Marginal Bone Level Changes at Dental Implants after 5 Years in Function: A Meta-Analysis

Lars Laurell, DDS, PhD/Dr Odont;* Dan Lundgren, DDS, PhD/Dr Odont†

ABSTRACT

Background: It is important that peri-implant bone breakdown caused by, for example, undue load and/or peri-implantitis, is prevented or minimized. Some continuous loss of marginal bone is generally accepted, but the question remains as to what extent it must occur.

Purpose: The purpose of this study was to compile and compare data on peri-implant marginal bone level changes from prospective studies that have registered the peri-implant marginal bone level radiographically at the time of prosthetic loading, and after 5 years of follow-up for implant systems currently available on the market.

Materials and Methods: A literature search was carried out to identify prospective studies on peri-implant marginal bone level changes around dental implants. To be included in a meta-analysis, the implant systems should have been subjected to at least two independent studies. Copycats without documentation were not accepted.

Results: Forty prospective studies that presented with a 5-year data were identified. Three implant systems met the inclusion criteria of having at least two independent studies; Astra Tech Dental Implant System® (Astra Tech AB, Mölndal, Sweden), Brånemark System (Nobel Biocare AB, Göteborg, Sweden), and Straumann Dental Implant System (Institute Straumann AG, Basel, Switzerland). The pooled mean marginal bone level change amounted to –0.24 mm (95% CI –0.345, –0.135) for the Astra Tech Dental Implant System, 0.75 mm (95% CI –0.802, –0.693) for the Brånemark System, and 0.48 mm (95% CI –0.598, –0.360) for the Straumann Dental Implant System over 5 years, with a statistically significant difference ($p < .01$) between the systems.

Conclusions: The identified implant systems showed an annual bone loss below or much below what hitherto has been set up as a limit for success. A careful documentation of marginal bone level changes should be mandatory for all implant systems before being marketed. It is also time for revision of existing success criteria to refine the basis for clinical quality judgment of implant treatment.

KEY WORDS: dental implants, marginal bone level changes, meta-analysis, 5 years follow-up

INTRODUCTION

Since the first systematic treatment with dental implants that started in the late 1970s, much has happened clinically as well as market wise regarding products as well as clinical measures and indications. During the first years, the systematic and well-controlled dental implant treatment was mainly confined to the Brånemark System (Nobel Biocare AB, Göteborg, Sweden) and the Straumann Dental Implant System (Institute Straumann AG, Basel, Switzerland). Criteria for survival and success were introduced based on systematic scientific documentation of treatment outcome.[1–3] However, since then, several other implant systems have been launched and surgical as well as prosthetic techniques have improved, and the demands for more sophisticated functional and aesthetic solutions have increased. Thus, new implant brands and new surfaces, different connections between implant and superstructure, and different time frames between surgical installation procedures and start of prosthetic loading have continuously been

*Assistant professor, Institute of Odontology, The Sahlgrenska Academy at University of Gothenburg, Gothenburg, Sweden; †professor, Department of Biomaterials, Institute of Clinical Sciences, The Sahlgrenska Academy at University of Gothenburg, Gothenburg, Sweden

Reprint requests: Professor Dan Lundgren, Dept Biomaterials, Institute for Surgical Sciences, Sahlgrenska Academy, Gothenburg University, PO Box 412, SE 405 30 Gothenburg, Sweden; e-mail: dan.lundgren@glocalnet.net

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introduced. Today, submerged versus nonsubmerged techniques, and immediate loading versus delayed loading are balanced against each other depending on the clinical situation. Generally, there is a strong desire to shorten the treatment time and simplify surgical as well as prosthetic measures for the better of both the dentist and the patient while still striving for a high rate of success for both implants and superstructures.

Common for most parties involved in implant treatment is the desire to achieve long-lasting good results for both the supporting implants and the prosthetic superstructure. The far most important factor for a good long-range prognosis of implant treatment is the achievement and maintenance of osseointegration of the implant in the jawbone. It is also important that peri-implant bone breakdown caused by, for example, undue load and/or plaque-induced peri-implant tissue infection (peri-implantitis), is prevented or at least minimized. This means that maintenance of the initially achieved peri-implant bone level as coronal as possible is a key factor for long-term success of any implant treatment.

Based on previous postulations,[1–3] it is widely accepted that a marginal bone loss in the order of 1 mm during the first year of service, that is, during the first year after initiation of prosthetic loading, and an annual bone loss thereafter not exceeding 0.2 mm, is a natural feature and consistent with successful treatment. The question arises, however, as to what extent implant systems, currently available on the market, will meet these criteria in daily clinic. It may be that these, for its time, well-founded success criteria need revision based on new knowledge and demands on maintenance of aesthetics and function.

The aim of the present meta-analysis was therefore to compile and compare data on peri-implant marginal bone level changes from prospective studies that have registered the peri-implant marginal bone level radiographically at the time of prosthetic connection, and after 5 years of follow-up for implant systems currently available on the market.

MATERIALS AND METHODS

A MEDLINE search (PubMed) was conducted, and works published in the English language from 1980 until December 2007 were included in the review. The following search terms were used in different combinations: "dental implants," "clinical or prospective studies," "long-term or 5-year follow-up," and "bone loss." Titles and abstracts were screened, and full-text analysis was performed in relevant publications. A manual searching was conducted for the following journals (for the year 2007): *Clinical Implant Dentistry and Related Research, Clinical Oral Implants Research, International Journal of Oral & Maxillofacial Implants, International Journal of Periodontics, Journal of Clinical Periodontology, Journal of Periodontology, and Journal of Prosthetic Dentistry*.

Furthermore, the Web sites from the following implant companies were searched for documentation: Astra Tech, Biomet/3i, Friadent/Dentsply, Lifecore Biomedical, Nobel Biocare, Osstem, Straumann, and Zimmer Dental.

Inclusion Criteria

The following criteria are needed to be included in the meta-analysis:

- The implant system should presently (2007) be available on the market. Copycats without documentation were not accepted even if the original system was well documented.
- At least two independent studies should have been published.[2] The studies should be prospective and reported in peer-reviewed dental journals in the English language.
- The studies should present radiographic data on change in marginal bone level between baseline and 5 years, or the marginal bone level at baseline and at 5 years. Baseline was considered as the time of initiation of prosthetic loading usually 3 to 6 months after implant placement. If follow-up time exceeded 5 years, only available 5-year data were included in the analysis.

Case studies or case reports with a minimum of 10 included patients, as well as controlled clinical trials, were accepted. Likewise, one as well as two stage surgeries were included.

Exclusion Criteria

Studies were excluded if focusing on the following:

- Advanced surgery, for example, sinus lift operations
- Bone augmentation procedures
- Implants placed immediately in extraction sockets
- Implants loaded immediately following implant placement

Immediate implant placements as well as immediate loadings were excluded as evidence of these treatment modalities as being predicatively reliable is lacking.[4,5]

From the identified articles, the following variables were extracted: type of study, number of included patients, number of placed implants, implant sites (maxilla/mandible, anterior/posterior), type of restoration, healing time before loading, number of lost implants, implant survival, number and percentage of patients and implants analyzed, mean marginal bone level change (MBLC) and standard deviation (SD) from baseline to 5 years. Mean MBLC data were either given in the studies or calculated by the authors by extracting presented mean marginal bone level data at baseline from mean marginal bone level data at 5 years. In those cases, standard deviation data on MBLC were not available.

Data Analysis

The statistical analyses were carried out by a statistician. Mean and standard deviation values from each study were used to assess *pooled* mean MBLCs and 95% confidence interval (CI) for each implant system. As standard deviation data were unavailable for a number of studies on Brånemark and Straumann implants, it was assumed that standard deviations between studies were homogenous. Consequently, the common standard deviation was assessed based on all available standard deviation data. To account for the difference in the number of subjects between the different studies, *weighted* mean values and 95% CI were assessed also.

Differences in MBLC values between systems were tested for statistical significance using the unpaired *t*-test. *p* Values less than .05 were considered statistically significant.

RESULTS

The combinations of search terms resulted in a list of 293 titles (PubMed until December 2007, manual searching in specified journals, and searching at companies' Web sites). Following screening of titles and abstracts by applying the defined inclusion and exclusion criteria, 68 potentially relevant publications were identified in which a full-text analysis was performed. Additional 28 publications were excluded mainly because of lack of data regarding marginal bone level changes between baseline and 5 years, too small sample size, retrospective study design, or less than two independent studies available for a specific implant system. Full-text analysis yielded 40 studies eligible for inclusion, and only three implant systems fulfilled the inclusion criteria: the Astra Tech Dental Implant System (Astra Tech AB, Mölndal, Sweden) with 10 studies,[6–15] the Brånemark System with 20 studies,[14,16–35] and the Straumann Dental Implant System with 11 studies.[33,36–45] The studies, together with the extracted data, are listed in Tables 1 to 3. The studies on the Astra Tech Dental Implant System encompassed 324 patients with 1,187 implants being radiographically evaluated, the studies on the Brånemark System included 1,051 patients with 3,719 implants, and finally the Straumann Dental Implant System included 614 patients with 1,364 implants. In all studies, except one, mean MBLCs were consistent with lowering of the marginal bone at the implant, that is, bone loss. Figure 1 depicts the MBLC mean values from the various studies showing more consistent results with the Astra Tech than with the Brånemark and Straumann implant systems.

Table 4 presents *pooled* mean values and 95% CI for MBLC for the three systems and the *weighted* mean values, taking into account the number of patients in each study. The *pooled* MBLC for the Astra Tech, Brånemark, and the Straumann implant systems amounted to −0.24 mm (95% CI −0.345, −0.135), −0.75 mm (95% CI −0.802, −0.693), and −0.48 mm (95% CI −0.598, −0.360), respectively. The corresponding *weighted* mean MBLC values were −0.27 mm (95% CI −0.356, −0.179), −0.72 mm (95% CI −0.776, −0.673), and −0.56 mm (95% CI −0.661, −0.481), respectively. The differences between systems were statistically significant ($p < .01$).

Figure 2 depicts as box-plot diagrams pooled MBLCs for the Astra Tech, Brånemark, and Straumann implant systems after 5 years. The diagram illustrates that there were larger differences in MBLC between the different Brånemark and Straumann studies than between the different Astra Tech studies.

DISCUSSION

The purpose of this meta-analysis study was to assess from the literature radiographic peri-implant MBLCs 5 years after initiation of prosthetic loading at dental implants currently available on the market. The analysis was made to find out to what extent currently available implant systems comply with presently accepted success criteria[1–3] and was made on data derived from prospective 5-year follow-up studies. No attempt was made to evaluate marginal bone level measurements for the

TABLE 1 Data from 5-Year Follow-Up Studies on the Astra Tech Dental Implant System

Author	Type of study	Number of patients included	Number of implants placed	Implant site: maxilla/ mandible anterior/posterior	Type of restorations	Healing time between implant placement and loading (months)	Number of implants lost	Implant survival (%)	Number of patients analyzed (*n*/%)	Number of implants analyzed (*n*/%)	Mean MBLC (mm)	Spreading (SD)
Makkonen et al.[6]	CCT	33	155	Edentulous mandible	FPD, OD	3–6	2	98.7	25/76	141/91	−0.48	±0.38
Arvidson et al.[7]	CS	107	618	Edentulous mandible	FPD	3–6	11	98.7	86/80	517/84	−0.26	±0.53
Davis and Packer[8]	CCT	25	52	Edentulous mandible	OD	3–6	3	94.0	18/72	36/69	−0.15	±0.65
Gotfredsen and Holm[9]	CCT	26	52	Edentulous mandible	OD	3–6	0	100	26/100	52/100	−0.20	±0.8
Palmer et al.[10]		15	15	Anterior maxilla	S	6	0	100	14/93	14/93	+0.12	±0.49
Gotfredsen and Karlsson[11]	CCT	50	133	Maxilla/mandible Anterior/posterior	FPD	3–6	3	97.6	32/64	70/53	−0.36	±1.04
Gotfredsen[12]	CCT	10	10	Anterior maxilla	S	3–6	0	100	10/100	10/100	−0.26	±0.38
Wennström et al.[13]	CS	51	149	Maxilla/mandible Anterior/posterior	FPD	3–6	4	97.3	47/92	137/92	−0.41	±0.78
Åstrand et al.[14]	CCT	33	184	Edentulous mandible and maxilla	FPD	3–6	3	98.4	30/91	170/92	−0.26	±0.22
Wennström et al.[15]	CS	40	45	Maxilla/mandible Anterior/posterior	S	3–6	1	97.7	36/90	40/89	−0.14	±1.04

CCT = controlled clinical trial; CS = case study; FPD = fixed partial denture (including cross-arch FPD); MBLC = marginal bone level change; OD = overdenture; S = single crown.

individual studies. There was a great heterogeneity among studies. Whereas the Astra Tech studies were mainly controlled clinical trials, case reports dominated as documentation for the Brånemark and Straumann implant systems. Only two controlled studies compared different implant systems.[14,33] There was a great variation in the percentage of treated patients and placed implants that were included in the meta-analysis. Percentages below 80% would render the study data questionable reliability. Furthermore, mean and standard deviation data on MBLCs were given in all Astra Tech studies, but had to be assessed from baseline and 5-year data on mean marginal bone level in most Brånemark and Straumann studies. Thus, there were no spreading data available for the meta-analysis. Therefore, the common standard deviation was assessed from available spreading data, presuming that standard deviation data were homogenous between studies. Ideally, a number of studies should have been excluded from the analysis because of questionable quality. However, the included studies were all published in peer-reviewed journals, and omitting studies for the lack of, for example, spreading data, would exclude valuable information. The various studies included anterior and posterior as well as maxillary and mandibular sites, and different types of fixed and removable superstructures. However, as the original study data did not indicate or give information about any influence of implant site or type of prosthetic reconstruction on the MBLCs, these factors were not considered in the analysis. In addition, the number of studies was too small to allow for such differentiation.

To be included in the analysis, basic inclusion criteria were set up, the most critical being that at least two independent studies should have been published[2] and each study should present radiographic data of the periimplant marginal bone level at baseline, that is, the time of prosthetic connection, and at 5 years follow-up. Surprisingly, only three implant systems fulfilled the inclusion criteria. No other system could present two or more studies with 5-year data on marginal bone remodeling.

The mean marginal bone loss was well below 1 mm over 5 years for the three systems (see Table 4). This would correspond to an annual mean bone loss of 0.05, 0.15, and 0.10 mm, respectively. This should be compared with the present success criteria[1–3] that allow for 1 mm bone loss during the first year, and further annual loss not exceeding 0.2 mm, which in turn corresponds to 1.8 mm over 5 years. However, it should be stressed that

TABLE 2 Data from 5-Year Follow-Up Studies on the Brånemark System

Author	Type of study	Number of patients included	Number of implants placed	Implant sites: maxilla/mandible anterior/posterior	Type of restorations	Healing time between implant placement and loading (months)	Number of implants lost	Implant survival (%)	Number of patients analyzed (*n*/%)	Number of implants analyzed (*n*/%)	Mean MBLC (mm)	Spreading (SD)
Jemt and Lekholm[16]	CS	67	259	Maxilla/mandible	FPD	3–4	7	97.2	58/87	Not available	−0.70	Not available
Ericsson et al.[17,18]	CS	11	63	Edentulous mandible	FPD	3–4	2	96.8	11/100	61/97	−0.94	Not available
Jemt T[19]	CS	76	449	Edentulous maxilla	FPD	5–7	34	92.1	62/82	350/78	−0.60	Not available
Lekholm et al.[20]	CS	159	558	Maxilla/mandible	FPD	3–6	36	93.3	132/83	408/73	−0.65	±0.85
Olsson M et al.[21]	CCT	23	69	Maxilla (full) Mandible (partial)	FPD	3–4	8	88.0	22/96	52/75	−0.30	Not available
Jemt T et al.[22]	CS	133	510	Maxilla/mandible	OD	3–4	44	90.8	92/69	181/35	−0.65	±0.80
Friberg et al.[23]	CCT	103	563	Edentulous mandible and maxilla	FPD	3–4	27	95.4	83/81	399/71	−0.81	Not available
Andersson et al.[24]	CCT	57	65	Mandible/maxilla Anterior/posterior	S	No information	1	98.5	49/86	55/85	−1.80	Not available
Andersson et al.[25]	CCT	38	38	Maxilla anterior	S	No information	0	100	34/89	34/89	−1.50	Not available
Naert et al.[26]	CCT	36	72	Mandible	OD	3–5	1	98.6	31/86	62/86	−0.57	Not available
Scheller et al.[27]	CS	82	99	Majority in anterior maxilla and mandible	S	3–6	4	95.9	57/70	42/42	−0.35	Not available
Friberg et al.[28]	CS	49	260	Edentulous mandible	FPD, OD	3–4	11	95.5	37/76	186/72	−0.70	±0.8
Jemt T et al.[29]	CCT	58	349	Maxilla	FPD	5–6	25	91.4	50/86	281/80	−0.59	±0.97
Jemt T et al.[30]	CCT	42	170	Maxilla/mandible	FPD	Not given	4	96.3	35/83	131/77	−0.32	±0.66
Attard and Zarb[31]	CS	45	265	Edentulous mandible and maxilla	FPD	3–6	31	88.1	45/100	228/86	−1.26	Not available
Attard and Zarb[32]	CS	45	132	Edentulous mandible and maxilla	OD	3–6	5	96.1	33/73	114/86	−1.40	Not available
Meijer et al.[33]	CCT	30	60	Edentulous mandible	OD	3	1	98.3	26/87	52/95	−0.70	±0.8
Åstrand et al.[14]	CCT	33	187	Edentulous mandible and maxilla	FPD	3–6	10	94.6	32/97	170/91	−0.11	±0.10
Örtorp and Jemt[34]	CCT	126	729	Edentulous mandible and maxilla	FPD	3–6	25	96.4	100/79	563/77	−0.50	±0.48
Jemt and Johansson[35]	CCT	76	450	Maxilla	FPD	>5	29	93.4	62/82	350/78	−0.50	±0.47

CCT = controlled clinical trial; CS = case study; FPD = fixed partial denture (including cross-arch FPD); MBLC = marginal bone level change; OD = overdenture; S = single crown.

TABLE 3 Data from 5-Year Follow-Up Studies on the Straumann Dental Implant System

Author	Type of study	Number of patients included	Number of implants placed	Implant site: maxilla/mandible anterior/posterior	Type of restorations	Healing time between implant placement and loading (months)	Implants lost	Implant survival (%)	Number of patients analyzed (*n*/%)	Number of implants analyzed (*n*/%)	Mean MBLC (mm)	Spreading (SD)
Behneke et al.[36]	CS	55	114	Maxilla/mandible Anterior/posterior	OD	3–4	5	95.3	47/86	94/82	−0.60	Not available
Weber et al.[37]	CS	46	112	Maxilla/mandible Anterior/posterior	FPD, S	3–4	1	99.1	40/87	56/50	−0.20	Not available
Hellem et al.[38]	CS	46	216	Edentulous mandible	OD, FPD	4	9	95.7	43/93	193/89	−0.20	±0.66
Mericske-Stern et al.[39]	CS	72	109	Maxilla/mandible	S	3 (mandible) 4–6 (maxilla)	1	99.1	26/36	26/24	−0.40	Not available
Behneke et al.[40]	CS	100	337	Edentulous mandible	FPD, S	3–4	4	98.8	83/83	283/84	−0.50	Not available
Mericske-Stern et al.[41]	CS	41	173	Edentulous maxilla	OD	4–6	8	94.2	11/27	36/21	−0.70	Not available
Hartman and Cochran[42]	CS	42	114	Maxilla/mandible Anterior/posterior	FPD	4–6	0	100	17/40	Not available	−0.38	Not available
Meijer et al.[33]	CCT	30	60	Edentulous mandible	OD	3	0	100	27/90	54/90	−0.90	±0.90
Bornstein et al.[43]	CS	51	104	Maxilla/mandible Posterior	FPD, S	1.5	1	99.0	49/96	100/96	−0.15	Not available
Romeo et al.[44]		188	330	Maxilla/mandible Anterior/posterior	FPD, S	3–6	4	99.0	188/100	330/100	−1.00	Not available
Blanes et al.[45]	CS	109	247	Maxilla/mandible posterior	FPD, S	3–6	4	97.9	83/76	192/78	−0.24	±1.16

CCT = controlled clinical trial; CS = case study; FPD = fixed partial denture (including cross-arch FPD); MBLC = marginal bone level change; OD = overdenture; S = single crown.

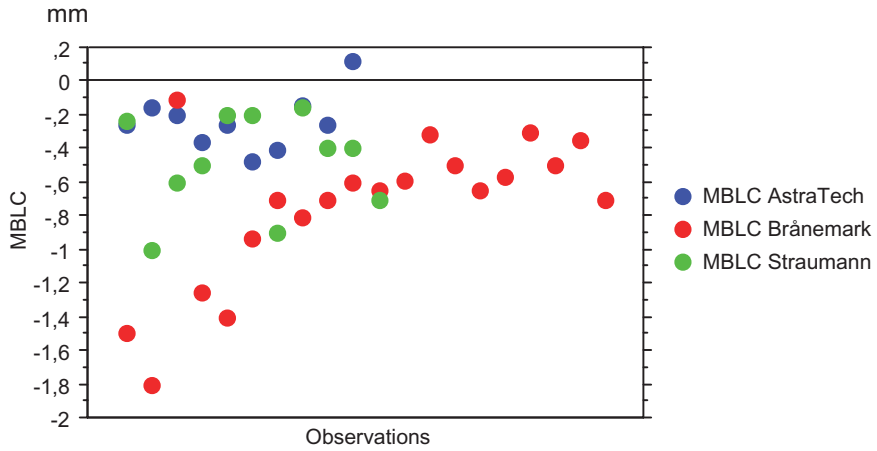

Figure 1 Univariate scattergram showing mean values for marginal bone level changes (MBLCs) for the Astra Tech, Brånemark, and Straumann implant systems.

in most of the studies in the present analysis, the major part of the marginal bone loss occurred during the first year after prosthetic loading, whereafter the marginal bone levels stabilized. The evidently very minor marginal bone loss around, in particular, the Astra Tech implants allows for meeting the increasing demand on aesthetics and function. Interestingly, several longitudinal epidemiological studies on periodontal marginal bone height changes in adult normal dentate populations[46–49] have demonstrated an annual bone height reduction of slightly below 0.1 mm. Based on the results of the present analysis, it becomes evident that marginal bone loss around these dental implants, under favorable conditions, is comparable with that of natural teeth.

Peri-implant MBLCs over a 5-year period were evidently very small for the investigated implant systems. However, there were statistically significant differences between systems. Although the clinical relevance of the differences between systems can be questioned, the values of the individual Astra Tech implant studies were much more consistent than for the Brånemark and Straumann systems (see Figures 1 and 2). Thus, the individual study mean MBLC values for the Astra Tech implants ranged between +0.12 and −0.48 mm as compared with −0.11 to −1.80 mm for the studies on the Brånemark implants, and from −0.15 to −1.0 mm for the Straumann implants. It should be remembered that a mean marginal bone loss of 1.0 or 1.8 mm implies that one or more cases have lost more, or even much more, bone.

The results in the present meta-analysis corroborate parts of the results reported by Eliasson and colleagues.[50] In their one-clinic, retrospective study, the same three implant systems (i.e., Astra Tech, Nobel Biocare, and Straumann) were evaluated by comparing the 5-year clinical outcome of early- and delayed-loading protocols. In that study, Astra Tech implants had a mean bone level change of −0.09 mm, Nobel Biocare −0.61 mm, and Straumann −1.03 mm after 5 years in function. No

TABLE 4 Pooled Mean and Weighted Mean Marginal Bone Level Changes (MBLCs) and 95% CI for the Astra Tech, Brånemark, and Straumann Implant Systems

Implant system	Pooled MBLC (mm)	95% CI	Weighted MBLC (mm)	95% CI
AstraTech ($n = 338$)	−0.24	−0.345, −0.135	−0.27	−0.356, −0.179
Brånemark ($n = 1027$)	−0.75	−0.802, −0.693	−0.72	−0.776, −0.673
Straumann ($n = 708$)	−0.48	−0.598, −0.360	−0.56	−0.661, −0.481

AstraTech ≠ Brånemark, $p = .0000$.
AstraTech ≠ Straumann, $p = .0031$.
Brånemark ≠ Straumann, $p = .0001$.

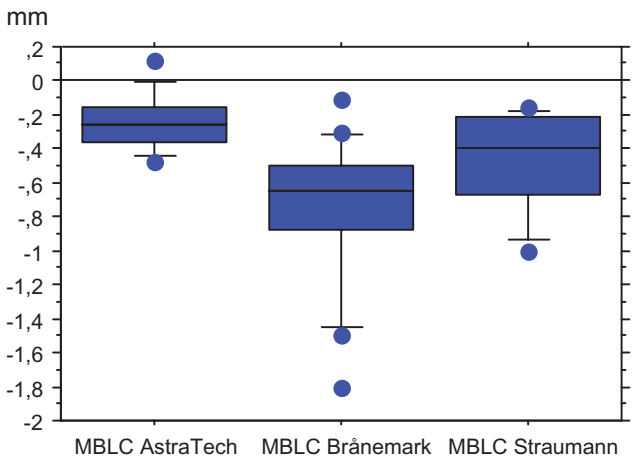

Figure 2 Box-plot diagram showing pooled marginal bone level changes (MBLCs) for the Astra Tech, Brånemark, and Straumann implant systems as assessed from the individual studies.

difference in bone loss was found between the early- and delayed-loading protocols.

The marginal bone loss values differed somewhat between the different systems in both the study by Eliasson and colleagues,[50] and in the present meta-analysis. The reason for the difference in marginal bone loss between the three systems found in the present analysis as well as between the individual studies can only be speculated upon. It could be related to systematic factors in terms of differences in surgical technique, for example, submerged versus nonsubmerged, differences in macro- and microdesign and surface structure of the implant, as well as prosthetic superstructure type and connection. Data from the various studies, however, do not indicate that the type of prosthetic reconstruction had any influence on either marginal bone loss or survival rate. Other nonsystematic factors could be choice of implant site, bone height and width, bone density and quality, patient age and sex, and hygiene regimen.

The results from the present study indicate that Astra Tech, Brånemark System, and Straumann implants perform better than the presently accepted success criteria,[1–3] and Astra Tech even much better. The results show what is achievable and suggest that peri-implant marginal bone loss exceeding what has been found in the present analysis could be indicative of pathology. Recent studies have suggested that a certain degree of marginal bone loss around implants be indicative of peri-implantitis, but there is no consensus as regards the actual magnitude of this bone loss.[51,52] It is reasonable to suggest that the presently accepted definition of acceptable ("normal") bone loss should be revised. It might even be time for a paradigm shift regarding the opinion of to what extent bone-anchored dental implants are prone to loose any supporting bone following prosthetic connection and loading.

CONCLUSIONS

Of all dental implant systems presently available on the market, there were only three systems that, by the end of 2007, had scientific documentation on peri-implant MBLCs in terms of two or more 5-year prospective clinical studies: the Astra Tech Dental Implant System, the Brånemark System, and the Straumann Dental Implant System. These systems showed a mean marginal bone loss over 5 years well below what is hitherto accepted as success. A systematic and careful documentation should be mandatory for all dental implant systems appearing on the market. It is also time for revision of existing success criteria to refine the basis for quality judgment of performed implant treatment.

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