Laser-Welded Titanium Frameworks Supported by Implants in the Partially Edentulous Mandible: A 10-Year Comparative Follow-Up Study

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ABSTRACT

Background: Comparative long-term knowledge of different framework materials in the partially edentulous implant patient is not available.

Purpose: To report and compare 10-year data on free-standing implant-supported partial prostheses with laser-welded titanium (test) and conventional gold alloy (control) frameworks.

Materials and Methods: Altogether, 52 partially edentulous patients were consecutively provided with laser-welded prostheses ($n = 60$) in the partially edentulous lower jaw (test group). A control group of 52 randomly selected patients with gold alloy castings ($n = 60$) was used for comparison. Clinical and radiographic 10-year data were retrospectively collected and evaluated for both groups.

Results: The overall 10-year implant cumulative survival rate (CSR) was 93.0% (loaded implants, 96.4%), with a 10-year implant CSR of 91.5 and 94.7% for test and control implants, respectively ($p > .05$). Out of a total of 22 lost implants, 17 implants (77.3%) were shorter than 10 mm. The overall 10-year prosthesis CSR was 93.7%, with a corresponding 10-year CSR of 88.4 and 100% for test and control groups, respectively ($p < .05$). Average 10-year bone loss was 0.46 mm (SD 0.47) and 0.69 mm (SD 0.53) for the test and control groups ($p < .001$), respectively. Only 1% of the implants had >3 mm accumulated bone loss after 10 years. Altogether, 10 of the prostheses in both groups had implant component mechanical problems (8.3%). None of the frameworks or implants fractured, but more fractures of porcelain veneers were observed in the test group ($p < .05$).

Conclusion: The protocol of implant treatment in the partially edentulous jaw functioned well during 10 years, although prosthodontic maintenance was required. However, laser-welded titanium frameworks presented more problems as compared with gold alloy frameworks. More loaded implants were lost ($p < .05$), and higher incidence of porcelain chipping was noted in the test group ($p < .05$). However, bone loss was on an average lower for the test group during the 10 years of follow-up ($p < .001$).

KEY WORDS: complications, fixed prostheses, framework design, implants, laser-welding, veneering material

INTRODUCTION

The conventional technique for fabricating screw-retained fixed prostheses on implants has basically remained unchanged during the last years.[1] The technique is based on high levels of handicraft and castable materials, is hard to rationalize, and is labor intensive. However, an alternative technique for framework fabrication with prefabricated titanium components that were joined by laser-welding was introduced in the late 80s.[2–9] Several modifications of the titanium framework designs have been tested since then.[10–12] These changes were made to improve the design of the final prosthesis as well as the precision and mechanical strength.[4,12,13]

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Other advantages with alternative metals such as titanium may be related to lower cost for the metal, good biological properties, and the advantage of using the same material in the superstructure as used in the implants.[12,14,15]

The findings in a recent 10-year study[9] clearly indicate that treatment in the edentulous mandible with implants and fixed prostheses is a predictable clinical protocol with few major problems in the long term, regardless of whether gold alloy or laser-welded titanium frameworks are used in the prosthesis. The study also demonstrates lower bone loss for the titanium frameworks.[9] However, certain problems with fractures of the metal frame have been observed with the first two generations of laser-welded titanium frameworks in the edentulous mandible.[9] Resin and acrylic teeth fractures in the edentulous jaw are also common but have shown no significant differences between the metals in the frameworks.[9] Using implant-supported titanium frameworks also in the partially edentulous patient includes higher demands for aesthetics, which introduces a need for alternative veneering materials in the partially edentulous patient. Also fewer implants, placed in more posterior regions, are used to support the prostheses in the partially edentulous jaw. This will distinguish the biomechanical situation in the partially edentulous patient from the experience in completely edentulous patients.[16–27] Five-year clinical experiences on implant-supported titanium-frameworks in the partially edentulous jaw have earlier been presented.[7] However, no report has analyzed the long-term outcome for partially edentulous implant patients with titanium framework veneered mainly with porcelain.

The purpose of the present study was to report the 10-year clinical and radiographic performance of early designed implant-supported laser-welded titanium prostheses with different veneering techniques placed in the partially edentulous mandible, and to compare the result of this treatment with implant patients provided with conventional cast gold alloy frameworks.

MATERIALS AND METHODS

Altogether, 204 patients were provided with free-standing fixed partial prostheses supported by implants in the partially edentulous mandible at one clinic (The Brånemark Clinic, Göteborg, Sweden) from November 1990 to September 1993. Most patients were provided with conventional cast gold alloy (Au) frameworks,[1,4]

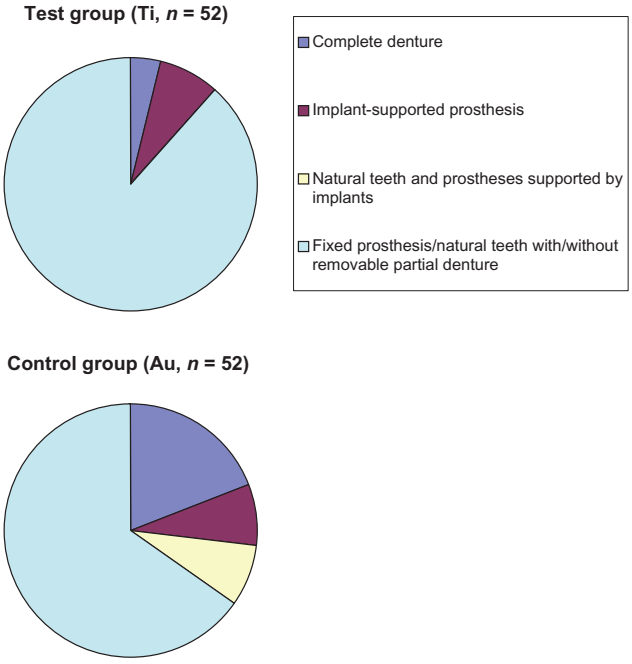

Figure 1 Status of the maxilla at the time of implant placement in the partially edentulous mandible for the test and control groups.

but 52 and 6 patients were at random treated with laser-welded titanium frameworks during this period in the mandible and maxilla, respectively. This titanium framework group was accounted for in a previous 5-year follow-up study.[7] However, since patients restored in the maxilla were few, the present test group only covered patients provided with titanium frameworks in the mandible. For comparisons, a randomized control group was included, covering the same number of patients as included in the test group, here restored with cast gold alloy frameworks.

Test Group

Fifty-two patients were included in the test group; 30 of the patients were women. The mean age at the time of implant placement was 58 years (SD 11.0, age range from 28 to 77). Twenty-nine patients reported no general health problems at all (56%), and 13 patients were smokers (25%). The dental status of the maxilla at the time of implant placement is presented in Figure 1.

In total, 174 turned Brånemark™ implants (Nobel Biocare AB, Göteborg, Sweden) were placed (Table 1) following a two-stage surgical procedure.[28,29] Seventeen of the implants were self-tapping.

After 3–4 months of healing, 114 standard and 55 EsthetiCone™ abutments (early conical abutment,

TABLE 1 Length and Diameter of the Implants Placed and Lost for the Test (Ti) and Control (Au) Groups

Length (mm)	Diameter (mm) 3.75 (Ti/Au)	4 (Ti/Au)	5 (Ti/Au)	Placed Brånemark Implants (Ti/Au)	Failed before Loading (Ti/Au)	Failed in Function (Ti/Au)
6	—	—	10/3	10/3	2/0	2/0
7	47/42	10/17	—	57/59	1/6	6/0
8.5	6/5	—	—	6/5	—	1/0
10	37/42	5/6	0/1	42/49	1/2	0/1
13	23/13	—	2/0	25/13	—	—
15	11/17	—	—	11/17	—	—
18	16/21	—	—	16/21	—	—
20	7/10	—	—	7/10	—	—
Total implants (Ti/Au)	147/150	15/23	12/4	174/177	4/8	9/1

developed before the multi-unit abutments, Nobel Biocare AB) were connected. Thereafter, 60 prostheses with laser-welded titanium frameworks (Figure 2) were fabricated and connected to the implants as described in the previous study[7] (Table 2). Acrylic resin teeth and individual composite resin veneers (Dentacolor Silicoater®, D-6393, Fa.Kulzer & Co GmbH, Wehrheim, Germany) were used in the early stage of inclusion in two and nine frameworks, respectively. At the end of the inclusion period, all remaining prostheses ($n = 49$, 82%) were provided with low-fusing porcelain (Procera Porcelain™, Nobel Biocare AB). Altogether, 16 pontics were included into the prostheses (mean 0.3, SD 0.73). The final try-in of the prostheses was performed according to routine protocol[1,12], and occlusion was adjusted as described previously.[7]

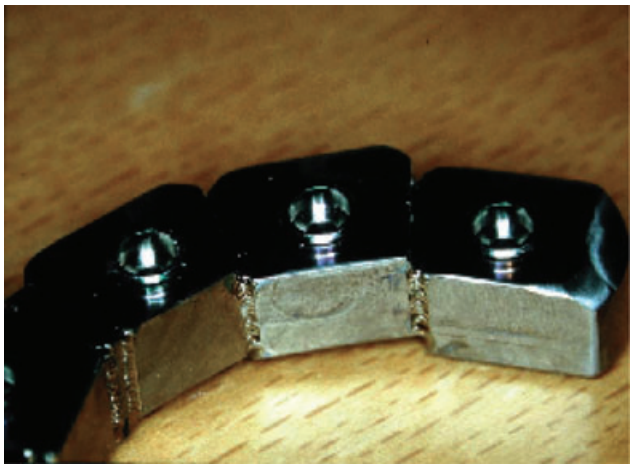

Figure 2 The "third generation" of laser-welded titanium framework (Ti-3) with vertical laser-welding joints.

Control Group

The control group comprised 52 patients provided with 60 fixed partial prostheses with cast gold alloy frameworks. This group was formed by randomly selecting one partially edentulous patient from every third week during the inclusion period. Thirty-three of the patients in the control group were females, and the mean age was 59 (SD 11.6; age ranged from 27 to 78) years at the time of first-stage surgery. Thirty-one patients reported no general health problems (60%), and 12 patients were smokers (23%).

In total, 177 turned Brånemark implants were placed (see Table 1), according to the same surgical protocol as for the test group. Twenty of these were self-tapping implants.

After healing, 141 standard, 27 EsthetiCone, and one angulated abutment cylinder (Nobel Biocare AB) were connected. Thereafter, 60 fixed partial prostheses with cast gold alloy frameworks (see Table 2) were fabricated and connected according to previous described techniques.[1,4] The frameworks were veneered with either resin teeth[1] (8 prostheses) or porcelain (52 prostheses).

Follow-Up and Registrations

After prosthesis placement, routine clinical and radiographic procedures followed.[7,30] All patients were encouraged to contact the clinic whenever they had problems with their prostheses. Intraoral apical radiographs were on a routine basis taken after prosthesis placement and after 1 year in function. During the early part of the inclusion period, all patients were also scheduled for routine radiographs after 5 and 10 years, while

TABLE 2 Number of Prostheses with Regard to Number of Supporting Implants for the Test and Control Groups

	Number of Supporting Implants per Prostheses				
Group	Prostheses	2	3	4	Mean (SD)
Test	60	16	39	5	2.8 (0.6)
Control	60	17	37	6	2.9 (0.6)
Total	120	33	76	11	2.8 (0.6)

patients included later were not on a routine basis scheduled for radiographs at these time intervals. Some patients also declined radiographic examinations.

Marginal bone level was assessed to the closest 0.3 mm[31] in relation to the implant threads and the fixture/abutment junction,[32] placed 0.8 mm coronal to the radiographic reference point, used in previous studies (Figure 3).[7,8] A mean value between the mesial and distal side of the implant was used in the statistical analyses.[33]

Data were retrospectively retrieved from the files regarding parameters accounted for more in detail in the previous study.[7] Definitions of treatment outcome with prostheses and performance of original prostheses have previously been presented.[12]

Prostheses were to be removed to test implant stability whenever radiograph signs and/or clinical symptoms were present to suspect that an implant had lost osseointegration.[34] However, since prostheses were not removed on a routine basis to confirm osseointegration, only survival criteria for implants have been used.[35,36] Additionally placed implants were not included when survival rates for implants were calculated. When a fixed prosthesis was replaced and the prosthesis was recorded as a failure as accounted for below, the remaining supporting implants were withdrawn for further follow-up.

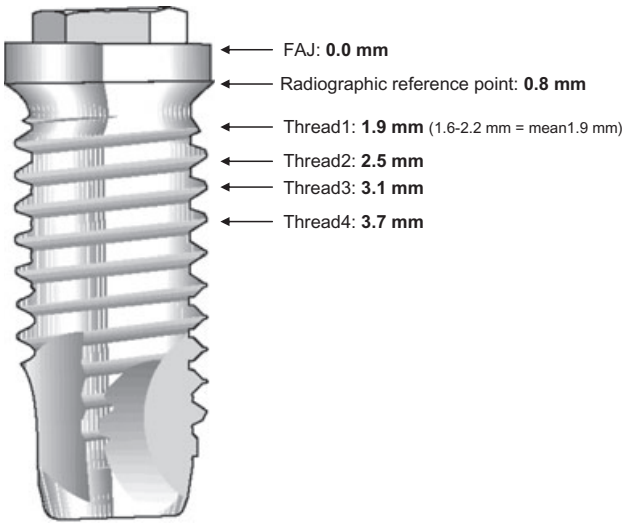

Figure 3 Radiographic measurements are presented in relation to the fixture/abutment junction (FAJ) and the threads of the implant. The radiographic reference point[31] is placed 0.8 mm apical to the FAJ. The first thread of the implant is placed on an average 1.9 mm (1.6–2.2 mm) below the FAJ, and the following threads are machined with a distance of 0.6 mm.

The prosthesis was considered as a failure when it was removed due to implant failures or replaced by a new prosthesis due to fractures or other problems (irreversible failure). In situations when the veneering material was changed or the prosthesis was shortened due to implant failures, the prosthesis was referred to as a modified survival, still in function (reversible failure). However, when the prosthesis was shortened, leaving only one implant to support one remaining single crown, the prosthesis was recorded as a failure, and the remaining implant was withdrawn from the study (but was not recorded as a failure). On the other hand, when the original prosthesis was provided with new pontics due to loss of adjacent teeth, the implant-supported prosthesis was still considered as a successful (surviving) restoration. In situations when a new prosthesis was made due to tooth loss of neighboring teeth, the construction was withdrawn but was not recorded as a failure.

Statistics

Conventional descriptive statistics (mean, SDs) were used for descriptive purposes. Cumulative survival rate (CSR) for implants and prostheses was calculated according to life table techniques.[37] Implant and prosthesis CSRs were analyzed with log rank test.[38] Fisher's exact test for implant-level analyses and Fisher's exact permutation test[38] for subject-level analyses were used to evaluate differences in reported problems, individual

TABLE 3 Life Table of Placed, Withdrawn, and Lost Implants

Framework	Test Group (Ti)				Control (Au)			
Period	Implants	Withdrawn	Failed	CSR	Implants	Withdrawn	Failed	CSR
First surgery	174	—	—	100	177	—	—	100
Prosth. conn.	169	1	4	97.6	169	—	8	95.3
1 year	165	1	3	95.8	166	2	1	94.7
2 years	160	5	—	95.8	160	6	—	94.7
3 years	157	2	1	95.2	154	6	—	94.7
4 years	157	—	—	95.2	149	5	—	94.7
5 years	150	7	—	95.2	144	5	—	94.7
6 years	142	7	1	94.5	144	—	—	94.7
7 years	137	5	—	94.5	134	10	—	94.7
8 years	131	6	—	94.5	120	14	—	94.7
9 years	131	—	—	94.5	120	—	—	94.7
10 years	124	3	4	91.5	107	13	—	94.7
Total	124	37	13	91.5	107	61	9	94.7
Loaded implant			9	93.7			1	99.4

CSR for implants in the test and control groups.
CSR = cumulative survival rate, Prosth. conn., prostheses connection.

changes in marginal bone resorption, differences in "bone gain," and for comparing the amount of short implants placed between the test and control groups. To evaluate differences between test and control groups on patient level for bone level and bone loss, Mann–Whitney *U* test was used.[38] The analyses were subjected to the same test for comparing data on the time between abutment operation and prostheses delivery.[37,38] Statistical significance was set to 5%.

RESULTS

Patients Lost due to Follow-Up

In total, 35 (33.7%) out of 104 patients were lost to follow-up and were excluded during the 10-year study period. Seven of these patients were deceased; 3 patients could not attend clinical examination due to general health problems; 2 patients were excluded because they moved from the city, and 15 patients did not show up for recall appointments. Another 8 patients were withdrawn with still stable implants after replacement/loss of original prostheses.

Surgical Outcomes

Altogether, 12 implants were lost before prosthesis placement (3.4%). These early failures were predominantly short implants (see Table 1) placed in the control group (Table 3). Thereafter, nine implants were lost in the test group and one in the control group during the follow-up period (see Table 3). This difference of implant failures after prosthesis placement was statistically significant on both implant and patient levels ($p < .05$), but not on a prosthesis level ($p > .05$, Table 4). However, there was a statistically insignificant difference ($p > .05$) of total implant failures from the first implant surgery to the first annual checkup between the groups (see Table 3; $p > .05$). The 10-year implant CSR was 91.5 and 94.7% for the test and control groups ($p > .05$ for 0–5 and 0–10 years; see Table 3), respectively. The overall 10-year implant CSR was 93.0% and for loaded implants 96.4%.

Two of 22 lost implants were found in two smokers, and the remaining 20 failing implants were placed in 12 non-smokers. Four and three implants were removed from the bilateral mandibles in 2 different patients, respectively, and 2 patients lost two implants each. The remaining failures were removed from 11 different patients.

With regard to the 10 failed loaded implants, two were removed from 3 patients each, and the remaining failures were observed in 4 different patients. Five of the prostheses with implant failures in the test group were supported by three implants, and one was supported by two implants. None of these prostheses had cantilevers. Only one loaded implant in the control

TABLE 4 Distribution of Reported Number of Problems (Prostheses) Related to the Test (Ti) or Control (Au) Groups during Different Time Intervals

Years	0–5 Years		5–10 Years		0–10 Years	
Framework	TI	Au	Test	Au	Ti	Au
No. of prostheses	55	51	44	38	44	38
Problems	Number of Observations (Number of Prostheses)					
	Mechanical Problems					
Loose prosthesis	1	5 (4)	5 (3)	2 (2)	6 (4)	7 (6)
Implant component fracture	0	4 (1)	3 (2)	0	3 (2)	4 (1)
Veneer fracture: chipping[†]	8 (4)	0	6 (6)	1	14 (9)*	1
Veneer fracture: severe[‡]	11 (5)	3 (2)	1	0	12 (6)	3 (2)
Loss of access hole filling	13 (10)*	3 (2)	2 (2)	2 (2)	15 (12)	5 (4)
	Biological and Prosthesis Problems					
Aesthetic, redesign	6 (4)	2 (2)	0	0	6 (4)	2 (2)
Shortened prosthesis	3 (3)	1	1	0	4 (3)	1
Soft-tissue inflammation	3 (3)	9 (7)	5 (4)	2 (2)	8 (6)	11 (8)
Implant loss after insertion	4 (3)	1	5 (4)	0	9 (6)	1
Other problems	7 (5)	4 (4)	4 (4)	2 (2)	11 (8)	6 (6)

The number of prostheses at the end of the time interval is also given.
*$p < .05$; prosthesis-level statistical comparison to the control group (Au).
[†]Treatment: polish or no treatment.
[‡]Treatment: adjustment in mouth or at laboratory.

group was lost, supporting a prosthesis with four implants.

Mean marginal bone levels (see Figure 3) during the follow-up period are given in Table 5. A statistically significant difference in mean marginal bone levels could be observed between the groups at the time of prosthesis placement and after 1 year of follow-up ($p < .05$), but the mean marginal bone level was similar at the final

TABLE 5 Mean Marginal Bone Levels in Relation to Fixture/Abutment Junction (FAJ; See Figure 3) in the Two Groups

	Bone Level in Relation to FAJ							
	Prosthesis		1 Year		5 Years		10 Years	
Examined	Test	Control	Test	Control	Test	Control	Test	Control
Prostheses	60	60	59	57	46	40	37	36
Implants	166	169	163	161	127	112	103	102
	Marginal Bone Level in Relation to FAJ (mm)							
Mean	1.29**	1.01	1.69*	1.38	1.66	1.53	1.73	1.74
SD	0.47	0.30	0.53	0.42	0.47	0.54	0.65	0.56
Bone level (mm)	Distribution of Number of Implants (%)							
0.0–0.8[†]	63 (38)	120 (71)	19 (12)	59 (37)	15 (12)	34 (30)	27 (26)	21 (21)
0.9–1.9[‡]	88 (52)	45 (27)	110 (67)	83 (52)	86 (68)	55 (49)	47 (46)	52 (51)
2.0–2.5	12 (7)	4 (2)	23 (14)	18 (11)	21 (17)	19 (17)	18 (17)	19 (19)
2.6–3.1	2 (1)	—	9 (5)	1 (1)	5 (4)	4 (4)	5 (5)	6 (6)
3.2–3.7	1 (1)	—	2 (1)	—	—	—	3 (3)	4 (4)
3.8–6.0	—	—	—	—	—	—	3 (3)	—

Percentage of distribution is given within brackets.
*$p < .01$; **$p < .001$; patient-level statistical comparison to the control group.
[†]Implant reference point[31] is placed 0.8 mm below FAJ (Figure 3).
[‡]First implant thread is placed 1.9 mm below FAJ (Figure 3).

TABLE 6 Mean Marginal Bone Loss at Implants in the Two Different Groups and Distribution of Individual Implants with regard to Degree of Bone Loss (mm)

	Bone Loss during Function							
	0–1 Year		1–5 Years		5–10 Years		0–10 Years	
	Test	Control	Test	Control	Test	Control	Test	Control
Prostheses	59	57	45	40	37	35	37	36
Implants	163	161	127	109	93	85	103	102
	Mean Marginal Bone Loss (mm)							
Mean	0.42**	0.39	0.14	0.17	0.20	0.25	0.46***	0.71
SD	0.35	0.36	0.22	0.26	0.42	0.34	0.47	0.52
Bone loss (mm)	Distribution of Number of Implants (%)							
0.0†	52 (32)	73 (45)	82 (65)	70 (64)	63 (68)	44 (52)	43 (42)	29 (28)
0.1–0.6‡	55 (34)	39 (24)	36 (28)	24 (22)	20 (22)	30 (35)	20 (19)	20 (20)
0.7–1.2	51 (31)	45 (28)	8 (6)	14 (13)	7 (8)	7 (8)	29 (28)	33 (32)
1.3–1.8	4 (2)	3 (2)	1 (1)	1 (1)	3 (3)	3 (4)	8 (8)	15 (15)
1.9–2.4	1 (1)	1 (1)	—	—	—	—	1 (1)	3 (3)
2.5–4.0	—	—	—	—	—	1 (1)	2 (2)	2 (2)

**$p < .01$; ***$p < .001$; patient-level statistical comparison to the control group.
†A bone gain was detected in 25 implants in the test and in four implants in the control group between 0 and 10 years in function, here registered as 0.0 mm.
‡Distance between the threads of the implants is 0.6 mm.

examination (see Table 5). Altogether, 10 implants (4.9%) showed a bone level below the third thread of the implant after 10 years in function (>3.1 mm; see Figure 3). The distribution of these implants was similar between the two groups (see Table 5).

The test and control groups lost on an average 0.46 mm (SD 0.47) and 0.71 mm (SD 0.52) of bone at the implants ($p < .001$) during 10 years in function, respectively (Table 6). Most bone loss was observed for the first year in function, and there was no trend of increasing levels of average bone loss by time (see Table 6).

Bone loss for individual implants is also given in Table 6, indicating only few implants (4.3%) with more than 1.8-mm bone loss (greater than three threads) during 10 years in function.

Prosthodontic Outcomes

The mean time between abutment operation and prostheses delivery was 38 (SD 18.0) and 47 (SD 30.4) days for the test and control groups, respectively ($p > .05$).

When considering new and all original prostheses (also modified) still in function after 10 years, the treatment protocol regarding implant-supported prostheses in the partial mandible reached an overall CSR rate of 98.9%.

Altogether, six titanium framework prostheses failed during the follow-up period, compared to none for the control group (Table 7). The 5- and 10-year prosthesis CSR of the test and control prostheses was 94.8 and 100.0% ($p > .05$), and 88.4 and 100.0% ($p < .05$), respectively. Including also the modified[12] prostheses in the test group, the 10-year CSR was 92.4% instead of 88.4%. The overall prosthesis CSR after 10 years was 93.7% (CSR modified[12] 95.8%).

Considering the six failed prostheses in the test group, one prosthesis was shortened during the first year, but remained as a single tooth restoration (could be recorded as "survival modified"[12]). Another prosthesis was replaced during the second year due to severe fractures of the veneers. Two of the failing prostheses were excluded from the study when replaced with new prostheses due to implant loss during the 2nd and 10th year of follow-up, respectively. The sixth prosthesis was recorded as lost after implant failures during the 10th year of follow-up when the prosthesis was redesigned to a single implant crown (could be recorded as "survival modified"[12]).

Maintenance

On average, the patients visited the clinic for checkups and maintenance 1.1 (SD 1.3) and 0.9 (SD 1.0) times per year during the 10-year period in the test and control groups, respectively.

TABLE 7 Life Table of Placed, Withdrawn, and Failed Prostheses

Framework	Test Group (Ti)				Control Group (Au)			
Period	Prostheses	Withdrawn	Failed	CSR	Prostheses	Withdrawn	Failed	CSR
Prosth. conn.	60	—	—	100	60	—	—	100
1 year	59	—	1	98.3	59	1	—	100
2 years	57	—	2	94.8	57	2	—	100
3 years	56	1	—	94.8	55	2	—	100
4 years	56	—	—	94.8	53	2	—	100
5 years	54	2	—	94.8	51	2	—	100
6 years	52	2	—	94.8	51	—	—	100
7 years	50	2	—	94.8	47	4	—	100
8 years	47	3	—	94.8	43	4	—	100
9 years	47	—	—	94.8	43	—	—	100
10 years	44	—	3	88.4	38	5	—	100
Total	44	10	6	88.4	38	22	0	100

CSR for test and control groups.
CSR = cumulative survival rate, Prosth. conn., prostheses connection.

Fourteen prostheses (31.8%) in the test group and 19 prostheses (50.0%) in the control group had no prosthodontic problems at all reported during the follow-up period (Figure 4).

Distribution of reported problems is given in Tables 4 and 8. Two prostheses in the test and four prostheses in the control group were provided with additional units due to loss of adjacent teeth. Four of these prostheses received only pontics, while the remaining two prostheses were also provided with an additional implant each, not accounted for in Table 3.

None of the frameworks fractured during the follow-up period. However, fractures of the veneering material were a relatively frequent problem. Significantly more veneer fractures were reported in the test group ($p < .05$; see Table 4). Most fractures occurred during the first 5 years of follow-up (see Table 8). Four of the titanium Dentacolor/acrylic prostheses experienced fractured veneers, and none of the gold alloy acrylic veneers fractured ($p > .05$). Severe fractures of the porcelain, needing adjustments in the laboratory, were found in 6.1 and 3.1% in the test and control groups ($p > .05$), respectively. Chippings of the porcelain were observed in 16.3 and 1.9% ($p < .05$), respectively.

During the follow-up period, none of the implants fractured, but 10 of the prostheses experienced other implant component mechanical problems (8.3%; see Tables 4 and 8). These were adjusted by retightening loose screws or by replacing fractured abutment/bridge locking screws with new ones followed by adjustment of the occlusion.

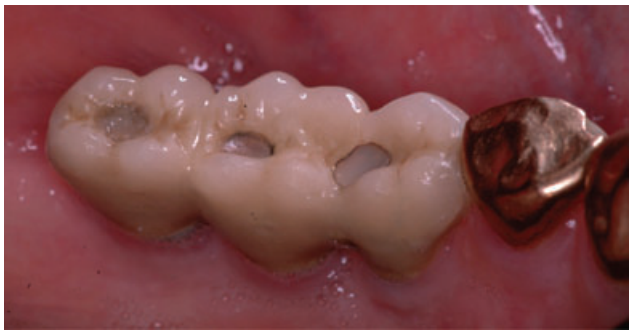

Figure 4 The "third generation" of a screw-retained titanium framework (Ti-3) veneered with low-fusing porcelain after 10 years in function without any complication at all.

DISCUSSION

Implant treatment in the partially edentulous jaw functioned well during 10 years, although prosthodontic maintenance was required. Overall implant prosthesis treatment in the partially edentulous mandible, including also all new and modified prostheses, reached a 10-year treatment CSR of 98.9%. Considering only original prostheses, the corresponding overall 10-year prosthesis CSR was 93.7% where both results are well in accordance with earlier publications.[18,20,25,27] The findings clearly indicate that treatment in the partially

TABLE 8 Number of Observations of Porcelain Fractures and Prosthetic Component Complications during 10 Years of Follow-Up in the Different Groups

Number of Prostheses (*n*)		Years: Complications	0–5 Number of Observations	5–10 Number of Observations	Total Observations	Total Prostheses *n* (%)
Baseline	Year 10			Porcelain fractures		
49	36	Ti porcelain	11	6	17	11* (22.4)
52	34	Au porcelain	3	1	4	3 (5.8)
				Loose/Fractured Prosthetic Screws		
60	44	Ti	2	5	7	3 (5.0)
60	38	Au	7	3	10	4 (6.7)
				Loose/Fractured Abutment Screws		
60	44	Ti	1	4	5	3 (5.0)
60	38	Au	6	6	12	3 (5.0)

*$p < .05$; prosthesis-level statistical comparison to the control group (Au).
Ti = test, Au = control.

edentulous jaw with implant-supported prostheses is a predictable clinical protocol in the long-term perspective. However, certain problems were related to the titanium frameworks ($p < .05$). Six of these prostheses were recorded as total failures mainly due to severe fractures of the veneers or implant failures. Many of the veneer fractures could be related to this early group of patients with laser-welded frameworks, when only limited experience of low-fusing porcelain veneering techniques onto titanium was present. With an increased learning curve, it could be expected that problems related to inexperience will decrease, reaching knowledge levels comparable with conventional porcelain fused to metal techniques, used for the control group. However, recent patient materials have reported a trend of more frequent fractures of porcelain in implant-supported prostheses as compared with tooth-supported prostheses.[26,39]

Besides higher incidence of veneer fractures in the test group, patients provided with titanium frameworks also presented more implant failures as compared to the control group ($p < .05$). Similar difference has also been reported in some earlier studies covering edentulous patients,[11,12] however, in contrast to other studies.[6,9] Since short implants have been documented to be more vulnerable to failures,[22,40,41] the slightly higher numbers of short implants placed in the test group (39%) as compared to the control group (34%) could be one possible contributing factor to explain this difference. However, a more reasonable difference to notice between the two groups is the longer mean time ($p > .05$) from second surgery to prosthesis delivery in the control group (47 days) as compared with the test group (38 days). With a longer time before prosthesis connection, early failing implants can be more easily identified and removed before loading with the prostheses in the control group. Higher numbers of failures before loading in the control group (see Table 3) and a statistical insignificant difference ($p > .05$) of total implant failures from first implant surgery to the first annual checkup between the groups support this assumption.

The observed mean marginal bone loss of all implants was found to be of similar or lower magnitude as observed by others with 10-year follow-up in partially edentulous situations.[19,27] It can be seen that the progression of bone loss for the major part of the patients and implants is slow and compares favorably with reports of implants used in the edentulous situation.[9] The implants supporting gold alloy frameworks show a significantly higher mean marginal bone loss than observed for the test group after 10 years in function ($p < .001$). This has also been noticed in a recent 10-year follow-up study in edentulous mandibles, restored with either cast gold alloy or laser-welded titanium framework.[9] Analysis of bone loss at individual implants shows that the majority of the implants present only small changes during the different time intervals. However, the difference ($p < .01$) between cast and titanium frameworks is probably that 11.8% (39.2% between 0 and 10 years) of implants supporting cast framework present more than 1-mm bone loss during the last 5 years, while only 6.5% (21.4% between 0 and

10 years) of implants show the same pattern for the test group (see Table 6).

Factors to be discussed in relation to this difference in bone loss could be systematic differences in framework design and veneers used, differences in framework stiffness, framework precision of fit, differences in their resistance to corrosion, and biocompatibility of the framework metal.[9,14] However, in the present study, all implants have been provided with abutments, placed with the top of the cylinders close to or above the mucosal margin. Therefore, potential differences in mucosal attachments between the framework materials or veneers 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 possibly corrosion between the metals or precision of fit. Even if the differences in bone loss are statistically significant, there is a low impact of the clinical relevance in this study, at least for the present time of follow-up and with the present low level of mean and individual level of bone loss. Also, when comparing the results in the present study with others,[42,43] there is a low level of "progressive" bone loss. A bone gain also found by others[44] was detected around 24.3 and 2.9% of the implants in test and control prostheses, respectively ($p < .001$, implant level; $p < .01$, patient level). This is probably due to an increase in mineralization leading to higher radio-opacity of previously unobserved bone[22] or possibly a more favorable bone reaction to implants in the test group.

CONCLUSIONS

Based on 10-year data on the treatment of implant-supported laser-welded titanium and cast gold alloy framework in the partially edentulous mandible, the following conclusions can be made:

1. The overall 10-year implant and prosthesis CSRs were 93.0 and 93.7%, respectively. The corresponding 10-year CSR of prostheses and implants for the test and control groups was 88.4, 91.5 and 100.0, and 94.7%, respectively.
2. Successful osseointegration with a small mean bone loss of 0.46 and 0.71 mm for test and control frameworks was maintained, respectively ($p < .001$).
3. Low levels of progressive bone loss on patient and implant levels were documented.
4. Implants and prostheses failed more often in the test group as compared with the control group ($p < .05$). Porcelain chippings was the major problem during the follow-up period, more observed in the test group ($p < .05$).
5. Mechanical problems with loose prostheses related to the implants were few and showed no difference between the groups (titanium group: 6.7%, gold alloy group: 10%, $p > .05$)

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REFERENCES

1. Zarb GA, Jansson T. Prosthetic procedures. In: Brånemark P-I, Zarb GA, Albrektsson T, eds. Tissue-integrated prostheses: osseointegration in clinical dentistry. Chicago, IL: Quintessence, 1985:241–282.
2. Sjögren G, Andersson M, Bergman M. Laser welding of titanium in dentistry. Acta Odontol Scand 1988; 46:247–253.
3. Jemt T, Linden B. Fixed implant-supported prostheses with welded titanium frameworks. Int J Periodontics Restorative Dent 1992; 12:177–184.
4. Jemt T. Three-dimensional distortion of gold alloy castings and welded titanium frameworks. Measurements of the precision of fit between completed implant prostheses and the master cast in routine edentulous situation. J Prosthet Dent 1995; 74:284–293.
5. Rubenstein JE. Stereo laser-welded titanium implant frameworks. Clinical and laboratory procedures with a summary of 1-year clinical trials. J Prosthet Dent 1995; 74:284–293.
6. Bergendahl B, Palmqvist S. Laser-welded titanium frameworks for implant-supported fixed prostheses: a 5-year report. Int J Oral Maxillofac Implants 1999; 14:69–71.
7. Örtorp A, Jemt T. Clinical experiences of implant-supported prostheses with laser-welded titanium frameworks in the partially edentulous jaw. A 5-year follow-up study. Clin Implant Dent Relat Res 1999; 2:84–91.
8. Jemt T, Henry P, Lindén B, Naert I, Weber H, Wendelhag I. Implant-supported laser-welded titanium and conventional cast frameworks in the partially edentulous jaw. A 5-year prospective multi-center study. Int J Prosthodont 2003; 16:415–421.
9. Örtorp A, Jemt T. Clinical experiences with laser-welded titanium frameworks supported by implants in the edentulous mandible: a 10-year follow-up study. Clin Implant Dent Relat Res 2006; 8:198–209.

10. Helldén L, Ericson G, Elliot A, et al. A prospective 5-year multicenter study of the cresco implantology concept. Int J Prosthodont 2003; 16:554–562.
11. Örtorp A, Jemt T. Clinical experiences of CNC-milled titanium frameworks supported by implants in the edentulous jaw. A 5-year prospective study. Clin Implant Dent Relat Res 2004; 6:199–209.
12. Örtorp A. On titanium frameworks and alternative impression techniques in implant dentistry. PhD thesis, Department of Prosthetic Dentistry/Dental Materials Science, The Brånemark Clinic, Göteborg University, Göteborg, Sweden, 2005.
13. Jemt T, Bäck T, Petersson A. Precision of CNC-milled titanium frameworks for implant treatment in the edentulous jaw. Int J Prosthodont 1999; 12:209–215.
14. Abrahamsson I, Berglundh T, Glantz P-O, Lindhe J. The mucosal attachment at different abutments. An experimental study in dogs. J Clin Periodontol 1998; 25:721–727.
15. Esposito M. Titanium for dental application (I). In: Brunette DM, Tengvall P, Textor M, Thomsen P, eds. Titanium in medicine. Berlin, Germany: Springer-Verlag, 2001:827–860.
16. Skalak R. Aspects of biomechanical considerations. In: Brånemark P-I, Zarb G, Albrektsson T, eds. Tissue-integrated prostheses: osseointegration in clinical dentistry. Chicago, IL: Quintessence, 1985:117–128.
17. Lindh T, Gunne J, Tillberg A, Molin M. A meta-analysis of implants in partial edentulism. Clin Oral Implants Res 1998; 9:80–90.
18. Gunne J, Åstrand P, Lindh T, Borg K, Olsson M. Tooth-implant and implant supported fixed partial dentures: a 10-year report. Int J Prosthodont 1999; 12:216–221.
19. Lekholm U, Gunne J, Henry P, et al. Survival of the Brånemark implant in partially edentulous jaws: a 10-year prospective multicenter study. Int J Oral Maxillofac Implants 1999; 14:639–645.
20. Hultin M, Gustavsson A, Klinge B. Long-term evaluation of osseointegrated dental implants in the treatment of partly edentulous patients. J Clin Periodontol 2000; 27:128–133.
21. Naert I, Koutsikakis G, Duyck J, Quirynen M, Jacobs R, van Steenberghe D. Biologic outcome of implant-supported restorations in the treatment of partial edentulism. Part I: a longitudinal clinical evaluation. Clin Oral Implants Res 2002; 13:381–389.
22. Naert I, Koutsikakis G, Quirynen M, Duyck J, van Steenberghe D, Jacobs R. Biologic outcome of implant-supported restorations in the treatment of partial edentulism. Part II: a longitudinal radiographic evaluation. Clin Oral Implants Res 2002; 13:390–395.
23. Goodacre C, Bernal G, Rungcharassaeng K, Kan J. Clinical complications with implants and implant prostheses. J Prosthet Dent 2003; 90:121–132.
24. Pjetursson B, Tan K, Lang N, Brägger U, Egger M, Zwahlen M. A systematic review of the survival and complication rates of fixed partial dentures (FPDs) after an observation period of at least 5 years I. Implant-supported FPDs. Clin Oral Implants Res 2004; 15:625–642.
25. Brägger U, Karoussis J, Persson R, Pjetursson B, Salvi G, Lang N. Technical and biological complications / failures with single crowns and fixed partial dentures on implants: a 10-year prospective cohort study. Clin Oral Implants Res 2005; 16:326–334.
26. Vult von Steyern P. All-ceramic fixed partial dentures. Studies on aluminum oxide- and zirconium dioxide-based ceramic systems. PhD thesis, Department of Prosthetic Dentistry, Faculty of Odontology, Malmö University, Malmö, Sweden, 2005.
27. Eliasson A, Eriksson T, Johansson A, Wennerberg A. Fixed partial prostheses supported by 2 or 3 implants: a retrospective study up to 18 years. Int J Oral Maxillofac Implants 2006; 21:567–574.
28. Lekholm U, Zarb G. Patient selection and preparation. In: Brånemark P-I, Zarb G, Albrektsson T, eds. Tissue-integrated prostheses: osseointegration in clinical dentistry. Chicago, IL: Quintessence, 1985:199–210.
29. Adell R, Lekholm U, Brånemark P-I. Surgical procedure. In: Brånemark P-I, Zarb G, Albrektsson T, eds. Tissue-integrated prostheses: osseointegration in clinical dentistry. Chicago, IL: Quintessence, 1985:211–232.
30. Jemt T, Linden B, Lekholm U. Failures and complications in 127 consecutively placed fixed partial prostheses supported by Brånemark implants: from prosthetic treatment to first annual check up. Int J Oral Maxillofac Implants 1992; 7:40–44.
31. Hollender L, Rockler B. Radiographic evaluation of osseointegrated implants of the jaws. Dent Maxillofac Radiol 1980; 9:91–95.
32. Friberg B, Jisander S, Widmark G, et al. One-year prospective three-center study comparing the outcome of a "soft bone implant" (prototype Mk IV) and the standard Brånemark implant. Clin Implant Dent Relat Res 2003; 5:71–77.
33. Strid KC. Radiographic results and radiographic procedures. In: Brånemark P-I, Zarb GA, Albrektsson T, eds. Tissue-integrated prostheses: osseointegration in clinical dentistry. Chicago, IL: Quintessence, 1985:187–198, 317–327.
34. Gröndahl K, Lekholm U. The predictive value of radiographic diagnosis of implant instability. Int J Oral Maxillofac Implants 1997; 12:59–64.
35. Albrektsson T, Zarb G, Worthington P, Eriksson AR. The long term efficacy of currently used dental implants: a review and proposed criteria of success. Int J Oral Maxillofac Implants 1986; 1:11–25.
36. Esposito M, Hirsch J-M, Lekholm U, Thomsen P. Biological factors contributing to failures of osseointegrated oral

implants (1). Success criteria and epidemiology. Eur J Oral Sci 1998; 106:527–551.
37. Colton T. Statistics in medicine. Boston, MA: Little, Brown and Company, 1974:241–250.
38. Altman DG. Practical statistics for medical research. 1st ed. London, UK: Chapman & Hall, 1991.
39. Brägger U, Aeschlimann S, Bürgin W, Hämmerle C, Lang N. Biological and technical complications and failures with fixed partial dentures (FPD) on implants and teeth after four to five years of function. Clin Oral Implants Res 2001; 12:26–34.
40. Friberg B, Jemt T, Lekholm U. Early failures in 4,641 consecutively placed Brånemark dental implants: a study from stage one surgery to the connection of completed prostheses. Int J Oral Maxillofac Implants 1991; 6:142–146.
41. Sennerby L, Roos J. Surgical determinants of clinical success of osseointegrated oral implants: a review of the literature. Int J Prosthodont 1998; 11:408–420.
42. Roos-Jansåker AM, Lindahl C, Renvert H, Renvert S. Nine- to fourteen-year follow-up of implant treatment. Part II: presence of peri-implant lesions. J Clin Periodontol 2006; 33:290–295.
43. Fransson C, Lekholm U, Jemt T, Berglundh T. Prevalence of subjects with progressive bone loss at implants. Clin Oral Implants Res 2005; 16:440–446.
44. Lindquist LW, Carlsson GE, Jemt T. Association between marginal bone loss around osseointegrated mandibular implants and smoking habits: a 10-year follow-up study. J Dent Res 1997; 76:1667–1674.