and severity of disease included as well as the heterogeneity in study design, length of follow-up, and exclusion/inclusion criteria" Heitz-Mayfield et al[19]

> "…but long-term evaluation to evaluate the validity and reliability of the techniques is needed." Valderrama & Wilson[23]

> "…there is a lack of high-quality comparative studies to support this statement. The results might be used to project treatment outcomes after surgical management of peri-implantitis." Chan et al[20]

Although thorough in following protocols for evidence-based systematic reviews of peri-implantitis, these conclusions offer little practical knowledge for the clinician faced with treating this emerging disease with a documented increasing prevalence.

Although nonsurgical therapy has been documented to be inadequate to manage peri-implantitis,[17,18] several recently proposed surgical therapies have been shown, in both humans and in animal models, to result in improvements in probing depth (PD) reduction, clinical bleeding on probing (BoP), and radiographic bone fill (RBF) of the defects as evidenced by radiographs with or without reentry data.[15–22,24–30] However, variations in the definition of peri-implantitis based on the threshold amount of bone loss combined with different defect morphology as well as different methods of surface decontamination (SDC) and treatment of bone loss make clinical comparisons and conclusions regarding the efficacy of one versus another treatment difficult.[31,32]

Furthermore, the lack of human histology prevents evaluation of re-osseointegration to the diseased implant

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Table 3. Mechanical Debridement and Use of Air Powder Abrasives

Study	Study Design	N Implant/ N Patient	Disease Definition	SDC	Surgical Method	Frequency of Maintenance (mo)	Time of Follow-up (mo)
Deppe et al[43]	QE	19/6	BoP, PD ≥ 5 mm, Progressive BL	APA	FF + SDC + SR	NS	37
	QE	15/7	BoP, PD ≥ 5 mm, Progressive BL	APA	FF + SDC + B-TCP + Auto + nR-Mbn	NS	37
Toma et al[41]	CS	10/7	BoP, PD ≥ 5 mm, IBL ≥ 3 mm	APA + Sal	FF + SDC	3.6	12

Study	BoPR	IPPD (mm)	PPDR (mm)	PPDR%	IBD (mm)	RBF (mm)	RBF%	CAL Gain	Marginal Recession ± (mm)
Deppe et al[43]	SBI: 1.6	6.2 ± 1.8	1.9	30	7.8 ± 1.6	–0.1	–1	0.3	MR–: 1.6
	SBI: 0.2	5.1 ± 1.7	2.6	51	7.4 ± 1.1	2.7	36	3	MR+: 0.4
Toma et al[41]	SBI: 0.32	5.11 ± 1.15	2	39	5.49 ± 1.58	0.31	6	NS	NS

Studies in the treatment of peri-implantitis that resulted in positive clinical outcomes and used air powder abrasives to decontaminate the implant surface. The study design, number of patients/implants, specific method of SDC, surgical protocol and frequency of postsurgical maintenance are included. The reduction in BoP, initial PD, probing depth reduction (mm and %) are also included. Initial bone defect depth, RBF in millimeters and %, clinical attachment level gain and marginal recession or growth are listed for each study.

surface following the treatment modalities described in the literature. Although more research is necessary to determine which therapies result in predictable positive outcomes, the one element common to all treatment methods being used today is the need for SDC of the affected implant.

Recently, 2 literature reviews presented an overview of methods used to detoxify the implant surface in the various treatment protocols.[23,33] The first presented the rationale evidence and "current understanding" of a variety of mechanical, chemical, laser, and implantoplasty procedures in describing "methods for implant surface detoxification." Because most of these data were obtained from animal studies, the conclusions that "all techniques/agents have been shown to be equally effective to detoxify the contaminated implant surface" provide little guidance when treating peri-implantitis in humans. Moreover, another limitation described by the authors of this review was that "corporate studies of different detoxification methods are heterogeneous."[33] The conclusion of the second review of 76 articles published between 1966 and 2013 was that "complete elimination of the biofilms is difficult to achieve. All therapies induce changes of the chemical and physical properties of the implant surface." The authors went on to state that "partial re-osseointegration after detoxification has been reported in animals." However, they noted that no similar data were available in humans.[23]

In an attempt to evaluate and compare the effectiveness of various methods of SDC as well as other aspects of the surgical protocols in naturally occurring peri-implantitis in humans, it is helpful to examine the clinical outcomes. Probing depth (PD) reduction, decreased BoP, marginal soft tissue changes, marginal recession (MR−) or gain (MR+) serve to evaluate the clinical level of success of the procedure and may allow for comparison between techniques. Moreover, bone level changes as measured on radiographs (RBF) or with bone sounding provide clinical surrogates for possible re-osseointegration, particularly if these measures stand up over time. Valderrama and Wilson in their overview of SDC stated, "Long-term evaluation" is necessary "to establish the validity and reliability of the techniques."[23]

A recent systematic review and meta-analysis of treatment outcomes concluded that "the application of grafting materials and barrier membranes resulted in greater PD reduction and improvement in RBF." However, they also noted that "there is a lack of high quality comparative studies to support this statement."[14] Moreover, in that review, there was no analysis of the specific methods of SDC associated with these improved outcomes.

The aim of the present study was to identify and evaluate surgical protocols for the treatment of peri-implantitis that reported positive clinical outcomes at 12 months or more follow-up, identify the methods of SDC and defect treatment used in these studies, and determine if there were any correlations between the SDC and/or defect treatment with these clinical outcomes. A second aim was to identify those protocols that maintained these positive outcomes with >12-month follow-up and identify any factors (ie, the frequency of professional maintenance used in these reports) that may have contributed to this.

MATERIALS AND METHODS

A literature search was performed using 4 electronic databases including OVID MEDLINE, PubMed, EMBASE and Dentistry and Oral Sciences Source, from January 1, 2001 to April 30, 2015 of studies in which methods of treatment of peri-implantitis were reported. The following search terms were used: implant SDC, peri-implantitis, peri-implantitis treatment, outcomes of peri-implantitis treatment, and "re-osseointegration." All articles

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Table 4. Mechanical Debridement and Chemical Treatment of the Surface

Study	Study Design	N Implant/N Patient	Disease Definition	SDC	Surgical Method	Frequency of Maintenance (mo)	Time of Follow-up (mo)
Leonhardt et al[44]	CS	26/9	BoP, IBL > 3 threads	Cu + 10% H_2O_2 + Sal	FF + SDC + ATB	3–6	60
Romeo et al[45,46]	RCT	16/9	BoP, PD > 4 mm, IBL	Cu + LATB + Sal	FF + SDC + SR + BR + APF + ATB	NS	24/36*s
	RCT	19/11	BoP, PD > 4 mm, IBL	Cu + LATB + Sal	FF + SDC + SR + BR + Imp P + APF + ATB	NS	24/36*
Roos-Jansaker et al[47]	CS	16/12	BoP, IBL ≥ 3 theads (1.8 mm)	Ti Cu + 3% H_2O_2 + Sal	FF + SDC + XG + R Mbn + ATB	NS	12
Rocuzzo et al[48]	CS	14/14(TPS)	PD ≥ 6 mm, Crater-like BL	P Cu + EDTA(24%) + CHX	FF + SDC + XG + (CTG)* + ATB	TM	12
	CS	12/12 (SLA)	PD ≥ 6 mm, Crater-like BL	P Cu + EDTA(24%) + CHX	FF + SDC + XG + (CTG)* + ATB	TM	12
Aghazadeh et al[49]	RCT	34/22	BoP, PD ≥ 5 mm, BL ≥ 3 mm	Ti Cu H_2O_2 (3%) + Sal	FF + SDC + Auto + r mbn + ATB	3	12
	RCT	37/23	BoP, PD ≥ 5 mm, BL ≥ 3 mm	Ti Cu H_2O_2 (3%) + Sal	FF + SDC + XG + r Mbn + ATB	3	12
Wohlfahrt et al[50]	RCT	16/16	BoP, PD ≥ 5 mm, IBL ≥ 4 mm infrabony defect	Ti Cu + ETH ac + Sal	FF + SDC + ATB	3	12
	RCT	16/16	BoP, PD ≥ 5 mm, IBL ≥ 4 mm infrabony defect	Ti Cu + ETH ac + Sal	FF + SDC + PTG + ATB	3	12
Wiltfang et al[26]	CS	36/22	BoP, IBL ≥ 4 mm	Cu + Imp P + ETCH	FF + SDC + Imp P + Auto + XG + ATB	3	12
Serino[51,52]	CS	71/27	IBL ≥ 2 mm	Cu + US + CHX	FF + SDC + ATB	6	60
De waal et al[28,29]	RCT	59/22	BoP, PD ≥ 5 mm, IBL ≥ 2 mm	Cu + CHX(0.12%) + 0.05% CPC + Sal	FF + SDC + BR + ARF	3.6	12
	RCT	49/22	BoP, PD ≥ 5 mm, IBL ≥ 2 mm	Cu + CHX (2%) + Sal	FF + SDC + BR + ARF	3.6	12
Roos-Jansaker et al[30,53,54]	QE	23/13	BoP, IBL ≥ 3 threads (1.8 mm)	Ti Cu + H_2O_2(3%) + Sal	FF + SDC + XG + R Mbn + ATB	3	60
	QE	22/12	BoP, IBL ≥ 3 threads (1.8 mm)	Ti Cu + H_2O_2(3%) + Sal	FF + SDC + XG + ATB	3	60

Study	BoPR	IPPD (mm)	PPDR (mm)	PPDR%	IBD (mm)	RBF (mm)	RBF%	CAL Gain	Marginal Recession ± (mm)
Leonhardt et al[44]	95%	NS	NS	NS	NS	9/19 no change in bone level; 4/19 bone loss ≥1 thread; 6/19 bone gain ≥1 thread	NS	NS	NS
Romeo et al[45,46]	SBI: 0.53	6.52 ± 1.62	1.02	15	(m) 3.45 (D) 3.49	(m)–1.44 (D) 1.54	(m) –42 (D) 44	–1.91	MR: 1.41

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Table 4. (Continued)

Study	BoPR	IPPD (mm)	PPDR (mm)	PPDR%	IBD (mm)	RBF (mm)	RBF%	CAL Gain	Marginal Recession ± (mm)
	SBI: 2.22	5.79 ± 1.69	2.58	45	(m) 3.81 (D) 3.94	(m) 0 (D) 0	(m) 0 (D) 0	0.32	MR: 1.46
Roos-Jansaker et al[47]	62.5%	5.1 ± 1.6	4.2 ± 1.5	82	3.8 ± 1.0	2.3 ± 1.2	61	1.4 ± 1.7	MR–: 2.8 ± 1.4
Rocuzzo et al[48]	34%	7.2 ± 1.5	2.1 ± 1.2	29	3.9 ± 1.6	1.6 ± 0.7	41	NS	NS
	60.4%	6.8 ± 1.2	3.4 ± 1.7	50	3.0 ± 0.9	1.9 ± 1	63	NS	NS
Aghazadeh et al[49]	44.80%	6.0 ± 1.3	2.0 ± 0.2	33	(m) 5.9 ± 1.8 (D) 5.8 ± 1.6	0.2 ± 0.3	4	NS	NS
	50.40%	6.2 ± 1.4	3.1 ± 0.2	50	(m) 5.2 ± 1.8 (D) 5.3 ± 1.8	1.1 ± 0.3	21	NS	NS
Wohlfahrt et al[50]	SBI: 0.56	6.5 ± 2.3	2.0 ± 2.3	30	6.8 ± 3.9	0.1 ± 1.9	–14.8	NS	NS
	SBI: 0.38	6.5 ± 1.9	1.7 ± 1.7	26	6.8 ± 2.7	2.0 ± 1.7	57	NS	NS
Wiltfang et al[26]	36%	7.5	4	53	5.1	3.5	68	2.7	MR–: 1.3
Serino 2011, 2014[51,52]	<15% Imp sites	NS	Not expressed in mm of mean PDR	NS	4.8 ± 1.8	NS	NS	NS	NS
De waal et al[28,29]	26.40%	5.0 ± 1.2	2.1	42	4.1 ± 1.6	0	0	NS	NS
	20.90%	4.7 ± 1.0	1.7	36	4.0 ± 1.5	–0.3	–17.5	NS	NS
Roos-Jansaker et al[30,53,54]	42.40%	5.6 ± 1.9	3.0 ± 2.4	54	4.6 ± 1.3	1.5 ± 1.2	33	1.9 ± 2.1	MR–: 1.3 ± 1.7
	82.90%	6.0 ± 2.2	3.3 ± 2.0	55	4.0 ± 0.8	1.1 ± 1.2	28	2.2 ± 2.24	MR–: 2 ± 1.8

Studies in the treatment of peri-implantitis that resulted in positive clinical outcomes and used chemical treatment to decontaminate the implant surface. The study design, number of patients/implants, specific method of SDC, surgical protocol and frequency of post-surgical maintenance are included. The reduction in BoP, initial PD, probing depth reduction (mm and %) are also included. Initial bone defect depth, RBF in millimeters and %, clinical attachment level gain and marginal recession or growth are listed for each study.
*Clinical outcomes published with 24 month follow-up and radiographic outcomes published with 36 month follow-up.

were screened and selected based on the following inclusion criteria:

1. Articles published in English
2. Studies reporting on the surgical treatment of peri-implantitis with 1 year or longer follow-up measurements
3. Case series of at least 15 implants with primarily positive outcomes for BoP, PD reduction, and/or RBF, and identify those which secondarily evaluated soft tissue level changes (MR+, MR–).
4. Studies that specifically described the methods of surface decontamination (SDC) used such that the treatment protocols could be replicated
5. Studies that described methods and materials used following SDC to treat bone loss.

The exclusion criteria included:

1. Studies reporting on nonsurgical treatment of peri-implantitis
2. Case reports containing <15 implants in total between the treatment groups
3. Animal studies
4. Studies with less than 12 months of follow-up
5. *In vitro* studies
6. Studies treating peri-implant mucositis
7. Studies reporting negative outcomes for reductions in BoP, PD reduction, and RBF
8. Literature reviews, systematic reviews and meta-analysis

RESULTS

The search of the keywords resulted in 639 articles. Of these, 26 articles satisfied the inclusion criteria. Methods of SDC were then divided into the following 5 categories:

1. Mechanical debridement (MD) with or without the use of saline
2. MD and use of lasers or photodynamic therapy
3. MD, use of air powder abrasives
4. MD and chemical treatment of the surface
5. Combination treatment of the implant surface, for example, air

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Table 5. Combination of Techniques for Surface Decontamination

Study	Study Design	N Implant/ N Patient	Disease Definition	SDC	Surgical Method	Frequency of Maintenance (mo)	Time of Follow-up (mo)
Deppe et al[43]	QE	22/10	BoP, PD ≥ 5 mm, Progressive BL	APA + CO_2 L	FF + SDC + SR	NS	37
	QE	17/9	BoP, PD ≥ 5 mm, Progressive BL	APA + CO_2 L	FF + SDC + B-TCP + Auto + nR-Mbn	NS	37
Froum et al[27]	CS	19/15	BoP, Interprox BL, PD ≥ 6 mm, BL ≥ 4 mm	G Cu + BC (APA) + Sal + LAT B + CHX	FF + SDC + EMD + XG/AG + GF + R Mbn + (CTG)* + ATB	3	44.4
	CS	32/23	BoP, PD ≥ 6 mm, Facial BL ≥ 4 mm	G Cu + BC (APA) + Sal + LAT B + CHX	FF + SDC + EMD + XG/AG + GF + R Mbne + (CTG)* + ATB	3	44.4

Study	BoPR	IPPD (mm)	PPDR (mm)	PPDR%	IBD (mm)	RBF (mm)	RBF%	CAL Gain	Marginal Recession ± (mm)
Deppe et al[43]	SBI: 1	5.7 ± 1.4	2.3	40	7.4 ± 1.1	0.6	8	0.6	MR−: 1.7
	SBI: 1.4	5.7 ± 1.4	3.2	56	7.6 ± 1.1	3.1	41	3.6	MR+: 0.4
Froum et al[27]	BoP decreased to 4 of 19 sites	8.8 ± 1.9	5.4 ± 1.5	61	6.44	3.75	58	6.7 ± 1.9	MR+: 1.3
	BoP decreased to 5 of 32 sites	7.9 ± 1.8	5.1 ± 1.9	64	4.3	3	70	6.1 ± 3.1	MR+: 1.0

Studies in the treatment of peri-implantitis that resulted in positive clinical outcomes and used a combination of techniques to decontaminate the implant surface. The study design, number of patients/implants, specific method of SDC, surgical protocol and frequency of post-surgical maintenance are also included. The reduction in BoP, initial PD, probing depth reduction (mm and %) are included. Initial bone defect depth, RBF in millimeters and %, clinical attachment level gain and marginal recession or growth are listed for each study.
(CTG)* used instead of membrane when no keratinized tissue was present.

powder abrasion followed by chemical disinfection with citric acid

In analyzing the results according to the 5 defined categories, the first, MD with or without use of saline, yielded 8 studies (Table 1).[34–41] The second use of LASERS or PDT yielded 3 and 1 study respectively (Table 2).[38–40,42] The third group, use of air powder abrasive abrasion yielded 2 studies (Table 3).[41,43] The fourth, use of chemicals for SDC, yielded 15 studies (Table 4).[26,28–30,44–54] The fifth, combination treatment for SDC, yielded 2 studies (Table 5).[27,43] A number of studies which did not satisfy the inclusion criteria were eliminated from those included in the present review (Table 6).[55–63]

In group 1, MD with or without saline, at 12-month follow-up, the best outcomes were achieved by Heitz-Mayfield et al[37] treating 36 implants reporting a PD reduction of 2.4 mm (45% of initial PD) and Schwarz et al[36] treating 9 implants reporting a PD reduction of 2.7 mm (39% of initial PD). Both studies used MD and saline for SDC. These studies, however, did not report hard tissue fill of the defect. Each reported postsurgical marginal recession (MR) of −1 mm and −0.3 mm, respectively.

In group 2, MD with the use of lasers or photodynamic therapy (PDT), the best outcomes reported were at 27.1 months around 19 implants by Romanos and Nentwig[42] using a CO_2 Laser for SDC. They reported a PD reduction of 3.52 mm (59% of initial PD) using a xenograft or autograft and resorbable membrane as part of the treatment protocol. RBF was not expressed in millimeters or percentage of initial defect and no measurements of MR were reported.

In group 3, MD with air powder abrasion, the best outcomes for PD reduction were reported by Deppe et al[43] around 15 implants after a mean follow-up of 37 months. Probing depth reduction was 2.6 mm (51% of initial PD) and RBF was 2.7 mm (36% fill of the initial defect). Following SDC, the defect treatment utilized guided bone regeneration (GBR) with Beta tricalcium phosphate (B-TCP) combined with

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Table 6. Reason for Exclusion of Publications Comparison Studies of Methods of SD

Author, y	No. Subjects/No. Implants	Follow-up (mo)	Reason for Exclusion
Haas et al[55]	17/24	9.5	Follow-up interval
Mombelli et al[56]	25/30	12	Nonsurgical treatment
Khoury and Buchman [57]	25/41	36	No Bop reduction reported
Salvi et al[58]	25/31	12	Nonsurgical treatment
Maximo et al[59]	35/47	3	Follow-up interval
Schar et al[60]	40/67	12	Nonsurgical treatment
Lagervall and Jansson[61]	150/382	26	No PDR, No BoP reduction reported
Mijiritsky et al[62]	16/18	7.5	Follow-up interval. No PDR reported
Matarasso et al[63]	11/11	12	Sample size

Studies that were excluded from the current review and the reason for exclusion.

an autogenous graft and a nonresorbable barrier. An overall gain in marginal gingival level of 0.4 mm was reported.

In group 4, MD and chemical treatment of the surface, the methods of SDC resulted in the greatest variability. The best outcomes regarding PD reduction were achieved in a 12-month study by Roos-Jansaker et al 2007[47] reporting an average PD reduction of 4.2 mm (82% of initial PD). In other 1-, 3-, and 5-year follow-up studies, Roos-Jansaker et al 2007, 2011, 2014[30,53,54] used H_2O_2 and saline for SDC and reported a PD reduction of 3.0 mm (54% of initial PD) and 3.3 mm (55% of initial PD) at 5 years posttreatment. In all of these studies, the defect treatment included the use of a xenograft and resorbable membrane. However, in the most recent study, PD reduction was reported as 3.3 mm (55% of initial PD) using a xenograft without a membrane barrier.[30] In the first study, a RBF of 2.3 mm (61% of initial defect) was reported.[47] In the 3 follow-up studies at 5 years, RBF was reported to be 1.5 mm (33% of total defect) with the use of a resorbable membrane and 1.1 mm (28% of initial defect) without the membrane. Marginal recession at 5 years was 1.3 mm in the membrane group and 2.0 mm in the nonmembrane group. In the most recent study, the authors concluded that a barrier membrane did not significantly enhance the treatment outcomes.[30] Another study in this group, Wiltfang et al[26] treated 36 implants using implantoplasty and an etching gel based on phosphoric acid for SDC. This was followed by the use of a combination of an autogenous bone graft and a xenograft. The authors reported a PD reduction of 4.0 mm (53% of initial PD) and RBF of 3.5 mm (68% of the initial defect). In addition, an average marginal recession of 1.3 mm was reported. These were 12-month postsurgical results.

In the final category (group 5), 2 different combination techniques for SDC were used. In one study, Deppe et al[43] used air powder abrasion (ABA) and a CO_2 laser, and in the other study, Froum et al[27] used a combination of ABA, saline spray, chemotherapeutic decontamination of the root, antibiotics, and chlorhexidine. The GBR protocol of Deppe et al[43] included tricalcium phosphate and autogenous bone combined with a nonresorbable membrane at an average 37 months postsurgery reported PD reduction of 3.2 mm (56% of initial defect) and a RBF of 3.1 mm (41% of the initial defect). An average gain in marginal soft tissue level of 0.4 mm was also reported. The Froum et al[27] study's GBR protocol included a xenograft/allograft combined with platelet-derived growth factor and enamel matrix derivative and covered with either an autogenous connective tissue or a collagen membrane. They reported a PD reduction of 5.4 mm (61% of initial PD) and 5.1 mm (64% of initial PD) and a RBF of 3.75 mm (58% of initial defect) and 3.0 mm (70% of initial defect) using radiographs and bone sounding, respectively, to determine fill. An average gain in marginal level of 1.3 mm was also reported. These measurements were taken at an average 3.7 years following surgery.

Because of the heterogeneity of the SDC methods in the 26 studies evaluated, no correlation could be made between the method of SDC used and the magnitude of positive clinical outcomes. The same was true with the methods used to treat the osseous defects associated with the peri-implantitis-effected implants.

However, with the exception of the Heitz-Mayfield et al,[37] all of the studies cited above, which reported the best clinical outcomes, used some form of bone grafting in the treatment of the osseous defects surrounding the peri-implantitis-effected implants. Moreover, in 9 of the 10 studies demonstrating the best clinical outcomes, all necessary periodontal therapy was performed before treatment of the peri-implantitis-effected implants. In the remaining study (Romanos and Nentwig[42]), no mention of pretreatment therapy was made.

Therefore, in each of the SDC categories, the studies with the best outcomes that reported PD reduction and RBF had the following factors included in their protocols[26,27,30,36,43]

1. All necessary periodontal therapies were performed before treatment of peri-implantitis-effected implants
2. In 4 of the 5 studies, defect morphology was specifically described, and in each as well as the other study, access to the debrided implant surface was a factor in obtaining thorough SAC. Defect morphology may also have effected outcomes, which is described as "a potential impact of the defect configuration on the clinical outcomes following surgical, regenerative therapy of peri-implantitis lesions."[36]
3. All protocols included the use of bone and/or bone substitute grafts.
4. All protocols used membrane barriers.

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5. All protocols that included information on the frequency of professional maintenance used a 3 month or less recall schedule.

DISCUSSION

Twenty-six studies met the inclusion criteria in the present review. However, those that were performed by the same authors and were reported on at different time periods were grouped together. One study, in fact, followed patients at 1, 3, and 5 years postsurgery demonstrating clinical outcomes that remained stable.[30] Studies included in the current review contained at least 15 implants between the treated groups with a minimum of 12 months of follow-up to identify SDC and defect treatment protocols that achieved and maintained positively predictable clinical outcomes.

The positive clinical results achieved in several longer-term studies with a variety of methods for performing SDC suggest that there may be more than one method which is clinically effective in decontaminating an exposed implant surface which has lost bone or soft tissue attachment as a consequence of peri-implantitis. However, the relationship between the length of time that the lesion was present to outcomes and the remaining treatment protocol could not be determined in the current review. Therefore, in evaluating positive outcomes which were maintained over time ($>$1 year), the clinician may have problems determining the most effective protocols and if protocols for decontamination that are less layered may have the same merit as combined protocols if the lesion is more long standing that is heavier or more complex microbiome.

There have been at least 9 literature reviews on the treatment of peri-implantitis and at least 2 on SDC. As seen in the present review, there was great heterogeneity in the studies with regard to, differences in initial bone loss around the implants, the type of implant surface treated, variation in materials and techniques used for treatment, and lack of reporting both hard and soft tissue changes, as well as improvements in BOP making comparison between studies difficult. Moreover, what was also lacking was consistency in the extent and definition of the initial peri-implant bone loss as well as standardized treatment of bone loss to compare SDC methods in studies with longer-term, positive outcomes. In addition, the implant surfaces treated should also be standardized as surface macrostructures and microstructures may have an influence on the effectiveness of the decontamination protocol.

At the present time, the current review of SDC techniques could not determine whether there is a correlation between SDC and outcomes because of the confounding factors mentioned above. It appears, however, that various methods of SDC (combined with various treatments of lost bone) are effective in producing positive clinical outcomes. Most of the longer-term ($\geq$12 months) studies included in this review which reported better clinical outcomes following SDC used some form of bone replacement grafting of the defects without apical flap positioning or a submerged protocol.[26,27,30,36,42,43] However, there was great heterogeneity to the both the graft materials used and the techniques employed in the reviewed studies making comparisons and conclusions regarding treatments difficult to evaluate.

The concern could be raised that the current review article should have looked at SD protocols that did not meet with success and compared them to those that have been successful. There are however several issues to this. First, the review would have been extremely extensive in the number of articles to consider, methodologies to compare etc. It is questionable as to how much benefit this might have yielded. Second, there are many factors to consider as to why failure may have occurred including chronicity of the lesion, morphology of the lesions treated, and skill level of the clinicians. Third, there is a selection bias with articles reporting on negative outcomes as most clinicians choose are reticent to share their shortcomings. Finally, clinicians seek to know what has worked and will attempt to use the information in practice. It is the hope that this review will provide clinicians with options that may help their patients.

When analyzing the protocols and results of the included studies, several recommendations may cautiously be suggested in treating peri-implantitis defects. When the goal of treatment is to save the implant, reduce PD and BoP, and gain bone lost because of peri-implantitis (while reducing or reversing marginal recession), the clinician should first concentrate on an effective method of SDC that eliminates biofilm and allows regenerative and/or repair of the hard and soft tissue around the implant. All of the SDC methods reported in the current review appear to have accomplished this. However, defect morphology that may be considered as an important factor in effecting complete SDC as well as clinical outcomes was specifically defined in only 11 of the 26 studies included in the current review.[26,27,30,34–36,38,39,42,49,50] The authors of the current review have noted that surface access may be a critical factor in accomplishing complete SDC.[64] Moreover, the studies showing the best outcomes for PD reduction (Roos-Jansaker,[30] Deppe et al[43] and Froum et al[27]) with at least 3 years of follow-up and an initial osseous defect of $>$4 mm, used bone grafts and/or bone replacement graft layered by a barrier membrane. One study showed similar RBF (1.5 mm and 1.1 mm) using xenograft with and without coverage with a resorbable membrane, respectively.[30] Two other studies, Deppe et al[43] and Froum et al[27], reported RFD of 3.1 mm (41% of initial defect) and 3.75 mm (58% of initial defect) using nonresorbable and resorbable barriers, respectively. One other important consideration was that in the protocols resulting in the best outcomes, periodontal therapy of the remaining dentition was performed before the treatment of peri-implantitis-effected implants. This should be further evaluated by future studies as a possible factor contributing to better outcomes.

CONCLUSION

An evaluation of surgical methods to treat peri-implantitis that resulted in positive clinical outcomes with 12 or

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more months of follow-up was performed and yielded 26 studies. The narrative review failed to reveal any correlation between any specific method of SDC or defect treatment protocol and positive clinical outcomes. However, surface access for SDC must be assumed to be a critical factor in the decontamination process regardless of the technique used. Moreover, defect configuration that was specifically discussed in 11 of the 26 studies reviewed may be considered a potential factor in achieving positive clinical outcomes in regenerative surgical techniques. Studies with various methods of SDC demonstrating better clinical outcomes included a regenerative approach using grafting materials as part of the overall algorithm of care. All protocols that included information on the frequency of professional maintenance used a 3-month or less recall schedule. Randomized clinical trials on SDC methodology with longer-term (>12 months) follow-ups are necessary to determine if any one method of SDC produces improved outcomes compared to others and whether one technique may be generalized to various implant surface morphologies. Similar controlled studies are needed to evaluate surgical protocols following SDC and to evaluate the effect of treatment of existing periodontal diseases before peri-implantitis surgery.

DISCLOSURE

The authors claim to have no financial interest, either directly or indirectly, in the products or information listed in the paper.

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