Single-Implant Survival: More Than 30 Years of Clinical Experience

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Purpose: The aim of this study was to report long-term clinical survival of single implants provided with turned and moderately rough surfaces in routine practice. Materials and Methods: All patients consecutively treated at a specialist center with single-crown implants from 1982 to 2013 were included. For all these patients, data on implant failure and last examination at the clinic were collected, and thereafter cumulative survival rates (CSR) were calculated for patients treated in the maxilla or mandible with turned or moderately rough surfaces, respectively. Results: In total, 2,417 patients (2,665 operations) were treated with 3,211 single implants during the inclusion period (31 years). Of these, 573 (615 operations, 754 implants) were followed up for at least 10 years. Overall proportions of patients followed up for 5 years up to 25 years decreased from 68.2% to 37.0% of treated patients. A higher follow-up compliance was observed for patients treated during the earlier period of inclusion. Patient CSR for 15 and 10 years for maxillary implant placement was 95.8% for turned surfaces and 98.5% for moderately rough surfaces, respectively. Corresponding patient CSR for 10 and 25 years for mandibles was 95.1% and 97.2%, respectively. No implant was reported as a failure after 10 years of follow-up. Conclusion: A significant number of patients can be expected to be lost to follow-up during long-term periods in routine practice. Single-implant treatment is an overall predictable treatment procedure over the long term, with a lower failure rate for implants with a moderately rough surface placed in the maxilla. This difference seems to be established already during the early phase of osseointegration. Int J Prosthodont 2016;29:551–558. doi: 10.11607/ijp.4892

The original Brånemark concept to restore patients with osseointegrated dental implants was first designed for the edentulous patient in the mid 1960s. After almost 18 years of development and clinical documentation of this treatment, the very first patient received an osseointegrated implant to restore a single missing tooth. Few single implants were placed during the early years that followed, but use of the single-implant technique increased after further modifications and development. Currently, it is probably the most common implant treatment protocol worldwide. Accordingly, it must be assumed that millions of patients have received one or several single-implant restorations worldwide, predominantly in a population that is younger than the original edentulous implant population. With such a large number of patients with a long expected remaining lifetime, it is important to have long-term clinical evidence for the treatment protocol. Dental implants were controversial in the early days of osseointegration, and the Brånemark team had to collect 10 to 15 years’ follow-up data on the initial treatment protocol for edentulous patients before osseointegration was accepted in the dental community. With regard to numbers and age of patients treated with single implants today, it should be expected that the treatment is based on solid long-term clinical evidence. However, recent reviews on single-implant protocols have shown that only about 400 patients worldwide are documented up to 10 years, and even fewer with implants with a modern medium rough surface. Accordingly, single-implant treatment has been documented as a successful procedure with predictable results for 5 years and, to a limited extent, up to 10 years of follow-up. However, survival data on even longer periods are very limited on single implants provided with a moderately rough surface, and it is unclear if available favorable results can be maintained for longer periods without unexpected increase of implant failures over time. To reflect the large population of single-implant patients currently treated worldwide, it would be favorable to collect implant survival data from a larger population of implant patients.
patients treated and followed up under more routine clinical circumstances (effectiveness) as compared with survival rates from a smaller, well-controlled population, treated and followed up under optimal conditions (efficacy).

The aim of the present study was to report long-term clinical survival of single implants consecutively placed on a routine basis at one clinic from 1982 to 2013. The focus of the present study is survival of implants still in function in routine practice.

Materials and Methods

The present study is a retrospective register/observation study\textsuperscript{14,15} based on all single-implant operations consecutively performed from 1982 to 2013 (31 years) using osseointegrated dental implants at the University of Gothenburg from 1982 to December 1985 and thereafter at the Brånemark Clinic (Public Dental Health Service in Region of Västra Götaland, Sweden). The study has been approved by the local ethical committee in Göteborg (no. 197-12).

In total, 9,124 patients were provided with 41,897 implants at 11,450 operations during the inclusion period. Altogether, 29,891 Brånemark System implants (Nobel Biocare) with a turned surface were consecutively placed between 2001 and 2013. Most of the implants with a moderately rough surface were Brånemark System implants with a gradient TiUnite surface (95.7%).

In the early period of inclusion, implant surgery was performed after a healing period of at least 1 to 3 months after tooth extraction. Brånemark System implants with a turned surface were consecutively placed according to a standard two-stage surgical protocol.\textsuperscript{16} The two-stage protocol was maintained for most operations in the maxilla after introduction of implants with a moderately rough surface.\textsuperscript{17-19} For the mandible, however, a one-stage surgical protocol was introduced on a routine basis at the clinic in connection with the use of implants with a moderately rough surface.\textsuperscript{17-19}

The first patient treated with osseointegrated implants was restored in the edentulous mandible in 1965 by the Brånemark team,\textsuperscript{1,2} followed by the first patient restored in the partially edentulous mandible in 1968. However, the first patient provided with one osseointegrated implant to restore a missing single tooth was treated 14 years later, in 1982.\textsuperscript{4}

All-single implant patients consecutively treated by the original Brånemark team and later at the Brånemark clinic up to 2013 have been included in the present study. Patients included in the study were all those that have been provided with single implants in the maxilla and/or mandible and thereafter restored with crowns based on different single-abutment techniques.\textsuperscript{3-9} The protocol and components for treatment of patients with single-implant crown restorations was developed by the original Brånemark team at the University of Gothenburg.\textsuperscript{3,4} Various techniques and components have been used for the single-crown restorations during the years, initially designed as premachined components and later as custom abutments, fabricated in both titanium and ceramics.\textsuperscript{3-9} A special healing abutment was introduced as well due to the logistic protocol for single-implant treatment. All single crowns were cemented to the premachined abutments, most often outside the mouth, and then secured through an access hole. For the majority of the custom abutments, crowns were baked directly to the abutment and secured by means of an access hole through the crown-abutment restoration. All patients treated at the clinic were referral patients who were followed up by the referring dentists after prosthetic treatment. More recently, patients have also been referred to the clinic for implant surgery only and subsequent restorative treatment has been performed by the referring dentists. As a routine protocol, all patients have been invited to participate in a follow-up program at the clinic and examined after 1 year and then every 5 years.\textsuperscript{15} Year of implant surgery and year of last visit to the clinic has been recorded to report time of patient follow-up and when patients were lost to follow-up.

Basic data was collected regarding age and sex of patients at implant operation, time and jaw at surgery, number and type of installed implants, and lost implants and time of last visit at the clinic. The primary endpoints in this study were implant failure and time of follow-up. Patients have been followed up from the first implant operation in 1982 to December 2014, covering at least 1 year of follow-up for those patients treated in 2013.

Statistical Analyses

In the present study, data are presented as numbers, frequencies, means, and standard deviations. Life tables have been calculated according to methods described by Kaplan and Meier.\textsuperscript{20} Calculations of cumulative survival rate (CSR) were performed up to the year when at least 25 patients were still followed up in the clinic. Patients may have been treated in both the maxilla and the mandible or several times in one jaw. Data has been reported on patient and/or operation level, and statistically not independent implant-level data has been handled with caution.
Results

Altogether, 2,431 patients provided with single-implant restorations were included in the database. Of these, 14 patients were excluded because they were from abroad, leaving 2,417 (26.5% of the total patient database). Many of the patients were aged 15 to 25 years (42.3%) (Fig 1) and mean age at first implant operation was 36.3 ± 18.75 years (range: 13 to 89 years). In total, 1,241 of the treated patients were female (51.3%). Data on last visit to determine time of follow-up is missing for one patient, here recorded as lost to follow-up after crown placement.

Distributions of treated patients, performed operations, and placed implants are presented in Table 1. Included patients (n = 2,417) were provided with 3,211 implants at 2,665 operations. Only one implant per operation was placed in 2,167 of these operations (81.3%). In the remaining operations, 238 patients were treated with more than one implant, 110 of them in both jaws. Of the operations, 31 were reentry operations in which lost single implants were replaced in the edentulous single-tooth site.

Patients provided with implants with turned surfaces in the maxilla or mandible were followed up for a maximum of 32 and 27 years, respectively. Corresponding maximum years of follow-up for patients with implants with moderately rough surfaces were 14 and 13 years, respectively. Distribution of total numbers of patients followed and lost to follow-up during the years is presented in Table 2. A small difference can be seen in distribution of patients lost to follow-up when data is reported for the entire group on patient or operation levels (Table 2). The proportion of the patients lost to follow-up progressively increased with time of follow-up (Table 2, Fig 2). In total, 1,185, 573, 231, 83, and 29 patients were followed up for at least 5, 10, 15, 20, and 25 years,
respectively. A higher follow-up compliance was noticed for patients treated in the earlier period of inclusion (Table 2, Fig 3). No difference was found in follow-up comparing male and female patients (Fig 4), and no obvious difference was found in follow-up compliance among age groups during the first years of follow-up (Fig 5). However, for the later part of the follow-up period, the oldest group of patients showed an increased level of dropout (Fig 5).

Altogether, 67 patients/operations were identified with 67 implant failures during follow-up, and no patient lost more than one implant (Table 3). A total of 58 patients lost implants at their first/only operation, while the remaining 9 patients had experienced more than one single-implant operation. Of the patients with failures, 34 were female (50.1%) and the mean age at first surgery was 37.6 ± 18.98 years.

A majority of implant failures were reported during the first year of follow-up (83.6%) (Table 3), with only one implant failure between 5 and 10 years and no failures after 10 years. No patient lost an implant that was placed after implant failure (reentry operation). The overall proportion of failing implants was higher in mandibles (n = 19; 3.5%) compared with maxillae (n = 48; 2.6%) and in patients provided with implants with a turned (n = 39; 4.4%)

### Table 2

<table>
<thead>
<tr>
<th>Follow-up (y)</th>
<th>Total group (%)</th>
<th>Patients followed up by time period (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (Baseline)</td>
<td>2,665 (100)</td>
<td>66 (100) 107 (100) 224 (100) 609 (100) 588 (100) 823 (100)</td>
</tr>
<tr>
<td>1</td>
<td>2,415 (90.6)</td>
<td>62 (93.9) 103 (96.3) 216 (96.4) 583 (95.7) 538 (91.5) 683 (83.0)</td>
</tr>
<tr>
<td>5</td>
<td>1,295 (68.3)</td>
<td>59 (89.4) 91 (85.0) 192 (85.7) 415 (86.1) 347 (59.0) 81 (56.3)</td>
</tr>
<tr>
<td>10</td>
<td>615 (50.7)</td>
<td>54 (81.8) 69 (64.5) 143 (63.8) 267 (43.8) 40 (33.6)</td>
</tr>
<tr>
<td>15</td>
<td>242 (46.6)</td>
<td>48 (72.7) 53 (49.5) 106 (47.3) 24 (24.2)</td>
</tr>
<tr>
<td>20</td>
<td>87 (41.2)</td>
<td>36 (54.5) 40 (37.4) 7 (22.6)</td>
</tr>
<tr>
<td>25</td>
<td>29 (38.2)</td>
<td>26 (39.3) 1 (14.3)</td>
</tr>
<tr>
<td>30</td>
<td>3 (37.5)</td>
<td>3 (37.5) 3 (37.5)</td>
</tr>
</tbody>
</table>

**Fig 3** Percentage of single-implant patients followed up over 25 years in relation to total number of patients treated during different time periods. A minimum of 25 patients were included at the end of the survival curve.

**Fig 4** Percentage of patients followed up over 30 years by gender.
compared with a moderately rough surface (n = 28; 1.8%).

Overall patient implant treatment CSR was 97.1% after 25 years of follow-up. Implant CSR was calculated to be 95.8% and 95.1% for operations placing implants with a turned surface in maxillae and mandibles after 25 and 15 years of follow-up, respectively (Fig 6). Corresponding CSRs for implants with a moderately rough surface were 98.5% and 97.2% after 11 years of follow-up, respectively (Fig 6). Reduction of survival rates following the first annual examination were within one percentage (0.00−0.96%) for all surfaces and jaws.

Discussion

The present study was designed as a retrospective study focusing on whether earlier published encouraging data on single-implant treatment could be maintained in larger routine implant populations over longer periods (effectiveness) when using implants with different surfaces, or whether an obvious decrease in implant survival rate could be expected. Certainly, many more parameters regarding single-implant treatment could have been collected and would have improved the information and value for the clinician. However, this would also have been much more time consuming and could have jeopardized completion of the study. More data and information on the treatment outcome would probably have not affected the clinical key question, and the present results suggest a continuous stable and predictable survival of single implants in large populations, slightly better for moderately rough implant surfaces (Fig 6).

The general consensus in dentistry and medicine is that all treatment procedures should be based on clinical evidence, where much of the evidence is established from systematic reviews and meta-analyses covering publications identified from PubMed.

Table 3 Distribution of Single Implant Failures by Jaw During Follow-Up

<table>
<thead>
<tr>
<th>Implants/operations (n)</th>
<th>Maxillae</th>
<th>Mandibles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Turned surface</td>
<td>Moderately rough surface</td>
</tr>
<tr>
<td>Early failures (0−1 y)</td>
<td>25</td>
<td>14</td>
</tr>
<tr>
<td>Late failures (&gt; 1−5 y)</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Late failures (&gt; 5−10 y)</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>39</td>
<td>28</td>
</tr>
</tbody>
</table>

Table 3 Distribution of Single Implant Failures by Jaw During Follow-Up

Fig 5 Percentage of patients followed up over 15 years by patient age at inclusion.

Fig 6 Up to 20-year cumulative survival rates for single-implant operations performed in maxillae and mandibles for implants with different surfaces. Calculations include at least 25 patients at termination.
searches and similar data sources.\textsuperscript{10,11,21} Selected publications should be judged according to strict protocols set up before the inclusion phase, aiming to address different key factors before inclusion.\textsuperscript{10,11,21} A common observation from these reviews is that most of the studies that show up on the first data list from the PubMed searches are excluded, and that eventually only a few manuscripts can be included in the review.\textsuperscript{10,11,21} One of many reasons for exclusion of studies is that they focus more on the results than on describing inclusion procedures and patient data.\textsuperscript{22}

The present study covers thousands of patients, operations, and implants included over a long period that comprises many methodologic challenges and problems. Certainly not all of these can be controlled in an optimal way, and therefore only two basic endpoints with low risk of misinterpretation have been used: implant failure and time of follow-up. Altogether, 2,417 patients were provided with single-implant restorations during inclusion (27%), where basically no patient was excluded from implant treatment. An earlier publication reported a decreasing number of implants per operation and a decrease in mean patient age during the years at the present clinic.\textsuperscript{15} With fairly even numbers of operations performed over the years,\textsuperscript{19} this means that single-implant treatment is more common today and that clinical experience has increased over time. Observed lower single-implant failure rates during the later period of inclusion and follow-up could be related to changed implant surface\textsuperscript{15} (Fig 6), but increased overall experience in the clinic could also play a role even though the individual surgeon’s learning curve has not been shown to be an important factor in the present clinic.\textsuperscript{23}

Life tables and calculation of CSRs were introduced in the late 1950s to estimate patient survival when data was incomplete and some patients were lost to follow-up.\textsuperscript{20} It must be assumed that it was never intended or even considered that persons returned to the clinic when data was incomplete and some patients were lost to follow-up, and that deaths were the same as failures (deceased) could also be represented as survivals in these estimations. This would be the case when using Kaplan-Meier calculations to follow up implant treatment on the implant level, covering patients restored with many implants where some are lost and some are still in function. Thus, when implant-level life tables are used in situations where patients are provided with many implants, the estimations become unpredictable because the observations are not independent from one another.\textsuperscript{24,25} However, in the present study where numbers of patients (n = 2,427) and operations (n = 2,665) are comparable, results on proportions of followed-up patients and operations are comparable (Table 2). This may allow for operation-level instead of patient-level calculation of single-implant survivals (Fig 6) without randomization of operations when implant failures are observed in one of several operations performed in the same patient.

Furthermore, Kaplan-Meier calculations are based on other assumptions, also relevant for the present study design. First, it is assumed that the survival prospects of patients/operations/implants that are lost to follow-up at any time should be the same as for those who continue to be followed.\textsuperscript{26} It is also assumed that survival probabilities are independent of recruitment time and “that the event happens at the time specified.”\textsuperscript{26} This means that it is questionable from a scientific point of view to include patients/operations/implants with a documented difference in survival (ie, implant surface or treated jaw)\textsuperscript{15} into the same life table. To compensate for this in the present study, separate life tables have been calculated for implants with different surfaces and for different jaws (Fig 6). Furthermore, patient compliance has been evaluated for different years of inclusion and age and gender of patients (Figs 3 to 5). Regarding the time when the event occurs and when it is observed, it is reasonable to assume that early implant failures are more easily noticed in the clinic while later failures may occur without being reported to the clinic, or that patients show up at a much later stage. A higher rate of complications has been reported for noncompliant patients than for compliant patients,\textsuperscript{27,28} and it is reasonable to consider all life table calculations with caution, particularly regarding long-term observations of failure events.

Life table calculations become an estimate first when one or more patients are lost to follow-up.\textsuperscript{29} In the present study it can be observed that many patients were lost to follow-up, a trend that became more pronounced the later the patients were included (Fig 3). Certainly, the larger the patient population and the longer the follow-up time, the higher the risk of losing patients to follow-up. In patient populations with a higher mean age at inclusion, 38% and 55% of deceased patients have been reported after 15 and 28 years, respectively.\textsuperscript{30} In the present study, mean age at surgery was much lower but patient lifestyle and increased tendency to relocate at a young age may contribute to lower compliance in younger age groups as well. A changed logistic protocol in the present referral clinic with more prosthetic treatment performed by the referring dentists could further decrease patient compliance. It has been reported that patients who are treatment pioneers or who participate in small research groups show higher compliance than patients treated on a more routine basis.\textsuperscript{2,31–33} The higher compliance for the earliest group of pioneer single-implant patients in the present study supports this assumption (Fig 3).
High or low levels of follow-up compliance could be used today as a measure for whether the treatment is special (efficacy) or routine (effectiveness) in a referral clinic and judged accordingly. These lower levels of compliance may be compensated for by including more patients so that greater numbers remain at termination of the study. Altogether, 573 patients were followed up for 10 years, which must be considered a high number since total number of patients available for meta-analyses earlier reached about 400 worldwide.10,11

Accordingly, when low failure levels are expected in a study it is important to include many patients to allow a reliable analysis of observed complications during follow-up. The present cut-off point for life table calculation was 25 patients, which is comparable with the numbers of patients included in studies with smaller populations. This threshold means that a theoretical late implant failure would increase the failure rate a maximum of 4%. Extending the life tables to the very last patient would increase the theoretical risk of a failure to reach 100% at the end, which is not recommended. This cut-off point should be set before the start of the study.

The present life tables show higher survival rates for implants provided with moderately rough surfaces compared with implants with a turned surface (Fig 6). This is in accordance with earlier studies showing lower failure rate for implants with a moderately rough surface.15,17-19 Furthermore, data indicate that the failure rate is higher in mandibles as compared to maxillae, irrespective of the implant surface used (Fig 6), which is not in accordance with earlier clinical reports from the present clinic. In earlier studies on edentulous patients, higher failure rates are reported for maxillary implants compared with mandibular implants.2,15,17,18 This difference may be related to the placement of single implants in the mandible in more demanding sites with higher loads in posterior regions, shorter implants, and lack of apical cortical support. Since most of the failures are observed early after surgery, this is more of a healing problem (establishing osseointegration) than a maintenance problem. Thus focus should be on how the implants are placed and loaded during the early phase. More one-stage surgical procedures performed in the mandible could also contribute to the difference in implant survival rate by jaw, which is especially pronounced during the early stage of healing and function.34 However, considering the overall 10-year results for single-implant treatment, the present study compares well with earlier reviews15,11 and indicates that single-implant treatment is a predicable option in somewhat longer time perspectives with no indication of increased failure rates in longer follow-up intervals.

Conclusions

Within the limitations of the present study design, numbers of included/lost patients, and complexity of long-term routine population data, certain conclusions could be made. Altogether 573 patients were followed up for 10 years (50.9%), 231 for 15 years (46.6%), and 83 for 20 years (40.7%). Patient follow-up compliance was higher for those patients treated in the early period of inclusion (1982–1988). Of 2,417 patients (2,665 operations, 3,211 implants), 65 patients were recorded with an implant failure. No implant was reported as a failure after 10 years of follow-up. The overall 25-year CSR for single-implant operations was 97.1%. Differences in survival rates were observed between implants with different surfaces and different jaws during the early phase of treatment (establishment of osseointegration). No or only small changes in survival rates were observed for surfaces and jaws after first year of function (maintenance of osseointegration). The CSR for 25 and 15 years was 95.8% and 95.1%, respectively, for single-implant operations using implants with a turned surface in maxillae and mandibles. The 11-year CSR was 98.5% and 97.2%, respectively, for single-implant operations using implants with a moderately rough surface in maxillae and mandibles.

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