Early Laser-Welded Titanium Frameworks Supported by Implants in the Edentulous Mandible: A 15-Year Comparative Follow-Up Study

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ABSTRACT

Background: Comparative long-term knowledge of different framework materials in the edentulous implant patient is not available for 15 years of follow-up.

Purpose: To report and compare a 15-year retrospective data on implant-supported prostheses in the edentulous mandible provided with laser-welded titanium frameworks (test) and gold alloy frameworks (control).

Materials and Methods: Altogether, 155 patients were consecutively treated with abutment-level prostheses with two early generations of fixed laser-welded titanium frameworks (titanium group). Fifty-three selected patients with gold alloy castings formed the control group. Clinical and radiographic 15-year data were collected and compared for the groups.

Results: All patients who were followed up for 15 years ($n = 72$) still had a fixed prosthesis in the mandible at the termination of the study. The 15-year original prosthesis cumulative survival rate (CSR) was 89.2 and 100% for titanium and control frameworks ($p = .057$), respectively (overall CSR 91.7%). The overall 15-year implant CSR was 98.7%. The average 15-year bone loss was 0.59 mm (SD 0.56) and 0.98 mm (SD 0.64) for the test and control groups ($p = .027$), respectively. Few (1.3%) implants had >3.1-mm accumulated bone loss after 15 years. The most common complications for titanium frameworks were resin or veneer fractures and soft tissue inflammation. Fractures of the titanium metal frame were observed in 15.5% of the patients. More patients had framework fractures in the earliest titanium group (Ti-1 group) compared to the gold alloy group ($p = .034$). Loose and fractured implant screw components were few (2.4%).

Conclusion: Predictable overall long-term results could be maintained with the present treatment modality. Fractures of the metal frames and remade prostheses were more common in the test group, and the gold alloy frameworks had a tendency to work better when compared with welded titanium frameworks during 15 years. However, on the average, more bone loss was observed for implants supporting gold alloy frameworks.

KEY WORDS: bone loss, complications, edentulism, framework design, implant-supported, laser-welded, long-term follow-up, mandible, prostheses, titanium

INTRODUCTION

The prosthetic option using titanium frameworks instead of gold alloy castings to restore patients with fixed prostheses supported by osseointegrated implants has been available for over 20 years.[1–3] The advantages of using titanium in the frameworks have been discussed during the years.[3–7] Titanium and its alloys have been studied thoroughly, and one advantage is biocompatibility with good resistance to corrosion and low allergic potentials.[8,9] This is well documented in both clinical[10] and experimental studies.[7,11] Furthermore, titanium

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allows for other techniques for framework fabrication as using premachined components and welding procedures. Several modifications of titanium components have been tested since the laser-welded titanium framework technique was introduced in the mid-1980s.[1–3] These changes were made to improve the design of the final prosthesis as well as the precision and mechanical strength of the framework.[2,12]

Similar clinical performance of the early laser-welded titanium prostheses as compared with conventional cast framework techniques has been presented.[2,3,13] However, problems with fractures of the titanium metal frames have been observed in the early laser-welded titanium frameworks,[2,3,14] but no detailed study on results longer than 10 years of follow-up is available. As 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 in the totally edentulous mandible.

The aim of the present study was to report the 15-year clinical and radiologic performance of two early generations of laser-welded implant-supported prostheses placed in the edentulous mandible, and to compare the result of this treatment with patients provided with cast gold alloy frameworks.

MATERIALS AND METHODS

This is a 15-year retrospective follow-up study on all patients provided with fixed, laser-welded titanium implant-supported prostheses in the edentulous mandible treated at one clinic (Brånemark Clinic, Göteborg, Sweden). The present groups of patients are the same as described in detail in two earlier publications (Figure 1).[3,14] All patients were treated in the mandible with fixed screw retained abutment-level prostheses including 10 to 12 teeth and supported by turned Brånemark System® implants (Nobel Biocare AB, Göteborg, Sweden). Standard abutments were connected according to standard two-stage surgical procedures after primary healing.[15] Status of the maxilla at the time of the implant has earlier been presented.[3,14] The study covered the period from prosthesis insertion, but data on all installed implants (before loading) are also given.

Control Group (Au Group)

The routine protocol was to provide the patients with a gold alloy framework. From this group, one patient each month from August 1987 to December 1991 was randomly selected by an independent dentist to form the control group (see Figure 1).[3] The mean age was 67 years (SD 9.7; range 39–86 years) at the time of the first-stage surgery. The patients were provided with four to six implants in the mandible (mean 5.3), supporting fixed prostheses with cast gold alloy frameworks and acrylic resin teeth.[3,14,16,17]

Test Group (Titanium Group)

Besides routine protocol using gold alloy frameworks, titanium frameworks were also tested in the patients. Basically, one patient per week was chosen by random from a protocol with all lower jaw edentulous patients by an independent dentist to receive titanium frameworks. The mean age of the patients in the test group was 64 years (range 35–87, SD 10.4) at the time of the first-stage surgery. Altogether, 155 patients were provided with four to six implants each (mean 5.3), supporting two different designs of laser-welded titanium frameworks as earlier described.[2,3] The first patients of the group ($n = 51$) received a standard titanium bar framework (Ti-1 group; Figure 2) consisting of titanium cylinders welded to titanium bar components.[1–3] The later patients included in the group ($n = 104$) received titanium frameworks with separate titanium components placed on the implant replicas, which were welded to an intact titanium bar (Ti-2 group; Figure 3).[1–3] Accordingly, the present group is denoted "titanium

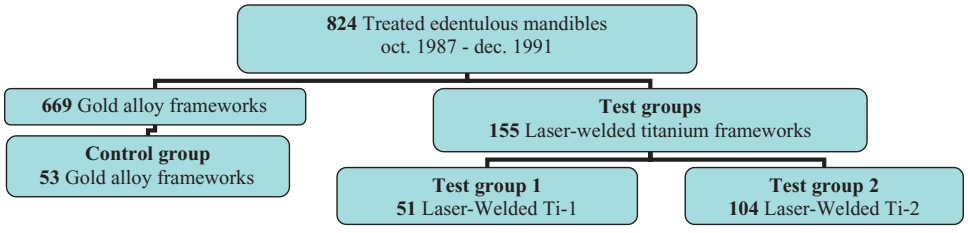

Figure 1 Test and control groups. Ti-1 = first generation of titanium frameworks; Ti-2 = second generation of titanium frameworks.

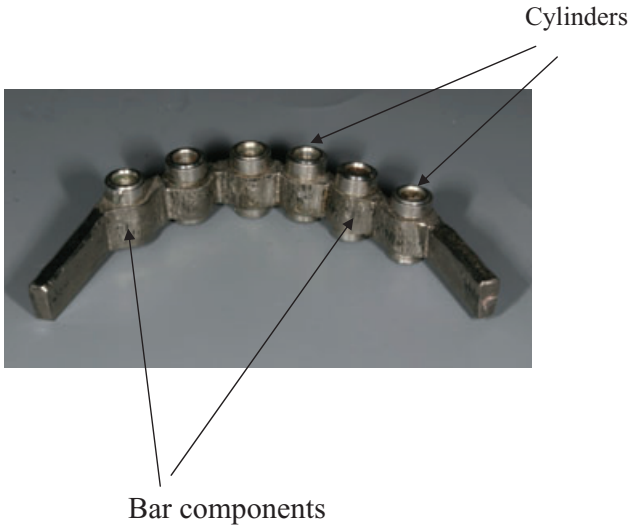

Figure 2 The first generation of titanium frameworks (Ti-1) was based on premachined titanium cylinders and a bar component. The cylinders were placed on the master cast, and the bar was assembled after certain customizations. These components were laser-welded to the bar by means of two lasers, placed on each side of the metal frame.

group" (Ti-group) when Ti-1 and Ti-2 groups are reported together. Resin was cured to the frameworks to retain the artificial acrylic resin teeth.

Follow-Up and Registrations

Routine clinical and radiographic procedures were followed as accounted for in more detail earlier.[3,14] Definitions of treatment outcome with prostheses and performance of original prostheses have previously been presented.[18] The prosthesis was considered as a failure when it was replaced by a new prosthesis, and stable implants were accordingly withdrawn. 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.[19] However, as prostheses were not removed on a routine basis to confirm osseointegration, only survival criteria for implants have been used.[20,21]

All radiographic examinations were performed in the Specialist Clinic for Oral and Maxillofacial Radiology (Göteborg, Sweden). This was performed by using intraoral apical radiographs, scheduled after prosthesis placement and after 1, 5, 10, and 15 years in function. However, some patients declined radiographic examinations because of various reasons. Fifty-six of 65 patients (86.2%) were x-rayed for a checkup on the 15th year with no differences in radiographic examination between the text and control groups.

Marginal bone levels were measured in relation to implant threads to the closest 0.3 mm,[22] using the fixture/abutment junction (FAJ) as a reference (Figure 4).[23] FAJ was placed 0.8 mm coronal to the radiographic reference point used in the previous study.[3] Bone loss was calculated as a difference between bone levels, measured at two different occasions. A mean value between the mesial and distal sides of the implant was used in the statistical analyses.[24]

Statistics

Conventional descriptive statistics (mean, SD, and range) were used for descriptive purposes. Cumulative survival rate (CSR) for implants and prostheses were calculated according to life table techniques.[25]

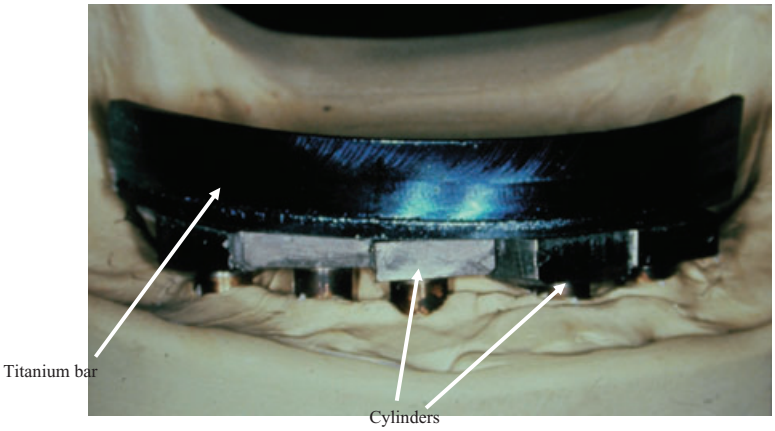

Figure 3 In the second generation of titanium frameworks (Ti-2), different pieces of titanium components with cylinders were used. These were placed on the master cast and then ground to the same level. To this flat plane, a titanium bar was welded with two lasers to complete the framework.

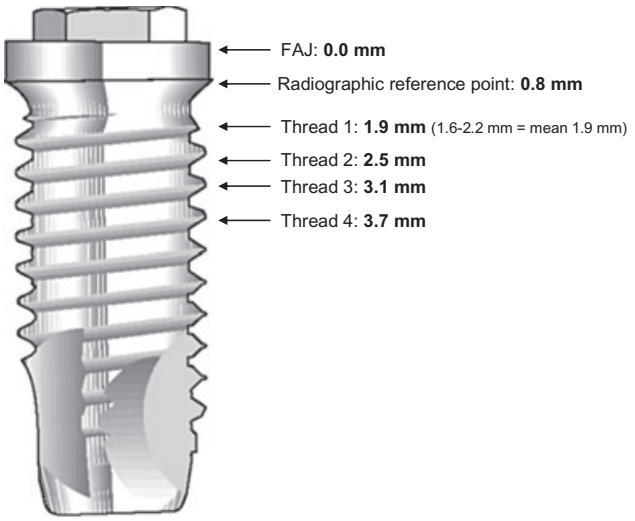

Figure 4 Radiographic measurements are presented in relation to the fixture/abutment junction (FAJ) and the threads of the implant. The radiographic reference point is placed 0.8 mm apical to the FAJ. The first thread of the implant is placed on an average 1.9 mm (1.6–2.2 mm) below FAJ, and the following threads are machined with a distance of 0.6 mm.

Differences in CSR for prosthesis in the test and control groups were analyzed with the log-rank test. Fisher's exact test was used to evaluate differences in reported problems between the test and control groups. Mann–Whitney *U* test was used to evaluate total mean appointments after 15 years between groups and to analyze the differences in time between abutment operation and radiologic examination of the fixtures between the groups. Differences in marginal bone level and bone loss were analyzed with the Mann–Whitney *U* test between groups.[26] Number of implants with a bone loss more than 1.2 mm (bone loss per implants) was analyzed by logistic regression using method of generalized estimation equations. A compound symmetry covariance pattern was used to model the dependency within individuals. The tests were performed on patient/prosthesis level, and statistical significance was set to $p < .05$.

RESULTS

Patients Lost to Follow-Up

The number of patients lost to follow-up are presented in Table 1. In total, 103 (66.4%) and 40 (75.5%) patients were lost to follow-up and excluded in the test and control groups during the 15-year study period, respectively. Accordingly, 65 (31.2%) of the patients were followed-up for 15 years. However, seven excluded patients were included when a specific 15-year total continuous prosthesis CSR was calculated (in total 72 patients, 34.6%). With exclusion of 70 deceased patients, the dropout rate was 35.1% for 15 years.

Implant Stability

Implant failure rate (Table 2) was low and comparable for the groups ($p = 1.000$). In total, 12 implants were lost. A cluster failure pattern could be observed where one patient in the Ti-2 group lost three implants and another patient lost two implants. The other seven loose implants were placed in seven different patients. Overall, the 15-year implant CSR was 98.7% (loaded implants 99.3%), and the CSR for the different groups are given in Table 2.

Prosthesis Stability

Overall, the 15-year prosthesis CSR was 91.7% for originally placed prostheses ($n = 65$). Considering 15 years of continuous function of a fixed prosthesis in the mandible, the corresponding CSR reached 100%

TABLE 1 Distribution of Followed-Up Patients and Lost to Follow-Up in the Total Test Groups (Ti: Ti-1 and Ti-2) and the Control Group (Au) with Regard to Time

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	—	—	—	—	—
0–5 years	124/42	16/5	4/2	2/0	3/4	6/0
6–10 years	85/29	24/4	2/1	1/5	9/3	3/0
11–15 years	52/13	11/10	1/1	6/3	13/2	2/0
15 years	52/13	51/19	7/4	9/8	25/9	11/0

Number of failed prosthesis is also given.

TABLE 2 Life Table of Placed, Withdrawn, and Lost Implants

Group	Test (Ti)				Control (Au)			
Period	Implants	Withdrawn	Failed	CSR (%)	Implants	Withdrawn	Failed	CSR (%)
First surgery	821	—	—	100	278	—	—	100
Loading	817	—	4	99.5	276	—	2	99.3
1–5 years	657	158	2	99.3	218	57	1	98.9
6–10 years	454	201	2	98.9	149	69	—	98.9
11–15 years	282	171	1	98.7	65	84	—	98.9
15 years	282	530	9	98.7	65	210	3	98.9
Loaded implants*			5	99.1			1	99.6

Cumulative survival rate (CSR) for implants in the total test groups (Ti: Ti-1 and Ti-2) and control group (Au).
*After prostheses connection.

($n = 72$). The corresponding 15-year CSR for the titanium group was 89.2%, and the CSR for the individual subgroups are given in Table 3. No significant differences regarding the 15-year prosthesis CSR were observed for the control compared with the titanium frameworks at 5-, 10-, and 15-year follow-ups ($p > .05$), respectively. However, at the same time intervals, the prosthesis CSR was significantly higher for the control frameworks as compared with the Ti-1 frameworks, with only $p = .041$.

Follow-Up Maintenance

On the average, the patients visited the clinic for check-ups and maintenance 1.5 (SD 1.6) and 1.3 (SD 1.0) times per year during the 15-year period in the titanium and control groups, respectively ($p = .494$). Significantly more visits in the Ti-1 group were observed when compared with the control group during the entire 15-year follow-up period ($p = .035$).

Fourteen (26.9%) and three (23.1%) of the followed-up patients reported no clinical problems at all during the entire 15-year study period in the test and control groups, respectively. Furthermore, no clinical problems at all before withdrawal were reported for another 64 patients (41.3%) and 24 patients (45.3%) in the test and control groups, respectively. Accordingly, altogether 50.3 and 50.9% of the patients were free of reported problems during follow-up, respectively.

Eleven of the titanium prostheses were replaced by new fixed prostheses, recorded as prosthesis failures (see Table 3). Eight of these were replaced following fractures of the metal frame; one was replaced because of the bulky design (Ti-1), and two were remade after new implants had been placed (Ti-2). Incidence of replaced titanium prostheses was not significant as compared with the control group ($p = .072$).

Clinical problems that were reported are presented in Tables 4 and 5. Fractures of the veneering material were a relatively frequent problem. However, no differences between the titanium and gold alloy groups during 15 years of follow-up were observed ($p = .970$). Eight of Ti-1 and 25 of Ti-2 prostheses with resin veneer fractures were adjusted in the laboratory (see Table 4). Four of the resin fractures were adjusted in the laboratory in the control group.

Altogether, 24 (15.5%) of the patients, who were provided with titanium frameworks, experienced fractures of the metal frame during follow-up. These were distributed as 14 patients (9.0%) with one framework fracture, 8 patients (5.2%) with a framework that fractured twice, and 2 patients (1.3%) with frameworks that exhibited metal fractures three times (see Table 5). All but three Ti-2 framework fractures were observed in close connection to the terminal implant (Figure 5). Two patients in the Ti-1 group with metal fractures of the posterior cantilever declined repair of the framework at the laboratory. More framework fractures were observed in the Ti-1 frameworks when compared with the control group ($p = .034$; see Tables 4 and 5).

In the control group, three of the frameworks fractured (5.7%), two frameworks fractured once, and one framework twice. Two of these four fractures were resoldered, and two were only polished in the mouth and maintained in function without being remade.

Only one implant fractured during the entire follow-up period, observed in the control group during the fifth year of follow-up. Altogether, five patients presented fractured implant components (2.4%), and

TABLE 3 Life Table of Placed, Withdrawn, and Failed Prostheses

	Test (Ti-1)				Test (Ti-2)				Control (Au)			
Period	Prostheses	Withdrawn	Failed	CSR (%)	Prostheses	Withdrawn	Failed	CSR (%)	Prostheses	Withdrawn	Failed	CSR (%)
Loading	51	—	—	100	104	—	—	100	53	—	—	100
1–5 years	42	5	4	91.4	82	20	2	97.7	42	11	—	100
6–10 years	29	13	—	91.4	56	23	3	93.2	29	13	—	100
11–15 years	20	9	—	91.4	32	22	2	87.6	13	16	—	100
15 years	20	27	4	91.4	32	65	7	87.6	13	40	0	100

Cumulative survival rate (CSR %) for the test and control groups.
Number of prostheses at the end of the time interval is given.

two prostheses (1.0%) exhibited mobility during the follow-up period because of loose, unstable screws (see Table 4). Soft tissue inflammation was more common in the Ti-2 group when compared with the gold alloy group during 0 to 15 years ($p = .032$).

Radiographs

Fifty-six of 65 patients (86.2%) were radiographically examined for a checkup on the 15th year with no differences in patient distribution between the test and control groups.

The mean time between abutment surgery and baseline radiographic examination after prosthesis placement was 58 days (SD 29.2) for the test groups and 47 days (SD 21.4) for the control group ($p < .001$). The corresponding time periods were 61 (SD 29.2) and 42 (SD 10.1) days for those 65 patients followed up for 15 years ($p = .004$), respectively.

Mean marginal bone levels for the different groups during the follow-up period are given in Table 6. A significant difference in marginal bone levels could be observed between the titanium and control groups at the time of prosthesis placement, indicating a more coronal average bone level for the control group ($p = .0057$). However, no statistically significant differences between bone levels at baseline could be found when analyzing mean bone level for only those patients followed up for the entire 15-year period ($p > .05$; see Table 6).

Altogether, 28 of 299 implants (9.4%) had a bone level below the third thread of the implant after 15 years (see Table 6; >3.1 mm). These 28 implants were observed in altogether 18 patients (32.1%).

Average marginal bone loss was 0.59 mm (SD 0.56) and 0.98 mm (SD 0.64) in the test and control groups ($p = .027$) during 15 years in function, respectively (Table 7). Significantly higher mean marginal bone loss was also observed for the control group after 10 years in function ($p = .043$). When comparing mean marginal bone loss after 1 year in function for all patients, no differences between the titanium and control groups could be found at the 1- to 5-year interval ($p = .112$). However, statistically higher mean bone loss levels were noticed for the control group at the intervals of 5 to 10 years ($p = .011$), 1 to 10 years ($p = .004$), and 1 to 15 years ($p = .005$), respectively. This significant difference was also found when analyzing mean bone loss for only those patients followed up for the entire 15-year period

TABLE 4 Distribution of Reported Number of Problems Related to the Lower Jaw Prosthesis in the Two Different Test Groups (Ti-1 and Ti-2) and the Control Group (Au) during the 15-Year Follow-Up

Years	0–15 Years		
Group	Ti-1	Ti-2	Au
Number of prosthesis at loading	51	104	53
Number of prosthesis at end of time interval	20	32	13
Problem	Number of Observations (Patients) Mechanical Problems		
New prosthesis	4	7	—
Framework fracture	17 (11)*	19 (13)	4 (3)
Implant component fracture	—	1	5 (3)
Loose screws (retightened)	—	2 (1)	1
Resin veneer fracture	12 (7)	31 (16)	10 (7)
New veneers due to wear	—	7 (7)	—
Loss of access hole filling	11 (9)	10 (9)	17 (12)
	Biologic and Other Problems		
Soft tissue inflammation	16 (10)	24 (20)*	15 (9)
Cheek/lip biting	5 (5)	2 (2)	1
Implant loss before insertion	—	4 (4)	2 (2)
Implant loss after insertion	1	4 (3)	1
Other problems	16 (10)	26 (15)	13 (13)

Patient level statistical comparison to the control group (Au).
*$p < .05$.
Ti-1 = first generation of titanium frameworks; Ti-2 = second generation of titanium frameworks.

TABLE 5 Number of Observations of Metal Framework Fractures during 15 Years of Follow-Up in the Different Groups and Time Intervals

	Number of Framework Fractures during 15 Years of Follow-Up				
		Year			
Group	Prostheses Year 0	0–5	6–10	11–15	0–15
Ti-1	51	10	4	3	17 (11)*
Ti-2	104	10	6	3	19 (13)
Ti	155	20	10	6	36 (24)
Au	53	0	3	1	4 (3)

Patient level statistical comparison to the control group (Au) 0–15 years.
Numbers of patients are given within brackets.
*$p < .05$.
Au = gold alloy; Ti = titanium test groups (Ti-1 and Ti-2); Ti-1 = first generation of titanium frameworks; Ti-2 = second generation of titanium frameworks.

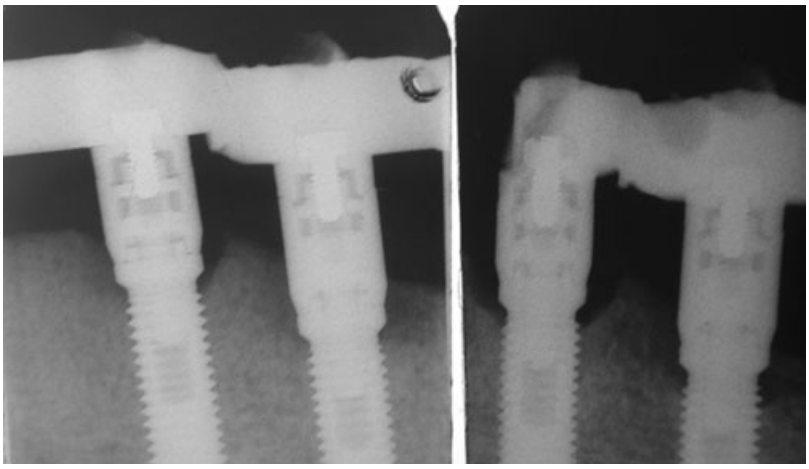

Figure 5 Fractured titanium framework (Ti-1) at the terminal implant and the posterior cantilever. (*Left*) X-ray at prosthesis delivery in 1989; (*right*) X-ray 15 years later with framework fracture.

of time. Significantly more bone loss for the control group was then observed during the intervals of 1 to 5 years ($p = .013$), 5 to 10 years ($p = .013$), 1 to 10 years ($p = .030$), and 1 to 15 years ($p = .005$), respectively.

Bone loss for individual implants is given in Table 7, indicating altogether only four (1.3%) of the implants with >3.1-mm accumulated bone loss after 15 years in three patients (5.4%). Three of these implants were placed in the anterior part of the mandible, close to the midline. No differences in prevalence of individual implants with bone loss >1.2 mm could be noted between the test and control groups ($p > .05$; see Table 7).

TABLE 6 Mean Marginal Bone Levels in Relation to Fixture/Abutment Junction (FAJ; see Figure 4) in the Titanium (Ti) and Gold Alloy (Au) Groups

	Examined Patients/Prostheses and Implants							
	Loading		After 1 Year		After 10 Years		After 15 Years	
Examined	Ti	Au	Ti	Au	Ti	Au	Ti	Au
Prostheses	154	53	146	49	75	19	45	11
Implants	812	276	769	255	400	99	243	56
	Marginal Bone Level in Relation to FAJ in Millimeter							
Overall mean	1.07*	0.96	1.41	1.28	1.61	1.79	1.63	2.06
Overall SD	0.35	0.26	0.48	0.38	0.57	0.44	0.71	0.69
Followed 15-year mean	1.06	1.08	1.29	1.25	1.48	1.77	1.63	2.06
Followed 15-year SD	0.39	0.40	0.44	0.39	0.57	0.52	0.71	0.69
Bone level (mm)	Overall Distribution of Individual Implants (%)							
0.0–0.8	70.9	80.1	41.7	45.9	32.2	22.2	37.4	16.1
0.8 ≤ 1.9 (Thread 1)	26.1	18.8	46.8	47.8	46.5	51.5	39.5	39.3
1.9 ≤ 2.5 (Thread 2)	1.5	1.1	7.7	5.1	13.0	13.1	12.8	19.6
2.5 ≤ 3.1 (Thread 3)	1.1	—	3.0	1.2	6.0	11.1	5.8	16.1
3.1 ≤ 3.7 (Thread 4)	0.2	—	0.6	—	1.8	1.0	2.1	7.1
3.7 ≤ 6.7	0.1	—	0.3	—	0.5	1.0	2.5	1.8

Patient level statistical comparison on mean marginal bone level to the (Au) control group.
*$p < .05$.

TABLE 7 Mean Marginal Bone Loss at Implants in the Titanium (Ti) and Gold Alloy (Au) Groups and Distribution of Individual Implants with Regard to Degree of Bone Loss (mm) during Function

	Examined Patients/Prostheses and Implants							
	0–1 Year		0–10 Years		11–15 Years		0–15 Years	
	Ti	Au	Ti	Au	Ti	Au	Ti	Au
Prostheses	146	49	75	19	41	8	45	11
Implants	769	255	400	99	220	41	243	56
	Mean Marginal Bone Loss in Millimeter							
Overall mean	0.34	0.34	0.58*	0.77	0.16	0.13	0.59*	0.98
Overall SD	0.32	0.32	0.44	0.37	0.26	0.11	0.56	0.64
Followed 15-year mean	0.25	0.27	0.46	0.71	0.16	0.13	0.59*	0.98
Followed 15-year SD	0.25	0.32	0.39	0.33	0.26	0.11	0.56	0.64
Bone loss (mm)	Distribution of Individual Implants (%)							
≤0.0†	57.1	55.7	40.2	29.3	68.6	63.4	44.0	21.4
0 ≤ 0.6	19.1	16.1	17.0	11.1	23.6	26.8	18.1	14.3
0.6 ≤ 1.2	20.0	24.7	29.2	41.4	5.9	7.3	23.0	35.7
1.2 ≤ 1.8	2.7	3.5	9.2	13.1	0.9	2.4	8.2	17.9
1.8 ≤ 2.4	0.9	—	3.2	5.1	0.5	—	4.5	5.4
2.4 ≤ 3.1	0.1	—	0.8	—	—	—	0.8	3.6
3.1 ≤ 5.9	—	—	0.2	—	0.5	—	1.2	1.8

Patient level statistical comparison to the control group during the different time intervals.
*$p < .05$.
†A bone gain was detected in nine implants in the test and in two implants in the control group between 0 and 15 years in function, here registered as 0.0 mm.

DISCUSSION

Long-term follow-up studies on patient groups with a mean age of 64 and 67 years at inclusion must inevitably suffer from obvious numbers of loss to follow-up in later stages of the study. The number of patients lost to follow-up was higher in this study than in comparable 15-year long-term follow-up reports.[27–29] On the other hand, when information on mean age at inclusion was available, these studies indicated to cover, on the average, younger groups of patients as compared with the present groups.[28,29] When considering older age groups, Engfors and colleagues[30] reported a 46% loss to follow-up in a group of patients after already 5 years of follow-up, however, comprising patients of over 79 years of age at the time of inclusion. Considering here a high number of deceased patients and increasing numbers of "no contact," indicating illness and institutionalized patients, it could be reasonable to accept a remaining 35% loss to follow-up in a population of high mean age at the final examination.

The treatment of edentulous patients with implants in the anterior mandible, provided with fixed prostheses with posterior cantilever, functioned well during 15 years, although prosthetic maintenance was required and altogether 5.3% of the original prostheses were replaced. However, overall implant prosthesis treatment was 100%, indicating a treatment result in agreement with previous publications in similar situations.[27,31] About 50% of the prostheses were free from reported complications during service, and the major single maintenance problem was related to the resin veneers/fillings (see Table 4). This treatment strategy with resin veneers was combined with screw retention to facilitate inevitable maintenance of the occlusal surface. Porcelain fused to metal veneers would probably reduce these maintenance problems but to a higher initial cost. As porcelain fractures seems to be higher in implant-supported prostheses as compared with tooth-supported prostheses,[32] it could also be assumed that maintenance cost could also be higher in the long-term, as porcelain fractures involve a higher

degree of technical complexity as compared with resin.

Herrmann[33] recently showed that implant failures should statistically be compared on a patient-level basis. Accordingly, in the present study, the few implants that were lost in function did not reveal any significant differences between the test and control groups, when implant loss was compared on patient level (see Tables 2 and 4). Thus, these findings could not confirm earlier reports where patients provided with titanium frameworks presented significantly more implant failures as compared with the gold alloy group, using implant rather than patient level for comparisons, however.[23,34,35] On the other hand, implant failures in the partially edentulous lower jaw has shown statistically higher failure rates for loaded implants with titanium frameworks on both implant and patient levels ($p < .05$) but not on a prosthesis level ($p > .05$).[23] These conflicting results indicate that it is important to clearly define on what level (implants/patients/prostheses) these statistical calculations are performed to compensate for cluster effects, which was earlier discussed by Herrmann.[33] The low frequency of implant failure in the mandible in this study is in accordance with what has been reported in another study on similar groups of patients.[31]

However, certain problems were related to the laser-welded titanium frameworks. Eleven of these prostheses (7.1%) were recorded as total failures mainly because of severe or several fractures of the metal frames close to the terminal implant (see Figure 5). Many of the fractures can be related to an early laser-welding technique with only limited experience of this technique in implant dentistry. This situation is comparable with the situation of frequent metal fractures that occurred when the cast cantilever bar frameworks were first introduced in the early implant protocol.[27,36] It could be expected that problems related to inexperience will decrease with an increased learning curve, reaching knowledge levels comparable with gold alloy frameworks that, in this study, represents a well-established casting technique with few fractured gold alloy frameworks. Still, laser welding could be considered a weak link, and in a recent 5-year follow-up study on the "fourth generation" of titanium frameworks with one-piece milled titanium frameworks in the edentulous jaw, these prostheses showed better results with no framework fractures at all.[34]

The significantly lower average bone level at baseline for the implants supporting titanium frameworks (see Table 6) could probably be referred to the significantly longer time interval between the second surgery and the time of baseline radiographic examination in this group. The following low levels of average bone loss in the present groups indicate similar or lower magnitudes of bone loss as also observed by others with a 15-year follow-up in the edentulous mandibles.[29,31,37] Accordingly, the progression of bone loss for the major part of the patients and implants was slow during the first 10 years and in accordance with results observed in other 10-year follow-up reports.[37–39] No trends of increasing levels of average bone loss were indicated for the last 5 years (11–15 years) in the present study (see Table 7), further supporting a stable average bone level for turned implants in the edentulous jaws after 10 to 20 years in function.[31]

It can be noticed that implants supporting titanium frameworks present a significantly ($p < .05$) lower mean marginal bone loss than observed for the gold alloy group after 10 as well as after 15 years in function (see Table 7). At a first view, this difference could be attributed to a significantly ($p < .05$) earlier placement of control frameworks (gold alloy) after abutment surgery, presenting a more coronal average level of marginal bone at baseline in this group (see Table 6). However, further analyses clearly indicate that implants supporting the control frameworks present significantly higher levels of bone loss ($p < .05$) in the following periods of follow-up, after the first-year examination. This observation is in accordance with a recent report, also showing higher average levels of bone loss for implants supporting gold alloy frameworks compared with titanium frameworks in the partially edentulous mandible.[23] The reason for this difference in bone response is not clear, but the findings with significantly more soft tissue inflammation problems around the implants in the Ti-2 group (see Table 4) when compared with the control group challenge the assumption that mucositis could be related with increased marginal bone loss, however.

Considering the difference in average bone loss between the groups, it can be noticed that the majority of the individual implants present only small changes during the different time intervals (see Table 7). Also, when comparing the results in the present study with others,[40,41] there is a low level of overall "progressive" bone loss. One reason for the significant difference in mean bone loss between implants at cast, gold alloy, and

titanium frameworks can probably be related to the fact that 28.7% of implants supporting gold alloy frameworks present more than 1.2-mm bone loss during 15 years, while only 14.7% of the implants show the same pattern for the titanium group, however, not statistically significant ($p > .05$). As discussed previously, another 10-year follow-up study has also reported significantly more bone loss at implants supported by gold alloy frameworks as compared with titanium frameworks in the partially edentulous mandible.[23] The reason for this difference is not clear, but systematic differences in framework design, differences in framework stiffness, difference in framework precision, and biocompatibility of the framework metal are factors that could be suggested.[2,6–9,11,12,42] Speculations on the potential difference in plaque adherence and corrosion between the metals could also be forwarded. However, even if the differences in bone loss are statistically significant, there is still a low clinical significance related to this difference in the present study.

CONCLUSIONS

Based on the 15-year data on the treatment of implant-supported laser-welded titanium and cast gold alloy framework in the edentulous mandible, the following conclusions can be made:

- Predictable clinical results were reported, with an overall 15-year implant CSR of 98.7% (loaded implants 99.3%) and 100% maintained fixed prosthesis function.
- The 15-year prosthesis CSR was significantly better for cast frameworks as compared with the first generation of titanium (Ti-1) frameworks ($p = .041$).
- More patients had framework fractures in the Ti-1 group compared with the gold alloy group ($p = .034$).
- 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 (<3.0%).
- A small mean bone loss of 0.59 and 0.98 mm for the test and control frameworks was recorded, respectively ($p = .027$), and only few implants (1.3%) presented an accumulated bone loss of >3.1 mm during 15 years in function.

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