Marginal Bone Loss at Implants: A Retrospective, Long-Term Follow-Up of Turned Brånemark System® Implants

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ABSTRACT

Background: Lately, presence of progressive bone loss around oral implants has been discussed.

Purpose: The aim of this study was to report in a large patient group with different prosthetic restorations marginal bone level and its change as measured in radiographs obtained from prosthesis insertion up to a maximum 20 years in service. Further, it also aimed to study the impact of gender, age, jaw, prosthetic restoration, and calendar year of surgery.

Materials and Methods: Out of 1,716 patients recorded for clinical examination during 1999, 1,346 patients (78.4%) could be identified. A total of 640 patients (3,462 originally installed Brånemark System® implants, Nobel Biocare, Göteborg, Sweden) with a follow-up of ≥5 years were included in the study, while patients with continuous overdentures and augmentation procedures were not. Distance between the fixture/abutment junction (FAJ) and the marginal bone level was recorded.

Results: The number of implants with a mean bone level of ≥3 mm below FAJ increased from 2.8% at prosthesis insertion to 5.6% at year 1, and 10.8% after 5 years. Corresponding values after 10, 15, and 20 years were 15.2, 17.2, and 23.5%, respectively. Implant-based bone loss was as a mean 0.8 mm (SD 0.8) after 5 years, followed by only minor average changes. Mean bone loss on patient level followed a similar pattern. Disregarding follow-up time, altogether 183 implants (107 patients) showed a bone loss ≥3 mm from prosthesis insertion to last examination. Significantly larger bone loss was found the older the patient was at surgery and for lower jaw implants.

Conclusions: Marginal bone support at Brånemark implants was with few exceptions stable over years.

KEY WORDS: bone level, bone loss, implant-supported, intraoral radiography, long-term follow-up

Long-term follow-up studies are cornerstones in clinical evaluations of medical and dental treatment modalities. In the field of dental implants, Adell and colleagues[1,2] presented two classical long-term follow-up studies that have been used to validate the use of osseointegrated implants to rehabilitate edentulous patients. Since then, numerous follow-up studies on dental implants have been published, but few cover periods of 10 years or more.[3–17]

Radiographic data on bone reactions around the implants are some of the most important parameters in these long-term follow-up studies. However, with regard to marginal bone loss, most of the reports present mean values, while frequency distribution data are rarely described. Only a few recent studies deal with the issue on a patient level in long-term perspectives.[7,10,13,15–19]

Many researchers have proposed criteria for success of oral implants. A commonly used criterion was suggested by Albrektsson and colleagues[20] and reviewed in

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1993.[21] According to Albrektsson and Isidor,[22] a successful implant should present less than 1.5 mm of bone loss during the first year in service, and less than 0.2 mm annually thereafter. In 1999, Wennström and Palmer[23] proposed a modification of the radiographic criteria regarding bone loss. They suggested that a maximal bone loss of 2 mm could be accepted over a 5-year period after prosthesis insertion.

The majority of publications until the late 1990s showed conventional implant therapy to be a reliable procedure with few complications and minor average bone loss around implants. Lately, however, studies have been published demonstrating continuous bone loss in higher frequencies than earlier demonstrated.[15,19,24,25] Roos-Jansåker and colleagues[15] found that in 20.4% of the Brånemark implants, the bone level was located 3 mm apical to the implant head after 9 to 14 years of function. Further, they claimed that 8% of the implants suffered from progressive bone loss (≥1.8 mm) after the observation period of 9 to 14 years when compared with the 1-year data. Furthermore, Fransson and colleagues[19] found, in the same patients as in the present study, that 28% of the patients showed progressive bone loss.

Berglundh and colleagues[26] thoroughly reviewed the literature on the incidence of biological and technical complications in longitudinal implant studies with at least 5 years follow-up. They found the percentage of implants with a bone loss of ≥2.5 mm after 5 years to be higher in studies on overdentures and fixed complete dentures than those including fixed partial dentures and single-tooth replacements (4.8 and 3.8 versus 1.0 and 1.3%, respectively).

One aim of this retrospective study was to determine, in a large group of patients with different prosthetic restorations, the marginal bone level and its change around turned Brånemark System® (Nobel Biocare, Göteborg, Sweden) implants over a long period of time, and to present data on both the implant and the patient level. Another aim was to study the impact of gender, age, jaw, type of prosthetic construction, and calendar year of surgery on bone level alterations.

MATERIALS AND METHODS

The present publication is a retrospective study based on the same patient material as presented in a publication by Fransson and colleagues.[19] Only patients who attended a clinical follow-up program during 1999 with a follow-up time of 5 years or more at one clinic (The Brånemark Clinic, Public Dental Health Service, Göteborg, Sweden) were included in the study. From 1,716 recorded clinical examinations during 1999, it was possible to identify 1,346 patients (78.4%) from computer records on checkup payment. The remaining 370 patients were not possible to find probably because of having been charged in a different way.

Patients with a follow-up period of less than 5 years ($n = 706$) were excluded from the group, as were patients continuously using overdentures or treated with osseous grafts or other augmentation procedures. In the remaining 640 patients, 3,462 implants had been placed.

All patients were treated with implant-supported (Brånemark System) complete fixed, partial fixed, or single-tooth restorations. All patients received standard turned Brånemark implants of various lengths using a well-defined two-staged surgical protocol.[27] Fixed prosthetic constructions were manufactured in either gold alloy or titanium.[28,29]

Table 1 describes the distribution of upper and lower jaw prostheses by gender and type of bridgework. In total, 393 patients were treated in the lower and 330 patients in the upper jaw; 83 of them had received implants in both jaws. The majority received implant-supported complete constructions; 172 in the upper jaw and 268 in the lower jaw. Age distribution at the time of implant placement per jaw and type of bridgework are shown in Figure 1. The year of surgery was registered from the records.

Most patients followed a prearranged schedule with clinical and radiographic examinations at prosthesis insertion, 1-year, 3-year, 5-year follow-ups and then every 5 years. Implants and patients available for the radiographic analysis are shown in Tables 2 and 3.

Intraoral radiographs for all edentulous patients were obtained at the Clinic of Oral and Maxillofacial Radiology. Later, radiographs in partial dentate patients and patients with single implant restorations were taken at The Brånemark Clinic. Up to September 2005, the examinations were carried out with an analogue technique, later by different digital ones. Because of difficulties to tolerate intraorally placed detectors, some patients were examined with dental scanograms (Scanora®, Soredex, Helsinki, Finland).[30,31] The analyzed radiographs covered a period up to 2006 to extend the follow-up time.

All radiographs from each patient were analyzed by two oral radiologists. One of them analyzed 66 patients

TABLE 1 Distribution of Upper and Lower Jaw Prostheses by Gender and Type of Bridgework

	Upper Jaw														
	None		Complete		One Partial		Two Partial		Partial + Single		One Single		Two Single		
Lower Jaw	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Σ
None			61	51	28	35	18	15			11	16	8	4	247
Complete	150	69	23	21		1	3	1							268
One partial	32	17	3	2	2	2	4	1	1						64
Two partial	28	12	4	5	2		4	1							56
Partial + single		1	2												3
One single												1			1
Two single	1														1
Σ	310		172		70		47		1		28		12		640

and the other 536 patients. In addition, radiographs from 38 randomly selected patients (229 implants) were independently analyzed by both observers. These 38 patients were chosen among the patients with progressive bone loss as identified by Fransson and colleagues.[19] Only originally placed implants were evaluated. Hence, implants replacing failed ones or teeth lost after original implant placement were not included. If an implant was displayed in more than one image, measurements were taken in the one showing the largest distance between the reference point and the bone level. The distance between the reference point (fixture/abutment junction [FAJ]) and the marginal bone level, on both the mesial and distal sides of the implants, was recorded. A magnification lens (×7) with a measuring scale divided in 0.1 mm was used when reading the analogue images. When reading the digital ones, the inbuilt measuring function of the PACS (Sectra Imtec AB, Linköping, Sweden) corrected for any magnification. When reading dental scanograms, the magnification factor (×1.7) was taken into account. The bone level at prosthesis insertion will serve as baseline when reporting bone loss over time.

The quality of the radiographs obtained at prosthesis installation and later was in general of a high quality with only 38 surfaces (0.13%) out of 30,466 ones being unreadable. The error of the radiographic assessment of the marginal bone level was determined through recordings made by both observers on 2,274 implant surfaces (38 patients with 229 implants). The mean difference between the two observers was 0.25 mm (SD 0.66). For these 38 patients, the bone level assessments are based on mean values of the two readings.

Statistical Methods

For descriptive purposes, mean; SD; median; 10th, 90th, and 97.5th percentiles; range; and frequencies are given. Mann–Whitney *U*-test was used for comparison of difference of bone loss between two groups, Kruskal–Wallis test was used for more than two unordered groups, and Spearman correlation coefficient for analyzing relations between bone loss and other continuous variables. All tests were two tailed and conducted at 5% significance level. In order to select independent predictors of bone loss, a stepwise multiple regression was used. Multiple linear regression with all variables included in the model was used for adjustment of other variables.

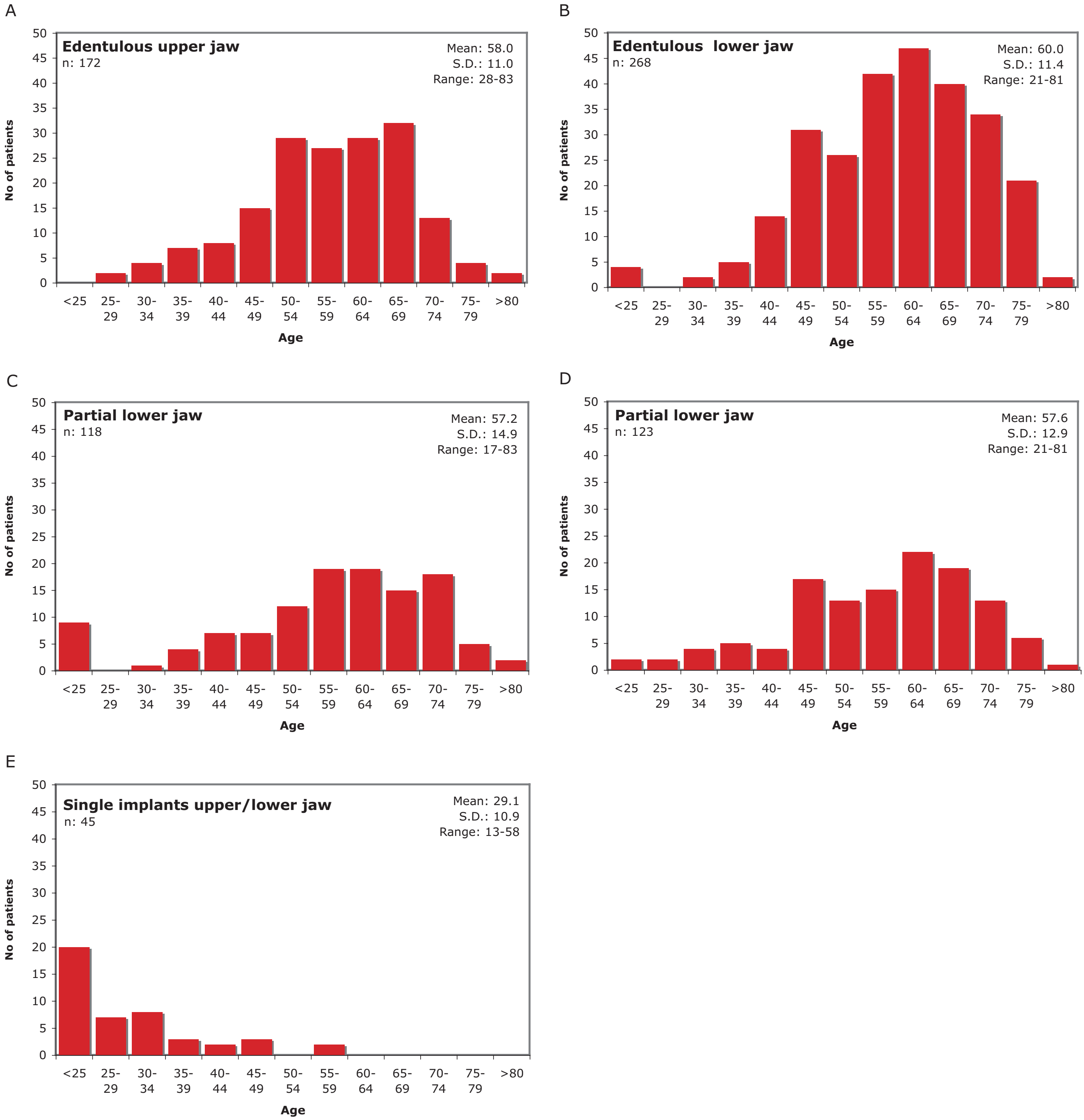

Figure 1 Age distribution at implant installation for upper and lower jaws, and type of prosthesis.

RESULTS

Implant Failures

Altogether, 61 implants (1.8%) in 43 patients (6.7%) had been removed, most of them from the upper jaw (36 in edentulous and 10 in partial dentate upper jaws). Thirty-two implants (52.5%) had been removed before the 4-year follow-up (Table 4), only a few being diagnosed with advanced marginal bone loss. The mean distance between FAJ and the marginal bone was 3.0 mm (SD 1.6, range 0.0 to 7.5) as measured in radiographs from the last examination made. Radiographic evidence of loss of osseointegration was found in eight patients, in each at one implant.

Bone Level Assessments

Differences in bone level of 1 mm or more between mesial and distal surfaces ($n = 390$) had leveled out in

TABLE 2 Bone Level (in mm) at Different Time Periods Based on a Mean Value Per Implant (*n*)

Year	*n*	Mean	SD	Median	Range
0	3,245	1.1	0.8	1.1	0–8.1
1	2,926	1.6	0.8	1.6	0–7.4
2	498	2.1	1.0	2.0	0–7.5
3	1,657	2.0	0.8	1.9	0–6.3
4	462	2.1	1.0	2.0	0–7.0
5	2,121	1.9	0.9	1.8	0–7.4
6	535	2.1	1.0	2.0	0–7.3
7	288	2.2	1.1	2.0	0–7.2
8	224	2.2	1.3	2.0	0–7.7
9	283	2.3	1.2	2.1	0–8.4
10	1,612	2.1	1.0	2.0	0–10.6
11	354	2.2	1.2	2.0	0–8.5
12	216	2.4	1.1	2.1	0–6.1
13	135	2.8	1.2	2.6	0.2–7.3
14	122	2.3	1.2	2.1	0.2–6.0
15	278	2.1	1.1	2.0	0–6.2
16	133	2.2	1.3	2.0	0–7.2
17	33	2.9	1.9	2.9	0–9.7
18	42	2.4	2.6	1.9	0–14.4
19	13	2.3	1.4	2.1	0.8–5.9
20	56	2.5	1.2	2.2	1.0–8.0

3.4% of the cases after 1 year, in 16.4% after 3 years, and in, respectively, 20.3, 28.9, and 50.0 after 5, 10, and 15 years after first observation of bone level difference. The number of implants with a bone level difference of ≥2 and ≥3 mm were few; 57 and 16, respectively, not taking into account when the observation was made.

At prosthesis insertion, the mean distance between FAJ and the marginal bone was 1.4 mm (SD 0.9; $n = 1,362$), as calculated on the implant level in the upper jaw, and 0.9 mm (SD 0.7; $n = 1,677$) in the lower jaw regardless of prosthetic construction. The distance between FAJ and the marginal bone increased over time, except for minor variations, both on the implant and the patient level (see Tables 2 and 3). Although low average values, there were implants with considerably larger distances between FAJ and the bone level (see Table 2). In Table 5, the frequency distribution of mean values per implant at different time periods is shown. Because the numbers of implants per year that were followed up to between 16 and 20 years were small, the data for those years were pooled. For implants examined more than once during this interval only, data from the latest examination were used.

Bone Loss Assessments

The overall mean bone loss, on the patient level, from prosthesis insertion (baseline) to the 1-year follow-up was 0.5 mm (SD 0.4; $n = 523$) and on the implant level 0.5 mm (SD 0.6; $n = 2, 756$). The accumulated mean bone loss increased over the years on both implant and patient levels, but at a low progression rate (Figures 2 and 3). Tables 6 and 7 show the implant- and patient-based frequency distributions of the bone loss for some of the time intervals.

Significant correlation between age at surgery and bone loss was found at year 1, 3, 5, and 10, strongest at 5 years ($r_s = 0.15$; $p = .0015$), and weakest at 10 years ($r_s = 0.12$; $p = .0380$). The older the patient, the more bone loss. When adjusted for jaw and type of bridgework a significant correlation was found at years 1, 3, and 5 with the strongest correlation at year 5 ($r_s = 0.12$; $p = .0128$).

Regarding gender, a significant difference ($p = .0289$) was found at year 15 with a larger bone loss

TABLE 3 Bone Level (in mm) at Different Time Periods on a Patient Level (*n*)

Year	*n*	Mean	SD	Median	Range
0	602	1.1	0.7	1.1	0–3.9
1	559	1.6	0.6	1.6	0.1–4.1
2	101	2.0	0.7	2.0	0.1–3.7
3	337	1.9	0.7	1.9	0.2–4.3
4	88	2.1	0.8	2.0	0.6–4.2
5	445	1.9	0.7	1.8	0.2–4.5
6	113	2.2	0.7	2.1	0.3–4.1
7	64	2.2	0.9	2.1	0.7–4.8
8	47	2.3	1.0	2.1	0.5–5.1
9	60	2.4	0.9	2.3	1.0–4.9
10	311	2.1	0.8	2.0	0.2–4.7
11	72	2.2	1.0	2.0	0.5–6.1
12	43	2.4	1.0	2.1	0.4–4.7
13	27	2.8	0.9	2.8	1.0–4.9
14	25	2.4	0.9	2.4	1.0–4.4
15	53	2.1	0.9	2.0	0.5–4.8
16	25	2.3	0.9	2.3	0.4–4.6
17	6	3.0	1.7	2.9	0.3–5.6
18	8	2.3	1.8	1.9	0.2–6.4
19	3	2.1	0.8	1.7	1.5–3.0
20	10	2.6	0.9	2.3	1.5–4.8

TABLE 4 Number of Removed Implants at Different Time Periods

	Abutment	Baseline	1 Year	2 Years	3 Years	4 Years	5 Years	6 Years	7 Years	8 Years	9 Years	10 Years	11 Years	12 Years	13 Years	14 Years
Edentulous upper jaw	5	2	2	2	11		5	4	2		1	2				
Edentulous lower jaw	1	1			1							1	1			
Partial upper jaw		1	1				1			2	4					1
Partial lower jaw	2			1	1	1						3		1		
Single lower jaw			1													

TABLE 5 Bone Level (in mm) for Individual Implants: A Frequency Distribution at Different Time Periods

	Bridge Installation		Year 1		Year 3		Year 5		Year 10		Year 15		Years 16–20	
	No. of Implants	%	No. of Implants	%	No. of Implants	%	No. of Implants	%	No. of Implants	%	No. of Implants	%	No. of Implants	%
<1	1,486	(45.8)	576	(19.7)	165	(10.0)	280	(13.2)	172	(10.7)	40	(14.4)	27	(10.4)
1.0–1.9	1,276	(39.3)	1,442	(49.3)	745	(45.0)	959	(45.2)	667	(41.4)	103	(37.1)	76	(29.2)
2.0–2.9	395	(12.2)	742	(25.4)	560	(33.8)	653	(30.8)	529	(32.8)	87	(31.3)	96	(36.9)
3.0–3.9	65	(2.0)	133	(4.5)	146	(8.8)	178	(8.4)	156	(9.7)	24	(8.6)	35	(13.5)
4.0–4.9	16	(0.5)	26	(0.9)	34	(2.1)	44	(2.1)	64	(4.0)	17	(6.1)	8	(3.1)
5.0–5.9	5	(0.2)	6	(0.2)	6	(0.4)	3	(0.1)	11	(0.7)	5	(1.8)	10	(3.8)
>6	2	(0.1)	1	(0.0)	1	(0.1)	4	(0.2)	13	(0.8)	2	(0.7)	8	(3.1)
N	3,245		2,926		1,657		2,121		1,612		278		260	

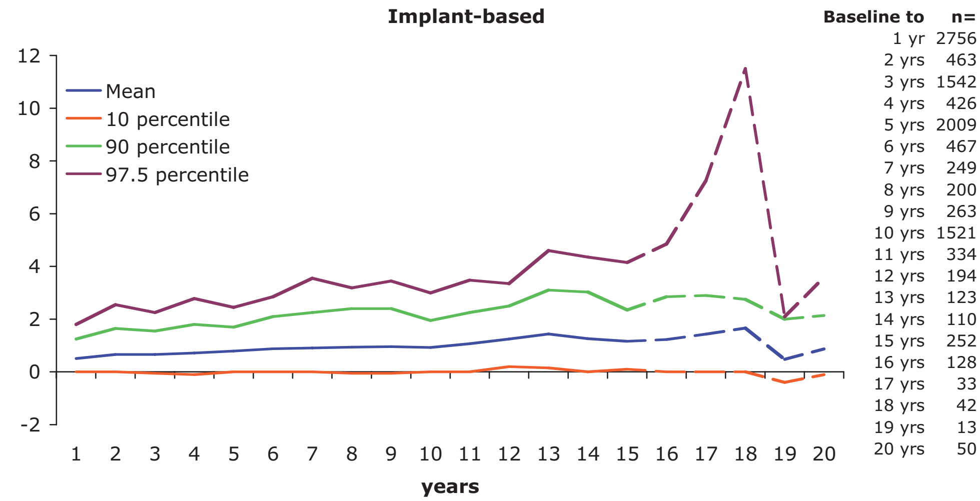

Figure 2 Distribution of implant-based annual bone loss up to 20 years after prosthesis insertion.

for women (1.32 mm; SD 0.90; $n = 30$) compared to men (0.88 mm; SD 0.42; $n = 19$). When adjusted for jaw and type of bridgework, no significant differences were found.

On the patient level, significant differences were found in bone loss between upper and lower jaw at year 1 ($p = .0054$), year 5 ($p = .0105$), and year 10 ($p = .007$) with more bone loss in the lower jaw (Table 8). A significant overall difference ($p = .0217$) in bone loss was found at year 5 between complete (0.83 mm; SD 0.57; $n = 245$), partial (0.73 mm; SD 0.51; $n = 145$), and single (0.64 mm; SD 0.63; $n = 24$). For calendar year of surgery, the overall test ($p = .0326$) also for year 5, showed a larger bone loss for surgery performed 1985 to 1989 with a mean of 0.85 mm (SD 0.58; $n = 163$) compared to 1980 to 1984 (0.53 mm; SD 0.35; $n = 16$), 1990 to 1994 (0.76 mm; SD 0.48; $n = 160$), and year 1995 and later (0.71 mm; SD 0.61; $n = 77$).

From multiple stepwise regression, jaw had most impact on bone loss at year 1 and age at years 3, 5, and 10, when only one variable was entered into each model. After adjustment for all other variables, jaw had a significant ($p = .0104$) impact on bone loss at year 1, age for both year 5 ($p = .0450$) and year 10 ($p = .0113$), and gender ($p = .0397$) for year 15.

When identifying individual implant surfaces, mesial or distal, with bone loss ≥3 mm compared to the bone level at prosthesis installation, regardless of follow-up time, 183 implant surfaces (5.3%) in 107 patients (16.7%) were found. The majority of these

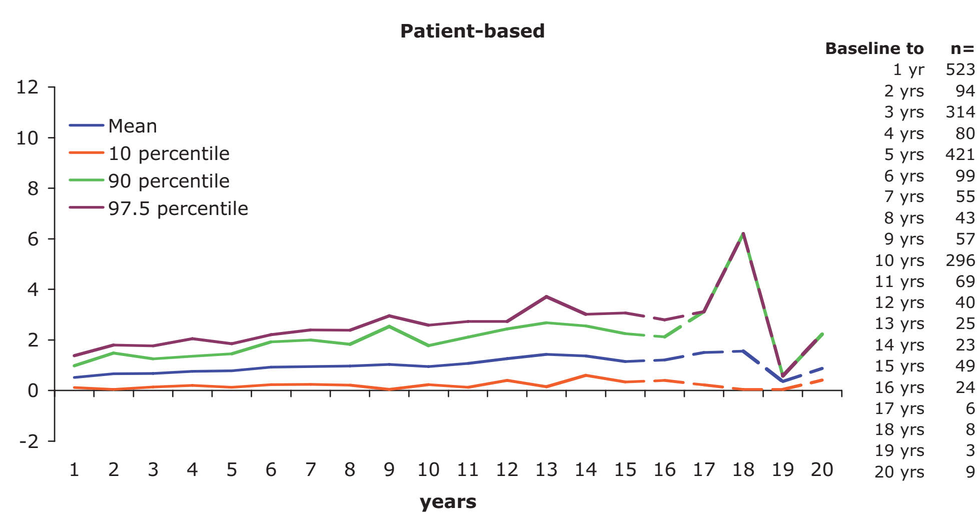

Figure 3 Distribution of patient-based annual bone loss up to 20 years after prosthesis insertion.

TABLE 6 Implant-Based Bone Loss (in mm), as a Mean of Distal and Mesial Implant Surfaces, and Its Frequency Distribution at Different Time Periods Using Bridge Installation as Baseline

	Baseline to 1 Year		Baseline to 3 Years		Baseline to 5 Years		Baseline to 10 Years		Baseline to 15 Years		Baseline to 16–20 Years	
n	2,756		1,542		2,009		1,521		252		249	
Mean (SD)	0.51 (0.55)		0.66 (0.69)		0.79 (0.75)		0.93 (0.91)		1.16 (1.02)		1.24 (1.63)	
10 percentile, 90 percentile	(0.00, 1.25)		(–0.05, 1.55)		(0.00, 1.70)		(0.00, 1.95)		(0.10, 2.35)		(0.10, 2.70)	
	n	(%)	*n*	(%)	*n*	(%)	*n*	(%)	*n*	(%)	*n*	(%)
<1	2,253	(81.7)	1,098	(71.2)	1,293	(64.4)	873	(57.4)	124	(49.2)	127	(51.0)
1.0–1.9	465	(16.9)	384	(24.9)	602	(30.0)	498	(32.7)	88	(34.9)	72	(28.9)
2.0–2.9	35	(1.3)	50	(3.2)	90	(4.5)	109	(7.2)	24	(9.5)	31	(12.4)
3.0–3.9	3	(0.1)	9	(0.6)	17	(0.8)	28	(1.8)	8	(3.2)	7	(2.8)
≥4	0	(0.0)	1	(0.1)	7	(0.3)	13	(0.9)	8	(3.2)	12	(4.8)

TABLE 7 Patient-Based Bone Loss (in mm), as a Mean of Distal and Mesial Implant Surfaces, and Its Frequency Distribution at Different Time Periods Using Prosthesis Insertion as Baseline

	Baseline to 1 Year		Baseline to 3 Years		Baseline to 5 Years		Baseline to 10 Years		Baseline to 15 Years		Baseline to 16–20 Years	
n	523		314		421		296		49		44	
Mean (SD)	0.52 (0.36)		0.67 (0.46)		0.78 (0.55)		0.95 (0.66)		1.15 (0.77)		1.26 (1.07)	
10 percentile, 90 percentile	(0.12, 0.98)		(0.14, 1.25)		(0.13, 1.45)		(0.23, 1.78)		(0.34, 2.25)		(0.41, 2.51)	
	n	(%)	*n*	(%)	*n*	(%)	*n*	(%)	*n*	(%)	*n*	(%)
<1	474	(90.6)	244	(77.7)	298	(70.8)	171	(57.8)	23	(46.9)	22	(50.0)
1.0–1.9	48	(9.2)	67	(21.3)	114	(27.1)	112	(37.7)	21	(42.9)	14	(31.8)
2.0–2.9	1	(0.2)	3	(1.0)	8	(1.9)	10	(3.4)	3	(6.1)	6	(13.6)
3.0–3.9	0	(0.0)	0	(0.0)	0	(0.0)	2	(0.7)	1	(2.0)	1	(2.3)
≥4	0	(0.0)	0	(0.0)	1	(0.2)	1	(0.3)	1	(2.0)	1	(2.3)

TABLE 8 Patient-Based Bone Loss Per Jaw and Type of Prosthesis Reconstruction (in mm) at Different Time Periods

	Baseline to 1 Year		Baseline to 3 Years		Baseline to 5 Years		Baseline to 10 Years		Baseline to 15 Years		Baseline to Last Value of 16–20 Years	
	n	Mean (SD)	*n*	Mean (SD)	*n*	Mean (SD)	*n*	Mean (SD)	*n*	Mean (SD)	*n*	Mean (SD)
Upper jaw	263	0.47 (0.37)	212	0.64 (0.47)	193	0.73 (0.62)	134	0.86 (0.78)	22	1.12 (0.86)	20	1.05 (0.65)
Lower jaw	316	0.56 (0.37)	125	0.72 (0.49)	247	0.82 (0.49)	178	1.00 (0.57)	29	1.14 (0.70)	28	1.34 (0.28)
Edentulous upper jaw	141	0.46 (0.37)	121	0.65 (0.46)	89	0.79 (0.67)	82	0.85 (0.78)	16	1.14 (0.97)	17	1.05 (0.67)
Edentulous lower jaw	217	0.56 (0.37)	41	0.77 (0.49)	165	0.87 (0.49)	126	1.02 (0.55)	22	1.33 (0.63)	22	1.46 (1.34)
Partial upper jaw	101	0.47 (0.37)	80	0.63 (0.50)	81	0.70 (0.54)	44	0.88 (0.68)	6	1.06 (0.51)	3	1.03 (0.66)
Partial lower jaw	98	0.55 (0.36)	82	0.70 (0.48)	80	0.74 (0.47)	52	0.95 (0.61)	7	0.55 (0.61)	5	1.09 (1.08)
Single upper/ lower jaw	22	0.46 (0.44)	13	0.45 (0.47)	25	0.57 (0.71)	8	0.79 (1.23)	0		1	0.05

surfaces (79%) were found in edentulous patients (59 in upper and 85 in lower jaw), while 39 surfaces were found in partially dentate patients (21 in the upper and 18 in the lower jaw). A bone loss of 3.0 to 3.9 mm was found in 112 (61.2%) of the 183 implant surfaces. Another 37 surfaces had lost 4.0 to 4.9 mm, 22 surfaces had lost 5.0 to 5.9 mm, seven surfaces 6.0 to 6.9 mm, two surfaces 7.0 to 7.9 mm, one surface had lost 8.6 mm, and two surfaces showed a bone loss of >10 mm (11.9 and 14.5 mm, respectively).

Bone Loss Assessments Using an Alternative Baseline

When using the bone level at 1 year as baseline, 78 implant surfaces (2.7%), mesial or distal, in 50 patients (8.9%) with a bone loss of $\geq$3 mm, regardless of follow-up time, were found. More than 50% (45 surfaces) had lost 3.0 to 3.9 mm, 17 had lost 4.0 to 4.9 mm, 10 surfaces 5.0 to 5.9 mm, and four surfaces 6.0 to 6.9 mm. One implant had a bone loss of 7.2 mm and another one 8.4 mm.

DISCUSSION

This retrospective study was solely based on longitudinal radiographic bone level assessments at oral implants supporting prostheses in function from 5 to 20 years. The largest number of patients was found at the earlier examinations; at prosthesis insertion 602 patients, 1-year checkup 559 patients, 5-year 445 patients, 10-year 311 patients, and 15-year 53 patients. To increase the number of patients followed longer than 15 years, data from patients ($n = 44$) followed up to between 16 and 20 years were pooled. Data from only one examination were used, the last one performed. Our study can be regarded as fulfilling the demand of a sufficiently long follow-up period as suggested by Berglundh and colleagues.[26]

Of the 1,716 patients recorded for clinical examination at The Brånemark Clinic during 1999, it was possible to include 1, 346 patients (78.4%) in our study. The remaining 370 patients (21.6%) had not charged according to established protocols at the clinic. Some patients may have been in need of additional implant treatment in other jaw regions causing the timing of their follow-up radiographic examinations to coincide with those of formerly treated regions. The latter was thus not separately registered and charged. Other patients may not have been charged because of a fast and uncomplicated examination, or because major clinical adjustments were necessary and the charging for the examination itself was missed or included in later payments.

The error of the radiographic assessment of the marginal bone level, determined through recordings made by the two observers, was as a mean relatively high. One reason could be that the patients chosen for determining interobserver variation were selected among the patients exhibiting progressive bone loss according to criteria suggested by Fransson and colleagues.[19] As shown by Gröndahl and colleagues,[32] the interobserver variation will be higher the larger the bone loss.

To allow comparisons between different studies, it is vital that the same reference point is used for bone level measurements or described in a manner making comparisons possible. Over the years, two different reference points have been used for Brånemark System implants. The radiographic reference point used in earlier studies is placed 0.8 mm apical to the FAJ. Today, FAJ is the most commonly used reference point. When no reference point is mentioned, the outcomes found become difficult to compare with those from other studies.[7,15] In the present study, it was decided to use FAJ as the reference point and the bone level at the time of prosthesis insertion as the baseline for bone loss measurements. Other baseline data have been used in the literature, such as those from the time of abutment connection or the 1-year examination.[9,15,19] The rationale for choosing the measurements from the time at prosthesis insertion as baseline data was to focus on the bone loss occurring over time in function. However, when using prosthesis placement as baseline, the bone loss taken place before implant loading will not be included. Therefore, it is important to present data on bone-level assessments to allow for assessments of the magnitude of the bone loss before prosthesis placement.

There is an ongoing debate on what criteria to apply to define implant treatment success. Lifetime survival of an implant is the ultimate goal. Factors to consider in relation to lifetime survival of the implant are, for example, progression rate of marginal bone loss, length of the implant, and expected remaining lifetime of the patient. It seems today that there is a consensus that a slow continuous bone loss can be accepted and not seen as indicative of failure. Different levels of acceptable bone loss have been discussed. According to Albrektsson and Isidor,[22] a bone loss <2.4 mm during the first 5 years in function can be accepted, while Wennström and Palmer[23] concluded that a bone loss of up to 2 mm between bridge installation and the 5-year control can be tolerated. Accordingly, larger degrees of bone loss than the mentioned should indicate an unsuccessful situation. At present, there are no data available to support that the suggested thresholds are relevant in distinguishing between implants with a successful prognosis and those at risk of being lost in the future.

Clinical studies related to the issue of progressive bone loss have recently been published.[15,19] Fransson and colleagues[19] used a threshold value for progressive bone loss at the position of or apical to the third marginal thread (about 3 mm apical to the FAJ) after 5 to 20 years in function. For these implants, radiographic bone levels at the 1-year checkup were determined, and any reduction, that is, from <3 threads at the 1-year to ≥3 threads at the 5 to 20 years of follow-up, were considered progressive bone loss. Hence, a bone loss of ≥0.1 mm during 4 to 19 years was registered as progressive bone loss. Using this criterion for inclusion, they found that 12.4% of the implants in 28% of the patients exhibited progressive bone loss.

Roos-Jansåker and colleagues[15] claimed that 7.7% of the implants suffered from progressive bone loss (≥1.8 mm) during an observation period of 9 to 14 years from the 1-year examination. However, the number of included implants cannot be compared between these two studies because there are obvious differences in inclusion thresholds for bone loss (0.1 mm as compared to 1.8 mm) as well as time of follow-up (5 to 20 years as compared to 9 to 14 years).[15,19] In the present study, the frequency of implants with a bone loss of ≥2.0 mm from prosthesis placement was 9.9% (see Table 6) in 4.4% of the patients after 10 years in function. The frequency would have been higher with lower threshold values of bone loss (0.1 or 1.8 mm) and lower with a time interval from 1-year to 10-year examination, excluding bone loss during the first year of follow-up. Further, 183 implants (5.3%) placed in 107 patients (16.7%) showed ≥3.0 mm bone loss at either the mesial or distal surface of the implant from prosthesis insertion to the last examination. The corresponding prevalence for follow-up periods starting at the first annual examination (1-year checkup) was 2.7% of implants in 8.9% of the patients.

Roos-Jansåker and colleagues[15] found that at 21% of the implants, the bone level was located at or apical to the third thread (≥3.1 mm) at the final examination compared to 12% at the 1-year examination. In the present study, the corresponding values at the 10-year examination was 15.2%, and 5.6% at the 1-year examination. Further comparisons of the present results with those by Roos-Jansåker and colleagues indicate a different distribution of complete and partially edentulous patients in the two groups, with the number of partial dentate patients being higher in the study by Roos-Jansåker and colleagues. Furthermore, the latter used the surface with the most pronounced bone loss (mesial or distal) for calculating implant data, while a mean value between surfaces was used in the present study. However, as noticed in this study, the difference between the mesial and distal implant surfaces was not great for the vast majority of measured implants.

Lower frequencies of pronounced bone loss have been observed in other long-term follow-up studies on turned Brånemark System implants in the edentulous patient.[13,16] The frequency of implants with >2.0 mm bone loss on the implant level from the time of the prosthesis placement to the 10-year checkup was reported to be 4.7% in the edentulous maxilla and 3.0% in the edentulous mandible.[13,16] For the partial dentate mandible, the corresponding frequency of implants with ≥1.8 mm bone loss (>3 threads) over a 10-year period was found to be 3.9%.[17] Also, Snauwaert and colleagues,[9] in their 15-year follow-up study, reported low frequencies of implants (1.8%) with bone loss beyond the third thread (bone level >3.1 mm below FAJ) at the last control (mean follow-up time 5.1 years). The frequencies of implants with ≥2.0 mm bone loss in the present study were 5.6 and 9.9% after 5 and 10 years of follow-up, respectively. Besides Snauwaert and colleagues,[9] the other two studies cover patients in the edentulous jaw only, a situation that may be somewhat more favorable than that in the present study, with no periodontally compromised teeth being present.[13,17]

Ekelund and colleagues,[10] in their 20-year long-term study, focused on signs of an increasing rate of bone loss during the later parts of the follow-up period (15 to 20 years). They reported a small mean marginal bone loss during the last 5 years of follow-up (0.2 mm) with only four implants (2.6%) presenting bone loss of more than 1.0 mm. Implants with earlier history (up to 15 years) of larger bone loss were not at a higher risk for bone loss during the later part of the follow-up period. These long-term observations coincide well with observations in other studies, as well as in the present one, showing no signs of increasing rate of annual bone loss around implants with turned surfaces (see Figures 2 and 3). However, in long-term perspectives, other patterns of bone loss at implants with other types of surfaces have been indicated.[24,33]

When studying risk factors for failures related to loss of osseointegration, Herrmann and colleagues[34] found poor bone quality and inadequate jawbone volume to be of major importance.

Also, implants placed in the maxillae showed a significantly higher failure rate than those placed in the mandible. However, no significant differences in implant failures were observed for gender, age, or number of implants supporting the restoration. When it comes to efforts in identifying patients and implants with a higher risk for future problems and failures related to continuous and possibly increasing rate of bone loss, several scientists have tried to separate between acceptable levels of bone loss and bone loss indicating risk for future complications and failures.[15,19,22–24] Albrektsson and Isidor[22] incorporated a time factor into their criterion of successful implants resulting in acceptable levels of bone loss of, for example, <2.4 and <3.4 mm after 5 and 10 years of follow-up, respectively. Because the chosen thresholds of bone loss for inclusion in earlier discussed studies on progressive bone loss are within the criterion for success, it raises the question if these thresholds are relevant.[15,19,22] As discussed earlier, there are no data available demonstrating that these thresholds can distinguish between implants with a successful and those with a poor prognosis. Using a 3.0 mm threshold, instead of a 2.0 mm one, after 10 years (close to the threshold suggested by Albrektsson and Isidor[22]) would, in the present study, reduce the numbers of implants "at risk" from 9.9 to 2.7%.

Several factors were found to have an influence on the marginal bone loss at the implant. Bone loss from prosthesis placement was found to increase significantly with increasing age of the patient at surgery. Significantly larger bone loss was also found for lower jaws compared to upper jaws for time intervals up to 10 years in function. More bone loss was found in patients with edentulous jaws than in other patient categories. The results indicate a complexity of reasons for bone level changes at turned Brånemark implants. Most of the differences in marginal bone loss, although statistically significant, are small from a clinical point of view.

To conclude, this long-term study demonstrated a low frequency of progressive bone loss, assessed from patient- and implant-based data, compared to recently published studies.

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