Radiographic Analyses of "Advanced" Marginal Bone Loss Around Brånemark® Dental Implants

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ABSTRACT

Background: Dental implant failures have a multifactorial background; dependency within patient/jaw exists. Failures caused by bone loss are rare. Lately, advanced bone loss around implants has been discussed.

Purposes: Our aim was to study advanced bone level changes (≥2 mm) regarding "clustering effect," prediction, and dependency. Further, we also aimed to study if the number of radiographs/radiographic examinations could be reduced.

Materials and Methods: Six hundred and forty patients (3,462 Brånemark implants) with radiographic follow-ups ≥5 years were included, whereas patients with overdentures and augmentation procedures were excluded.

Results: Progression rate for implants with advanced bone loss was largest during the first year; thereafter, slow. A cluster effect was found with more advanced bone loss in few patients. Position was important for lower jaw implants with larger bone loss for implants placed close to midline. Age, jaw type, and implant placement were identified as predictors. The longer the follow-ups, the more bone loss around a randomly selected and examined implant, and the more implants per patient, the higher the risk for bone loss ≥2 mm around any other implant. Still, it seems safe to exclude radiographic follow-ups during the first 5 years. Dependency within the patient was found, hence the "one-implant-per-patient technique" can be applied.

Conclusion: The number of intraoral radiographs per examination and, more importantly, radiographic examinations can be reduced without jeopardizing good clinical management, a statement valid even for Brånemark implants with advanced bone loss.

KEY WORDS: dental implants, dependency, intraoral radiographic examination, prediction, progressive bone loss

Even though dental implant treatment in general is associated with high long-term success rates, failures do occur. According to Esposito,[1] these can be classified as biological, mechanical, iatrogenic, and functional failures depending on their nature. Biological failures have been classified according to when they occur; early failures when osseointegration is not established and late ones when achieved osseointegration is not maintained. Failures caused by advanced marginal bone loss are rare. An implant that is progressively losing its bone support can still be clinically stable and can be saved with adequate treatment.[2] A mobile implant, however, is equivalent with a failure.

Esposito and colleagues[3] reviewed the literature regarding different reasons for implant failures. They found that infection, impaired healing, and overload were considered the major etiological factors for loss of dental implants. Scurria and colleagues[4] identified implants placed in the maxilla or in posterior regions of the jaws as running a greater risk of being lost than those placed in other regions. In a study by Roos-Jansåker and colleagues,[5] a significant relationship was observed between implant loss and periodontal bone loss of remaining teeth. They also found that maxillary implants, as opposed to mandibular ones, showed more implant loss when many implants were placed in the jaw. Contrary to several other researchers, they did not find a relationship between smoking habits and implant

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loss.[6–9] Potential risk factors for implant loss have also been evaluated by Herrmann and colleagues.[10] They found a higher failure rate for implants placed in the maxilla, in bone of poor bone quality, in jaws with a reduced bone volume, and when used in connection with overdentures.

In most studies on implant success rates, the individual implants are regarded as independent, an assumption that has been questioned.[8,11–14] Herrmann and colleagues[13] clearly showed that dependency existed between implants placed in the same jaw and patient. They stated that if independency cannot be proven, only one randomly selected implant should be used for statistical analysis. This is of importance as few patients account for most of the failures, a phenomenon that has been called the "clustering effect."[15] In a multicenter study, Herrmann and colleagues[13] found that the risk for a second implant failure among the remaining implants in the same jaw/patient increased after the first failure occurred.

Whether a dependency within the patient, or jaw, exists with regard to marginal bone loss has, to our knowledge, not been evaluated. In studies evaluating marginal bone loss around implants, different criteria are used, such as what amount of marginal bone loss that is acceptable over time and what starting point to use for monitoring it. Fransson and colleagues[16] and Roos-Jansåker and colleagues[17] used radiographic data from a 1-year follow-up as baseline data, while Snauwaert and colleagues[18] used the data from the time of abutment connection. Most studies, however, have used the time of prosthesis insertion as the starting point. One reason behind a decision to choose 1-year data as the starting point might be that it is known that the bone loss around dental implants during the first year in function is larger than the annual bone loss during the following years. The bone loss during the first year in function has been regarded as part of a bone remodeling phase. According to Albrektsson and Isidor,[19] a bone loss during the first year in service can be up to 1.5 mm without being classified as a sign of failure. To explore the marginal bone loss during the healing period, Åstrand and colleagues[20] started to radiographically monitor the marginal bone level already at the time of fixture insertion. They found the bone loss between fixture placement and prosthesis insertion to be several times larger than between prosthesis insertion and the 5-year follow-up.

As most clinically significant marginal bone level changes occur during the first year in function, it has been recommended that radiographs should be taken 6 to 12 months after crown/bridge installation and then with intervals of 2 to 3 years, if not otherwise indicated by clinical signs and symptoms.[21] Others recommend, in the absence of clinical signs of infection, radiographs to be taken 1 year after implant installation and no more than every other year thereafter.[22] Gröndahl and Lekholm[23] suggested, however, that a more critical approach to the use of radiography in the evaluation of implant treatment efficacy should be applied, implying that radiography should be performed only when it is likely to benefit the patient. They also suggested that the intervals between repeated examinations ought to be determined based on the incidence of various pathological changes associated with implant treatment and their consequences.

Most implant failures caused by loss of osseointegration occur during the healing period (early loss) and within the first 2 years of loading, to decrease thereafter. There are different opinions on the progression rate of the marginal bone loss around implants. Most studies demonstrate minor bone loss around implants in general with a steady state after a couple of years in function.[20,24–26] Lately, however, studies have been published demonstrating continuous bone loss and peri-implantitis in higher frequencies than earlier demonstrated.[16,17,27,28] Fransson and colleagues[16] found, among the same patients as in the present study, that 12.4% of the implants in 28% of the patients exhibited advanced bone loss, that is, the bone level at the 1-year follow-up was located at <3 threads to ≥ 3 threads at the 5 to 20 years of follow-up. In contrast, Sundén Pikner and colleagues[29] found 5.3% of the implants in 16.7% of the patients to suffer from advanced bone loss when using a bone loss of 3 mm or more at one of the implant surfaces after prosthesis insertion as the threshold. To our knowledge, little is known about the pattern of advanced bone loss over time and if prediction possibilities exist.

The ideal parameters for monitoring implant conditions should be sensitive enough to discriminate small bone level changes. So far, there is strong evidence that the intraoral radiographic examination is superior to all conventional periodontal indices, although combining data from clinical and radiographic parameters is to be recommended.[30,31] An optimal intraoral radiograph is based on a strict paralleling technique with clearly depicted threads on both implant surfaces.

Most studies report bone level changes as mean values on an implant level, eliminating the possibility to study individual implants within a patient or differences between patients. To our knowledge, it is not known if one randomly chosen implant can be used to represent the condition for all other implants of a particular patient or prosthetic construction. If that is the case, it might be possible to perform radiography on just one implant per patient and follow-up time, an interesting issue that will save discomfort for the patient and substantially reduce the radiation dose.

One aim of this study was to determine if a "clustering effect" exists for advanced marginal bone loss. Another aim was to evaluate if it is possible to predict when bone level changes will occur over time, and if the bone loss will differ depending on the implant position within the bridgework. A final aim was to determine the risk for missing diagnostic information regarding bone loss if a randomly selected implant per patient is chosen for radiography.

MATERIALS AND METHODS

Out of 1,716 patients who had attended a clinical and radiographic follow-up examination in 1999 at The Brånemark Clinic, Public Dental Health Service, Göteborg, Sweden, 1,346 patients (78.4%) could be identified. Patients treated with different bone augmentation procedures were excluded, as were patients continuously using overdentures. Further, patients with a follow-up of <5 years were excluded. A total of 640 patients with 3,462 standard turned Brånemark implants (Brånemark System®, Nobel Biocare, Göteborg, Sweden) of various lengths were finally included in this retrospective, radiographic study. Forty percent of the patients were men, and the mean age of the entire group was 56.7 years (SD 14.2, range 13 to 83 years). Table 1 shows the distribution of upper and lower jaw prostheses by type of prosthetic construction. Among the patients, 83 had received implant treatment in both jaws.

Intraoral radiographs for all edentulous jaws had been obtained at the Clinic of Oral and Maxillofacial Radiology. Lately, radiographs in partial dentate jaws and in patients with only single implant restorations had been taken at The Brånemark Clinic. Up to 2005, the examinations were carried out with an analogue technique, later by different digital systems. In some patients, because of intolerance to accept an intraoral-placed detector, dental scanograms (magnification ×1.7, Scanora®, Soredex, Orion Corporation, Helsinki, Finland) had been used. All radiographs of each patient, even those obtained up to 2006, were evaluated. Two oral radiologists analyzed the images, 66 patients by one of them, and 536 patients by the other. In addition, radiographs from the remaining 38 patients (representing 229 implants) were separately analyzed by both of the observers. For these 38 patients, a mean value per implant surface was calculated and used in the analysis. The distance between a reference point (fixture/abutment junction) and marginal bone level, on both mesial and distal surface, was recorded to the closest 0.1 mm. If an implant was displayed in more than one image, measurements were to be taken in the image showing the largest distance between the reference point and the bone level. When reading the radiographs, the implant position was noted, that is, by estimated tooth position.

TABLE 1 Distribution of Upper and Lower Jaw Prosthetic Restorations

	Upper Jaw							
Lower Jaw	None	Complete	One Partial	Two Partial	Partial + Single	One Single	Two Single	Σ
None		112	63	33		27	12	
Complete	219	44	1	4				268
One partial	49	5	4	5	1			64
Two partial	40	9	2	5				56
Partial + single	1	2						3
One single						1		1
Two single	1							1
Σ		172	70	47	1	28	12	

TABLE 2 Number of Patients (%) and Implants Evaluated at Different Time Intervals

Year	Patients	Implants
0	602 (94.1)	3,245
1	559 (87.3)	2,926
2	101 (15.8)	498
3	337 (52.7)	1,657
4	88 (13.8)	462
5	445 (69.5)	212
6	113 (17.7)	535
7	64 (10.0)	288
8	47 (7.3)	224
9	60 (9.4)	283
10	311 (48.6)	1,612
11	72 (11.3)	354
12	43 (6.7)	216
13	27 (4.2)	135
14	25 (3.9)	122
15	53 (8.3)	278
16	25 (3.9)	133
17	6 (0.9)	33
18	8 (1.3)	42
19	3 (0.5)	13
20	10 (1.6)	56

The quality of the radiographs obtained at prosthesis installation (baseline) and later was in general high with only 38 (0.13%) implant surfaces unreadable out of 30,466 analyzed ones. Table 2 shows the number of patients and implants evaluated at different follow-up intervals.

The mean difference for the bone level assessments when analyzed by both radiologists was 0.25 mm (SD 0.66; $r = .82$) for the 2,274 implant surfaces (38 patients with 229 implants). For more information, see Sundén Pikner and colleagues.[29]

Statistical Methods

For descriptive purposes, mean, SD, range, and frequencies are given. For comparison of dichotomous variables between two groups, Fischer's exact test was used. For comparison of the amount of bone loss that had taken place 1 year before first bone loss ≥2 mm was observed with that taken place during the subsequent year, Wilcoxon signed rank test was used. If a measurement was missing 1 year before or after, a linear interpolation was used based on earlier and later measurement values. Wilcoxon signed rank test was also used when testing the influence of implant position on bone loss on patient level. Univariate and multiple logistic regressions using the method of generalized estimation equations were used to select independent predictors for bone loss ≥2 mm. A compound symmetry covariance pattern was used to model the dependency within the patient. The odds ratio (OR) given is the OR for bone loss ≥2 mm for one unit increase in the predictor. The 95% confidence interval for OR is given. All significance tests were two tailed and conducted at the 5% significance level.

We wanted to develop a strategy where not all implants of the same patient are examined. In order to calculate the conditional probability that any of the other implants has a bone loss ≥2 mm given the bone loss of a randomly chosen implant and number of implants per patient, the following analysis was done. We considered the bone loss of the different implants of the same patient as a vector having a multivariate normal distribution. For each number of implants ($n = 2, \ldots, 8$), the corresponding matrix of covariance was estimated. The numbers of the main diagonal of the matrix were equal, and all numbers outside the diagonal were equal. The conditional distribution of a random vector given that one of its elements equals a number x, is again a vector, which has a multivariate normal distribution. The matrix of covariance of the last mentioned vector was determined from the first matrix. By solving a system of nonlinear equations, we found constants, which determined linear combinations of independent variables having the same multivariate distribution as the conditional one. Numerical integration yielded the results presented in Figure 1.

RESULTS

When selecting patients ($n = 256$) with a radiographic examination at baseline and follow-ups both after 1 and 10 years, and identifying the implant surface (mesial or distal) with the largest bone loss, 71.5% of the patients showed a bone loss of 1 to 3 mm after the first year in function. During the same time interval, 2.3% showed a loss >3 mm. Accordingly, in 26.2% of the patients, the worst bone loss during the first year was <1 mm. The corresponding values for the time interval 1 to 10 years were 37.5% (<1 mm), 55.5% (1 to 3 mm), and 7.0% (>3 mm). While the frequency of patients with bone loss >3 mm at the worst implant surface had more than doubled during the interval 1 to 10 years an

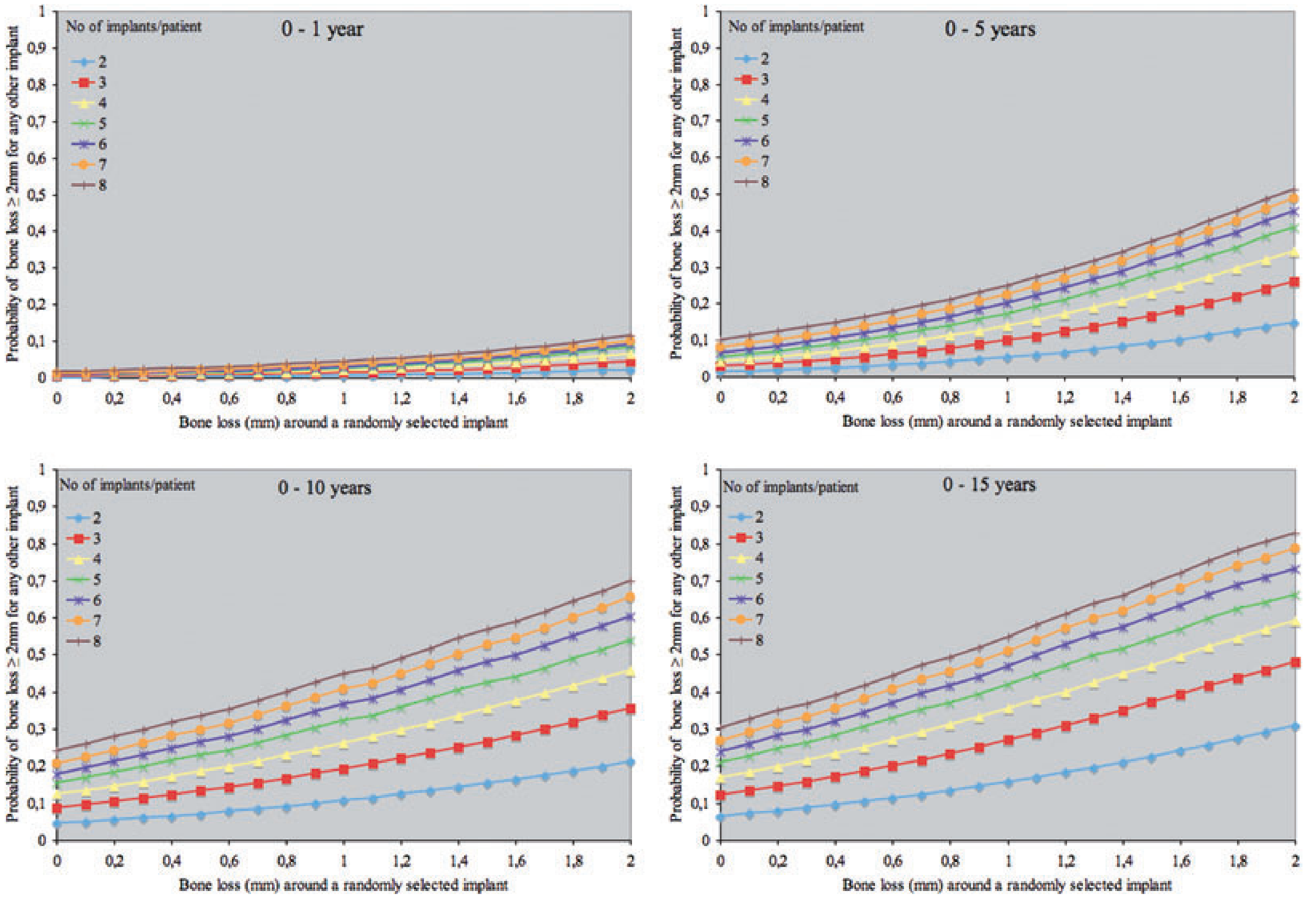

Figure 1 Predicted probability (%) that any of the other implants per patient has a bone loss ≥2 mm given the bone loss of the investigated implant after four different time intervals using prosthesis insertion as baseline.

overwhelming majority, 93%, still exhibited more moderate degrees of bone loss. The difference in mean bone loss for year 0 to 1 versus mean bone loss year 1 to 10 was 0.0015 mm (median –0.10 mm). Hence, the progression rate was lower after the first year in function.

For patients ($n = 211$) with a mean bone loss of ≥2 mm, regardless of follow-up interval, the occurrence of the largest bone loss, maximum of distal or mesial surface, was significantly larger ($p < .0001$) 1 year before the first bone loss of ≥2 mm was found (mean 0.94 mm, SD 0.79) than 1 year after (mean 0.0 mm, SD 0.26). The mean difference was –0.94 mm (SD 0.86). The corresponding data on the implant level ($n = 390$) were 0.93 mm (SD 0.89) for the year before and 0.02 mm (SD 0.34) for the year after the occurrence of bone loss of ≥2 mm with a mean difference of –0.91 mm (SD 0.97).

For patients with ≥3 implants ($n = 371$) supporting lower jaw prosthetic devices, implants placed in end positions within the bridgework showed a significantly lower bone loss than the implants in other positions. After 1 year, the mean difference was –0.10 mm (SD 0.42; $n = 297$; $p = .0001$), after 3 years –0.12 mm (SD 0.51; $n = 107$; $p = .0041$), after 5 years –0.15 mm (SD 0.50; $n = 227$; $p < .0001$), and after 10 years in service it was –0.33 mm (SD 0.65; $n = 170$; $p < .0001$). No such differences were found for upper jaw implants.

Implants placed around the mandibular midline in edentulous jaws showed a higher number of implants with a loss of ≥2 mm compared to other implants (Table 3) regardless of follow-up time. No such pattern was found for the upper edentulous jaw (Table 4).

When trying to predict a bone loss of ≥2 mm from prosthesis insertion up to 5, 6 to 10, and 11 to 15 years in the entire group of patients, minor bone loss from abutment connection to prosthesis insertion (baseline) was found to be an independent predictor at all three time intervals (Table 5). Implants with larger bone loss during this early time period showed a minor bone loss after prosthesis insertion than did other implants.

TABLE 3 Implant-Based Bone Loss as a Mean for Different Time Intervals, and Loss by Position of the Implant for the Complete Lower Jaw

	0–1 year *n* (%)		0–5 years *n* (%)		0–10 years *n* (%)		0–15 Years *n* (%)	
Bone loss <2 mm	1,117	(98.7)	824	(94.8)	601	(90.2)	93	(80.9)
Bone loss ≥2 mm	15	(1.3)	45	(5.2)	65	(9.8)	22	(19.1)
45			2		1		2	
44	3		4		5			
43			6		6		4	
42	1		2		4		1	
41	2		8		16		5	
31	3		10		17		5	
32	2		2		2		1	
33	3		5		7		1	
34			4		7		2	
35	1		1				1	
36			1					
Σ	15		45		65		22	

Further, placement of the implant within the prosthetic construction was found to be an independent predictor. For implants placed in the middle of the construction versus in an end position, larger bone loss was found. Jaw type was also found to be an independent predictor at 5 years with more bone loss for upper jaws. At year 6 to 10, age was found to be a predictor with more bone loss the older the patient. Gender, type of prosthetic construction, and calendar year for surgery were not correlated to bone loss of ≥2 mm. When using 1-year data as baseline, instead of prosthetic insertion, placement within the prosthetic construction was found to be an independent predictor of bone loss ≥2 mm, but only at year 11 to 15. There were, however, only 20 patients with bone loss ≥2 mm from year 1 to 5, 59 patients up to year 6 to 10, and 38 patients year 11 to 15.

TABLE 4 Implant-Based Bone Loss as a Mean for Different Time Intervals, and Loss by Position of the Implant for the Complete Upper Jaw

	0–1 year *n* (%)		0–5 years *n* (%)		0–10 years *n* (%)		0–15 years *n* (%)	
Bone loss <2 mm	832	(98.1)	476	(91.7)	420	(89.4)	76	(85.4)
Bone loss ≥2 mm	16	(1.9)	43	(8.3)	50	(10.6)	13	(14.6)
15	3		2		3		1	
14			1		5		1	
13	2		11		6		3	
12	2		2		3		2	
11	1		4		6			
21	1		8		8		1	
22			3		3		2	
23	2		4		6		1	
24	2		6		5		1	
25	3		2		5		1	
Σ	16		43		50		13	

TABLE 5 Implant-Based Prediction of Bone Loss ≥2 mm from Year 0 (Baseline) at Three Time Intervals with Adjustment for Within Subject Correlation

	5 years		6–10 years		11–15 years	
Parameter	Univariate OR (95% CI) *p* Value	Multivariate OR (95% CI) *p* Value	Univariate OR (95% CI) *p* Value	Multivariate OR (95% CI) *p* Value	Univariate OR (95% CI) *p* Value	Multivariate OR (95% CI) *p* Value
Age	1.01 (1.00–1.03) 0.1102		1.02 (1.00–1.03) 0.0162		1.01 (0.99–1.03) 0.4922	
Bone loss (baseline-abutment)	0.58 (0.35–0.96) 0.0355	0.54 (0.33–0.88) 0.0126	0.70 (0.51–0.94) 0.0195	0.69 (0.51–0.94) 0.0172	0.58 (0.38–0.89) 0.0134	0.55 (0.36–0.85) 0.0075
Calendar year of surgery	1.03 (0.95–1.11) 0.5283		1.02 (0.96–1.08) 0.5677		0.98 (0.90–1.07) 0.7032	
Gender (1 = M, 2 = F)	0.77 (0.45–1.31) 0.3367		0.92 (0.63–1.33) 0.6431		1.69 (0.98–2.94) 0.0611	
Prosthetic construction (1 = comp, 2 = part, 3 = sing)	0.61 (0.35–1.08) 0.0874		0.93 (0.64–1.34) 0.6884		0.75 (0.43–1.30) 0.3049	
Jaw (1 = lower, 0 = upper)	0.62 (0.36–1.06) 0.0809	0.46 (0.26–0.84) 0.0107	0.96 (0.66–1.39) 0.8277		1.15 (0.70–1.88) 0.5805	
Position (1 = end, 0 = middle)	0.49 (0.32–0.74) 0.0007	0.41 (0.25–0.67) 0.0003	0.59 (0.45–0.78) 0.0002	0.59 (0.44–0.79) 0.0004	0.61 (0.43–0.86) 0.0044	0.60 (0.42–0.85) 0.0037

CI = confidence interval; OR = odds ratio.

When identifying individual implant surfaces, mesial or distal, with a bone loss ≥3 mm (range 3 to 14.5 mm) compared to the bone level at prosthesis insertion, regardless of follow-up time, 183 implant surfaces in 107 patients were found. The majority of them (79%) were found in edentulous patients (59 in upper jaws and 85 in lower jaws), while the remaining 39 implants were found in partially dentate patients (21 in upper jaws and 18 in lower jaws). Hence, none was found in connection with single tooth restorations. In 112 (61.2%) of the 183 surfaces, a loss of 3 to 3.9 mm was found. Another 37 surfaces (20.2%) had lost 4.0 to 4.9 mm, 22 had lost 5.0 to 5.9 mm, seven between 6.0 and 6.9 mm, two between 7.0 and 7.9 mm, one had lost 8.6 mm, and two showed a bone loss >10 mm. Of the 183 implant surfaces, 123 (67.2%) showed a continuous loss with its maximal loss at the last observation (range 5 to 20 years), while 60 (32.8%) had their maximal loss 1 to 15 years before the last radiographic examination. Of the 107 patients, 63 patients had one implant each, 25 patients two, 10 patients three, five patients four, and four patients five implants with this degree of bone loss. Figure 2 shows the progression of bone loss per jaw and type of prosthetic construction for each of the 183 implants with advanced bone loss. Seventeen of the 107 patients (15.9%) had lost one implant or more to be compared to 26 patients (5.0%) of the other 533 patients ($p = .004$). Among the 183 implants with a bone loss ≥3 mm at one of the surfaces, six implants were lost.

Figure 1 shows the conditional probability (%) of any bone loss of ≥2 mm for not radiographically examined implants at four different time intervals, 1, 5, 10, and 15 years after prosthesis insertion, given different degrees of bone loss of a randomly chosen and radiographed implant and number of included implants per

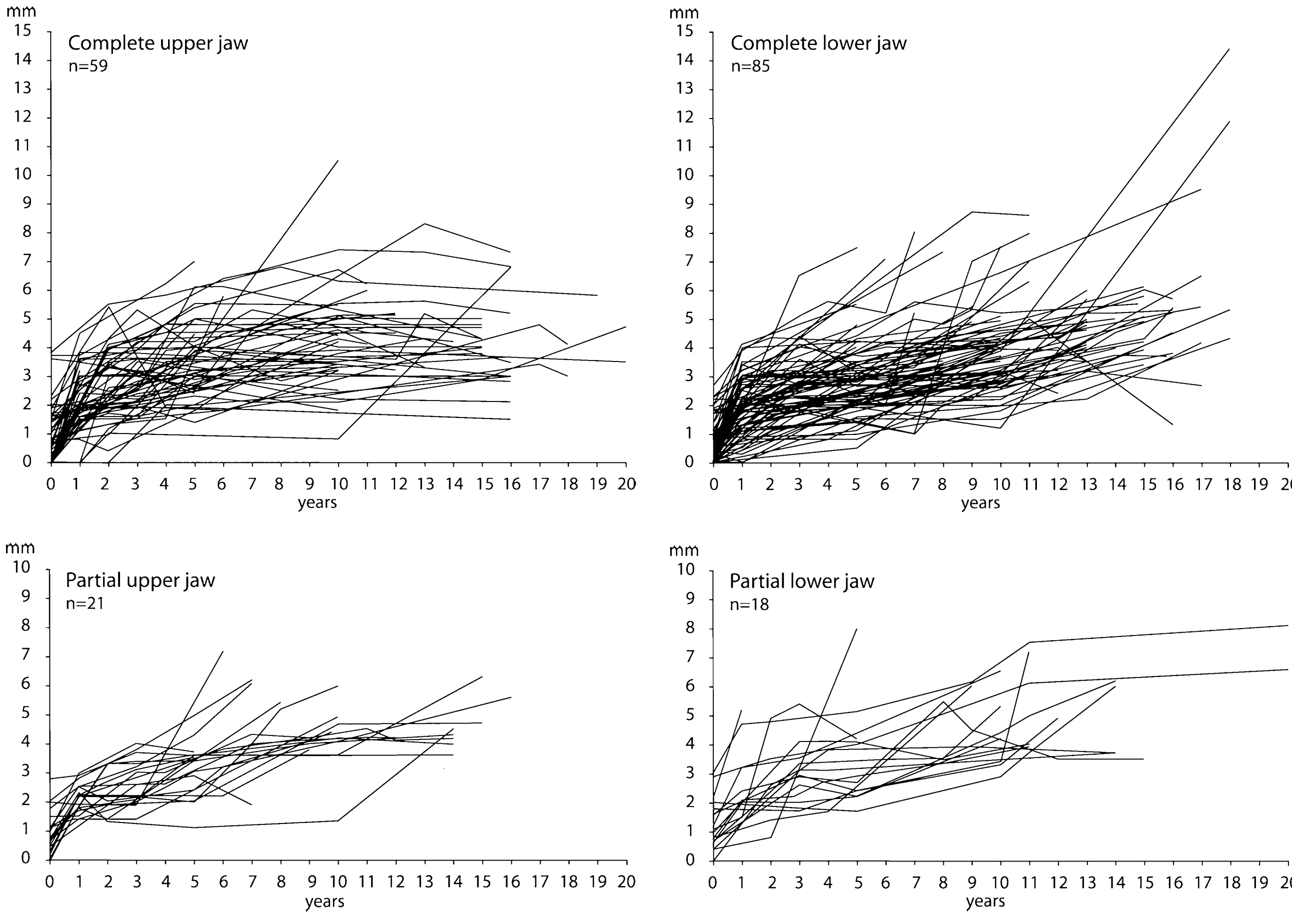

Figure 2 Progression of bone loss per jaw and type of prosthetic construction for each of the 183 surfaces with advanced bone loss ≥3 mm as a threshold.

patient. The probability for a bone loss ≥2 mm at any of the unexamined implants will, for example, be 20% after 5 years if the patient has six implants and the examined implant suffered from a mean bone loss of 1 mm compared to baseline. If 20% is decided to be a too high probability, then all remaining five implants should also be examined. The longer follow-up period, the more bone loss around the randomly selected and examined implant, and the higher the number of placed implants, the higher the probability for bone loss of ≥2 mm around any of the unexamined implants. The estimated risk of bone loss ≥3 mm for unexamined implants was not tested as the number of implant surfaces/implants with such a bone loss was found to be too small.

DISCUSSION

The results of this retrospective study demonstrate that the progression rate of bone loss was larger during the first year in service than during the next coming 9 years when studying the implant surface with the largest bone loss within each patient ($n = 256$) during a 10-year follow-up period. During the first year in function, 2.3% of the implant surfaces demonstrated a bone loss ≥3 mm, while the corresponding value for the next coming 9 years was 7.0%. These findings are concordant with most studies on turned Brånemark implants and when including all implants within the patient.[8,18,32–36]

Over the years, many authors have tried to define the criteria for success of oral implants. The most commonly used criteria are those suggested by Albrektsson and colleagues[37] who regard a bone loss of <0.2 mm annually after the first year in service and still be successful. Duyck and Naert[38] stated that a mean bone loss of 0.9 to 1.6 mm during the first year followed by an annual bone loss within 0.01 to 0.2 mm could be within acceptable limits. Later, Wennström and Palmer[39] claimed that a bone loss <2 mm during the first 5 years should be required for an implant system to be considered successful. It is noteworthy that criteria have become more strict over time, although the difference between them must be regarded as of minor clinical significance. It can be questioned whether the radiographic technique, even when using high-quality intraoral radiographs, is sensitive enough to discriminate such small bone level changes. The reliability of radiographic measurements of bone level changes at tooth surfaces was reviewed by Benn.[40] He concluded that current techniques are insufficient to measure true bone loss until at least 1.0 mm of bone has been lost. Obviously, there are differences between a tooth and a threaded implant, but still changes <1 mm must be judged with considerable caution.[41] However, the same uncertainty may not apply to the reading of a consecutive series of a large number of implants, assuming evaluations may be falsely positive as well as falsely negative. If so, the uncertainty in a sample of this size is probably much smaller than 1.0 mm.

After 5 years in function, 5.2% of the implants supporting a complete lower jaw restoration showed a bone loss of ≥2 mm. The corresponding value for complete upper jaw implants was 8.3%. According to the criteria suggested by Wennström and Palmer,[39] these implants showed an unacceptable bone loss and should be regarded as failing. Recent research, however, has demonstrated that further bone loss can be prevented with adequate treatment and that even bone restitution is possible.[2] The percentage of implants supporting a complete prosthetic construction, regardless of jaw, that had a bone loss of ≥2 mm increased with longer time. The results, however, showed that for patients with a mean bone loss of ≥2 mm, regardless of follow-up interval, the occurrence of the largest bone loss, maximum of distal or mesial surface, was significantly larger 1 year before than 1 year after the occurrence of bone loss indicating that the bone loss might not be continuous. The same finding was made when following the implant surfaces with a bone loss of ≥3 mm. Of the 183 implant surfaces, 32.8% showed their maximal bone loss 1 to 15 years before the last radiographic examination.

It is generally assumed that the most distally placed implants supporting a prosthetic device are more at risk for bone loss because they are exposed to larger forces, bending movements, and stress concentrations. We found the position of the implant to be important for lower jaw restorations, but not for the upper jaw implants. However, less bone loss was observed for implants placed in an end position. In the lower edentulous jaw, anterior implants suffered from larger bone loss than the other implants within the restoration. This is in accordance with the results found by Carlsson and colleagues[42] and Ekelund and colleagues.[24] Lindquist and colleagues[43,44] found smoking to be significantly correlated with bone loss around all lower jaw implants, while poor oral hygiene significantly influenced the loss around anterior implants. According to Rangert and colleagues[45] and Brunski and Skalak,[46] the more extensive bone loss around anterior implants can be a consequence of tensile forces because of loading of the posterior cantilever extensions or other biomechanical factors.

Placement of the implant within the prosthetic construction, regardless of jaw, was found to be an independent predictor of a bone loss of ≥2 mm from prosthetic insertion up to 15 years in service with minor bone loss around implants placed in an end position. The jaw type was also found to be an independent predictor at 5 years with larger bone loss for the upper jaw. Larger bone loss from abutment connection to prosthesis insertion was also found to be an independent predictor for minor bone loss after loading the implant. Age was found to be a predictor for bone loss at 6 to 10 years, while factors like gender, type of prosthetic restoration, and calendar year at surgery were not. Several studies have failed to show a correlation between gender or age and increased failure rates.[15,44,47,48] Nevertheless, Salonen and colleagues[49] suggest that advanced age is a contribution factor to implant failure, and also Brocard and colleagues[50] found lower success rates for implants placed in older patients. Sundén Pikner and colleagues[29] found in general larger degrees of bone loss the older the patient. In contrast, in a study by Bryant and Zarb,[51] the results indicate a better result for elderly compared to younger individuals. Smoking has been identified as a risk factor, and it has been shown that patients with a history of periodontitis are more likely to develop advanced bone loss around implants than periodontally healthy patients.[5–9,43,52] Because of the retrospective design of our study, a classification of the patients with respect to their experience of periodontal disease, smoking, and oral hygiene cannot be made.

In an attempt to make the success criteria suggested by Albrektsson and Isidor[19] more suitable for individual implant evaluations, Lekholm and colleagues[53] recommended some minor changes. Regarding the marginal bone support, a failure was considered to exist when the bone loss reached the marginal third of the implant length or was ≥3 mm (Herrmann, personal communication). In the present study, using the prosthetic insertion as baseline and a bone loss of ≥3 mm as a threshold value for advanced bone loss, 183 implant surfaces (5.3% of the implants) of all 3,462 implants in 107 patients (16.7%) were identified. The majority (79%) of the implants with this degree of bone loss were found among patients with complete fixed prosthesis. In 32.8%, the maximal bone loss occurred 1 to 15 years before the last observation, indicating that the bone level can come to a steady state even at surfaces with a more advanced bone loss. Among the 107 patients, 70 (38%) of the 183 implants with a bone loss of ≥3 mm were found in 19 patients, 18% of all. Thus, there seems to be a tendency for a clustering effect also regarding marginal bone loss around implants as for implant failure caused by loss of osseointegration. The marginal bone loss seems to follow the pattern seen for advanced bone loss around teeth, that is, a minor population suffers from more advanced bone loss.[54]

The 107 patients (16.7% of the entire group of patients) with at least one implant surface with a bone loss of ≥3 mm showed a significantly higher implant loss compared to the entire group of patients, indicating a relation between implant loss and marginal bone loss. Such a relationship was also demonstrated by Hultin and colleagues,[55] who found significantly larger bone loss around remaining, stable implants in patients who had lost implants after loading than those with no implant losses. In addition, Strietzel and colleagues[56] found a statistically significant correlation between implant loss and bone loss at the time of second-stage surgery.

Based on the criteria for success suggested by, for example, Albrektsson and Isidor,[19] the bone loss taking place before loading the implants is not taken into account. Figure 3 shows the results when recalculating the data presented in Figure 2 for those 183 implant surfaces with a bone loss of ≥3 mm when the bone level at year 0 (prosthesis insertion), regardless of its actual value, was set at 0 mm. With this way of handling the data, even fewer implants will reach an unacceptable bone loss according to commonly accepted criterion for success. As already mentioned, Åstrand and colleagues[20] found the bone loss between implant placement and prosthesis insertion to be several times greater than between prosthesis insertion and 5-year follow-up. It might, therefore, be better to report the degree of remaining bone at different time intervals than the accumulated bone loss. The remaining bone support of an implant might be a better parameter to use when distinguishing between implants with a good prognosis and those at risk of being lost in the future. With such an approach, all bone level changes will be included whenever having occurred.

In an effort to reduce the radiation burden to the population according to the recommendations by the International Commission on Radiological Protection (1991),[57] as well as the cost and discomfort for the patient, the probabilities of a bone loss of ≥2 mm over different periods of time, given different degrees of bone loss at one randomly selected implant, were calculated. Based on the results, it seems safe to exclude radiography during the first 5 years of follow-up, regardless of number of implants per patient. With longer follow-up times, the probability of a bone loss ≥2 mm around any other implant, in patients having ≥4 implants, will increase to 50% or more given a bone loss ≥2 mm around the examined implant. Thus, implants placed in the same patient cannot be regarded as independent, not only with respect to loss of osseointegration, but also to marginal bone loss. Consequently, the "one-implant-per-patient technique" introduced by Mau[11] can be useful as a simple method to decrease the radiation dose.

It has to be kept in mind that the purpose of the radiographic examination is not solely to study the bone level and its changes over time. Radiography is also used to diagnose loss of osseointegration and mechanical complications like fractures of abutment screws or the implant pillar itself. Based on four 5-year multicenter studies focused on partial edentulism, overdenture treatment, single tooth replacement, and implant-retained prostheses in edentlulous patients and including 487 patients treated with turned Brånemark implants, Herrmann and colleagues[13] found that the majority of failed implants (79 out of 108) occurred between implant placement and loading ($n = 43$) or during the first year in function ($n = 36$). This result coincides well with long-term follow-up studies.[24,33,36,58] According to Lekholm and colleagues,[58] the most common mechanical complication is veneer material fractures, followed by loosening of components and

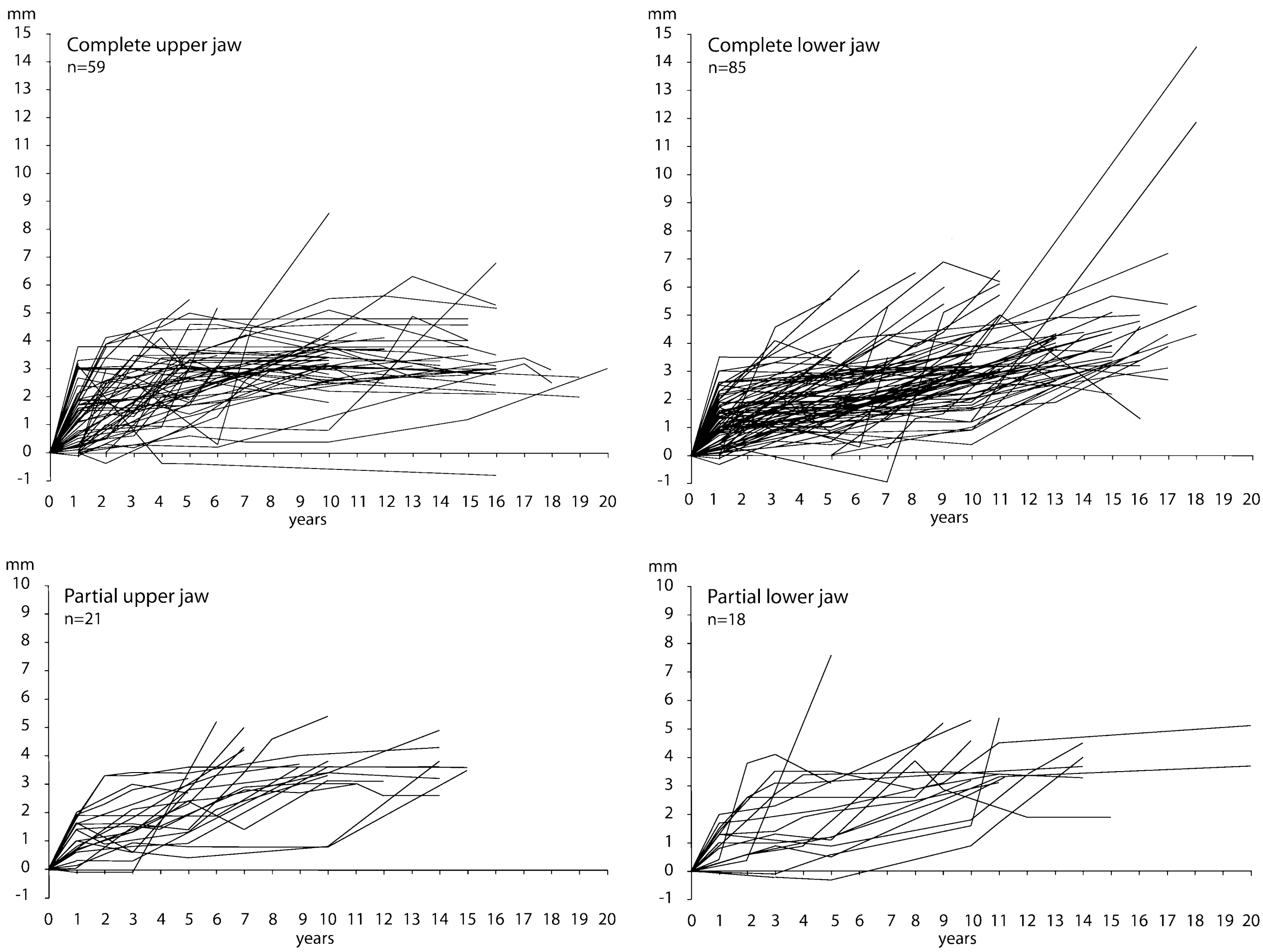

Figure 3 Based on the progression of bone loss around the 183 surfaces with a bone loss ≥3 mm (Figure 2) when the bone level at prosthesis insertion (year 0), regardless its actual value, was set at 0 mm.

abutment, and bridge-locking screw fractures. Radiography can be used as a diagnostic method for detecting abutment screw fractures given that the projection geometry is correct, while the other mentioned complications have to be diagnosed with clinical methods. Fractures of the abutment screw and the implant itself are rare.[24,36,53]

The geometry and surface roughness of the implant may influence the ability to obtain and preserve marginal bone support.[59,60] Hence, a more rapid bone loss than that found in this study might be expected with rougher implant surfaces.[27] Other factors of importance for bone loss around implants can be the surgical technique used and immediate loading.

To conclude, the progression rate for implants with an advanced bone loss (bone loss ≥2 mm) was largest during the first year and thereafter slow. Further, the bone loss was not found to be continuous, even at surfaces with an advanced bone loss. A clustering effect was found with more advanced bone loss in a few patients. A relation between implant loss and advanced bone loss was found. Finally, the number of intraoral radiographs per examination and, above all, the number of radiographic examinations can be reduced without jeopardizing good clinical management.

Our recommendation is that intraoral radiographs should be taken when it is likely to benefit the patient. Intervals between follow-up examinations ought to be determined based on the incidence of various pathological changes associated with oral implant treatment and its consequences. Patient-related negative factors regarding bone loss, such as smoking, poor oral hygiene, history of periodontitis, implant system used, and implant position in the prosthetic restoration should also be taken into account when deciding when radiographs should be taken.

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