# Long-Term Treatment Outcomes in Edentulous Patients with Implant Overdentures: The Toronto Study

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***Purpose:*** Few long-term studies on overdentures report both implant and prosthodontic outcomes. The aim of this prospective study was to report long-term prosthodontic- and implant-related treatment outcomes of patients treated with design-specific implant-supported overdentures. ***Materials and Methods:*** Between 1982 and 1992, 45 consecutively treated patients received a total of 47 overdentures (42 mandibular and 5 maxillary) supported by Brånemark implants. Prospective clinical and radiographic data were collected over the observation period; this study presents the most recent treatment outcomes. ***Results:*** Thirty patients (mean age 70 years) with 32 prostheses attended the final recall visit, with 67% of patients followed for 15.53 years (range 10 to 19 years). Six implants failed, and the prosthetic plan and implant cumulative survival rates were both in excess of 90%. Mean marginal bone loss around implants after the first year of loading was small (0.05 mm/year), although the individual variation was high. Linear regression analysis of bone loss indicated that gender, bicortical stabilization, bone quality, and healing time were predictors of bone loss for the first year of loading but not for the ensuing years. Prosthetic maintenance included fractured components, denture relining, and replacement of prostheses. On average, the longevity of overdenture prostheses was 12 years, and laboratory relining was necessary every 4 years. ***Conclusion:*** This study confirmed the long-term outcome success of patients treated with design-specific overdenture prostheses supported by Brånemark implants. However, prosthetic maintenance was required, a fact that should be discussed with patients prior to treatment. *Int J Prosthodont 2004;17:425–433.*

Several studies confirm the merits of osseointegration in the provision of fixed prostheses for edentulous patients.[1,2] The resultant enhanced retention and stability suggested the merit and feasibility of a similar clinical experience with an abbreviated implant prescription supporting an overdenture.[3,4] Numerous studies have subsequently confirmed this hypothesis (Table 1). The demand for prosthetic management of edentulous patients is likely to persist, since less affluent members of society are particularly prone to tooth loss and likely to favor less expensive dental treatment methods[17,18]; overdentures are a prudent treatment of choice for edentulous patients seeking implants.[19,20]

It is currently recognized that treatment outcomes should expand beyond mere measures of implant survival and marginal bone behavior.[21] Maintenance issues have been reviewed[22] and concern expressed that the prosthodontic maintenance of overdentures will ultimately outweigh their cost benefit.[23] Published short-term data suggest that overdentures will require frequent maintenance, especially during the first year, and that maintenance may be attachment specific.[23–30] Few long-term studies presenting maintenance data are available.[5,7,13,16] Furthermore, although attempts at classifying prosthodontic maintenance are available,[31]

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**Table 1** Studies of Implant-Supported Overdenture Prostheses*

| Study | No. of patients/ implants | Implant system | Follow-up period | Implant outcomes | | Prosthodontic discussion |
|---|---|---|---|---|---|---|
| | | | | Implant success | Bone level | |
| Zarb and Schmitt[5,6] | 45/132; majority in Mn | Brånemark | 3–13 y | 96.2% | 0.2 mm > 1 y | Yes |
| Naert et al[7] | 207/449 Mn | Brånemark | 0.5–9.0 y; minority followed > 7 y | 97% | 0.70 mm for 1st y, then 0.05 mm | Yes |
| Snauwert et al[8] | 38/90 Mx; 648/317 Mn (prostheses, not patients) | Brånemark | 5.1 y (1–15 y); 58 prostheses > 10 y | 89.0% Mx 95.8% Mn | < 0.5 mm > 1 y | Limited |
| Freeman et al[9] | 19/38 | Brånemark | 5.25–11.50 y; 15 patients > 10 y | 98.7% | – | Yes |
| Mericske-Stern et al[10] | 38/88 (both arches in 1 patient) | ITI (Straumann) | 14.1 y (11.4–19.7 y) | 84.6% | ≈ 1.85–2.50 mm | No |
| Kiener and coworkers[11,12] | 41/173 Mx | ITI | 4.2 y (1–9 y); minority > 5 y | 91.6% | 0.7 mm > 1 y | Yes |
| Dudic and Mericske-Stern[13] | 119/258 Mn | ITI | 9.3 y (5–15 y) | 96% | – | Yes |
| Ferrigno et al[14] | 35/178 Mx; 129/348 Mn | ITI | 10 y; minority > 10 y | 86.9% Mx > 90.0% Mn | 0.14 mm > 1 y | No |
| Lambrecht et al[15] | 66/201 Mn; 8/26 Mx | ITI solid screw | 10 y; minority > 10 y | 96.4% | – | No |
| Meijer et al[16] | 61/122 Mn (60 patients with complete dentures) | Brånemark and IMZ (Interpore) | 10 y; 26 patients not followed at 10 y | 93% | – | Yes |

*These studies were selected because they report specific patient selection criteria and success outcomes, although not necessarily common to all. Freeman et al[9] and Dudic and Mericske-Stern[13] are retrospective, although the former is an investigation of a previously reported prospective study. Mn = mandible; Mx = maxilla.

there is still no clear understanding of what constitutes routine maintenance repairs versus complications, since the difference is quantitative[32] and subjective. This underscores the need for evaluation of maintenance as part of routine follow-up services, plus discussion during treatment planning.[33]

It was the aim of this study to report the long-term outcome results of a prospective study on edentulous patients treated with overdenture implant-supported prostheses and to describe overall maintenance requirements of the prosthodontic management.

## Materials and Methods

The original Toronto implant prosthodontic study was carried out in 90 prosthetically maladaptive edentulous patients. The first 45 patients were treated with implant-supported fixed prostheses in an attempt to test the veracity of Brånemark et al's earlier work.[34] The present ongoing prospective study formerly included the remaining 45 consecutively treated patients (36 women and 9 men) who were prescribed overdenture prostheses in 47 arches (42 mandibular and 5 maxillary) supported by Brånemark implants (Nobel Biocare). Patient selection for this study started in early 1982 and continued up to 1992, and patients were followed prospectively at the Implant Prosthodontic Unit, University of Toronto. Patient management followed a set protocol: All patients were treated because of a history of maladaptive prosthetic experience, and each patient's conventional prostheses were first optimized the year prior to commencement of their treatment. Inclusion criteria are described elsewhere.[34] Once treated, each patient's information was updated regularly according to the frequency of recall visits. All but two of the mandibular prostheses were opposed by complete dentures, whereas maxillary overdenture prostheses were opposed by natural teeth in three patients and implant-supported overdentures in the other two.

### *Clinical Procedures*

All patients were treated with a two-stage surgical procedure, with the duration of the interstage healing phase varying with the jaw location of the implant. Two to three implants were placed in the mandible and two to five were placed in the maxilla, as determined by jaw morphology and prosthetic plan. Surgery was mainly performed under local anesthesia and oral sedation. The surgeon graded the bone quantity and quality at the time of surgery, and this was matched to a pretreatment radiographic classification as proposed by Lekholm and Zarb.[35] Four staff oral surgeons placed the majority of the implants.

At second-stage surgery, the implants were exposed to the oral environment and standard abutments were attached. Traditional complete denture principles and techniques were applied in the construction of

prostheses, as described previously,[5] and employed a Class I removable partial denture design that yielded specific implant-gingiva–supported prostheses. Mandibular prostheses were supported and retained via a gold alloy ovoid Dolder bar (Cendres et Métaux) soldered to prosthetic abutments. The maxillary prostheses were supported as follows: two with a bar-clip assembly, one with a healing abutment, and the other two with magnets. Of the latter prostheses, one had the magnet attachment converted to a ball attachment at the last recall visit when a new prosthesis was constructed on the patient's request. Prosthodontic staff carried out the prosthodontic treatment initially; in latter years, graduate residents provided maintenance and replacement treatment under supervision. Treatment outcomes were based on the criteria presented at the Toronto Consensus Conference.[36]

The follow-up visits were scheduled on an annual basis, but not always regularly attended by all patients. Each recall visit included an updating of the medical history, plus a clinical examination. Osseointegration status of all individual implants was initially evaluated at second-stage surgery and then monitored clinically and radiographically during recall visits when each prosthesis was removed. Implants were clinically evaluated for mobility by torquing the abutment screws to 20 Ncm with a calibrated torque wrench. Any mobility or painful response to the torquing was designated a failed implant. Standardized periapical radiographs using a locating jig that controlled for angulation were taken[37,38] to monitor bone height. All calculations with respect to bone loss were conducted in a blind fashion. The main investigator was calibrated with an experienced investigator. Implant survival outcomes were based on clinical testing only; therefore, implant losses were considered failures.

Maintenance considerations for each prosthesis were recorded as per traditional protocols. They included the nature and number of events per patient, such as fractured hardware and acrylic resin superstructure, prosthesis remaking, and laboratory relining.[39] Prosthetic success was defined as an unmodified original prosthetic treatment plan. Prosthesis longevity was defined as the period from insertion to replacement of the prosthesis, which meant that revisions of prostheses (eg, change of retentive mechanisms) were not considered terminal events. Likewise, prosthodontic issues that could be easily rectified were not considered complications, since the latter were viewed exclusively as events that led to loss of the original prosthetic plan. The prosthesis was then removed, and the condition of the soft tissue around the implants was assessed for any signs of inflammation. Detailed periodontal-related indices were initially used but discontinued in later years because of reported lack of correlation with loss of osseointegration.[6] However, for this study, an oral hygiene score of the implant framework and abutments was routinely obtained by inspection of the dental records, together with observation of oral hygiene at the last recall visit: Frameworks and/or abutments with no to minor plaque accumulation were labeled as good to fair hygiene, and frameworks/implants with heavy plaque and/or calculus buildup on the abutments were labeled as poor oral hygiene.

### *Statistical Methods*

Clinical data were collected and input for analysis in an SPSS statistical package (SPSS). Bivariate analyses were carried out to explain the association between the independent variables and measured outcomes. The tests carried out were the Mann-Whitney *U* test for continuous variables and the chi-square test for categoric data to test for statistical significance. Survival analyses of the implants were carried out with a Kaplan-Meier test and life table analysis. An intraclass correlation study was done prior to bone measurements to calibrate the main investigator and to assess the degree of agreement between the investigator and an experienced investigator in the Department of Prosthodontics. Multivariate analyses were performed to identify factors that explained the bone loss measured around Brånemark endosseous dental implants. Specifically, multiple linear regression was used to test the joint effect of independent variables on continuous dependent variables such as bone loss outcomes. Statistical significance was set at $P < .050$.

## Results

### *Patient Demographics*

Thirty patients (24 women and 6 men) attended the 2002 recall visit. Fifteen patients were lost to follow-up: 10 patients because of death and 5 because of migration (Tables 2 and 3). Sixty-nine percent of patients reported a chronic medical condition managed with medications. This included cardiac conditions, endocrine disorders, arthritides, and osteoporosis. Seventy-eight percent of patients were nonsmokers, whereas 22% were active smokers at the time of surgery. There was no attempt to quantify actual smoking consumption, since these data were judged to be unreliable.

### *Prosthodontic Outcomes*

All 32 prostheses (27 mandibular and 5 maxillary) were clinically stable at the last recall visit (Table 4). In total, 15 mandibular overdentures were not followed, since 10 patients had died. However, reliable information

**Table 2** Patient Demographics (n = 30)

| Parameter (y) | Mean | Standard deviation | Minimum–maximum |
|---|---|---|---|
| Age at initiation of study | 57.27 | 11.18 | 32–76 |
| Age at last recall | 70.18 | 9.96 | 48–92 |
| Length of edentulism prior to placement of implants | 13.97 | 9.88 | 1–44 |
| Follow-up time | 15.53 | 2.39 | 10–19 |

**Table 3** Life Table Analysis of Patient and Implant Follow-up

| Interval | No. of patients entering interval | No. of patients withdrawn during interval | No. of patients lost | Cumulative proportion of patients followed (%) | No. of implants entering interval | No. of implants withdrawn during interval | No. of implant failures during interval | Cumulative proportion of implants surviving (%) |
|---|---|---|---|---|---|---|---|---|
| Baseline | 45 | 0 | 0 | 100.00 | 132 | 0 | 0 | 100.00 |
| Stage two | 45 | 0 | 0 | 100.00 | 132 | 3[a] | 3 | 97.70 |
| 1–5 y | 42 | 0 | 1[b], 3[c] | 91.11 | 126 | 2[d], 7[e] | 2 | 96.14 |
| 6–10 y | 33 | 0 | 6[b], 1[c] | 75.43 | 114 | 12[d], 3[e] | 0 | 96.14 |
| 11–15 y | 22 | 0 | 3[b] | 67.30 | 86 | 6[d] | 0 | 96.14 |
| 16–20 y | 7 | 0 | 1[c] | 63.64 | 58 | 2[e] | 1[f] | 93.09 |

a = implants put to sleep; b = patient died; c = patient lost to follow-up; d = implant not followed because of patient death; e = implant not followed because of patient migration; f = implant lost because of trauma/fracture.

**Table 4** Cumulative Success Rate of Implant-Supported Overdenture Prostheses

| Interval | No. of prostheses entering interval | No. of prostheses lost to follow-up | No. of prostheses lost | Cumulative proportion of overdenture implant-supported design surviving (%) |
|---|---|---|---|---|
| Loading | 47 | 0 | 0 | 100 |
| 1–5 y | 47 | 3[a], 1[b] | 0 | 100 |
| 6–10 y | 35 | 1[a], 6[b] | 0 | 100 |
| 11–15 y | 24 | 3[b] | 0 | 100 |
| 16–20 y | 5 | 1[a] | 0 | 100 |

a = prostheses lost because of patient migration; b = prostheses lost because of patient death.

from patients' relatives revealed that these patients had worn their overdentures successfully and had been followed regularly as part of this study until the time of death. Another 5 prostheses were lost to follow-up because of patient migration and were considered failures in the analysis. Overall, a 100% cumulative success rate of the overdenture prosthetic plan was maintained for a 15-year follow-up period. No prosthesis was converted to a conventional denture because of implant loss. However, considering patients lost to follow-up as potential failures, the cumulative survival rate would be 91.4% at 15 years.

Prosthesis maintenance over the observation period included a variety of requirements (Table 5). The lifespan of clip matrices was 4.48 ± 3.40 years (range 1 to 14 years), whereas magnets required changing every 3.00 ± 2.00 years (range 7 months to 6 years). Maintenance also included laboratory relines as well as prosthesis replacement necessitated by heavy acrylic resin teeth wear. On average, a patient received 1.55 implant-supported overdenture prostheses (range 1 to 3) throughout the study period. The longevity of the first prosthesis was 12.47 ± 3.94 years, whereas overall prosthesis longevity was 10.39 ± 5.59 years. On average, patients received 1.8 ± 1.3 relines (range 1 to 6), with a mean of 4.41 ± 2.75 years prior to the first relining of the overdentures. Laboratory relines occurred on average every 4.40 ± 2.81 years.

Maintenance of the opposing dentures consisted of laboratory relines as well as fabrication of new prostheses, with patients receiving a mean of 1.46 ± 0.58 complete dentures (range 1 to 3). The longevity of the first complete denture was 13.32 ± 3.89 years, whereas overall prostheses longevity was 11.49 ± 5.38 years. On average, patients received 1.69 ± 0.94 relines (range 1 to 4). The mean time prior to the first relining of the complete dentures was 2.82 ± 1.25 years. Laboratory relines then occurred on average every 3.89 ± 2.57 years.

**Table 5** Prosthodontic Maintenance*

| Type of maintenance | Study group | | | |
|---|---|---|---|---|
| | Active | Dead | Lost to follow-up | Total |
| Overdenture converted to conventional denture | NA | NA | NA | NA |
| Broken gold screw | 5 (3) | 0 | 0 | 5 (3) |
| Gold screw loosening | 10 (7) | 3 (2) | 0 | 13 (9) |
| Broken abutment screw | 1 (1) | 0 | 0 | 1 (1) |
| Abutment screw loosening | 9 (4) | 2 (2) | 1 (1) | 12 (7) |
| Tissue hyperplasia/inflammation | 16 (13) | 2 (2) | 0 | 18 (15) |
| Fractured denture teeth | 5 (3) | 0 | 0 | 5 (3) |
| Fractured overdenture | 9 (3) | 2 (2) | 0 | 11 (5) |
| Fractured opposing denture | 3 (3) | 0 | 0 | 3 (3) |
| Fractured patrix framework | | | | |
| Bar fracture | 1 (1) | 1 (1) | 0 | – |
| Magnet keeper screw fracture | 8 (3†) | 0 | 0 | 10 (5) |
| Fractured matrix component | 20 (9) | 7 (2) | 0 | 27 (11) |
| Tightening of clip | 21 (15) | 2 (1) | 1 (1) | 24 (17) |
| Laboratory reline of overdenture | 29 (18) | 5 (3) | 1 (1) | 35 (22) |
| Laboratory reline of opposing denture | 22 (13) | 9 (5) | 4 (3) | 35 (21) |
| Remake of overdenture | 19 (15) | NA | 1 (1) | 20 (16) |
| Remake of opposing denture | 13 (10) | NA | 1 (1) | 14 (11) |

*No. of instances (No. of patients).
†One patient accounted for six events and was converted to a bar-clip assembly.
NA = not applicable.

### *Implant Outcomes*

A total of 132 Brånemark implants (17 maxillary and 115 mandibular) were placed in this group of patients. At the last recall visit, 12 implants (9%) were unaccounted for because of patient dropout. All 91 loaded implants were tested with a standardized manual torque wrench at 20 Ncm. No mobility or pain was elicited during this test, and all implants were judged to be clinically osseointegrated.

The cumulative success rate of the implants is presented in Table 3. Three implants were not included in the final prosthodontic design because of an unfavorable position and were put to sleep. Three implants failed to integrate by second-stage surgery. Another three implants failed following loading. One late implant failure occurred after 17 years of loading because of trauma and fracture of the implant. The cumulative success rate of the implants at 16 years of functional loading was 93.09%.

None of the factors in the patients' history could explain the cause of the few early implant failures. These investigated factors were gender, perforation of the cortices during stage-one surgery, bicortical stabilization of the implant in the jawbone, type of implant (Brånemark standard or MkII, Nobel Biocare), oral hygiene, and smoking history (Fisher's exact test, $P > .050$). Other nonsignificant variables investigated included history of a chronic medical condition, location in maxilla or mandible, and jawbone quantity and quality (chi-square test, $P > .050$). Continuous variables investigated were years of edentulism prior to stage-one surgery, implant length (51% of implants placed were 10 mm or shorter), and months of healing prior to stage two; these three factors were also nonsignificant (Mann-Whitney *U* test, $P > .050$). Similar nonsignificant results were obtained with Kaplan-Meier analyses because of the few implant failures.

Long-term bone measurements around mandibular dental implants were initially assessed to determine any measurement differences in the observed sites. There was a trend for implants placed in the maxilla to have more bone loss in the first year of loading; however, the small number of maxillary implants precluded a meaningful analysis. Mean bone loss during the first year and subsequent years is presented in Table 6. Of interest, the rate of annual crestal bone loss gradually decreased after the first year of loading. However, the range of bone loss was high, with some implant sites losing about 4 mm of bone, although all implants were still osseointegrated and in function. The bone level changes in the first year of loading indicated that women had more bone loss than did men (Mann-Whitney *U* test, $P = .004$), an observation that should be considered with caution, since the majority of patients were women.

Implants without bicortical fixation (Mann-Whitney *U* test, $P = .005$) and those placed in patients who had been edentulous for fewer than 10 years prior to implant surgery also had more bone loss in the first year. More peri-implant bone loss in smokers (Mann-Whitney *U* test, $P = .016$) and in patients with poor oral hygiene ($P = .021$) was observed during the first year of functional loading. This trend was not maintained in the following years, probably because of the low numbers of patients

**Table 6** Crestal Bone Loss (mm/y) in Mandibular Implant Sites

| Interval | Mean | Standard error | Minimum mean | Maximum mean | No. of sites |
|---|---|---|---|---|---|
| 0–1 y | 1.010 | 0.081 | 0.460 | 3.860 | 82 |
| 1–5 y | 0.098 | 0.013 | −0.405 | 0.770 | 152 |
| 6–10 y | 0.023 | 0.028 | −0.720 | 1.020 | 76 |
| 11–15 y | 0.048 | 0.017 | −0.397 | 0.133 | 58 |
| Overall | 0.051 | 0.008 | −0.183 | 0.770 | 188 |

**Table 7** Linear Regression Model for Year 1 Bone Loss and Overall Mean Bone Loss (mm/y)

| | Year 1* | | | Overall (1–15 y)† | | |
|---|---|---|---|---|---|---|
| Factor | Beta | SE | Significance | Beta | SE | Significance |
| (Constant) | — | .420 | .092 | — | .049 | .833 |
| Gender (male/female) | −.711 | .184 | .000 | −.087 | −.087 | .312 |
| Bicortical stabilization (not present/present) | −.263 | .116 | .001 | −.056 | −.056 | .487 |
| Healing period prior to loading (mo) | .244 | .062 | .020 | .110 | .110 | .188 |
| Oral hygiene (good/poor) | .103 | .141 | .225 | −.085 | −.085 | .281 |
| Bone quality (type I to III/type IV)[35] | .266 | .141 | .002 | .145 | .145 | .072 |
| Abutment length ($<$ 4 mm/$>$ 4 mm) | .003 | .171 | .976 | .018 | .018 | .826 |
| Smoking status | .082 | .187 | .375 | −.032 | −.032 | .717 |

*$F$ = 22.590, $P < .001$, $R^2$ = .674.
†$F$ = 0.849, $P$ = .548, $R^2$ = .033.
SE = standard error.

who were smokers (22%) and were known to have a history of poor oral hygiene (19%). Bivariate analysis of the overall bone loss showed the same trend for implants placed in type IV bone having more bone loss (Mann-Whitney $U$ test, $P$ = .001). Bicortical stabilization was still significant, with implants without bicortical stabilization experiencing more bone loss (Mann-Whitney $U$ test, $P$ = .047).

The linear regression model for year 1 indicated that gender, absence of bicortical fixation, increased healing time prior to stage two, and presence of type IV bone were independent factors that explained the bone loss observed in this group of patients. However, none of these factors were statistically significant in the model for overall bone loss (Table 7).

## Discussion

Treatment outcomes for this group of prosthetically maladaptive patients were excellent. This appears to confirm our original observation[3,5] that implant-stabilized prostheses can resolve functional problems that preclude a comfortable long-term denture experience. It also suggests that an abbreviated removable version of the original fixed Brånemark method may be a viable alternative, although the need for maintenance requirements must be addressed. The number of patients in this study was relatively small, but the recall rate over the extended study period was encouraging. Only 5 of the 15 patient dropouts were because of patient migration. The remaining 10 patients died but had been scrupulously monitored up to their last clinical recall visit.

The implant survival rate after 15 years was 96.14%. Five implants were early failures, whereas a late failure occurred after 17 years of loading because of fracture. It is worth noting that we reported that the early failures occurred in patients with compromised bone morphology, a situation also observed by various authors.[40–43] These results emphasize that once osseointegration is established, it is maintained with the good prognosis for long-term function apparent with the Brånemark implant in spite of aging and compromised health. Mericske-Stern and coworkers[44,45] observe that advanced age, reduced dexterity of elderly patients, and environmental conditions of overdentures do not represent a higher risk for either bone or implant loss.

Mean bone loss around mandibular implants was greatest for year 1 and within the limits suggested in the literature for subsequent years,[7,36,46] indicating that the prognosis for long-term function was not compromised. Factors that might explain bone loss in the first year were lack of bicortical stabilization and poor-quality bone. Yet, in our analyses of long-term bone loss, none of these factors were statistically significant. Time-consuming and apparently irrelevant periodontal indices were discontinued earlier in this study[6] because of lack of correlation with long-term osseointegration outcomes. However, data on oral hygiene behavior were routinely

noted in patients' charts to exclude any possible association with marginal bone loss. Oral hygiene did not appear to be a major factor associated with overall marginal bone loss in this study. This may be due to the presumption that this prosthetic design facilitates a better oral hygiene regimen. In fact, only 19% of our patients had difficulty in maintaining good oral hygiene.

Numerous authors stress the need for information on the longevity and maintenance of implant-supported prostheses and opposing dentures,[22,47,48] since it is important not to separate implant success from a successful prosthodontic result.[21,49] The prosthetic plan survival rate was 100% at 15 years, or 91.4% if we consider the prostheses lost to follow-up as potential failures. Prosthetic revisions were required in two patients because of implant loss, which resulted in conversion of the retentive mechanism from bar-clip assembly to a magnet and healing abutment, respectively. In another two patients, unfavorable biomechanical loading required a change in the bar design, while in another patient, repeated magnet keeper screw fracture required conversion to a bar prescription. Although these events may be viewed as biologic and prosthodontic complications and a nuisance to the patients, we regard their prosthetic significance as limited because they did not result in loss of the prosthetic plan, a subjective interpretation open to debate. Discussion about what constitutes maintenance or complications may be counterproductive, since the common denominators for all interventions, such as time and associated treatment costs, mostly affect patients and ultimately influence their choice of treatment.

Long-term maintenance requirements for all patients included diverse component and acrylic resin fractures and minor soft tissue inflammation, all easily rectified with hygiene instrumentation and technical repairs. Within the timeframe of this study, 40% of the patients needed a new prosthesis. Remakes of the first prosthesis occurred after a mean of 12.47 $\pm$ 3.94 years, and the longevity of the overdentures was 10.39 $\pm$ 5.59 years. Prosthetic relines were required on average every 4.40 $\pm$ 2.81 years in 47% of active patients, similar to previous literature.[50] Relines were prescribed as a response to complaints of food accumulation around the implant housing and to compensate for residual ridge resorption under distal extension areas. The latter problem was observed mainly with overdentures retained by two implants[51] and with large distal extension areas. Overdenture patients who had been edentulous for less than a decade exhibited greater annual mandibular posterior ridge resorption, whereas the choice of bar design did not affect the observed levels of residual ridge resorption.[52] Furthermore, improved function with overdentures could create a stimulus for load-related bone formation, which could curtail physiologic age-related loss in bone mineral content.[53] When present, opposing complete dentures frequently demonstrated time-dependent reduced stability and relines were required. In a retrospective study, maxillary residual ridge resorption was described as being continuous, subject to high individual variability, and more pronounced in the anterior part.[54] Interestingly, in our study, the first reline of the opposing denture was required earlier, at 2.81 $\pm$ 1.25 years, and thereafter every 3.89 $\pm$ 2.57 years, corroborating another study that reports that 33% of patients require a reline after the first year of function.[50] The frequency of the need for clip matrix tightening (38%) and replacement (24%) was low and close that in shorter-term studies.[13,25,55]

It is conceded that the study's research design does not conform to the highest prescribed level of clinical research evidence. However, the choice of management options for prosthodontically maladaptive patients more than two decades ago was singularly restricted.

The alternative of employing an abbreviated version of the osseointegration technique as a management solution became the catalyst for this treatment strategy. This long-term prospective study confirms the merits of overdentures as a method of managing the problems of prosthodontically maladaptive patients. However, patients seeking treatment with implant-supported overdentures should be aware of maintenance issues and associated costs that can be incurred over time, although a previous study[56] showed that the overdenture is less expensive to fabricate and maintain compared to the fixed approach. This suggests that overdentures should be considered as the first choice for patients with mandibular maladaptive denture problems, particularly if they are able to tolerate a removable prosthesis. Patients' subjective outcomes and economic evaluation of this clinical study will be presented in future reports.

## Conclusions

1. This study confirmed favorable long-term osseointegration results in patients treated with design-specific implant-supported overdentures.
2. Cumulative implant success was 96.14% at 15 years, with the majority of failures caused by lack of osseointegration in encountered poor-quality bone.
3. Mean marginal bone loss around mandibular implants was 1.01 mm for the first year of loading and around 0.05 mm/year after the first year; however, the amount of peri-implant bone loss varied considerably among patients.
4. Cumulative survival of the overdenture prosthetic plan was 100% at 15 years. The longevity of overdenture prostheses was 10.39 $\pm$ 5.59 years. Relines

were required on average every 4 to 5 years for both overdentures and opposing complete dentures.
5. These long-term results underscore the need to discuss maintenance requirements with patients during the treatment planning phase. Such an exercise should not revolve solely around the implant success per se, but should emphasize the necessity for replacement and incurred costs related to prosthodontic treatment over time.
6. This study suggests that the first choice for patients with mandibular denture problems who can tolerate a removable prosthesis should be an implant-supported overdenture.

## References


1. Adell R, Lekholm U, Rockler B, Brånemark P-I. A 15-year study of osseointegrated implants in the treatment of edentulous jaws. Int J Oral Surg 1981;10:387–416.
2. Henry PJ, Bower RC, Wall CD. Rehabilitation of the edentulous mandible with osseointegrated dental implants: 10-year follow-up. Aust Dent J 1995;40:1–9.
3. Zarb GA, Schmitt A. The longitudinal clinical effectiveness of osseointegrated dental implants: The Toronto study. Part II: Prosthetic results. J Prosthet Dent 1990;64:53–61.
4. Zarb GA. The Toronto overdenture study: Interim conclusions. In: Schepers E, Naert I, Theuniers G (eds). Overdentures on Oral Implants. Leuven, Belgium: Leuven University Press, 1991:43–57.
5. Zarb GA, Schmitt A. The edentulous predicament. II: The longitudinal effectiveness of implant-supported overdentures. J Am Dent Assoc 1996;127:66–72.
6. Schmitt A, Zarb GA. The notion of implant-supported overdentures. J Prosthet Dent 1998;79:60–65.
7. Naert IE, Hooghe M, Quirynen M, van Steenberghe D. The reliability of implant-retained hinging overdentures for the fully edentulous mandible. An up to 9-year longitudinal study. Clin Oral Invest 1997;1:119–124.
8. Snauwert K, Duyck J, van Steenberghe D, Quirynen M, Naert I. Time dependent failure rate and marginal bone loss of implant supported prostheses: A 15-year follow-up study. Clin Oral Invest 2000;4:13–20.
9. Freeman C, Brook I, Joshi R. Long-term follow-up of implant-stabilised overdentures. Eur J Prosthodont Restorative Dent 2001;9: 147–150.
10. Mericske-Stern R, Aerni D, Buser D, Geering AH. Long-term evaluation of non-submerged hollow cylinder implants. Clin Oral Implants Res 2001;12:252–259.
11. Kiener P, Oetterli M, Mericske E, Mericske-Stern R. Effectiveness of maxillary overdentures supported by implants: Maintenance and prosthetic complications. Int J Prosthodont 2001;14:133–140.
12. Mericske-Stern R, Oetterli M, Kiener P, Mericske E. A follow-up study of maxillary implants supporting an overdenture: Clinical and radiographic results. Int J Oral Maxillofac Implants 2002;17:678–686.
13. Dudic A, Mericske-Stern R. Retention mechanisms and prosthetic complications of implant-supported mandibular overdentures: Long-term results. Clin Implant Dent Relat Res 2002;4:212–219.
14. Ferrigno N, Laureti M, Fanali S, Grippaudo G. A long-term follow-up study of non-submerged ITI implants in the treatment of totally edentulous jaws. Clin Oral Implants Res 2002;13:260–273.
15. Lambrecht JT, Fillippi A, Ratzer Kunzell A, Schiel HJ. Long-term evaluation of submerged and nonsubmerged ITI solid-screw titanium implants: A 10-year life table analysis of 468 implants. Int J Oral Maxillofac Implants 2003;18:826–834.
16. Meijer HJ, Raghoebar GM, van't Hof MA. Comparison of implant-retained mandibular overdentures and conventional complete dentures: A 10-year prospective study of clinical aspects and patient satisfaction. Int J Oral and Maxillofacial Implants 2003;18:879–885.
17. Weintraub JA, Burt BA. Oral health status in the United States: Tooth loss and edentulism. J Dent Educ 1985;49:368–378.
18. Burt BA. Epidemiology of dental diseases in the elderly. Clin Geriatr Med 1992;8:447–559.
19. Zarb GA. Introduction. Proceedings of the Academy of Prosthodontics Halifax Symposium—Towards Optimized Management of the Edentulous Predicament. June 1997. J Prosthet Dent 1998;79:3–5.
20. Feine JS, Carlsson GE, Awad MA, et al. The McGill consensus statement on overdentures. Int J Prosthodont 2002;15:413–414.
21. Carr AB. Successful long-term treatment outcomes in the field of osseointegrated implants: Prosthodontic determinants. Int J Prosthodont 1998;11:502–512.
22. Payne AG, Solomons YF. The prosthodontic maintenance requirements of mandibular mucosa- and implant-supported overdentures: A review of the literature. Int J Prosthodont 2000;13:238–243.
23. Walton JN, MacEntee MI. Problems with prostheses on implants: A retrospective study. J Prosthet Dent 1994;71:283–288.
24. Hemmings KW, Schmitt A, Zarb GA. Complications and maintenance requirements for fixed prostheses and overdentures in the edentulous mandible: A 5-year report. Int J Oral Maxillofac Implants 1994;9:191–196.
25. Watson RM, Jemt T, Chai J, et al. Prosthodontic treatment, patient response, and the need for maintenance of complete implant-supported overdentures: An appraisal of 5 years of prospective study. Int J Prosthodont 1997;10:345–354.
26. Watson RM, Davis DM. Follow up and maintenance of implant supported prostheses: A comparison of 20 complete mandibular overdentures and 20 complete mandibular fixed cantilever prostheses. Br Dent J 1996;181:321–327.
27. Davis DM, Packer ME. Mandibular overdentures stabilized by Astra Tech implants with either ball attachments or magnets: 5-year results. Int J Prosthodont 1999;12:222–229.
28. Walton JN, MacEntee MI, Glick N. One-year prosthetic outcomes with implant overdentures: A randomized clinical trial. Int J Prosthodont 2002;17:391–398.
29. Watson GK, Payne AG, Purton DG, Thomson WM. Mandibular overdentures: Professional time for prosthodontic maintenance during the first year of service using three different implant systems. Int J Prosthodont 2002;15:379–384.
30. Chaffee NR, Felton DA, Cooper LF, Palmqvist U, Smith R. Prosthetic complications in an implant-retained mandibular overdenture population: Initial analysis of a prospective study. J Prosthet Dent 2002;87:40–44.
31. Payne AG, Walton TR, Walton JN, Solomons YF. The outcome of implant overdentures from a prosthodontic perspective: Proposal for a classification protocol. Int J Prosthodont 2001;14:27–32.
32. Mericske-Stern R. The advent of osseointegration and its impact on prosthodontic management of edentulous patients. In: Zarb G, Lekholm U, Albrektsson T, Tenenbaum H (eds). Aging, Osteoporosis, and Dental Implants. Chicago: Quintessence, 2002:147–160.
33. MacEntee MI, Walton JN. The economics of complete dentures and implant-related services: A framework for analysis and preliminary outcomes. J Prosthet Dent 1998;79:24–30.
34. Zarb GA, Schmitt A. The longitudinal clinical effectiveness of osseointegrated dental implants: The Toronto study. Part I: Surgical results. J Prosthet Dent 1990;63:451–457.
35. Lekholm U, Zarb GA. Patient selection and preparation. In: Brånemark P-I, Albrektsson T, Zarb GA (eds). Tissue-Integrated Prostheses: Osseointegration in Clinical Dentistry. Chicago: Quintessence, 1985:199–209.
36. Zarb GA, Albrektsson T. Consensus report: Towards optimized treatment outcomes for dental implants. Int J Prosthodont 1998;11:389.

37. Cox JF, Pharoah M. An alternative holder for radiographic evaluation of tissue-integrated prostheses. J Prosthet Dent 1986;56: 338–341.
38. Chaytor DV, Zarb GA, Schmitt A, Lewis DW. The longitudinal effectiveness of osseointegrated dental implants. The Toronto study: Bone level changes. Int J Periodontics Restorative Dent 1991;11: 112–125.
39. Zarb GA. Relining or rebasing of complete dentures. In: Zarb G, Bolender C, Carlsson GE (eds). Boucher's Prosthodontic Treatment for Edentulous Patients. St Louis: Mosby-Year Book, 1997:390–400.
40. Engquist B, Bergendal T, Kallus T, Lindén U. A retrospective multicenter evaluation of osseointegrated implants supporting overdentures. Int J Oral Maxillofac Implants 1988;3:129–134.
41. Smith R, Berger R, Dodson TB. Risk factors associated with dental implants in healthy and medically compromised patients. Int J Oral Maxillofac Implants 1992;7:367–372.
42. Jemt T, Chai J, Harnett J, et al. A 5-year prospective multicenter follow-up report on overdentures supported by osseointegrated implants. Int J Oral Maxillofac Implants 1996;11:291–298.
43. Ekfeldt A, Johansson LA, Isaksson S. Implant-supported overdenture therapy: A retrospective study. Int J Prosthodont 1997;10: 366–374.
44. Mericske-Stern R, Zarb GA. Overdentures: An alternative implant methodology for edentulous patients. Int J Prosthodont 1993;6: 203–208.
45. Mericske-Stern R, Steinlin Schaffner T, Marti P, Geering AH. Peri-implant mucosal aspects of ITI implants supporting overdentures. A five-year longitudinal study. Clin Oral Implants Res 1994;5:9–18.
46. Quirynen M, Naert I, van Steenberghe D. Fixture design and overload influence marginal bone loss and fixture success in the Brånemark system. Clin Oral Implants Res 1992;3:104–111.
47. Guckes AD, Scurria MS, Shugars DA. A conceptual framework for understanding outcomes of oral implant therapy. J Prosthet Dent 1996;75:633–639.
48. Anderson JD. The need for criteria on reporting treatment outcomes. J Prosthet Dent 1998;79:49–55.
49. Naert IE. Patient evaluation and treatment planning. J Dent 1997;25 (suppl 1):S5–S11.
50. Payne AG, Solomons YF. Mandibular implant-supported overdentures: A prospective evaluation of the burden of prosthodontic maintenance with 3 different attachment systems. Int J Prosthodont 2000;13:246–253.
51. Jacobs R, Schotte A, van Steenberghe D, Quirynen M, Naert I. Posterior jaw bone resorption in osseointegrated implant-supported overdentures. Clin Oral Implants Res 1992;3:63–70.
52. Wright PS, Watson RM. Effect of prefabricated bar design with implant-stabilized prostheses on ridge resorption: A clinical report. Int J Oral Maxillofac Implants 1998;13:77–81.
53. von Wowern N, Gotfredsen K. Implant-supported overdentures, a prevention of bone loss in edentulous mandibles: A 5-year follow-up study. Clin Oral Implants Res 2001;12:19–25.
54. Kreisler M, Behneke N, Behneke A, d'Hoedt B. Residual ridge resorption in the edentulous maxilla in patients with implant-supported mandibular overdentures: An 8-year retrospective study. Int J Prosthodont 2003;16:295–301.
55. den Dunnen AC, Slagter AP, de Baat C, Kalk W. Professional hygiene care, adjustments and complications of mandibular implant-retained overdentures: A three-year retrospective study. J Prosthet Dent 1997;78:387–390.
56. Attard NJ, Wei X, Laporte A, Zarb GA, Ungar WJ. A cost minimization analysis of implant treatment in mandibular edentulous patients. Int J Prosthodont 2003;16:271–277.

*Literature Abstract*

## Comparison of fracture tests of denture base materials

Fracture of denture base is a common complication in removable and implant-retained/supported prostheses. Strength of denture base resin indicates the resistance against fracture. The purposes of this study were to define the fracture toughness of denture base resins and to compare such results with impact strength measurements. The authors performed four kinds of mechanical tests (three impact strength measurements and one fracture toughness test) with seven different heat-polymerized denture base resins (five high-impact and two conventional). Three series of impact strength test (one series of Charpy test and two series of Izod test) were performed with 12 specimens. Eight specimens were used for fracture toughness test to determine the maximum stress intensity factor and the work of fracture. The result of each test was analyzed with one-way ANOVA with a post-hoc Tukey-Kramer test. The results showed that loading conditions and specimen geometry influenced the impact strength results. With fracture toughness test, the difference in strength between conventional products and "high-impact" products was more apparent. The authors concluded that a fatigue test would be more suitable to simulate the clinical failure mechanism even though it would be more time consuming.

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