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Crestal Bone Loss Around Adjacent Dental Implants Restored with Splinted and Nonsplinted Fixed Restorations: A Systematic Literature Review

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Keywords
Crestal bone loss; adjacent implants; splinted; connected; fixed restorations.

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Abstract

Purpose: The aim of this systematic review was to compare the crestal bone loss around splinted and nonsplinted adjacent implants.
Materials and Methods: To address the focused question, "Is crestal bone loss around adjacent implants different with splinted from that with nonsplinted restorations?," indexed databases were searched from 1965 up to and including May 2016 using various combinations of the following keywords: "implant," "splinted," "nonsplinted," "unsplinted," "connected," "unconnected," "nonconnected," and "bone loss." Letters to the editor, commentaries, historic reviews, case reports, case series, animal studies, and studies on full-arch rehabilitation were excluded.
Results: Six studies were included with titanium implants ranging from 114 to 1187 implants. All studies had nonsplinted and splinted restorations that ranged from 20 to 234 restorations and from 60 to 970 restorations, respectively. In all the studies, the follow-up period after the restoration placement ranged between 1 and 22 years, with a mean follow-up ranging between 3 and 10.18 ± 3.18 years. In all studies, the mean crestal bone loss for implants restored with nonsplinted restorations ranged between 0.30 ± 0.65 and 1.3 ± 0.2 mm, whereas the mean crestal bone loss for implants restored with splinted restorations ranged between 0.50 ± 0.8 and 1.22 ± 0.95 mm.
Conclusion: Within the limitations of this review it is concluded that adjacent implants restored with splinted and nonsplinted fixed restorations did not exhibit a difference in crestal bone loss. The evidence from this systematic review suggests further investigation.

Oral rehabilitation using dental implants has become the treatment of choice for the replacement of missing teeth in partially and totally edentulous patients.[1,2] The overall success and predictability of dental implant treatment includes primary stability, formation of direct bone-to-implant contact (BIC),[3] and quantity and/or quality of residual bone.[4-7] Moreover, excessive occlusal forces (occlusal overload) on restored implants may also influence the long-term implant-supported prosthesis success, resulting in excessive forces to the implant, crestal bone loss (CBL), and unstable gingival levels.[8,9]

Although rehabilitation of implants placed in partially edentulous patients with single crowns and/or fixed partial dentures presents a high predictability,[10,11] studies using finite element analysis and photoelastic modeling have suggested that splinted restorations (SR) allow better force distribution as compared to nonsplinted restorations (NSR).[12,13] NSR have also been reported to undergo higher occlusal forces, which may increase the stress on the prosthodontic components.[14] Nevertheless, contradictory results have also been reported. In a 36-month follow-up study, Bilhan et al[15] found no statistically significant difference in CBL around SR and NSR dental implants. Vigolo et al[16,17] reported similar results. Furthermore, NSR offer better emergence profile, normal-sized proximal contact, and easier oral hygiene maintenance.[13]

According to our comprehensive search, CBL around implants restored with SR compared to NSR has not been systematically reviewed. It was hypothesized that implants restored with SR present similar CBL compared to implants restored with NSR. Therefore, the aim of this study was to systematically compare the CBL around implants restored with NSR and SR.

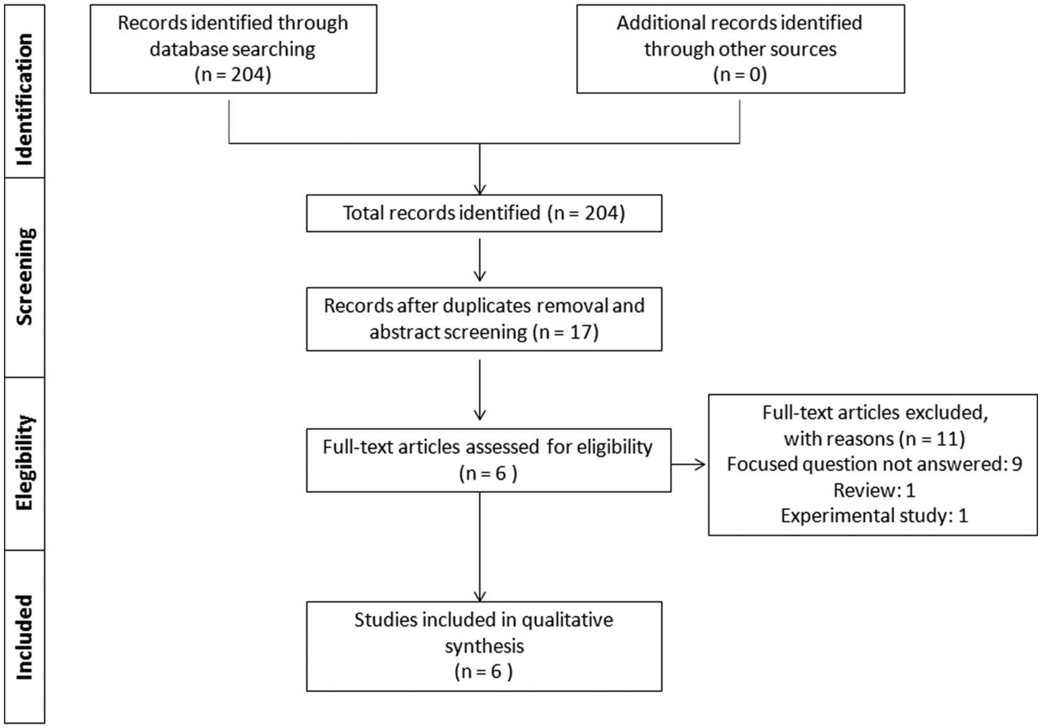

Figure 1 Article selection flowchart for the systematic review according to PRISMA guidelines.

Materials and methods

Focused question

Based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, a specific question was constructed according to the Participants, Interventions, Control, Outcomes (PICO) principle (Fig 1). The focused question addressed was "Is CBL around adjacent implants different with SR from that with NSR?"

(P) Participants: Patients undergoing implant treatment.
(I) Types of interventions: Implants restored with SR.
(C) Control Intervention: Implants restored with NSR.
(O) Outcome Measures: CBL around implants restored with fixed SR and NSR restorations.

Eligibility criteria

The following eligibility criteria were entailed: (a) original clinical studies; including randomized controlled trials, prospective and retrospective studies, and cohort studies; (b) patients undergoing implant treatment; and (c) patients with adjacent implants that have been restored with splinted and/or nonsplinted restorations. Letters to the editor, commentaries, historic reviews, case reports, case series, animal studies, and studies on full-arch rehabilitation were excluded.

Literature search protocol

PubMed/Medline (National Library of Medicine, Washington, DC), EMBASE, Scopus, Web of Knowledge, and Google Scholar databases were searched from 1965 up to and including May 2016 using the following Medical Subject Headings (MeSH): (1) dental implant, (2) implant-supported, and (3) alveolar bone loss. Other relevant non-MeSH keywords were used in the search process to identify articles discussing peri-implant bone loss and/or dental implants restored with splinted and/or nonsplinted restorations. Non-MeSH keywords included: (4) splinted, (5) nonsplinted, (6) unsplinted, (7) connected, and (8) unconnected. These keywords were used in the following combinations: 1, 2, 3, and 4, 5, or 6; 1, 2, 3 and 7 or 8; 1, 2, and 4, 5 or 6; 2 or 3, and 4, 5, or 6.

Titles and abstracts of studies identified using the above-described protocol were independently screened by authors and checked for agreement. Full texts of studies judged by title and abstract to be relevant were read and independently evaluated for the stated eligibility criteria. Reference lists of potentially relevant original and review articles were hand-searched to identify studies that remained unidentified in the previous step. Once again, the articles were checked for disagreement via discussion among the authors (Fig 1). Kappa scores (Cohen kappa coefficient)[18] were used to determine the level of agreement between the two reviewers (PubMed/Medline kappa score = 0.90; EMBASE kappa score = 0.85; Scopus kappa score = 0.90; Web of Knowledge = 0.90; Google Scholar = 0.80).

Quality assessment

Quality assessment of studies was performed using the Critical Appraisal Skills Program (CASP) Cohort Study Checklist.[19] A systematic approach based on 12 specific criteria was used:

Table 1 General characteristics of studies included

Authors, year (country)	Number of patients	Gender (F/M)	Mean age (age range in years)	Number of Implants	Mean follow-up (follow-up range in years)	Crestal bone loss diagnosis method	Mean crestal bone loss (mm)
Bilhan et al,[15] 2010 (Turkey)	36	21/15	54.97 (42-67)	126 F: 73 M: 53	3	Oral examination, panoramic, computer software	Single: –0.96 ± 0.19 (distal) –0.94 ± 0.26 (mesial) Splinted: –0.99 ± 0.15 (distal) –0.97 ± 0.14 (mesial)
Vigolo et al,[16] 2015 (Italy)	44	23/21	51 (37-58)	114	10	Oral examination, periapical, magnifying lens (6x)	Single: –1.3 ± 0.2 Splinted: –1.2 ± 0.2
Vigolo et al,[17] 2010 (Italy)	44	23/21	51 (37-58)	123	5	Oral examination, periapical, magnifying lens (6x)	Single: –0.8 ± 0.2 Splinted: –0.7 ± 0.2
Wagenberg et al,[20] 2015 (USA)	312	179/133	NA	312	7.4 (2-12)	Periapical, peak-to-peak distance	Single*: –0.30 ± 0.65 Splinted: –0.5 ± 0.8
Wagenberg et al,[21] 2013 (USA)	541	NA	58.75 ± 13.07 (12-88)	1187 F: 660 M: 527	10.18 ± 3.18 (1-22)	Periapical, peak-to-peak distance	Single: –0.44 ± 0.68 Splinted: –0.55 ± 0.85
Mendonca et al,[22] 2014 (Brazil)	198	112/86	M: 62.1 ± 11 F: 58.8 ± 12.6 (45-81)	453 F: 281 M: 172	9.7 ± 0.7 (3-16)	Oral examination, periapical, computer software	Single: –1.27 ± 1.15 Splinted: –1.22 ± 0.95

*Statistically significantly different from splinted.

(1) Study issue is clearly focused; (2) Cohort is recruited in an acceptable way; (3) Exposure is accurately measured; (4) Outcome (CBL) is accurately measured. (5) Confounding factors are addressed; (6) Follow-up is long and complete; (7) Results are clear; (8) Results are precise; (9) Results are credible; (10) Results can be applied to the local population; (11) Results fit with available evidence; and 12) There are important clinical implications. Each criterion was given a response of either "Yes," "No," or "cannot tell." Each study could have a maximum score of 12. CASP scores were used to grade the methodological quality of each study assessed. Those studies with a CASP quality score below 8 were excluded from the analysis, because they might have diminished the validity of the review conclusions.

Results

Study selection and characteristics

Through the initial search, 204 articles were identified. One hundred and eighty-seven articles were either duplicates or did not fulfill the inclusion criteria. In the second step of evaluation, 11 more full-text articles that did not answer the focused question were excluded (Appendix). The remaining six studies[15-17,20-22] were included in the present systematic review and processed for data extraction.

All studies[15-17,20-22] were performed on humans and under private healthcare settings. These studies were conducted in the following countries: Brazil, Italy, United States, and Turkey. The number of study participants ranged between 36 and 541 individuals with age ranging between 12 and 88 years. The mean ages of the participants ranged between 51 and 62.1 ± 11 years (Table 1).

Implant-related characteristics of the studies included

In all studies,[15-17,20-22] titanium implants were used, ranging from 114 to 1187 implants. In four studies,[15,20-22] implants were placed in anterior and posterior mandible and maxilla, whereas Vigolo et al[16,17] placed implants in the posterior maxilla alone. Three studies[16,17,22] reported lengths of implants used ranging from 7 to 13 mm. The length was not reported in the other three studies.[15,20,21] Mendonca et al[22] used tapered and cylindrical implants in their study. The implant design was not reported in the remaining five studies.[15-17,20,21] In three studies,[20-22] regular and wide implant platform designs were used, while Vigolo et al[16,17] used regular platform implants. The implant platform characteristics were not reported in one study.[15] In two studies,[20,21] rough and smooth surfaced implants were used, and in Wagenberg et al's study[20] only rough surfaced implants (anodic oxidized surfaces) were used. The implant surface characteristics were not reported in three studies (Table 2).[15-17]

Prosthesis-related characteristics of the studies included

In all studies,[15-17,20-22] both NSR and SR were placed and ranged from 20 to 234 restorations and from 60 to 970 restorations, respectively. In three studies,[16,17,22] metal ceramic (MC) restorations were used. The material characteristics were not reported in three studies.[15,20,21] In two studies,[16,17] an external implant-abutment connection was used. Mendonca et al.[22] used external and internal connections. The abutment connection characteristics were not reported in three studies.[15,20,21] In two studies,[16,17] the restorations were cemented with a temporary cement, and four studies[15,20-22] did not report the type of material used for cementation. In three studies,[16,17,22] the

Table 2 Characteristics of implants used in studies included

Authors	Number of implants	Implant design	Implant length (N = number)	Implant platform (N = number)	Implant surface characteristics (N = number)	Location of implant (N = number)
Bilhan et al[15]	126 F: 73 M: 53	NA	NA	NA	NA	Mandible and maxilla, anterior and posterior
Vigolo et al[16]	114	NA	10, 11.5, and 13 mm	Regular	NA	Posterior maxilla: 114
Vigolo et al[17]	123	NA	• 10 mm: 50 • 11.5 mm: 42 • 13 mm: 31	Regular	NA	Posterior maxilla: 123
Wagenberg et al[20]	312	NA	NA	• Regular: 236 • Wide: 76	Rough: 312	Mandible and maxilla, anterior and posterior
Wagenberg et al[21]	1187 F: 660 M: 527	NA	NA	• Regular: 940 • Wide: 247	• Rough: 314 • Smooth: 873	• Anterior mandible: 156 • Posterior mandible: 320 • Anterior maxilla: 314 • Posterior maxilla: 396
Mendonca et al[22]	453 F: 281 M: 172	Tapered: 80 Cylindrical: 373	• 7 mm: 67 • 8.5 mm: 145 • 10 mm: 241	• Regular: 264 • Wide: 189	• Rough: 157 • Smooth: 296	• Mandible: 60 • Maxilla: 393 • (Anterior and posterior)

F = female; M = male; NA = not available.

timespan between implant placement and loading with SR and NSR ranged between 12 and 19 weeks. Bilhan et al[15] evaluated the CBL around implants loaded in three timeframes after implant placement: <12 weeks, 12 to 24 weeks, and >24 weeks. The timing between the implant placement and loading was not reported in two studies[20,21] (Table 3). This significant heterogeneity among all the studies[15-17,20-22] did not allow pooling of results and statistical analysis.

Crestal bone loss assessment

In five studies,[16,17,20-22] CBL was evaluated using periapical radiographs. Mendonca et al[22] took periapical radiographs using the long-cone parallel technique, where CBL was digitally measured as the linear distance from the platform level to the first BIC on mesial and distal areas of the implants. In two studies,[16,17] an individual acrylic resin stent was used with the long-cone technique to control the imaging geometry, and the CBL was measured using a 6× magnifying lens to evaluate the apical end of the implant smooth collar. Wagenberg et al[20,21] established the CBL using periapical radiographs to measure the known distance between the implant thread peaks (peak-to-peak). Bilhan et al[15] analyzed panoramic radiographs using a software program to determine the CBL (distance from the most supracrestal part of the implant to the bone crest).

Main outcomes

In all the studies included,[15-17,20-22] the follow-up period after the restoration placement ranged from 1 to 22 years, with a mean follow-up ranging from 3 to 10.18 ± 3.18 years. In all studies,[15-17,20-22] the mean CBL for implants restored with NSR ranged from –0.30 ± 0.65 to –1.3 ± 0.2 mm; whereas the CBL for implants restored with SR ranged from –0.50 ± 0.8 mm to –1.22 ± 0.95 mm. In five studies,[15-17,21,22] there was no statistically significant difference in the peri-implant CBL around implants restored with SR and NSR. Wagenberg et al[20] reported a statistically significant difference in CBL around anodized oxidized surface implants restored with SR (–0.50 ± 0.8 mm) and NSR (–0.30 ± 0.65 mm) after a mean follow-up of 7.4 years.

CASP quality assessment of studies included

CASP quality assessment showed that all studies[15-17,20-22] were conducted on humans with a total quality score ranging from 9 to 11 out of 12. The most common shortcomings among the studies[15-17,20-22] were the inadequate diagnostic tools used to measure the peri-implant CBL, short follow-up, and the omission of confounding variables like smoking. Despite that, the average quality score of the six studies included was very good (9.67 out of 12). Quality assessment of the individual papers is summarized in Table 4.

Discussion

It has been suggested that a CBL of 1.5 mm around implants is acceptable, followed by an annual CBL of 0.2 mm.[22] Interestingly, in all the studies[15-17,20-22] included in the present review, the overall mean peri-implant CBL was less than 1.5 mm and was independent of the type of restoration used (SR or NSR). Five of the studies[15-17,21,22] included in the present

Table 3 Characteristics of implant-supported fixed restorations in studies included

Authors	Number of restorations	Restoration material	Implant-abutment connection	Torque	Retention type	Timespan between placement and loading
Bilhan et al[15]	• Single: 20 • Splinted: 106	NA	NA	NA	NA	<12 weeks, 12-24 weeks, and >24 weeks
Vigolo et al[16]	• Single: 54 • Splinted: 60	MC	External	32 Ncm	Cemented: Zinc-oxide eugenol-based temporary cement	19 weeks
Vigolo et al[17]	• Single: 60 • Splinted: 63	MC	External	32 Ncm	Cemented: Zinc-oxide eugenol-based temporary cement	19 weeks
Wagenberg et al[20]	• Single: 72 • Splinted: 240	NA	NA	NA	NA	NA
Wagenberg et al[21]	• Single: 217 • Splinted: 970	NA	NA	NA	NA	NA
Mendonca et al[22]	• Single: 234 • Splinted: 219 • 2 units: 84 • 3 units: 17	MC	• External: 362 • Internal: 91	NA	NA	• Mandible: 12 weeks • Maxilla: 18 weeks

MC = metal ceramic.

Table 4 CASP quality assessment of articles reviewed

Authors	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9	Item 10	Item 11	Item 12	Total quality score (0 to 12)
Bilhan et al[15]	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	9
Vigolo et al[16]	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	10
Vigolo et al[17]	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	9
Wagenberg et al[20]	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	No	Yes	9
Wagenberg et al[21]	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	11
Mendonca et al[22]	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	10
Average score													9.67

Item 1: study issue is clearly focused; item 2: cohort is recruited in an acceptable way; item 3: exposure is accurately measured; item 4: outcome is accurately measured; item 5: confounding factors are addressed; item 6: follow-up is long and complete; item 7: results are clear; item 8: results are precise; item 9: results are credible; item 10: results can be applied to the local population; item 11: results fit with available evidence; item 12: there are important clinical implications.

systematic review showed no significant difference in the CBL around implants supporting SR or NSR. Although Wagenberg et al[20] reported a statistically significant difference in the CBL around immediately placed rough-surfaced implants restored with NSR (–0.30 ± 0.65 mm) compared to SR (–0.5 ± 0.8 mm), the clinical relevance of a mean difference of –0.2 mm is questionable.

The results of the present systematic review showed that CBL is comparable among dental implants restored with SR and NSR, and selection is based on the clinician's preference. Therefore, our hypothesis was accepted according to the presented evidence; however, other factors should be considered when making this selection. Caution should be practiced in patients with parafunctional habits, unfavorable occlusal relationships, compromised crown/implant ratio, unfavorable mesiodistal distribution of implants, and difficulty in oral hygiene maintenance. A variety of factors may have biased the present results. One potential factor is the type of restoration retention used,[23] since results from four of the studies included[15,20-22] did not report if cement- or screw-retained restorations were used. Moreover, in the remaining two studies,[16,17] only cement-retained restorations were used. Therefore, it is difficult to estimate the influence of retention type (screw- versus cement-retention) on CBL around implants restored with SR and NSR. Removing the excess cement by the dentist and the dental plaque by the patient might be more difficult with SR than with NSR. On the other hand, cement-retained splinted restorations could have better passive fit.[24] Further well-designed, split-mouth clinical trials are needed in this regard. Since the bone architecture and density varies between the maxilla and mandible,[25] it is hypothesized that jaw location may influence CBL around implants. In a recent study, Ozgur et al[26] showed that CBL is higher around implants placed in the posterior maxillary region than in mandible; however, according to the present results CBL in the maxilla and mandible was comparable. In four of six included studies[15,20-22] implants were placed in the anterior and posterior mandible and maxilla, whereas in the remaining two studies,[16,17] implants were placed in the posterior maxilla. Since a limited number of studies[15-17,20-22] addressed the focused question, it is difficult to conclude that the jaw location influences CBL around SR or NSR. Hence, further long-term clinical studies are needed in this regard.

In all the studies,[15-17,20-22] mesial and distal CBL assessment was based on the linear distance from the implant-abutment connection to the most coronal portion of crestal bone using radiographs (periapical or panoramic). It is noteworthy that studies[27,28] have shown that CBL can be expected in the labial aspect after extractions, and the only accurate way to measure the labial and lingual changes in bone height is by computed tomography.[29] Therefore, reliable and accurate measuring tools are necessary to evaluate peri-implant CBL. Furthermore, upon a vigilant evaluation of all the studies[15-17,20-22] included in the present systematic review, it was observed that the time in situ varied significantly (1 to 22 years) between the included studies and that other related factors (such as soft tissue thickness,[30] implant positioning,[31] crestal or subcrestal placement, platform switching,[32] crown-to-implant ratio,[33] and presence of adjacent teeth[15]) that have been associated with CBL remained unaddressed. However, splinting of short implants in particular has been recommended by some authors.[22,34]

Within the limits of the evidence available, the rehabilitation of adjacent implants placed in partially edentulous patients with splinted and/or nonsplinted fixed prostheses presents comparable predictability regarding the long-term CBL. Advantages of SR include better stress and strain distribution, and reducing overloading.[34] On the contrary, a NSR improves esthetics by offering better emergence profile and giving the impression of individual teeth, eliminates the need for large prostheses, and allows flossing and easier inter-proximal hygiene.[22,35] Although both splinted and nonsplinted implant-supported fixed restorations are clinically acceptable and predictable, clinicians should consider other factors associated with the overall success of treatment depending on the biological, functional, and esthetic needs of patients. Further long-term clinical trials are needed to assess the significance of splinting adjacent implants on the CBL and other peri-implant parameters.

The evidence from this systematic review suggests further investigation with consideration of other associated parameters like implant design, augmentation technique, treatment protocol, surgical procedure, occlusal relation, systemic health and patient's needs and satisfaction.

Conclusion

Within the limitations of this review it is concluded that adjacent implants restored with splinted and nonsplinted fixed restorations did not exhibit a difference in CBL.

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35. Norton MR: Multiple single-tooth implant restorations in the posterior jaws: maintenance of marginal bone levels with reference to the implant-abutment microgap. Int J Oral Maxillofac Implants 2006;21:777-784

Appendix: List of excluded articles

(a) Capelli M, Esposito M, Zuffetti F, et al: A 5-year report from a multicentre randomised clinical trial: immediate nonocclusal versus early loading of dental implant in partially edentulous patients. Eur J Oral Implantol 2010;3:209-219 (Focused question not answered).
(b) Golab KG, Balouch A, Mirtorabi S: One-year multicenter prospective evaluation of survival rates and bone resorption in one-piece implants. Clin Implant Dent Relat Res 2016;18:392-400 (Focused question not answered).
(c) Guichet D, Yoshinobu D, Caputo A: Effect of splinting and interproximal contact tightness on load transfer by implant restorations. J Prosthet Dent 2002;87:528-535 (Experimental study).
(d) Lindh T, Gunne J, Tillberg A, et al: A meta-analysis of implants in partial edentulism. Clin Oral Implants Res 1998;9:80-90 (Review).
(e) Naert IE, Rosenberg D, van Steenberghe D, et al: The influence of splinting procedures on the periodontal and peri-implant tissue damping characteristics. A longitudinal study with the Periotest device. J Clin Periodontol 1995;22:703-708 (Focused question not answered).
(f) Naert I, Koutsikakis G, Quirynen M, et al: Biology outcome of implant-supported restorations in the treatment of partial edentulism. Part 2: A longitudinal radiographic evaluation. Clin Oral Implants Res 2002;13:390-395 (Focused question not answered).
(g) Perelli M, Abundo R, Corrente G, et al: Short (5 and 7 mm long) porous implant in the posterior atrophic mandible: a 5-year report of a prospective study. Eur J Oral Implantol 2011;4:363-368 (Focused question not answered).
(h) Perelli M, Abundo R, Corrente G, et al: Short (5 and 7 mm long) porous implants in the posterior atrophic maxilla: a 5-year report of a prospective single-cohort study. Eur J Oral Implantol 2012;5:265-272 (Focused question not answered).
(i) Rodrigo D, Cabello G, Herrero M, et al: Retrospective multicenter study of 230 6-mm SLA-surfaced implants with 1- to 6-year follow-up. Int J Oral Maxillofac Implants 2013;28:1331-1337 (Focused question not answered).
(j) Sivolella S, Stellini E, Testori T, et al: Splinted and unsplinted short implants in mandibles: a retrospective evaluation with 5 to 16 years of follow-up. J Periodontol 2013;84:502-512 (Focused question not answered).
(k) Sohn DS, Lee JM, Park IS, et al: Retrospective study of sintered-porous surfaced dental implants placed in the augmented sinus. Int J Periodontics Restorative Dent 2014;34:565-571 (Focused question not answered).