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Impact of implant–abutment connection and positioning of the machined collar/microgap on crestal bone level changes: a systematic review

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Abstract

Objectives: To address the following focused question: What is the impact of implant–abutment configuration and the positioning of the machined collar/microgap on crestal bone level changes?
Material and methods: Electronic databases of the *PubMed* and the *Web of Knowledge* were searched for animal and human studies reporting on histological/radiological crestal bone level changes (CBL) at nonsubmerged one-/two-piece implants (placed in healed ridges) exhibiting different abutment configurations, positioning of the machined collar/microgap (between 1992 and November 2012: n = 318 titles). Quality assessment of selected full-text articles was performed according to the ARRIVE and CONSORT statement guidelines.
Results: A total of 13 publications (risk of bias: high) were eligible for the review. The weighted mean difference (WMD) (95% CI) between machined collars placed either above or below the bone crest amounted to 0.835 mm favoring an epicrestal positioning of the rough/smooth border ($P < 0.001$) (P-value for heterogeneity: 0.885, I2: 0.000% = no heterogeneity). WMD (95% CI) between microgaps placed either at or below the bone crest amounted to −0.479 mm favoring a subcrestal position of the implant neck ($P < 0.001$) (P-value for heterogeneity: 0.333, I2: 12.404% = low heterogeneity). Only two studies compared different implant–abutment configurations. Due to a high heterogeneity, a meta-analysis was not feasible.
Conclusions: While the positioning of the machined neck and microgap may limit crestal bone level changes at nonsubmerged implants, the impact of the implant–abutment connection lacks documentation.

Nowadays, there is considerable evidence supporting the view that the insertion of endosseous dental implants is commonly associated with a physiological remodeling process of the alveolar bone (Albrektsson et al. 1986). After 3 years in function, the cumulative interproximal, clinical radiographic bone loss was calculated to be below 0.5 mm (Abrahamsson & Berglundh 2009; Lang & Jepsen 2009). While clinical studies did not reveal a significant influence of any particular implant surface or design on crestal bone preservation (Abrahamsson & Berglundh 2009; Lang & Jepsen 2009), preclinical animal and human studies have pointed to numerous confounding biological, technical, and biomechanical factors.

Of particular importance seems to be the establishment of the biological width (Berglundh et al. 1991), and therefore, the need for a certain soft tissue thickness at implant placement (Linkevicius et al. 2009). A design strategy including the connection of a smaller-diameter abutment relative to the platform diameter of the titanium implant (referred to as platform-switching) was proven to reduce the epithelial component of the biological width, thus resulting in a preservation of crestal bone levels in both animals (Becker et al. 2007, 2009) and humans (Atieh et al. 2010). In addition, the implant–abutment connection (Koo et al. 2012), the size of the machined neck (Schwarz et al. 2008; Hermann et al. 2011), but also the size

of the microgap at the implant–abutment interface (Hermann et al. 2001; Broggini et al. 2006), and its insertion relative to the alveolar crest (Jung et al. 1996) may contribute to physiological bone remodeling after implant placement. At the time being, however, these confounding factors have not been systematically evaluated in the available literature.

Therefore, the aim of this systematic review was to address the following focused question: What is the impact of implant–abutment configuration and the positioning of the machined collar/microgap on crestal bone level changes?

Materials and methods

PICO question

The focused question serving for literature search was structured according to the PICO format: P: animals/patients with stable implants at healed ridges; I: Implants exhibiting specific abutment configurations (i.e. internal: flat vs. conical; external vs. internal)/positioning of the machined collar/positioning of the microgap, C: Control implants exhibiting the same macrodesign, but different configurations as I, and O: histological or radiographical crestal bone levels.

Search strategy

The *PubMed* database of the US National Library of Medicine and the *Web of Knowledge* of (Thomson Reuters) were used as electronic databases to perform a systematic review of the available literature. Screening was performed independently by two authors (F.S. and A.H.). Disagreement regarding inclusion was resolved by discussion. The level of agreement between both reviewers was determined by free-marginal kappa scores.

The combination of key words (i.e. medical subject headings MeSH) and free text terms included as follows:

"dental implants" (MeSH) OR "implants" OR "titanium implants" OR "titanium dental implants"
AND
"bone remodeling" (MeSH) OR "crestal bone" OR "crestal bone level" OR "crestal bone change" OR "crestal bone loss" OR "crestal bone remodeling"
AND
"implant–abutment connection" (MeSH) OR "implant–abutment configuration" OR "conical" OR "flat" OR "microgap" OR "microbial leakage" OR "machined neck" OR "machined collar" OR "insertion depth"

AND
"animal model" (MeSH) OR "animal study" OR "preclinical study" OR "dog study" OR "canine study" OR "monkey study" OR "swine study" OR "pig study" OR "clinical study" OR "human study" OR "randomized controlled clinical trial" (MeSH) OR "randomized controlled clinical study" OR "comparative study".

Additionally, the following journals were searched manually between 1990 and November 2012:

Clinical Implant Dentistry and Related Research; *Clinical Oral Implants Research*; *International Journal of Oral and Maxillofacial Implants*; *Journal of Clinical Periodontology*; *Journal of Periodontology*. Finally, the references of all selected full-text articles and related reviews were scanned.

Study inclusion and exclusion criteria

For electronic search and title management, a commercial software program (Endnote X6; Thomson, London, UK) was used. For the first stage of study selection, the following inclusion criteria were used:

1. Publication in the international peer-reviewed literature
2. English language
3. Animal or clinical (prospective randomized controlled or comparative) studies
4. Histological (animals) and radiological (animals and humans) assessment of crestal bone levels (CBL) after implant placement and nonsubmerged healing.

At the second stage of selection, all full-text articles identified during the first stage were acquired. During this procedure, the preselected studies were evaluated according to the following exclusion criteria:

1. Comparison of implants exhibiting a different macrodesign,
2. Assessment of factors other than implant–abutment configuration/positioning of the machined collar/positioning of the microgap,
3. Animal studies: inclusion of less than two animals per observation period/group,
4. Human studies: study design other than prospective randomized controlled or comparative trials,
5. Locally or systemically compromised sites and/or conditions.

Quality assessment of selected studies

A quality assessment (Berglundh et al. 2012; Tonetti et al. 2012) of all selected full-text articles was performed according to the

ARRIVE guidelines for reporting *in vivo* experiments in animal research (Kilkenny et al. 2010) as well as the revised recommendation of the CONSORT statement for the evaluation of randomized controlled trials (Schulz et al. 2010).

Predefined gradings (Schwarz et al. 2012) were applied to the following ARRIVE items (Kilkenny et al. 2010): Methods/Ethical statement (5), Methods/Study design (6), Methods/Experimental procedure (7), Methods/Experimental Animals (8), Methods/Housing and keeping (9), Methods/Sample size (10), Methods/Allocation animals to experimental groups (11), Methods/Experimental outcomes (12), and Methods/Statistical methods (13) (Table 1). Similar gradings were also used for the quality assessment of finally selected clinical studies (Schulz et al. 2010): Methods/Trial design (3), Methods/Participants (4), Methods/Interventions (5), Methods/Outcomes (6), Methods/Sample size (7), Methods/Randomization (8 and 9), Methods/Blinding (11), and Methods/Statistical methods (12) (Table 2).

Quality assessment was performed in two different phases. In particular, during phase I, quality assessment was based on the published full-text article performed independently by both authors. In phase II, disagreements were resolved by discussion.

After forming the scores at the second phase of quality assessment, an overall estimation of plausible risk of bias (low, moderate, or high) was made for each selected study. In brief, a low risk of bias was estimated when all of the criteria were met. A moderate risk was considered when one or more criteria partly met, while a high risk of bias was estimated when one or more criteria not met (*Cochrane Handbook for Systematic Reviews of Interventions*, version 5.1.0., http://www.cochrane.org/resources/handbook).

Data extraction and method of analysis

Median values were calculated for each item (i.e. ARRIVE, CONSORT) and each publication (PASW Statistics 20.0; SPSS Inc., Chicago, IL, USA). For data analysis, the radiographic and/or histological assessment of mean CBL values (i.e. estimated from respective coronal reference points to the first level of bone-to-implant contact) after respective healing periods was extracted and defined as primary outcome. Heterogeneity between studies, subgroup analyses, meta-analyses (fixed-effects model), and forest plots were calculated using a commercially available software program (Comprehensive Meta-Analysis V2; Biostat, Englewood, NJ, USA).

Table 1. Categories to assess the quality of finally selected animal studies (Kilkenny et al. 2010; Schwarz et al. 2012)

Item	Description	Grading
5	METHODS	0 = clearly insufficient
	Ethical statement – nature of the review permission, relevant licenses, national and institutional guidelines for the care, and use of animals	1 = possibly sufficient
		2 = clearly sufficient
6	METHODS	0 = clearly insufficient
	Study design – number of experimental and control groups, any steps taken to minimize bias (i.e. allocation concealment, randomization, blinding)	1 = possibly sufficient
		2 = clearly sufficient
7	METHODS	0 = clearly insufficient
	Experimental procedure – precise details (i.e. how, when, where, why)	1 = possibly sufficient
		2 = clearly sufficient
8	METHODS	0 = clearly insufficient
	Experimental animals – species, strain, sex, developmental stage, weight, source of animals	1 = possibly sufficient
		2 = clearly sufficient
9	METHODS	0 = clearly insufficient
	Housing and husbandry – conditions and welfare-related assessments and interventions	1 = possibly sufficient
		2 = clearly sufficient
10	METHODS	0 = clearly inadequate
	Sample size – total number of animals used in each experimental group, details of calculation	1 = possibly adequate
		2 = clearly adequate
11	METHODS	0 = no
	Allocation animals to experimental groups – randomization or matching, order in which animals were treated and assessed	1 = yes
12	METHODS	0 = no
	Experimental outcomes – definition of primary and secondary outcomes	1 = unclear/not complete
		2 = yes
13	METHODS	0 = no
	Statistical methods – details and unit of analysis	1 = unclear/not complete
		2 = yes

Table 2. Categories to assess the quality of finally selected clinical studies (Schulz et al. 2010)

Item	Description	Grading
3	METHODS	0 = clearly insufficient
	a. Description of trial design and allocation ratio	1 = possibly sufficient
		2 = clearly sufficient
4	METHODS	0 = clearly insufficient
	a. Eligibility criteria for participants	1 = possibly sufficient
		2 = clearly sufficient
5	METHODS	0 = clearly insufficient
	Interventions for each group – details	1 = possibly sufficient
		2 = clearly sufficient
6	METHODS	0 = clearly insufficient
	a. Definition of primary and secondary outcome measures	1 = possibly sufficient
		2 = clearly sufficient
7	METHODS	0 = clearly insufficient
	a. Sample size calculation	1 = possibly sufficient
		2 = clearly sufficient
8	METHODS	0 = no
	a. Method used to generate the random allocation sequence	1 = unclear/not complete
		2 = yes
9	METHODS	0 = no
	Mechanism used to implement the allocation sequence	1 = yes
11	METHODS	0 = no
	a. Blinding after assignment to interventions	1 = unclear/not complete
		2 = yes
12	METHODS	0 = no
	a. Statistical methods – details and unit of analysis	1 = unclear/not complete
		2 = yes

Results

Study selection

A total of 318 potentially relevant titles and abstracts were found during the electronic and manual search. During the first stage of study selection, 293 publications were excluded based on title and abstract (inter-reviewer agreement $k = 0.93$). For the second phase, the complete full-text articles of the remaining 25 publications were thoroughly evaluated. A total of 12 papers had to be excluded at this stage because they did not fulfill the inclusion criteria of the present review (inter-reviewer agreement $k = 1.0$) (Tables 3 and 4).

Finally, a total of 13 publications fulfilled the inclusion criteria required for this systematic review (Fig. 1).

Quality assessment of selected publications

Quality assessment of selected studies per checklist item (i.e. ARRIVE, CONSORT) is summarized in Tables 5–7.

In particular, the majority of publications reporting on animal studies were associated with minimum gradings when evaluating checklist items 9 (i.e. Housing and husbandry), 10 (i.e. Sample size), and 11 (i.e. Allocation animals to experimental groups). For items 6 (i.e. Study design) and 8 (i.e. Experimental animals), the majority of publications were graded with medium scores, while maximum gradings were commonly assigned to the remaining checklist items 5 (Ethical Statement) and 6 (Study design) (Tables 5a, 6a, and 7a).

The majority of publications reporting on human studies were associated with minimum gradings when evaluating checklist items 4 (i.e. Eligibility criteria), 7 (i.e. Sample size calculation), 8 (i.e. Random allocation sequence), 9 (i.e. Allocation concealment), and 11 (i.e. Blinding of examiner). While the evaluation of items 5 (i.e. Interventions) and 6 (i.e. Outcome measures) was heterogeneous among publications, medium scores were commonly assigned to checklist item 3 (i.e. Study design). Maximum gradings were only assigned to checklist item 12 (i.e. Statistical method) (Tables 5b, 6b, and 7b).

According to the given definition, in all publications evaluated, the estimated risk of bias was considered as high (Tables 5–7).

Subdivision of selected publications

All selected publications were subdivided according to differences in the implant–abutment configuration, machined collar size, and insertion depth, respectively:

1. Three animal and two human studies assessed the impact of different locations of the machined collar on crestal bone level changes (Table 5a and b),
2. Five animal and one human studies assessed the impact of the positioning of the microgap relative to the alveolar crest on bone remodeling (Table 6a and b), and
3. One animal and one human study compared crestal bone level changes at different implant–abutment configurations (i.e. internal: flat vs. conical or external vs. internal) (Table 7a and b).

Table 3. Excluded animal studies at the second stage of selection and the reason for exclusion

Publication	Reason for exclusion
Alomrani et al. (2005)	Report on the same (radiographic) data set as Hermann et al. (2011)
Jung et al. (2008)	Report on the same (radiographic) data set as Cochran et al. (2009)
Pontes et al. (2008b)	Report on the same (radiographic) data set as Pontes et al. (2008a)
Novaes et al. (2009)	Report on the same (radiographic) data set as Barros et al. (2010)
Welander et al. (2009)	Control implants were lacking a machined collar
Weng et al. (2011b)	Report on the same (radiographic) data set as Weng et al. (2010)
Heitz-Mayfield et al. (2013)	Different implant designs

Table 4. Excluded clinical studies at the second stage of selection and the reason for exclusion

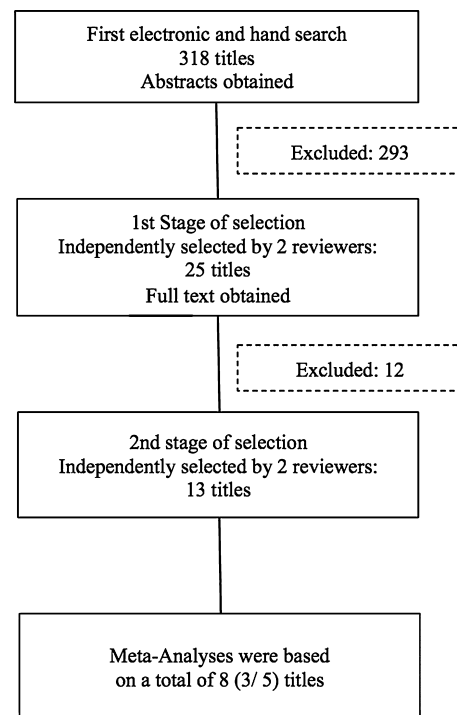| Publication	Reason for exclusion
Shin et al. (2006)	Different implant designs
Stein et al. (2009)	Different implant designs
Degidi et al. (2011)	Retrospective study design
Boynuegri et al. (2012)	No radiographic assessment
Penarrocha-Diago et al. (2012)	Different implant designs

Fig. 1. Search strategy.

Machined collar and insertion depth

All three animal studies used the canine model for research on the impact of the positioning of the machined collar on crestal bone level changes (Hermann et al. 2000, 2011; Schwarz et al. 2008) (Table 5a).

In particular, Hermann et al. (Hermann et al. 2000) used an experimental, one-piece full-body screw-type implant design (length: 9 mm, inner diameter: 3.5 mm, outer diameter 4.1 mm) exhibiting different lengths of the machined collar (the present data set considered types A: 3 mm and B: 4 mm). While type A implants were placed with the rough (sand-blasted and acid-etched surface – SLA)/ smooth border at the alveolar bone crest, this border was located 1.0 mm below the crest at type B implants. All implants were connected with healing abutments and left to heal in a nonsubmerged position for 6 months. Mean histological CBL values were 2.98 ± 0.27 mm and +3.88 ± 0.42 mm in the A and B groups, respectively. Accordingly, at 6 months, the alveolar crest was commonly located close to the rough/smooth border in both groups.

In a similar study design, Schwarz et al. (2008) used commercially available SLA-surfaced two-piece implants (flat-to-flat internal connection, length: 11 mm, outer diameter 3.8 mm) with machined neck sizes of 1.6 mm (CAM) and 0.4 mm (CAM+). According to the suggestions given by the manufacturer, both CAM and CAM+ implants were inserted at 0.4 mm above the alveolar bone. While the rough/smooth border was located in an epicrestal position at CAM+ implants, a machined neck part of 1.2 mm was positioned subcrestally in the CAM group. Healing abutments were connected, and the animals were killed after 2 and 12 weeks of healing (the present data set considered 12 week data of 2 animals). At 12 weeks, mean CBL values were significantly higher at CAM (2.4 ± 0.3 mm) when compared with CAM+ (1.6 ± 0.1 mm) implants (Schwarz et al. 2008).

In a most recent animal study (Hermann et al. 2011), one-piece implants (length: 9 mm, inner diameter: 3.5 mm, outer diameter 4.1 mm) exhibiting a machined collar of 1.8 mm (the present data set considered types A and C) were inserted either with the rough/smooth border located at (control) or 1 mm below the bone crest (test). After a nonsubmerged healing period of 6 months, mean bone loss was 0.52 ± 0.4 mm at control and 1.28 ± 0.21 mm at test sites.

A comparable implant type and design (hollow screw and hollow cylinder, machined collar of 2.8 mm) was also used in a prospective clinical study (Hammerle et al. 1996) and inserted according to the same surgical procedures (i.e. rough/smooth border located at, or 1 mm below the bone crest). After 12 months, mean CBL values were 2.5 ± 0.7 mm and 2.6 ± 0.8 mm at test and control implants, respectively. An identical relationship between the amount of crestal bone remodeling and the location of the rough/smooth border at one-piece implants (hollow cylinder and solid-screw implants, titanium plasma-sprayed surface, machined collar of 2.8 mm) was also reported by Hartman and Cochran (Hartman & Cochran 2004). In particular, at 6 months, test implants (1.72 mm) exhibited a more pronounced bone remodeling than control implants (0.68 mm). In both groups, these values remained almost unchanged over an observation period of up to 60 months (Table 5b). Unfortunately, SD values were not reported in this publication, and therefore, these data were could not be considered in the meta-analysis (Hartman & Cochran 2004).

Based on these three animal (Hermann et al. 2000, 2011; Schwarz et al. 2008) studies, the weighted mean difference (95% CI) between machined collars placed either above or below the bone crest amounted to 0.835 mm (standard error: 0.130; variance: 0.017; lower limit: 0.580; upper limit: 1.090; Z-value: 6.420) favoring an epicrestal positioning of the rough/smooth border ($P < 0.001$) (P-value for heterogeneity: 0.885, I2: 0.000% = no heterogeneity) (Fig. 2).

Microgap and insertion depth

All animal studies ($n = 5$) also used the canine for research on the impact of the positioning of the microgap relative to the alveolar crest (i.e. epicrestal vs. subcrestal) on bone remodeling (Pontes et al. 2008a; Cochran et al. 2009; Barros et al. 2010; Weng et al. 2010; Huang et al. 2012).

In particular, Pontes et al. (2008a) used root-form two-piece SLA-surfaced implants (internal hexagon, length: 10 mm, outer diameter 4.3 mm) with the microgap located at (BoneLevel), or 1 (minus 1) or 2 (minus 2) mm below the bone crest. These implants were allocated to either a conventional (i.e. 120 days after submerged healing) or immediate (i.e. 24 h) restoration. At 90 days, the histological analysis revealed no significant differences in mean CBL values within groups (Conventional – BoneLevel: 1.46 ± 0.31 mm; minus 1: 1.26 ± 0.43 mm; Minus 2: 1.0 ± 0.32 mm; Immediate – BoneLevel:

Table 5. Quality assessment of finally selected (a) animal and (b) human studies: machined collar and insertion depth

Publication	Animals (n)	Methods	Implant type	Depth (mm)	Follow-up	5	6	7	8	9	10	11	12	13	Risk of bias
(a)															
Hermann et al. (2000)	5 Dogs	Histology (m-d)	Exp. (one-piece)	(0/−1)	6 Months	2	1	1	1	0	1	1	2	2	High
Schwarz et al. (2008)	4 Dogs	Histology (m-d)	Camlog (two-piece)	(0/−1.1)	12 Weeks	2	1	1	1	0	0	1	2	2	High
Hermann et al. (2011)	5 Dogs	Histology (m-d)	Exp. (one-piece)	(0/−1)	6 Months	2	1	2	1	0	1	1	2	2	High
Median						2	1	1	1	0	1	1	2	2	

Publication	Patients (n)	Methods	Implant type	Depth (mm)	Follow-up	3	4	5	6	7	8	9	11	12	Risk of bias
(b)															
Hammerle et al. (1996)	11	Radiology (m-d)	ITI (one-piece)	(0/−1)	1 Year	1	0	2	1	0	1	0	0	2	High
Hartman & Cochran (2004)	27	Radiology (m-d)	ITI (one-piece)	(0/−1.1)	5 Years	1	1	2	1	0	0	0	0	2	High
Median						1	0.5	2	1	0	0.5	0	0	2	

Exp., experimental; negative values: subcrestal positioning of the machined neck; m-d: mesio-distal.

Table 6. Quality assessment of finally selected (a) animal and (b) human studies: microgap and insertion depth

Publication	Animals (n)	Methods	Implant type	Depth (mm)	Follow-up	5	6	7	8	9	10	11	12	13	Risk of bias
(a)															
Pontes et al. (2008a)	6 Dogs	Histology (m-d)*	connect (two-part)	(0/−1/−2)	3 Months	2	1	2	1	0	0	0	2	2	High
Cochran et al. (2009)	5 Dogs	Histology (m-d)*	ITI (two-part)	(+1/0/−1)	8 Months	2	1	2	1	0	0	1	2	2	High
Barros et al. (2010)	6 Dogs	Histology (m-d)	Neodent (two-part)	(0/−1.5)	2 Months	2	1	2	1	0	0	1	2	2	High
Weng et al. (2010)	6 Dogs	Histology (m-d)	Dentsply, NobelBiocare (two-part)	(0/−1.5)	3 Months	1	1	2	1	0	0	0	2	2	High
Huang et al. (2012)	6 Dogs	Radiology	Astra, Bicon (two-part)	(0/−1.5)	4 Months	2	1	2	1	0	0	0	2	2	High
Median						2	1	2	1	0	0	0	2	2	

Publication	Implants (n)	Methods	Implant type	Depth (mm)	Follow-up	3	4	5	6	7	8	9	11	12	Risk of bias
(b)															
Veis et al. (2010)	282	Radiology (m-d)	Biomet 3i (two-piece)	(+1−2/0/−1−2)	2 Years	1	0	1	1	0	1	0	0	2	High

Negative values: subcrestal positioning of the microgap; m-d, mesio-distal; *not indicated but estimated based on histological views.

Table 7. Quality assessment of finally selected (a) animal and (b) human studies: implant–abutment connection

Publication	Animals (n)	Methods	Abutment connection	Follow-up	5	6	7	8	9	10	11	12	13	Risk of bias
(a)														
Becker et al. (2007)	9 Dogs	Histology (v-o)	Internal: flat vs. conical	4 Weeks	2	1	2	1	0	0	0	2	2	High

Publication	Implants (n)	Methods	Abutment connection	Follow-up	3	4	5	6	7	8	9	11	12	Risk of bias
(b)														
Koo et al. (2012)	40	Radiology (m-d)	External vs. internal	1 Year	1	1	2	2	0	0	0	1	2	High

m-d, mesio-distal; m-v, vestibulo-oral.

1.54 ± 0.57 mm; minus 1: 1.07 ± 0.73 mm; minus 2: 0.82 ± 0.51 mm (the present data set considered the immediate restoration protocol). However, between group comparisons have pointed to a significantly improved outcome at immediately restored sites (Pontes et al. 2008a). In contrast, Cochran et al. (2009) reported on increased mean CBL values, when two-piece SLA (hydrophilic)-surfaced implants (internal conical abutment connection, platform-switched configuration, length: 8 mm, outer diameter 4.1 mm) were placed at 1 mm below the bone crest (1.13 mm vs. 0.38 mm) (as respective standard deviations have not been reported, the data could not be considered in the meta-analysis). Interestingly, a slight bone gain of 0.19 mm was noted for implants placed with

the neck 1 mm above the crest (Cochran et al. 2009). The influence of insertion depth and interimplant distances (i.e. 2 and 3 mm) at two-piece SLA-surfaced implants (internal Morse cone connection, platform-switched configuration, length: 9 mm, outer diameter 4.5 mm) was investigated by Barros et al. (2010). After 8 weeks of healing, mean CBL values in the interimplant area were significantly lower at implants placed in a subcrestal (i.e. 1.5 mm), when compared with implants placed in an epicrestal position (2 mm – epicrestal: 0.92 ± 0.61 mm; subcrestal: 0.49 ± 0.38 mm; 3 mm – epicrestal: 0.68 ± 0.57 mm; subcrestal: 0.37 ± 0.29 mm). These differences, however, were less pronounced when the free end areas were considered (2 mm – Epicrestal: 0.91 ± 0.60 mm;

subcrestal: 0.79 ± 0.31 mm; 3 mm – epicrestal: 0.92 ± 0.56 mm; subcrestal: 0.79 ± 0.46 mm) (the present data set considered the free ends area) (Barros et al. 2010). Weng et al. (2010) evaluated the location of the microgap (epicrestal vs. 1.5 mm subcrestal) at two different screw-type implants exhibiting either an external-hex (smooth collar: 0.75 mm, length: 8.5 mm, outer diameter 3.75 mm) or an internal morse-taper connection (smooth collar: 1. 5 mm, length: 8 mm, outer diameter 3.5 mm). After 3 months of nonsubmerged healing, mean CBL values were comparable within groups (hexed group – epicrestal: 0.98 ± 0.41 mm; subcrestal: 0.76 ± 0.41 mm; Morse group – epicrestal: 2.08 ± 1.20 mm; subcrestal: 1.26 ± 1.48 mm) (Weng et al. 2010). In a radiographic

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Author, Year	Subgroup within study	Statistics for each study							Difference in means and 95% CI
		Difference in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	
Hermann et al. 2000	0 vs. −1 mm	0,900	0,223	0,050	0,462	1,338	4,031	0,000	
Schwarz et al. 2008	0 vs. −1.1 mm	0,740	0,241	0,058	0,268	1,212	3,073	0,002	
Hermann et al. 2011	0 vs. −1 mm	0,850	0,214	0,046	0,431	1,269	3,972	0,000	
		0,835	0,130	0,017	0,580	1,090	6,420	0,000	

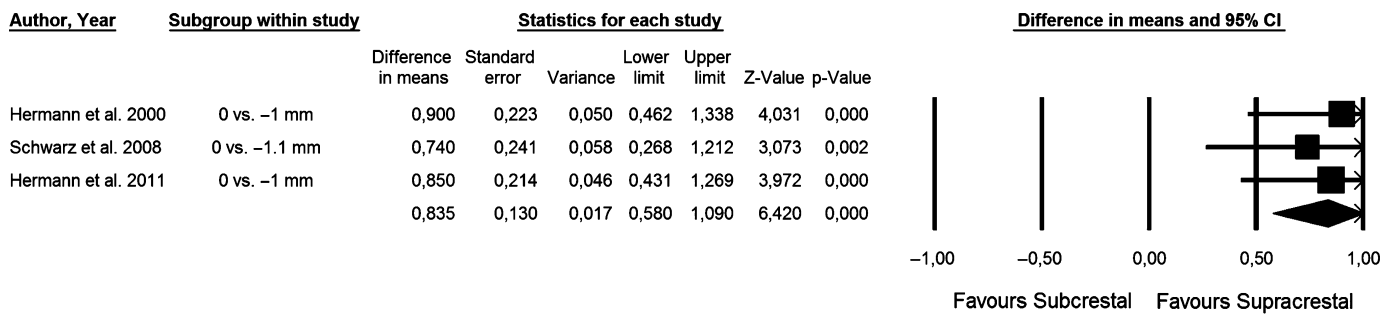Favours Subcrestal   Favours Supracrestal

Fig. 2. Forest plot indicating weighted mean difference (95% CI) between machined collars placed either above (i.e. supracrestal) or below (i.e. subcrestal) the bone crest. P-value for heterogeneity: 0.885, I2: 0.000% (= no heterogeneity).

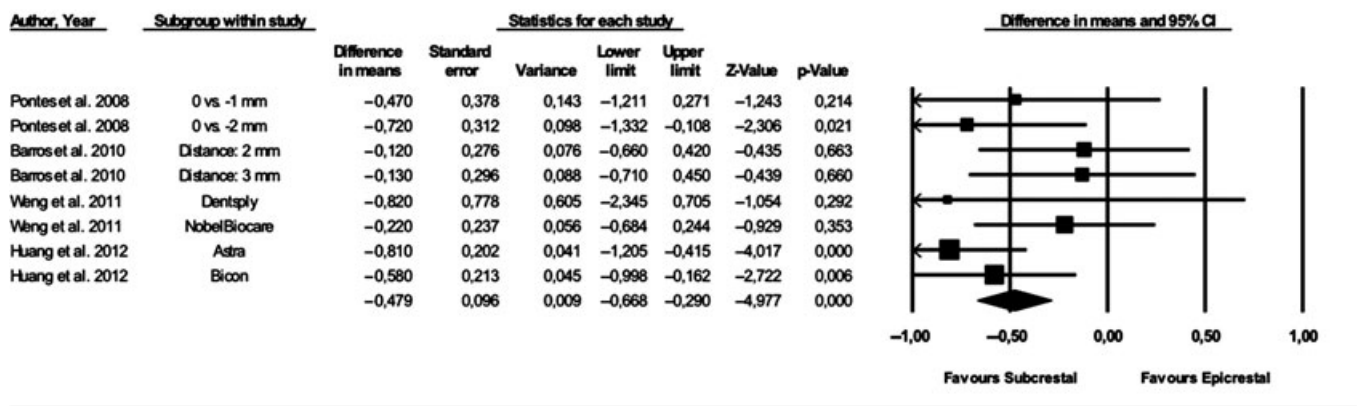| Author, Year	Subgroup within study	Statistics for each study							Difference in means and 95% CI
		Difference in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	
Pontes et al. 2008	0 vs -1 mm	−0,470	0,378	0,143	−1,211	0,271	−1,243	0,214	
Pontes et al. 2008	0 vs -2 mm	−0,720	0,312	0,098	−1,332	−0,108	−2,306	0,021	
Barros et al. 2010	Distance: 2 mm	−0,120	0,276	0,076	−0,660	0,420	−0,435	0,663	
Barros et al. 2010	Distance: 3 mm	−0,130	0,296	0,088	−0,710	0,450	−0,439	0,660	
Weng et al. 2011	Dentsply	−0,820	0,778	0,605	−2,345	0,705	−1,054	0,292	
Weng et al. 2011	NobelBiocare	−0,220	0,237	0,056	−0,684	0,244	−0,929	0,353	
Huang et al. 2012	Astra	−0,810	0,202	0,041	−1,205	−0,415	−4,017	0,000	
Huang et al. 2012	Bicon	−0,580	0,213	0,045	−0,998	−0,162	−2,722	0,006	
		−0,479	0,096	0,009	−0,668	−0,290	−4,977	0,000	

Favours Subcrestal   Favours Epicrestal

Fig. 3. Forest plot indicating weighted mean difference (95% CI) between microgaps placed either at (i.e. epicrestal) or below (i.e. subcrestal) the bone crest. P-value for heterogeneity: 0.333, I2: 12.404% (low heterogeneity).

study, Huang et al. (2012) compared two different implant types (screw-design) exhibiting either a tapped-in (TI) (length: 8 mm, outer diameter 3.5 mm), or screwed-in (SI) (length: 8 mm, outer diameter 3.5 mm) tapered internal abutment connection. After 16 weeks of healing, mean CBL values were significantly lower in the subcrestal (TI: 0.78 ± 0.42 mm; SI: 0.46 ± 0.26 mm), when compared with the epicrestal (TI: 1.36 ± 0.31 mm; SI: 1.27 ± 0.42 mm) groups, respectively (Huang et al. 2012) (Table 6). In a prospective clinical study, Veis et al. (2010) evaluated radiographic bone levels at two-piece implants with either matching or platform-switched abutment connections. After 2 years, mean CBL values were significantly lower at implants placed in either a subcrestal (i.e. 1–2 mm), or a supracrestal (i.e. 1–2 mm) position (matching – supracrestal: 0.60 ± 0.50 mm; epicrestal: 1.23 ± 0.96 mm; subcrestal: 0.81 ± 0.79 mm; platform-switch – supracrestal: 0.69 ± 0.47 mm; epicrestal: 1.13 ± 0.42 mm; subcrestal: 0.39 ± 0.52 mm) (Veis et al. 2010) (Table 6b).

Based on four animal (Pontes et al. 2008a; Barros et al. 2010; Weng et al. 2011a; Huang et al. 2012) studies, the weighted mean difference (95% CI) between microgaps placed either at or below the bone crest amounted to −0.479 mm (standard error: 0.096; variance: 0.009; lower limit: -0.668; upper limit: −0.290; Z-value: −4.977) favoring a subcrestal position of the implant neck (P < 0.001) (P-value for heterogeneity: 0.333, I2: 12.404% = low heterogeneity) (Fig. 3).

Due to the low number and high heterogeneity among the selected studies, a meta-analysis was not feasible for microgaps placed either at or above/above or below the bone crest.

Implant–abutment connection

In the canine model, Becker et al. (2007) histologically assessed crestal bone changes at screw-typed wide-diameter two-piece implants (SLA, machined neck: 0.4 mm, length: 11 mm, outer diameter 5.0 mm) exhibiting either a conical (CPS) or tube-in-tube (i.e. flat-to-flat) internal connection (CAM). Wide-body healing abutments were connected and left to heal in a nonsubmerged position. Between group comparisons at 28 days revealed slightly reduced mean CBL values at CPS (vestibular aspect: 1.3 ± 0.4 mm; lingual aspects: 1.2 ± 0.5 mm) when compared with CAM (vestibular aspect: 1.9 ± 0.3 mm; lingual aspects: 1.8 ± 0.6 mm) implants. Despite an identical macrodesign, however, both groups also differed with regard to the outer implant–abutment configuration (CAM: matching abutments; CPS: platform-switched abutments) (Becker et al. 2007) (Table 7a).

In a prospective clinical study, Koo et al. (2012) compared epicrestally inserted root-form implants (acid-etched surface, microthreads in the neck area, length: 8.5–13 mm, outer diameter 4.3 mm) exhibiting either an external or internal implant–abutment connection. Radiographic evaluation after 1 year revealed significantly higher mean CBL values for the external (1.14 ± 0.54 mm), when compared with the internal (0.24 ± 0.29 mm)–abutment connection (Table 7b).

Due to the limited number and high heterogeneity among the selected studies (i.e. differences in implant–abutment configurations – external vs. internal; conical vs. flat), a meta-analysis was not feasible.

Discussion

The present systematic review was conducted to address the following focused question: What is the impact of implant–abutment configuration and the positioning of the machined collar/microgap on crestal bone level changes?

In general, literature search revealed that the impact of these confounding factors has only been addressed in a total of thirteen publications. Most of these studies, among others, had a focus on the positioning of the machined collar and the implant neck relative to the alveolar bone and were mainly conducted in animals using the canine model. Basically, quality assessment of the selected animal and few human studies, performed according to the ARRIVE guidelines and CONSORT statement (Berglundh & Stavropoulos 2012; Tonetti & Palmer 2012), revealed a high risk of bias, which should be taken into account when evaluating the overall outcome of this systematic review. In this context, it must also be emphasized that systematic reviews of research involving animals are feasible and commonly used to "maximize the use of animal evidence to inform likely health effects in humans" (Peters et al. 2006).

Data synthesis has identified that a supracrestal positioning of the machined collar at both one- and two-piece implants may be favored over a subcrestal positioning (weighted mean difference [WMD]: 0.835 mm) (Hammerle et al. 1996; Hermann et al. 2000, 2011; Schwarz et al. 2008). However, when evaluating the outcomes reported in these studies, it must be emphasized that mean CBL values assessed after respective healing periods commonly did not consider the initial positioning of the implant neck relative to the alveolar crest (Hammerle et al. 1996; Hermann et al. 2000, 2011). Accordingly, the net bone loss at implants exhibiting a subcrestal insertion of the machined neck was even more pronounced than implied by mean CBL values, thus endorsing an epicrestal positioning of the smooth/rough border. Basically, this outcome is also supported by the results of a retrospective follow-up examination of 127 patients treated with CAM tube-in-tube implants. Implants that had been placed with the machined neck in a supracrestal position revealed a significantly lower radiographic bone remodeling (1.11 ± 0.87 mm) than implants that were placed according to the original protocol (i.e. 0.4 mm above the crest) (1.71 ± 1.14 mm) (Al-Nawas et al. 2011). As microbial leakage apparently did not contribute to the marginal bone resorption at either CAM or CAM+ implants (Schwarz et al. 2008; Steinebrunner et al. 2008), the pronounced bone remodeling at subcrestally inserted machined necks was most likely due to their reduced osteoconductive surface properties (Wennerberg & Albrektsson 2009). However, further controlled clinical studies also considering different neck designs are needed to clarify these issues.

When evaluating the positioning of the microgap at two-piece implants relative to the alveolar crest, data synthesis has identified that a subcrestal positioning may be favored over an epicrestal insertion of the implant neck (WMD: −0.479 mm) (Pontes et al. 2008a; Barros et al. 2010; Weng et al. 2011a; Huang et al. 2012). The evaluated histological data were commonly in agreement with the respective radiographic assessments (Pontes et al. 2008b; Novaes et al. 2009; Weng et al. 2011b), but also supported by the clinical analysis of Veis et al. (2010). Accordingly, despite a more pronounced bone remodeling, a subcrestal positioning of the microgap may help to retain the bony coverage of the rough surface. However, as this aspect has mainly been addressed for implants placed in animals with different surface characteristics, diameters, and follow-up times, it remains unclear whether a subcrestal positioning of two-piece implants should be advocated in patients.

The observation that a subcrestal positioning of the neck may limit crestal bone changes is also supported by a retrospective histological analysis of retrieved human implants. While the subcrestal insertion was commonly associated with the establishment of a close bone-to-implant contact on top of the implant shoulder, a crestal bone resorption of 0.5–1.5 mm was present at implants placed in an epicrestal position (Degidi et al. 2011). In this context, however, it must also be emphasized that, at least adjacent to experimental implants, the location and size of the microgap at or below the alveolar crest had a major impact on bone remodeling. These detrimental effects were less pronounced when the interface was initially positioned in a supracrestal position (Hermann et al. 2000, 2001). The present systematic review revealed that a direct comparison of either epi- vs. subcrestal or sub- vs. supracrestal positions of the implant neck has, so far, only been addressed in two studies (Cochran et al. 2009; Veis et al. 2010). The available data suggest that a supracrestal position may be favored over an epicrestal position; however, this trend could not be confirmed when comparing implants placed in supra- and subcrestal positions. Similarly, only two studies (1 animal; 1 human) addressed the influence of different implant–abutment configurations on crestal bone level changes. While an internal connection has been proven to be superior to an external connection (Koo et al. 2012), the beneficial aspect of either internal conical or internal flat-to-flat implant–abutment configurations cannot be estimated (Becker et al. 2007). However, a historical comparison of nonsubmerged conical and internal flat-to-flat (tube-in-tube) implants exhibiting the same macrodesign did not reveal any relevant differences in mean CBL values (1.11–1.14 mm vs. 1.0 mm) after 8 weeks of healing in the canine model (Becker et al. 2009, 2012). Finally, it must be noted that the consensus of the eighth European workshop on periodontology has acknowledged that "animal models may not completely recreate the anatomical, physiological, biomechanical/functional, or pathological environment of the clinical conditions in humans" (Berglundh & Stavropoulos 2012). Nevertheless, the present data synthesis has pointed to a close correlation of mean CBL values assessed in the canine and humans and may therefore underline the applicability of preclinical in vivo research in implant dentistry.

Within its limitations, the present systematic review has identified the importance of a correct positioning of the machined neck and microgap to limit crestal bone level changes at nonsubmerged implants. At the time being, however, the impact of the implant–abutment connection lacks documentation and may not allow for any conclusions.

Conflict of interests

The authors declare that they have no conflict of interests related to this systematic review.

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