Clinical Experiences with Laser-Welded Titanium Frameworks Supported by Implants in the Edentulous Mandible: A 10-Year Follow-Up Study

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ABSTRACT

Background: Long-term follow-up studies for more than 5 years are not available on laser-welded titanium frameworks.

Purpose: To report and compare 10-year data on implant-supported prostheses in the edentulous mandible provided with laser-welded titanium frameworks and conventional gold alloy frameworks.

Materials and Methods: Altogether, 155 patients were consecutively treated with prostheses at abutment level with two generations of fixed laser-welded titanium frameworks (test groups). A control group of 53 randomly selected patients with conventional gold alloy castings was used for comparison. Clinical and radiographic 10-year data were collected for the three groups.

Results: All patients followed-up for 10 years ($n = 112$) still had fixed prostheses in the mandible (cumulative success rate [CSR] 100%). The overall 10-year cumulative success rate (CSR) was 92.8 and 100.0% for titanium and gold alloy frameworks, respectively. Ten-year implant cumulative survival rate (CSR) was 99.4 and 99.6% for the test and control groups, respectively. Average 10-year bone loss was 0.56 (SD 0.45) mm for the titanium group and 0.77 (SD 0.36) mm for the control group ($p < 0.05$). The most common complications for titanium frameworks were resin or veneer fractures, soft tissue inflammation, and fractures (12.9%) of the metal frame. Loose and fractured implant screw components were below 3%.

Conclusion: Excellent overall long-term results with 100% CSR could be achieved with the present treatment modality. Fractures of the metal frames and remade prostheses were more common for the laser-welded titanium frameworks, and the first generation of titanium frameworks worked poorly when compared with gold alloy frameworks during 10 years ($p < 0.05$). However, on average more bone loss was observed for implants supporting gold alloy frameworks during 10 years. The reasons for this difference are not clear.

KEY WORDS: bone loss, edentulism, implant-supported, laser-welded, long-term follow-up, lower jaw, prostheses, titanium

Titanium frameworks have been used for almost 20 years as an option to gold alloy castings to restore edentulous and partially edentulous patients with fixed prostheses supported by osseointegrated implants.[1–15]

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Several advantages for using titanium in the frameworks have been addressed during the years[16–19], where one interesting reason to use titanium has been that the material allows for other techniques for framework fabrication using premachined components. Since the first titanium frameworks were tested in implant dentistry, several modifications of the premachined titanium components and the overall framework design have been made.[10,15]

In the first three generations of Procera® (Nobel Biocare, Göteborg, Sweden) titanium frameworks, different premachined framework components were fabricated and were then simply selected and assembled in the laboratory with a laser-welding technique.[1,2,10,15] Follow-up studies have indicated similar clinical per-

formance of titanium prostheses as compared with conventional cast framework techniques.[2,4,5,8] However, some problems with fractures of the titanium metal frames have been observed in the first two generations of laser-welded titanium frameworks,[5,8] but all follow-up studies on laser-welded techniques are on a relatively short- or medium-term basis. Thus, there have been no detailed reports on long-term results in patients with these framework designs, and since fracture problems are related to fatigue and are time-dependent problems, longer follow-up periods would be of interest to further evaluate the performance of laser-welded techniques.

The aim of this study was to report the 10-year clinical and radiological performance of two generations of laser-welded implant-supported prostheses, placed in the edentulous mandible, and to compare the result of this treatment with patients provided with conventional cast frameworks.

MATERIALS AND METHODS

This is a 10-year retrospective follow-up study on all patients consecutively provided with fixed, laser-welded titanium implant-supported prostheses in the edentulous mandible treated at one clinic (The Brånemark Clinic, Göteborg, Sweden) between October 1987 and December 1991. The study populations are the same groups as described in detail in an earlier publication.[8]

Altogether, 824 edentulous patients were treated at the clinic during the inclusion period with fixed prostheses including 10 to 12 teeth and were supported by Brånemark System® implants (Nobel Biocare AB, Göteborg, Sweden), and standard abutments in the mandible. Of these, 669 patients were provided with conventional screw-retained fixed prostheses with gold alloy frameworks and resin teeth,[20,21] and 155 patients (19%) were provided with either of the first two generations of laser-welded titanium frameworks by Procera (Figures 1 and 2).[10,15] The study starts with prosthesis insertion, but data on all installed implants were also given.

Test Groups

One hundred fifty-five patients with a mean age of 64 years (range 35–87, SD 10.4) at the time of first-stage surgery were included in the study (Table 1). Patients were provided with four to six Brånemark System implants (Nobel Biocare AB) each (mean 5.3) according to standard two-stage surgical procedures[22] (Table 1). Standard abutments (Nobel Biocare AB) were connected at the second surgical stage. At the time of first-stage surgery, 76.1% of the patients wore a complete maxillary denture (Figure 3).

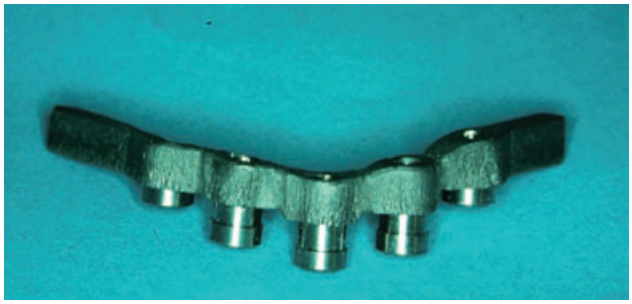

Figure 1 The first generation of titanium frameworks. Bar component with cylinders. Components were joined by laser welding.

The patients were provided with two designs of laser-welded titanium frameworks, described in more detail elsewhere.[2,8,10,15] The first group of patients (n = 51) received the first generation of laser-welded frameworks (Ti-1, Figure 1), which were based on premachined titanium cylinders and bar components.[1,2] The second test group (n = 104) received titanium frameworks (second generation of titanium frameworks [Ti-2], Figure 2) where different pieces of titanium components with cylinders and an intact bar were used. The different pieces were placed on the master cast and were then ground to the same level in which afterward, a titanium bar was welded with two lasers to complete the framework.[8] Eventually, resin was cured to these two different bar designs to retain the artificial acrylic resin teeth.

Group Control

A control group was formed by randomly selecting one patient each month from August 1987 to December

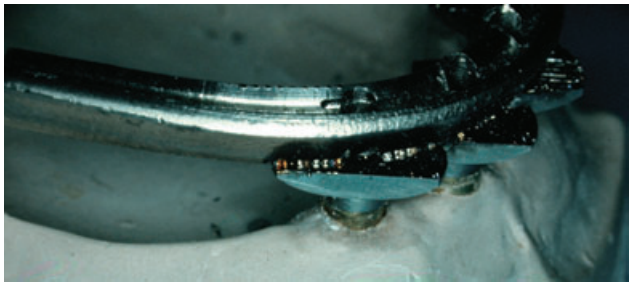

Figure 2 The second generation of titanium frameworks. After the components were ground to the same level, a titanium bar was placed in position. The bar was then horizontally welded to the components with a laser.

TABLE 1 Distribution of Patients with Regard to Gender and Placed Implants in the Test and Control Groups

	Number of Patients		Number of Brånemark System® Implants	
Groups	Males	Females	Standard	Self-Tapping
Ti-1	26	25	253	18
Ti-2	52	52	513	37
Au	26	27	262	16
Total	104	104	1028	71

Test group 1 (Ti-1) and test group 2 (Ti-2) comprise the first and second generation of titanium frameworks, respectively. Control group is denoted as "Au."
Ti-1 = first generation of titanium frameworks; Ti-2 = second generation of titanium frameworks.

1991.[8] The control group comprised 53 patients with a mean age of 67 years (SD 9.7; range 39–86 years) at the time of first-stage surgery (Table 1). The patients were provided with four to six Brånemark System implants (Nobel Biocare AB) in the mandible (mean 5.3 implants), followed by placement of standard abutments (Nobel Biocare AB) at a second surgical stage (Table 1). They were provided with fixed prostheses with cast gold alloy frameworks and resin teeth.[20,21] At the time of first-stage surgery, 67.9% of the patients wore a complete maxillary denture (Figure 3).

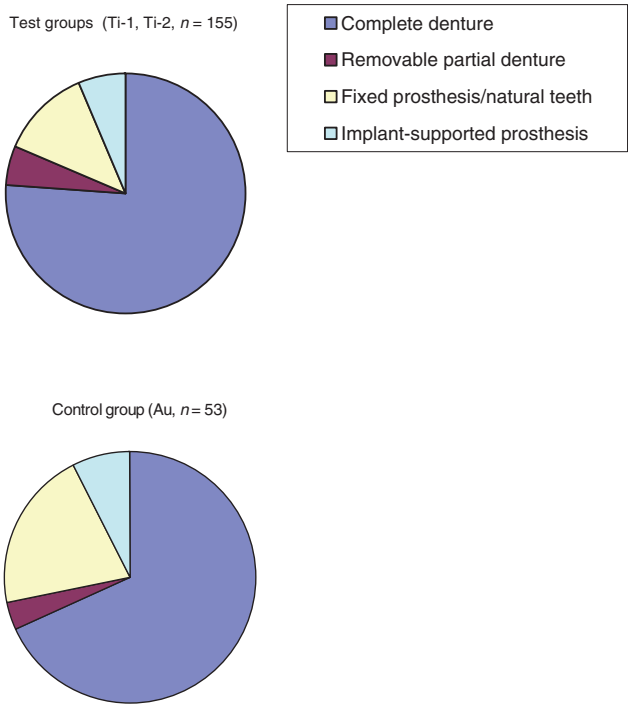

Figure 3 Status of the maxilla at the time of implant placement in the mandible for the test and control groups. Au = control group; Ti-1 = first generation of titanium frameworks; Ti-2 = second generation of titanium frameworks.

Follow-Up and Registrations

After prosthesis placement, routine clinical and radiographic procedures were followed as accounted for in more detail earlier.[8,21] All patients were encouraged to contact the clinic whenever they had problems with their prostheses. Intraoral apical radiographs were taken on a routine basis at the Radiological Specialist Clinic (Public Dental Health Service, Göteborg, Sweden) after prosthesis placement and after 1 year in function. Thereafter, radiographic examinations were scheduled after 5 and 10 years in function.

Marginal bone loss was measured, and bone level was assessed to the closest 0.3 mm[23] in relation to the fixture/abutment junction[24], placed 0.8 mm coronal to the radiographic reference point used in a previous study.[8] A mean value between the mesial and distal side of the implant was used in the statistical analyses.[25] Prostheses were to be removed to test implant stability whenever signs on radiographs and/or clinical symptoms were present to suspect that an implant had lost osseointegration.[26]

Data were retrospectively retrieved from the files regarding parameters accounted for more in detail in the previous study.[8] Focus was especially made to collect information on problems, changes and adjustments noted during the last 5 years of the inclusion period (5–10 years). Definitions of treatment outcome with prostheses and performance of original prostheses have previously been presented.[14] The prosthesis was considered as a failure when it was replaced due to severe metal fractures of the construction, with a design that was not acceptable, or due to implant loss.

Statistics

Conventional descriptive statistics (mean, SDs, and range) were used for descriptive purposes. Cumulative survival rate (CSR) for implants and cumulative success rates (CSR) for prostheses were calculated according to life Table techniques.[27] Log-rank test was used to formally test differences in CSR for prosthesis in the different groups. Fisher's exact test and chi-square test were used to evaluate differences in reported problems between the test and control groups. Changes in marginal bone resorption were analyzed with Wilcoxon's test within groups and with the Mann-Whitney *U* test

TABLE 2 Distribution of Patients Followed Up and Lost to Follow-Up in the Total Test Group (Ti*) and the Control Group (Au) during the Inclusion Period

Time	Number of Followed-Up Patients (Ti/Au)	Number of Patients Lost to Follow-Up				Failed Prosthesis (Ti/Au)
		Deceased (Ti/Au)	Moved (Ti/Au)	Ill (Ti/Au)	No Contact (Ti/Au)	
Prostheses inserted	155/53	—	—	—	—	—
1 year	149/53	3/0	1/0	—	—	2/0
2 years	141/49	2/1	2/0	—	2/3	2/0
3 years	136/45	4/1	0/1	1/0	0/2	—
4 years	128/43	4/1	1/0	1/0	1/1	1/0
5 years	124/41	3/1	—	—	0/1	1/0
6 years	119/38	4/0	—	—	1/3	—
7 years	112/38	4/0	—	—	1/0	2/0
8 years	100/35	6/2	—	1/0	5/1	—
9 years	93/31	5/1	1/0	0/1	1/2	—
10 years	84/28	3/1	1/0	0/2	4/0	1/0
Total 10 years	84/28	38/8	6/1	3/3	15/13	9/0

Number of failed prosthesis is also given.
*The total test group (Ti) comprises both first and second generation of titanium test groups.

between groups.[28] All tests were performed on patient/prosthesis level, and statistical significance was set to $p < 0.05$.

RESULTS

Patients Lost to Follow-Up

In total, 71 (45.8%) and 25 (47.2%) patients were lost to follow-up in the test and control groups during the inclusion period, respectively (Table 2). Thirty-eight (53.5%) and eight (32%) of these patients were deceased. Of 71 lost patients in the test groups, 28 of the patients belonged to the Ti-1 group, and the remaining 56 patients were in the Ti-2 group (Tables 2 and 3).

Implant and Prosthesis Stability

Loss of implants for the test and control groups is given in Tables 3 and 4. The failure rate was low and comparable for the groups ($p > 0.05$). The 10-year implant CSR was 99.6% for the Ti-1 group, 98.6% for the Ti-2 group, and 98.9% for the control group (Table 3). Corresponding 10-year CSR for loaded implants was 99.6% for the Ti-1 group, 99.3% for the Ti-2 group and 99.6% for the control group (Table 3).

None of the patients resumed using a removable denture during the follow-up period, and accordingly, the treatment protocol with fixed prostheses supported by implants in the edentulous mandible showed a 100% success rate. However, four of the Ti-1 (7.8%) and five of the Ti-2 (4.8%) prostheses were replaced by new fixed titanium prostheses during 10 years (Table 4). No Ti-1 prosthesis was replaced after 5 years, but three of the Ti-2 prostheses were replaced between 5 and 10 years in function (Table 4). The 10-year CSR for titanium frameworks were 91.4 and 93.1% for Ti-1 and Ti-2 prostheses, respectively. In the control group, all the patients had their original prostheses during the entire period (CSR 100%, Table 3). Five- and ten-year prostheses CSR was significantly higher for cast gold alloy frameworks compared with the Ti-1 frameworks ($p < 0.05$), but no significant differences were observed for the control compared with the Ti-2 frameworks ($p > 0.05$). The overall 10-year prosthesis CSR was calculated as 94.5%.

Follow-Up Maintenance

The distribution of patients with regard to number of clinical appointments per year is presented in Table 5. On average, patients in the test and control groups visited the clinic for checkups and maintenance 1.3 (SD 1.7) and 1.1 (SD 1.1) times per year during the 10-year period, respectively.

Twenty-one of the patients in the Ti group (25%) and seven patients in the control group (25%) reported

TABLE 3 Life Table of Patients/Prostheses and Placed Implants

	Placed/Examined		Lost to Follow Up		Failed		CSR (%)	
Period	Patients/Prosth.	Implants	Patients/Prosth.	Implants	Prosth.	Implants	Prosth.	Implants
Ti-1								
1st surgery	51	271	—		—	—		100
Prosth. connection	51	271	—		—	—	100	100
1 year	49	260	—	10	2	1	96.0	99.6
2 years	44	234	4	26	1	—	93.6	99.6
3 years	43	228	1	6	—	—	93.6	99.6
4 years	43	228	—	—	—	—	93.6	99.6
5 years	42	223	—	5	1	—	91.4	99.6
6 years	40	213	2	10	—	—	91.4	99.6
7 years	39	208	1	5	—	—	91.4	99.6
8 years	35	187	4	21	—	—	91.4	99.6
9 years	33	175	2	12	—	—	91.4	99.6
10 years	28	149	5	26	—	—	91.4	99.6
Total	28	149	19	121	4	1	91.4	99.6
Ti-2								
1st surgery	104	550	—		—	—		100
Prosth. connection	104	546	—		—	4	100	99.3
1 year	100	524	4	21	—	1	100	99.1
2 years	97	508	2	16	1	—	99.0	99.1
3 years	93	490	4	18	—	—	99.0	99.1
4 years	85	449	7	41	1	—	97.8	99.1
5 years	82	434	3	15	—	—	97.8	99.1
6 years	79	417	3	15	—	2	97.8	98.6
7 years	73	388	4	29	2	—	94.9	98.6
8 years	65	346	8	42	—	—	94.9	98.6
9 years	60	320	5	26	—	—	94.9	98.6
10 years	56	299	3	21	1	—	93.1	98.6
Total	56	299	43	244	5	7	93.1	98.6
Loaded implants						3		99.3
Au								
1st surgery	53	278	—		—	—		100
Prosth. connection	53	276	—		—	2	100	99.3
1 year	53	275	—		—	1	100	98.9
2 years	49	256	4	19	—	—	100	98.9
3 years	45	234	4	22	—	—	100	98.9
4 years	43	223	2	11	—	—	100	98.9
5 years	41	213	2	10	—	—	100	98.9
6 years	38	196	3	17	—	—	100	98.9
7 years	38	196	—	—	—	—	100	98.9
8 years	35	180	3	16	—	—	100	98.9
9 years	31	159	4	21	—	—	100	98.9
10 years	28	144	3	15	—	—	100	98.9
Total	28	144	25	131	0	3	100	98.9
Loaded implants						1		99.6

CSR for loaded implants is also given.

Au = control group; CSR = cumulative success rate for prostheses (Prosth.), cumulative survival rate for implants; Ti-1 = first generation of titanium frameworks; Ti-2 = second generation of titanium frameworks

TABLE 4 Distribution of Reported Number of Problems Related to the Prosthesis (Patients after 10 Years) in the Two Different Test Groups (Ti-1 and Ti-2) and in the Control Group (Au) during the Inclusion Period

	Number of Observations (patients)								
	Period 0–5 years			Period 5–10 years			Total period 0–10 years		
	Ti-1	Ti-2	Au	Ti-1	Ti-2	Au	Ti-1	Ti-2	Au
Problem	($n = 42$)	($n = 82$)	($n = 41$)	($n = 28$)	($n = 56$)	($n = 28$)	($n = 28$)	($n = 56$)	($n = 28$)
New prosthesis	4	2	—	—	3	—	4 (4)	5 (5)	—
Framework fracture	10	10	1	4	6	1	14 (9)*	16 (11)	2 (2)
Resin veneer fracture	6	24	7	4	9	3	10 (6)	33 (16)	10 (7)
Loss of access hole filling	4	7	13	2	2	2	6 (5)	9 (8)**	15 (12)
Soft-tissue inflammation	11	13	11	6	9	1	17 (10)	22 (19)	12 (8)
Cheek/lip biting	4	2	—	—	—	1	4 (4)	2 (2)	1 (1)
Implant component fracture	—	1	4	—	1	—	—	2 (2)	4 (2)
Loose screws (retightened)	—	1	—	—	—	1	—	1 (1)	1 (1)
Implant loss before insertion	—	4	2	—	—	—	—	4 (4)	2 (2)
Implant loss after insertion	1	1	1	—	2	—	1 (1)	3 (2)†	1 (1)
Other problems	14	20	12	3	9	1	17 (12)	29 (16)	13 (13)

Number of patients at the end of the time interval is given within brackets.
*$p < 0.05$; **$p < 0.01$; patient level statistical comparison to the control group (Au).
†Two prostheses were remade due to implant loss.
Ti-1 = first generation of titanium frameworks; Ti-2 = second generation of titanium frameworks.

no problems at all during 10 years of follow-up. The frequency of resin veneer fractures was observed as a more obvious problem in the Ti-2 group, but had a tendency to be less frequent during the last 4 years for all groups (Tables 4 and 6). For the test groups, 5 (Ti-1) and 18 (Ti-2) of these resin fractures were mended in the laboratory during the inclusion period (Table 6). Four of the resin fractures were mended in the laboratory in the control group.

Altogether, 12.9% of the patients with titanium frameworks (test groups) experienced one (7.1%) to a maximum of three (5.8%) metal fractures (Figure 4).

TABLE 5 Distribution of Patients in Percentage (%) with Regard to Number of Clinical Appointments per Year in the Total Test Group (Ti = Ti-1 + Ti-2) and in the Control Group (Au)

Follow-Up		Distribution of Appointments per Year in %						Mean Number of Appointments (SD)	
Year	Patients (Ti/Au)	0	1	2–4	5–7	8–10	>10	Ti	Au
1	149/53	1/2	52/58	39/26	4/9	2/4	2/0	2.3 (2.5)	2.1 (1.9)
2	141/49	19/18	65/59	7/18	6/4	0/0	2/0	1.5 (2.2)	1.4 (1.4)
3	136/45	8/13	77/71	10/13	3/2	1/0	1/0	1.4 (1.9)	1.2 (1.0)
4	128/43	32/30	54/49	10/21	2/0	1/0	2/0	1.1 (1.8)	1.1 (1.1)
5	124/41	14/2	71/78	10/15	5/2	0/2	1/0	1.4 (1.5)	1.6 (1.6)
6	119/38	49/45	38/45	7/11	3/0	3/0	0/0	1.1 (1.9)	0.8 (1.0)
7	112/38	24/24	56/68	15/5	3/3	2/0	0/0	1.3 (1.6)	1.3 (1.0)
8	100/35	47/54	43/43	9/3	1/0	0/0	0/0	0.8 (1.0)	0.6 (0.7)
9	93/31	44/68	46/26	9/6	1/0	0/0	0/0	0.8 (1.1)	0.4 (0.6)
10	84/28	0/0	98/96	1/4	0/0	1/0	0/0	1.4 (1.3)	1.1 (0.6)

Overall mean number of appointments per year (SD) is also presented.
Ti-1 = first generation of titanium frameworks; Ti-2 = second generation of titanium frameworks.

TABLE 6 Number of Observations of Resin Veneer and Metal Framework Fractures During 10 Years of Follow-Up in the Different Groups

	Number of Observations during 1 to 10 Years of Follow-Up										
	1	2	3	4	5	6	7	8	9	10	Total
Resin veneer fractures											
Ti-1 ($n = 51$)	1	1	—	3	1	1	—	—	3	—	10
Ti-2 ($n = 104$)	6	6	5	4	3	3	2	1	—	3	33
Au ($n = 53$)	—	2	1	3	1	1	1	—	—	1	10
Framework fractures											
Ti-1 ($n = 51$)	4	1	—	3	2	—	—	1	—	3	14
Ti-2 ($n = 104$)	1	3	2	1	3	1	4	—	—	1	16
Au ($n = 53$)	—	—	—	—	—	—	1	—	—	1	2

Number of included prostheses is given within brackets (n).
Au = gold alloy control group; Ti = titanium test groups (Ti-1 and Ti-2); Ti-1 = first generation of titanium frameworks; Ti-2 = second generation of titanium frameworks.

These fractures (Table 6) were observed in 9 and 11 patients in the Ti-1 (17.6%) and Ti-2 (10.6%) groups, respectively. Eight of the metal frames fractured twice in the Ti-1 and Ti-2 groups, and one Ti-2 frame fractured three times. The frequency of the fractures of the titanium frameworks was more evenly distributed during the inclusion period compared with fractures of the gold-alloy frameworks, occurring during the 7th and 10th year of follow-up (Table 6). All but two framework fractures (in two Ti-2 frameworks) were observed in close connection with the terminal implant.

Nine of the titanium prostheses were replaced by new fixed prostheses, recorded as prosthesis failures in Table 3. Six of these were remade following fractures of the metal frame; one was replaced due to bulky design (Ti-1), and two were remade after new implants had been placed (Ti-2); however, using the original prostheses up to this surgery had been completed. In the control group, two frameworks fractured once (3.8%), but they were resoldered and maintained in function without being remade ("survival, modified").[14]

In the test and control groups, five patients altogether presented fractured implant components (2.4%), and two prostheses (1.0%) exhibited mobility during the follow-up period due to unstable screws (Table 4). Losses of fillings at the screw site were more common in the gold alloy group when compared to Ti-2 prostheses ($p < 0.01$).

Radiographs

Mean marginal bone levels for the different groups during the follow-up period are given in Table 7. The

TABLE 7 Mean Marginal Bone Level (mm) in Relation to the Fixture/Abutment Junction (FAJ) at the Time of Placement and after 1, 5 and 10 Years of Follow-Up

	Mean Bone Level (SD) in Relation to FAJ							
	Loading		After 1 Year		After 5 Years		After 10 Years	
Treatment group	*n*	Mean (SD)	*n*	Mean (SD)	*n*	Mean (SD)	*n*	Mean (SD)
Ti-1	51	1.02 (0.27)	49	1.38 (0.45)	41	1.58 (0.55)	24	1.53 (0.54)
Ti-2	102	1.11 (0.38)*	95	1.42 (0.48)	49	1.54 (0.52)	50	1.62 (0.60)
Total Ti	153	1.08 (0.35)*	143	1.41 (0.47)	88	1.56 (0.53)	74	1.59 (0.58)
Au	53	0.96 (0.26)	49	1.26 (0.38)	34	1.47 (0.40)	19	1.80 (0.44)

Number of x-rayed patients (n).
Patient level statistical comparison to the control group (Au).
*$p < 0.01$.
Au = gold alloy control group; Ti = titanium test groups (Ti-1 and Ti-2); Ti-1 = first generation of titanium frameworks; Ti-2 = second generation of titanium frameworks.

TABLE 8 Distribution of Individual Implants with Regard to Degree of Bone Loss (mm) during 10 Years and during the Last 5 Years of Follow-Up (5–10 Years)

No. of Implants (mm)	Bone Loss						Marginal Bone Level			
	0–10 Years			5–10 Years			After 10 Years			
	Ti-1	Ti-2	Au	Ti-1	Ti-2	Au	(mm)	Ti-1	Ti-2	Au
0	47	115	34	97	108	62	0.8*	41	88	28
<0.5	16	26	5	16	14	6	>0.8–1.8	37	59	20
0.5–1.0	37	43	19	12	28	14	1.9–2.4	33	80	36
>1.0–1.5	17	63	32	3	8	13	2.5–3.0	13	24	10
>1.5–2.0	8	12	10	1	—	3	3.1–3.6	4	10	9
>2.0–2.5	1	6	4		2		3.7–4.2	—	4	—
>2.5–3.0	2	1	—				4.3–4.8	—	—	—
>3.0–4.0	—	—	—				4.9–5.4	—	1	1
>4.0–5.0	—	1	—				5.5–6.0	—	—	—
							6.1–6.6	—	1	—
Total	128	267	104	129	160	98		128	267	104

Bone levels in relation to FAJ for individual implants after 10 years are also presented.
*Level of radiographic reference point.
Au = gold alloy control group; Ti = titanium test groups (Ti-1, Ti-2); Ti-1 = first generation of titanium frameworks; Ti-2 = second generation of titanium frameworks.

mean time between abutment operation and prostheses delivery was 59 days (SD 41.5) for the test groups and 51 days (SD 34.2) for the control group. A significant difference in marginal bone levels could be observed between the titanium and control groups at the time of prosthesis placement (Table 7, $p < 0.01$). Altogether, 30 implants (6%) showed a bone level at or below the third thread of the implant after 10 years (Table 8, ≥3.1 mm).

Bone loss was on average 0.56 mm (SD 0.45) for the titanium group and 0.77 mm (SD 0.36) for the control group during the 10-year follow-up period (Table 9, $p < 0.05$). During the last 5 years of inclusion, the test group presented a mean bone loss of 0.1 mm (SD 0.19), compared with an average bone loss of 0.3 mm (SD 0.27) for the control group (Table 9, $p < 0.01$).

Comparing bone loss for individual implants, it can be observed that 16.3% of the implants supporting cast frameworks presented more than 1 mm bone loss after the fifth annual checkup, compared with 3.1 and 6.2% of the implants in the Ti-1 and Ti-2 groups, respectively (Table 8). However, most implants experienced a bone loss not exceeding 1.5 mm (91.0%), and only four implants (0.8%) altogether presented bone loss of more than 2.5 mm after 10 years follow-up (Table 8). These were all implants placed in the anterior part of the mandible, close to the midline.

TABLE 9 Mean Marginal Bone Loss in mm (SD) During the Follow-Up Period

Group	*n*	0–1 year Mean (SD)	0–5 years Mean (SD)	5–10 years Mean (SD)	0–10 years Mean (SD)
Ti-1	51	0.36 (0.34)	0.55 (0.43)	0.09 (0.16)**	0.56 (0.41)*
Ti-2	102	0.31 (0.33)	0.50 (0.39)	0.15 (0.21)*	0.57 (0.47)
Total Ti	153	0.33 (0.33)	0.52 (0.41)	0.12 (0.19)**	0.56 (0.45)*
Au	53	0.29 (0.32)	0.52 (0.41)	0.30 (0.27)	0.77 (0.36)

Number of x-rayed patients at the time of placement (n).
Patient level statistical comparison to the control group (Au).
*$p < 0.05$; **$p < 0.01$.
Au = gold alloy control group; Ti = titanium test groups (Ti-1, Ti-2); Ti-1 = first generation of titanium frameworks; Ti-2 = second generation of titanium frameworks.

DISCUSSION

Treatment of patients with implant-supported fixed prostheses in the edentulous mandible showed a very favorable overall result in this study after 10 years of follow-up. Only five implants were lost in function (CSR 99.5%), and no differences between the test and control groups could be found ($p > 0.05$). This low frequency of implant failure in the lower jaw is in accordance with what have been reported in other studies on similar groups of patients.[29,30,31,32] All patients were still using fixed prostheses after 10 years, which corroborates with similar reports of successful treatments with implant-supported fixed prostheses in the edentulous mandible.[29,30,32,33] These findings clearly indicate that treatment of edentulous patients with implants in the anterior mandible, provided with fixed prostheses with the posterior cantilever is a predictable clinical protocol with few major problems in the long-term perspective.

However, certain problems were observed with the titanium frameworks, and nine of them were remade. The prosthesis failures were mainly due to fractures of the metal frames close to the terminal implant and the posterior cantilever (Figure 4). One reason for these fracture problems might be lack of experience with a new protocol, as in comparison to the situation of frequent metal fractures that occurred when the cast bar frameworks were first introduced many years ago.[34,35] The gap between the surfaces to be assembled by laser welding must be narrow and as parallel as possible, and the final depth of the welded seams is only about 0.6 to 0.8 mm.[1,15] Thereafter, this welded seam should not be ground, and manipulation of a titanium laser joint could be significantly weakened when ground or polished by an inexperienced technician or dentist. Furthermore, it cannot be excluded that the chemical composition of the highly reactive titanium is altered in the welded joint during the laser-welding operation, and this might in turn influence mechanical properties in this region.[1] Also, different defects in welded specimens have been described, such as gas pores and cracks, at fractured surfaces in a study performed by Sjögren and colleagues.[1] The tendency of a lower ratio of fractures in the Ti-2 group possibly indicates a learning pattern with a better awareness of the problem from the involved staff. The improvement could also reflect a better design with a more robust framework, seen as an intact titanium bar, and horizontally oriented welding joints (Figure 2, Ti-2). However, the present control group represents a well-established casting technique with few fractured gold alloy frameworks, in accordance with another report.[14]

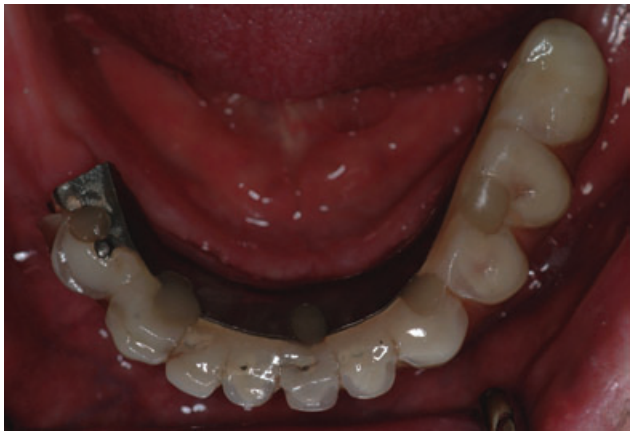

Figure 4 Fractured titanium framework close to the terminal implant and the posterior cantilever.

Resin veneer fracture is a well-documented problem in implant dentistry.[14,15,35,36] Certainly, the present resin veneer technique is not originally designed for fixed implant restorations but rather for complete dentures. However, using alternative porcelain fused to metal veneering techniques also seems to involve potential problems in implant dentistry, with higher risk for chippings from the porcelain in implant-supported prostheses compared with tooth-supported prostheses.[7,37,38] Acrylic resin was wrapped around the early Ti-1 frames, resulting in a final prosthesis that could be bulkier and that caused a slightly higher incidence of hyperplasia[2], but on the other hand also providing a more secure retention of the artificial teeth in the prosthesis than for Ti-2 frameworks. Bergendal and Palmqvist[39] reported more resin fractures in their titanium-framework prostheses than in cast frameworks, which could not be confirmed in this study. Instead, a significantly reduced risk of loose access hole fillings for Ti-2 compared to gold alloy prostheses was observed ($p < 0.05$), probably due to different design, allowing deeper access holes and thereby better retention for the composite resin in the Ti-2 frameworks.

The biological response to treatment is reflected by the stable bone level and minimal bone loss for both the titanium and the gold alloy groups. The small but significantly lower baseline bone level at the implants supporting titanium frameworks (Table 7) should probably be referred to the longer time interval between second

surgery and the time of baseline radiographic examination in this group, although not reaching a significant level in this study. This difference in bone levels disappear during the first 5 years in function, showing marginal bone loss on an average of 0.5 mm for both groups during this time (Table 9). This bone loss is well in accordance with results observed in other 5-year follow-up reports.[14,40] Thereafter, a steady-state situation can be observed with a final marginal bone loss on an average of 0.6 mm after 10 years in function for titanium frameworks, and 0.8 mm for cast gold alloy frameworks (Table 9). Again, these changes are comparable or lower than observed in other studies after 10 years of follow-up.[31,33,35] It is compelling to notice that the implants supporting gold alloy frameworks show a small but significantly higher bone loss than observed for the entire titanium group (Table 9, $p < 0.05$). This difference seems to evolve during the last 5 years of follow-up (Table 9). Analysis of bone loss at individual implants shows that the majority of the implants present only small changes during the different time intervals (Table 8). The small significant difference between cast and titanium can probably be related to the fact that more than 16% of implants supporting cast frameworks present more than 1 mm bone loss during the last 5 years, while only 3 to 6% of implants show the same pattern for the test groups. Whether this difference will increase by time is an open question, and the cause for this pattern to evolve first after 5 years in function is not clear.

Factors to be discussed in relation to this difference in bone loss could be systematic differences in framework design, differences in framework stiffness, framework precision of fit, and biocompatibility of the framework metal. The area of precision of fit is complex, and the literature lacks consistency on whether any adverse biological effects are due to decreased quality of fit and what level of clinical fit is acceptable.[15]

In an animal study performed by Abrahamsson and colleagues[19], they reported how mucosal attachments formed to titanium abutments, a phenomenon that had not been observed with gold alloy abutments. They suggested that the differences in the adhesive properties of the two materials or the differences in their resistance to corrosion were responsible for this phenomenon.[19] However, in this study, all implants have been provided with standard abutment cylinders, placed with the top of the cylinders close to the mucosal margin. Accordingly, few frameworks have been placed submucosally, and the distance between the prosthesis-abutment margin and the bone must have been at least 3 mm. Therefore, potential differences in mucosal attachments between the framework materials must be of less importance for the observed differences at the marginal bone. Instead, speculations on the cause could rather focus on the potential difference in plaque adherence and corrosion between the metals, but why these differences should present radiological differences first after more than 5 years is not clear. However, since the distribution of individual implants with regard to bone loss during the first and last 5 years of function does not indicate an increased pattern of implants with more bone loss in the later period, it can be noted that even if the differences in bone loss is statistically significant, there is a low impact of the clinical relevance in this study, at least for the present time of follow-up.

CONCLUSION

On the basis of 10-year data on the treatment of edentulous mandibles with fixed prostheses supported by implants, the following conclusions can be made:

- Excellent clinical results can be achieved, with few implant failures (CSR 99.5%) and 100% maintained fixed prosthesis function during 10 years of follow-up.
- The 10-year prosthesis CSR was 91.4, 93.1, and 100% for the two generations of laser-welded titanium and cast gold alloy frameworks, respectively. The CSR was significantly better for cast frameworks compared with the Ti-1 ($p < 0.05$).
- Implants supporting titanium frameworks showed significantly lower bone levels at baseline ($p < 0.05$) compared with cast gold alloy frameworks. The difference was 0.1 mm between the groups.
- Implants supporting cast gold alloy frameworks showed significantly more bone loss during the last 5 years of follow-up ($p < 0.05$). The overall difference in bone loss ($p < 0.05$) was 0.2 mm between cast and titanium frameworks after 10 years of follow-up ($p < 0.05$).
- Besides fractures of titanium frameworks, resin veneer fractures, and soft tissue inflammations were the most common complications during follow-up. Mechanical problems related to the implants were few (<3%).

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