

Long-Term Evaluation of ANKYLOS® Dental Implants, Part I: 20-Year Life Table Analysis of a Longitudinal Study of More Than 12,500 Implants

Mischa Krebs, DMD, Dr med. dent;* Kai Schmenger, Dipl. Biol;† Konrad Neumann, Dr rer. nat;‡
Paul Weigl, DMD, Dr med. dent;§ Walter Moser, Dr. ing;¶
Georg-Hubertus Nentwig, DMD, PhD, Dr med. dent*

ABSTRACT

Purpose: Scientific evidence is limited regarding the long-term (>10 years) outcomes of large enough numbers of implants (>500) to allow for reliable comparison of subgroups. The purpose of this study was to analyze the outcomes of dental implants placed in an active University Clinic setting and followed for up to 20 years.

Materials and Methods: Data documenting the implant placement, prosthetic reconstruction, and annual follow-up of patients treated at Frankfurt University were extracted from a Structured Query Language database and patients' written records and evaluated statistically.

Results: Between April of 1991 and May of 2011, 12,737 ANKYLOS® (DENTSPLY Implants Manufacturing GmbH, Mannheim, Germany) implants were placed in 4,206 patients for a variety of clinical indications. The Kaplan–Meier cumulative survival rate (CSR) was 93.3% after 204 months. Most of the failures (198/1.6%) occurred during the first year after implant placement and before prosthesis delivery. A significantly higher ($p < .001$) number of implants placed in the mandible and in hard quality bone failed than those placed in the maxilla or in weak and normal quality bone. Female patients had significantly higher CSRs (93.7% 204 months) than male patients (92.8% 204 months/ $p = .029$). The implants showed low rates of peri-implant bone loss after 204 months (horizontal: ≤ 1 mm: 85.7%, vertical: ≤ 1 mm: 85.2%).

Conclusion: ANKYLOS dental implants followed for up to 20 years have high CSRs and low rates of peri-implant bone loss.

KEY WORDS: clinical research, clinical study, crestal bone loss, implant, implant survival, long-term survival, marginal bone loss, survival rate

*Department of Oral Surgery and Implantology, School of Dentistry (Carolinum), Johann Wolfgang Goethe-University Frankfurt am Main, Frankfurt am Main, Germany; †Dentsply Implants, Mannheim, Germany; ‡Institute Medical Biometrics and Clinical Epidemiology, Charité, Berlin, Germany; §Department of Prosthodontics, School of Dentistry (Carolinum), Johann Wolfgang Goethe-University Frankfurt am Main, Frankfurt am Main, Germany; ¶Atesos AG, Aarau, Switzerland

Reprint requests: Dr. Mischa Krebs, Department of Oral Surgery and Implant Dentistry, Dental School (Carolinum), Johann Wolfgang Goethe-University Frankfurt am Main, Theodor-Stern-Kai 7, Frankfurt am Main 60590, Germany; e-mail: mischa@dr-krebs.net

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INTRODUCTION

Osseointegrated dental implants today are commonly used in many prosthetic situations. For both fully and partially edentulous patients, implants are used to retain removable and fixed dentures. Yet although knowledge about their long-term behavior has become increasingly important, long-term studies (observation time >10 years) including large enough numbers of implants (>500) to allow for reliable comparison of subgroups are rare.

The ongoing changes in the implant market may in part account for this. The designs of most implants that were available 20 years ago have changed and now are uncommon or unavailable. However, the presented implant system (ANKYLOS®, DENTSPLY Implants Manufacturing GmbH, Mannheim, Germany), invented

in 1985 by Nentwig and Moser and brought onto the market in 1987 (Germany),^{1,2} has undergone only minor changes and is still available. The key features of this system, including the implant dimensions, the progressive thread design, and the morse taper connection facilitating a wide platform shift, remained unchanged.³ In 2005, a new surface (sandblasted and acid etched, instead of just sandblasted) was introduced, and the machined implant collar and shoulder were also changed to have a microroughened surface. In 2008, the internal geometry apical to the tapered portion was changed while leaving the dimensions of the conical internal connection unchanged. This design gives clinicians the option of working with either an indexed or nonindexed abutment. Despite these changes, any ANKYLOS ever placed today could still be restored with currently available parts.

The objective of the present study was to analyze the outcomes of dental implants in all indication classes placed in an active University Clinic setting and followed for up to 20 years.

MATERIAL AND METHODS

Data were obtained from the Department of Oral Surgery and Implantology of the Frankfurt University about all patients receiving implants in the department from April of 1991 through May of 2011. Generally excluded from receiving implants within the department were patients receiving chemotherapy or those who have recently had radiation in the maxillofacial area, patients who have suffered a heart attack within the previous 6 months, and those with untreated active periodontitis. Smoking was not an exclusion criterion; smokers were noted as such, but the number of cigarettes consumed per day was not recorded. Bruxers also were not excluded, but if there was a history of bruxism, the oral surgeon noted excessive abrasions, facets, or other symptoms of bruxism; this was documented. All patients treated in the department signed an informed consent form before any implant treatment.

The department's standard implant-placement protocol requires no antibiotic prophylaxis. In cases where bone grafting was performed, amoxicillin (2 g) or clindamycin (600 mg) was typically administered at least 1 hour before surgery. Also, in most cases receiving sinus-lift procedures or other bone grafting procedures, steroids were prescribed as a prophylaxis against

swelling. For nongrafted cases, a minimally invasive full-thickness flap was elevated, leaving the periosteum on the buccal areas of the bone undisturbed.

For patients with soft bone in either the upper or lower jaw, a bone-condensing procedure was performed using bone spreaders (Ustomed, Tuttlingen, Germany) to improve primary stability. Until 2001, second-stage surgery was performed after 3 months in upper and lower jaws. From 2001 on, second-stage surgery typically has been performed 6 weeks after implant placement, assuming that no grafting has been performed. Implants were directly loaded with an abutment and provisional fixed prosthesis. Patients were advised to minimize loads on their temporary prostheses by consuming a soft/liquid diet. Whenever possible, provisional restorations were fabricated to function out of full occlusion.

Final restorations were normally delivered 6 weeks after the second-stage surgery.

Beginning in 1991, all implants inserted in the department were documented with predefined standardized parameters in a Structured Query Language (SQL) database. In addition to this database, written records were maintained for every surgery. Parameters included at the time of implant placement were:

- the implant length and diameter;
- the implant type;
- the indication (single tooth in anterior region [1a], single tooth in posterior region [1b], free-end gap [2a], interdental space [2b], heavily reduced number of residual teeth [2c], edentulous upper jaw [3a], and edentulous lower jaw [3b]);
- the bone quality (hard = D1, normal = D2&D3, and soft = D4)^{4,5};
- the tooth position (Federation Dentaire Internationale [World Dental Federation]); and
- when and what kind of bone grafting was performed.

After delivery of the definitive prosthesis, patients were asked to return for a prosthetic control (PC) visit, during which the following parameters were recorded:

- implant mobility (0 = no mobility, 1 = tactile mobility, 2 = visible mobility, 3 = mobility on pressure of the tongue);
- papilla bleeding index (0 = no bleeding, 1 = bleeding after 1–15 seconds, 2 = immediate bleeding,

- 3 = bleeding in the interdental triangle, 4 = profuse bleeding)^{6,7};
- modified plaque index (0 = no plaque, 1 = separate flecks of plaque at the cervical margin, 2 = thin band of plaque at the cervical margin, 3 = plaque in the lower third of the tooth crown, 4 = plaque up to two-thirds of the tooth crown, 5 = plaque in more than two-thirds of the tooth crown)⁸;
 - vertical and/or horizontal bone loss in millimeters, as determined by the clinician chairside from panoramic radiographs, using the implant dimensions as the reference.^{9–11} The bone loss was classified into three subgroups: ≤1 mm; 1 to 2 mm; >2 mm; and
 - type of prosthetic reconstruction (implant-supported, tooth-supported, or hybrid reconstruction) and whether any splinting to the neighboring teeth or implants was done.

All patients were asked to return for annual follow-up visits (regular control [RC]). Dropouts occurred when patients moved, died, or stopped coming to recall appointments. The patients were invited to the RC appointments via letter. Since 2010, patients were also invited by phone calls. If pain or any other problem caused a patient to return for an unplanned visit (irregular control [IC]), this was documented, along with the reason for the unplanned visit. At both the annual follow-up visits and any IC visits, the same parameters that were assessed at the first PC visit were again evaluated and recorded.

Clinicians performing the controls were instructed according to a calibration protocol by experienced oral surgeons.

Implants were considered as “successful” if there was an:

- absence of persistent subjective complaints, such as pain, foreign body sensation, and/or dysesthesia;
- absence of recurrent peri-implant infection with suppuration. If any mucositis or peri-implantitis did occur, affected implants were included in recalls for special care. If treatment was unsuccessful, the implants were removed;
- absence of mobility; and
- absence of any continuous peri-implant radiolucency.¹²

All implants that broke, became loose, or suffered from recurrent peri-implant infections were removed.

Database Conversion

In 2007, all the data in the department’s SQL database were compared with the written records for each patient. If any differences were found, the patient chart was reviewed, and the database was corrected.

Between 2006 and 2008, preparations were undertaken to transfer all the data from the previous SQL database to the impDAT™ program (Kea Software GmbH, Pöcking, Germany). Transfer scripts were defined for every single parameter, and some parameters were added to impDAT to preserve all the information previously collected. Several tests of the transfer were performed using a limited number of records, and the outcome was compared 1:1 (SQL: impDAT). After several refinements, the final transfer script was used in 2008 on all the data, and a random validity test of all parameters was performed and documented.

After the data was transferred to impDAT, additional information was collected at all initial PC appointments, as well as at any visits due to prosthetic complications. Comparable information was added to the impDAT records of all patients who were restored before the transfer to impDAT.

Statistical Analysis

Statistical evaluations were carried out using SPSS 19.0 (SPSS Inc., Chicago, IL, USA) and R 2.14.1 (R Foundation for Statistical Computing, Vienna, Austria; <http://www.r-project.org>). The time between implant placement and failure was defined as survival time. If no failure occurred, the time from placement to last visit was defined as censored survival time. Survival data were analyzed using Kaplan–Meier curves, the Log-Rank test, and Cox-regression, where appropriate. In particular, Kaplan–Meier analysis was used to determine the cumulative survival rates (CSRs). For comparison of two groups, the Mann–Whitney *U* test for ordinal or metric and chi-square test for categorical data were used.

The level of significance was $\alpha = 0.05$. Due to the explorative nature of the study, the level of significance for multiple testing was not adjusted.^{11–19}

RESULTS

Between 1991 and 2011, 12,737 ANKYLOS implants were placed in 4,206 patients who were followed for an average of 60.7 months; the longest follow-up time was 240 months. Three hundred nineteen (319) of the

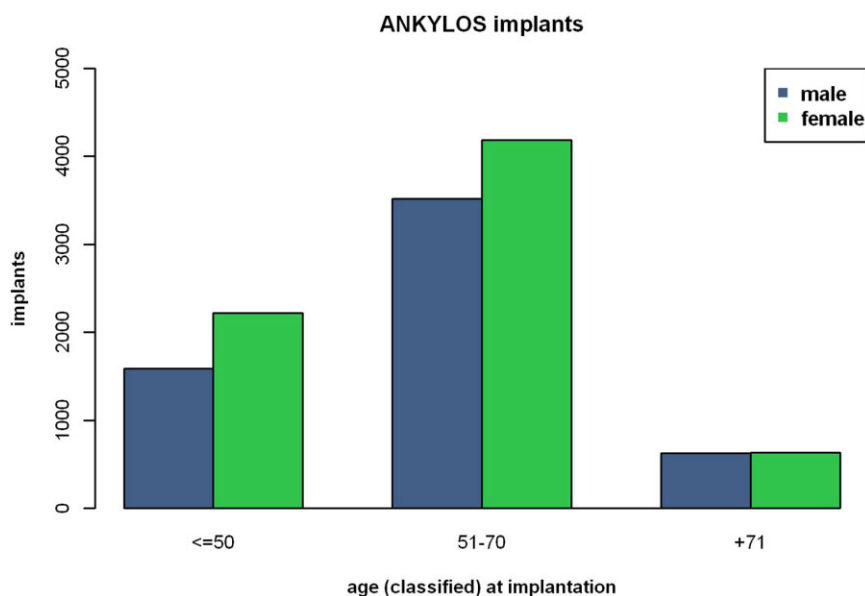


Figure 1 Distribution of implants placed in the three age groups.

implants failed, resulting in an absolute survival rate of 97.5%.

Of the patients, 2,354 (56.0%) were women, and 1,852 (44.0%) were men. The age of the patients at the time of implant placement was classified into three subgroups, with patients who received more than one implant counted once for each implant that was received. The age breakdown was as follows (38 implants placed in patients with unknown age) (Figure 1):

- A1: ≤50 years: 3,758 implants;
- A2: 51 to 70 years: 7,684 implants; and
- A3: ≥71 years: 1,257 implants.

The 12,737 implants were placed by 36 oral surgeons, including both advanced trained clinicians (professors, assistant professors) as well newcomers to the field (residents after they finished the first year of their education in oral surgery).

A number of 17,949 RC (93.9%) were carried out, whereas patients applied to 684 IC (3.6%; 488 controls without information about the reason of visit).

A number 1,715 out of 4,206 patients missed the follow-up appointment (dropouts: 40.8%, 1%/44 died, 1%/53 moved, 1.9%/79 changed the surgeon, 1.5%/63 refused to come to further control follow-up).

The majority of the patients (30.9%) received one implant (1,300 patients). The maximum number of implants placed in any patient was 19 (one patient). In the first fully documented year (1992), 258 implants

were placed. The number placed annually then climbed steadily until 2001. Since then, approximately 800 to 900 implants per year have been placed. The number of implants lost annually mirrored that pattern, with roughly 20 to 40 implants lost per year since 2002. The Kaplan–Meier CSR was 98.2% after 12 months, 97.3% after 60 months, 96.1% after 12 months, 94.5% after 180 months, and 93.3% after 204 months (125 implants) (Figure 2). As the statistical significance of small groups is questionable, especially when such subgroups are being compared, all time-to-event analyses were limited to subgroups followed for 204 months or less. Most subgroups with longer follow-up times included less than 100 implants.

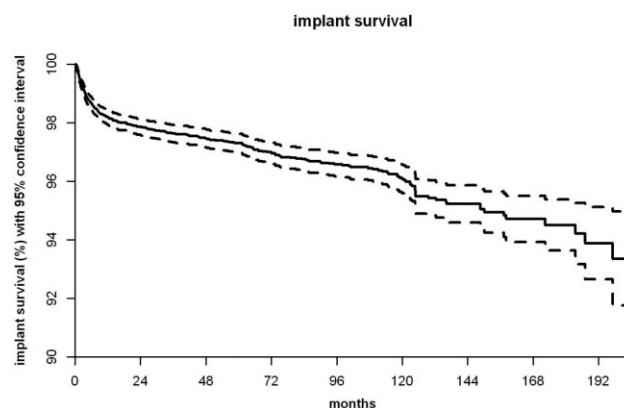


Figure 2 Kaplan–Meier cumulative survival rate (CSR) of all 12,737 ANKYLOS (95% confidence interval).

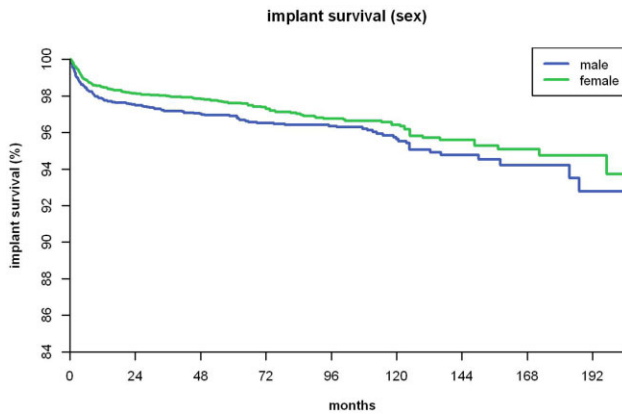


Figure 3 Kaplan–Meier cumulative survival rate (CSR) of male and female patient group.

Gender

The CSRs for male patients (97.8% 12 months; 92.8% 204 months) were significantly ($p = .029$) lower than those for female patients (98.5% 12 months; 93.7% 204 months) (Figure 3).

Age

Implant survival was similar in the three age groups. The small differences at 3 months (A1: 99.3%, A2 99.3%, A3 98.5%), 6 months (A1: 98.9%, A2: 98.7%, and A3: 98%), and 120 months (A1: 96.5%, A2: 95.9%, and A3: 96.0%) were not significant ($p = .46$). Also, for failures within the first year, no significant differences between the age groups could be detected ($p = .45$).

Implant Dimensions and Surface

The main implant length used was 11 mm (8,185 implants, 64.3%); 18.8% of the implants (2,389 implants) were 14 mm long, 12.5% (1,585 implants)

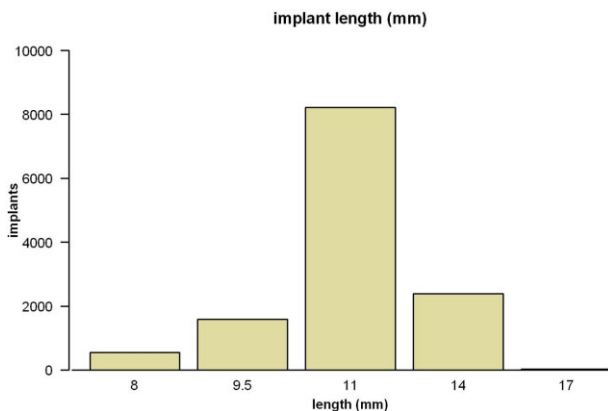


Figure 4 Distribution of implant length.

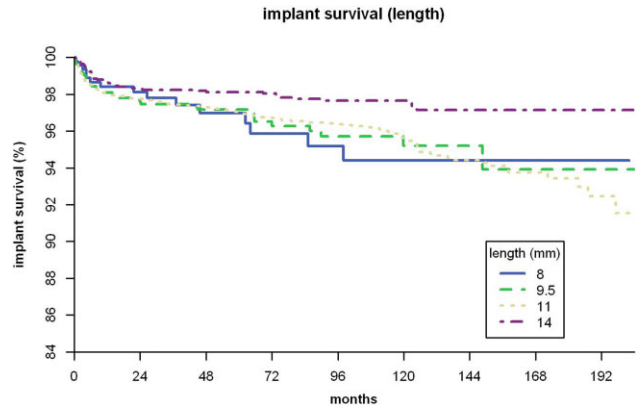


Figure 5 Kaplan–Meier cumulative survival rate (CSR) concerning implant length.

were 9.5 mm long, 4.2% (539 implants) were 8 mm long, and 0.2% (30 implants) were 17 mm long (Figure 4). Although 14-mm implants had a significantly higher survival rate than shorter implants (14 vs 11 mm $p < .001$; 14 vs 9.5 mm $p = .012$; and 14 vs 8 mm $p = .054$), the differences between 11-mm, 9.5-mm, and 8-mm implants were not significant ($p = 1.00$) (Figure 5).

The main diameter inserted was 3.5 mm (9,997 implants, 78.6%). The diameter of 2,483 implants (19.5%) was 4.5 mm; 241 implants (1.9%) had diameters of 5.5 mm, and only five were 7 mm (Figure 6). No significant difference between the CSRs of the different diameters was found ($p = .72$).

Comparison of implant lengths within each of the two main diameter groups (3.5 mm and 4.5 mm, 98.1% of all implants placed) showed no significant influence of implant length on survival of 4.5-mm diameter implants ($p = .48$) but a significant difference for the

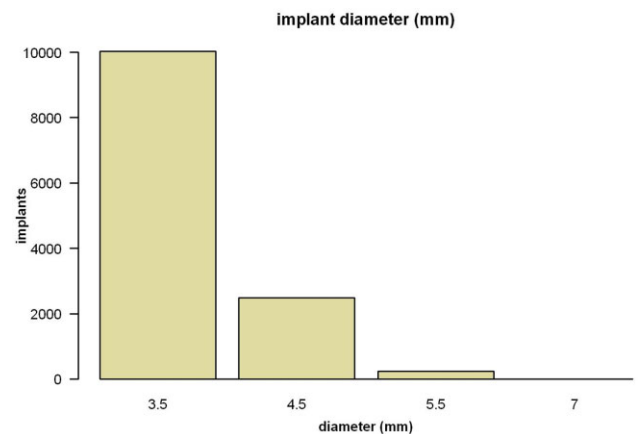


Figure 6 Distribution of implant diameter.

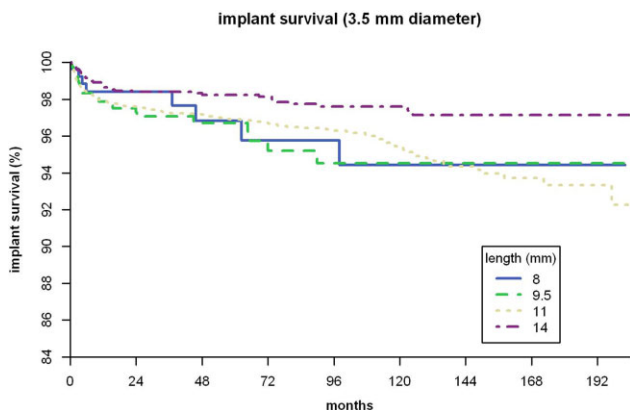


Figure 7 Kaplan–Meier cumulative survival rate (CSR) concerning implant length in 3.5-mm diameter implants.

3.5-mm diameter implants ($p = .006$). The 14-mm implants had a higher survival rate than shorter implants (Figure 7).

There was no significant difference between sandblasted and sandblasted and acid-etched implants ($p = .334$).

Jaw and Indication Classes

A slim majority (53.1%) of the implants were placed in the maxilla. Their CSRs were 98.6% after 12 months and 94.7% after 204 months. This was statistically significantly better ($p = .041$) than the CSRs of the mandibular implants – 97.8% after 12 months and 92.1% after 204 months (Figure 8).

When indications were analyzed, 3,042 implants (23.9%) were found to have been placed in edentulous jaws (maxilla: 1,392 (10.9%); mandible: 1,650 (13.0%)); 2,170 (17.1%) in single-tooth gaps (anterior: 800

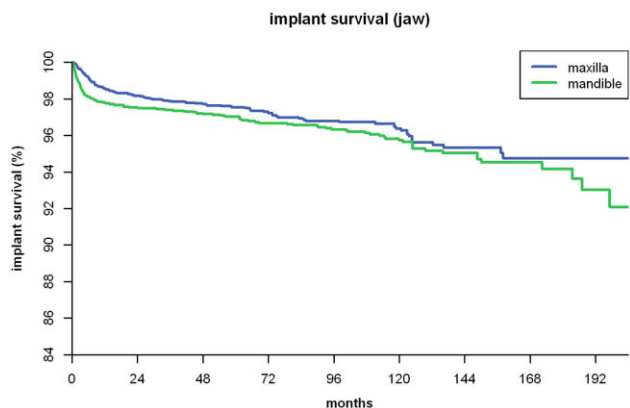


Figure 8 Kaplan–Meier cumulative survival rate (CSR) concerning jaw.

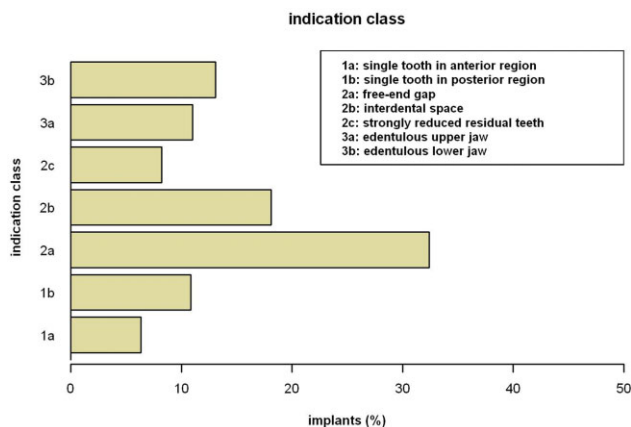


Figure 9 Distribution of implants in clinical indication classes (%).

(6.3%); posterior: 1,370 (10.8%)); 7,394 (58.0%) in partially edentulous patients (free-end situations: 4,079 (32%); interdental space: 2,284 (17.9%); heavily reduced residual teeth: 1,031 (8.1%); single tooth excluded); unknown: 131 (1.0%) (Figure 9). There were no significant differences in the CSRs between the indication classes ($p = .47$).

Implant Failures

Altogether, 319 implant failures were documented. Peri-implantitis (122/38.2%) and failed osseointegration (106/33.2%) were the main reasons for explanation. Further reasons were mechanical complications (30/9.4%), overloading (28/8.8%), and others (33/10.3%). To compare the implant failures with the time elapsed since implant placement, failures were divided into three sub-groups (≤ 6 months, 6–60 months, and >60 months). Failure time was associated with the reasons for explanation ($p < .001$). Failing osseointegration mainly occurred within the first 6 months after implant placement. Peri-implantitis as a reason for implant failure occurred in the three groups in similar amounts and was therefore the main reason for late implant failure. Overloading mainly took place in the 6 to 60 months group, whereas mechanical complications mainly occurred in the >60 months group (Figure 10).

Bone Quality

A large majority (63%) of the implants were placed in normal bone, whereas 26% were placed in weak (soft) bone, and 11% were placed in hard bone (Figure 11). The CSRs for the implants placed in normal and soft

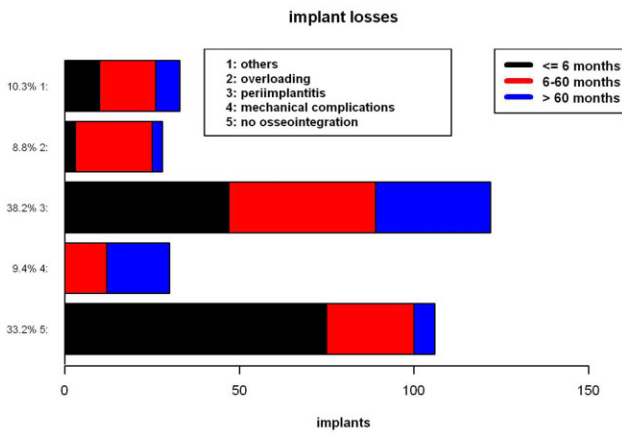


Figure 10 Distribution of implant failures.

bone were similar, but implants placed in hard bone had significantly lower CSRs ($p < .001$) throughout the entire observation period (Figure 12).

Bruxism

A minority of 423 patients (10.1%) were classified as bruxers. Although the CSRs of bruxers at 12 months (97.7%) were only 0.6% lower than that of nonbruxers (98.3%), the difference rose over time and reached 3.4% at 120 months (93.2%/96.6%), That was highly significant ($p < .001$) (Figure 13).

Bone Grafting

Bone-grafting or bone-expanding alveolar ridge procedures were used in conjunction with placement of 7,601 implants (59.7%). There was no significant difference between implants placed with and without bone grafting ($p = .42$).

Soft-Tissue Recessions and Bone Loss

After 204 months, no soft-tissue recession was noted around 63.9% of all implants, whereas 31.9% experi-

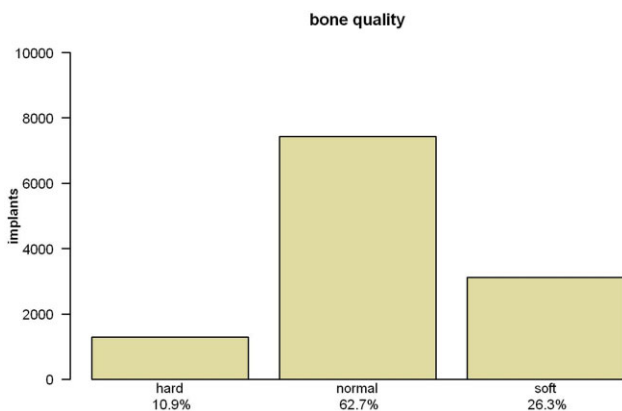


Figure 11 Distribution of bone quality.

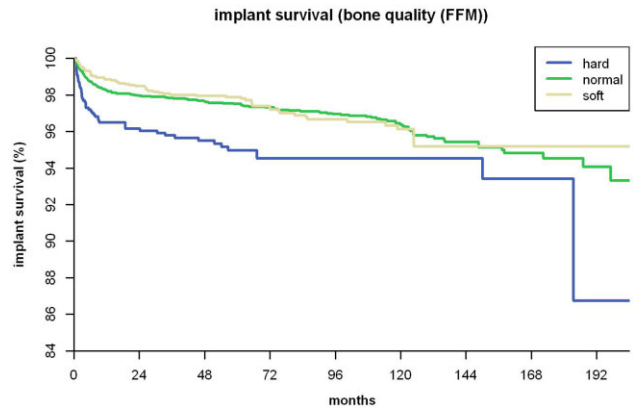


Figure 12 Kaplan–Meier cumulative survival rate (CSR) concerning bone quality.

enced recession that revealed part of the abutment, and 2.8% had recession that exposed the shoulder of the implant (Figure 14). Failed implants had significantly more horizontal ($p = .027$) and vertical ($p < .001$) crestal bone loss than surviving implants. Overall, after 204 months, 85.7% of all ANKYLOS implants showed a horizontal bone loss of ≤ 1 mm (≤ 1 mm: 126; 1–2 mm: 14; ≥ 2 mm: 7) (Figure 15), and 85.2% showed a vertical bone loss of ≤ 1 mm (≤ 1 mm: 115; 1–2 mm: 11; ≥ 2 mm: 9) (Figure 16).

DISCUSSION

As expectations regarding the survival time of dental implants have grown, long-term studies of large numbers of implants (>500) placed in fully and partially edentulous patients and followed for long periods of time have become increasingly important. On the other hand, long-term clinical follow-ups are difficult to

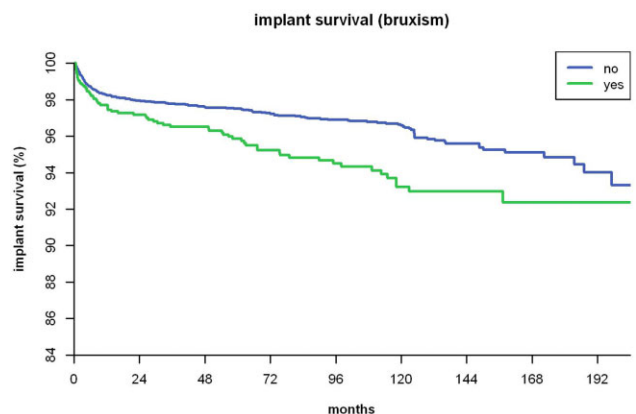


Figure 13 Kaplan–Meier cumulative survival rate (CSR) concerning bruxism.

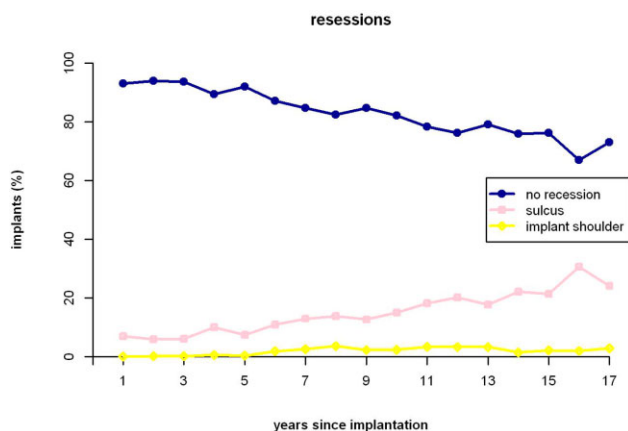


Figure 14 Percentage of dental implants with soft tissue recessions.

achieve. Patients who undergo implant therapy have a relatively high mean age. Some patients die after 10 to 20 years. Others may become too ill to keep appointments for clinical examinations, or they may move or lack the motivation to keep returning.^{20–22} All these factors may explain why few long-term studies exist to compare with the present one. Although 5- to 11-year data for more than 500 implants from different implant systems are available, and CSRs of between 82 and 99% have been reported^{11,15,19,23–29} (Table 1), data covering more than 11 years are rare and not completely comparable.

Snauwaert and colleagues²¹ split up their study group into compromised and noncompromised patients. Those who were grafted (with autologous bone) and underwent radiotherapy in the head and neck area were defined as compromised. In total, 4,971 Brånemark implants (Nobel Biocare USA, Yoba Linda,

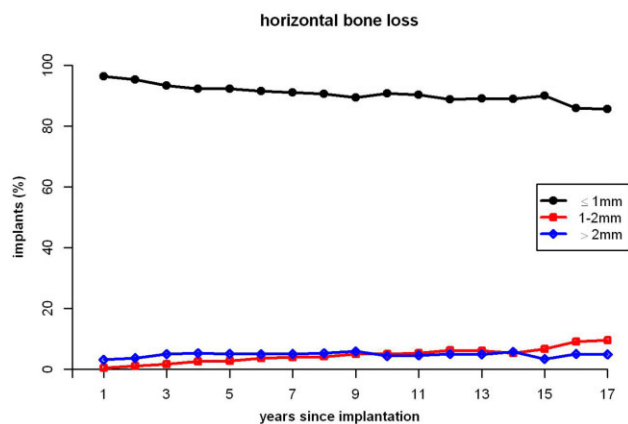


Figure 15 Amount of horizontal crestal bone loss.

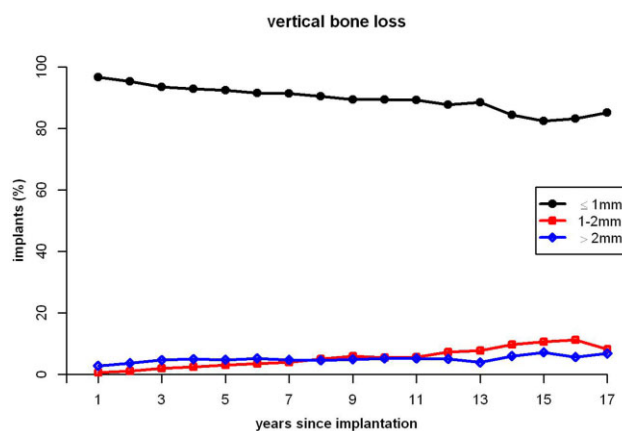


Figure 16 Amount of vertical crestal bone loss.

CA, USA) were installed and followed for up to 15 years; the average follow-up period was 5.1 years. No CSR was reported for the whole group but only for early and late failures. Absolute survival rates of 93.9% and 81% were reported for the noncompromised and compromised groups, respectively, yielding an absolute survival rate of 93% for both groups overall.

Naert and colleagues³⁰ surveyed more than 1,956 Brånemark implants that were placed in partially edentulous sites, restored with bridges and crowns, and followed for up to 16.5 years (average 5.5 years). Of the total, 379.5 implants were followed for up to 9 years, and 96.5 were followed for up to 12 years. The CSR for both subgroups was 91.1%. Only 2.5 implants were followed for up to 16 years; they also showed a CSR of 91.1%.

Some groups have reported 20-year data for limited numbers of Brånemark implants supporting fixed prostheses. For example, Lekholm and colleagues³¹ reported a 91% CSR for 69 implants placed by a single dentist and followed for 20 years. Astrand and colleagues²⁰ reported an absolute survival rate of 99.2% (but no CSR) for 123 implants placed in mandibles and/or maxillae of 21 edentulous patients, restored with fixed prostheses, and followed for 20 years. Ekelund and colleagues³² found a 20-year CSR of 98.9% in a group that received fixed bridges in edentulous jaws.^{31,32}

These studies may have limited relevance to the daily routine of the average dental practice. If a single highly experienced clinician is treating all the patients, his or her results may not represent those achievable by clinicians possessing average technical skills. Furthermore, studies often focus on the survival of implants placed in favorable locations in patients free from medical conditions or social behaviors that could be

TABLE 1 Five- to Eleven-Year Studies Reporting More Than 500 Implants

Article	Observation Time (Years)	Number of Implants	Type of Implants	Cumulative Survival Rate (%)
Perry & Lenchewski 2004	5	1,099	F2	90.05
Feldman et al. 2004	5	2,294	3i	97.70
Gomez-Roman et al. 1997	5	696	F2	96
Lazzara et al. 1996	5	1,969	3i	95
Carr et al. 2003	6.5	674	ITI	97
Brocard et al. 2000	7	1,022	ITI	92.20
Nedir et al. 2004	7	528	ITI	99.40
Buser et al. 1997	8	2,359	ITI	96.70
Willer et al. 2003	10	1,250	IMZ	82.40
Strietzel et al. 2004	11	1,554	F2	94.80

adverse to the implants' survival. Studies are more useful when they include the performance of implants placed in a broad array of patients and analyze such variables as the implant length and diameter, quantity and quality of bone, and absence or presence of various biomedical conditions.³³

No comparable data exists covering a large number of implants placed in fully and partially edentulous patients and followed for 17 years. The present study showed a 12-year CSR of 95.2% (involving 1,161 implants), whereas Naert and colleagues presented a 11.5- to 12-year CSR of 91.1% for 96 implants.

The annual follow-up appointment for patients included in the present study allowed for implants exhibiting any signs of mucositis or peri-implantitis to be identified and treated. Those with recurrent infections were removed, as were mobile implants and implants surrounded by a continuous radiolucency. Consequently, the cumulative success rates presented correspond to the CSRs observed.

Although Snauwaert and colleagues and several others^{21,34,35} found that gender did not affect implant failure rates, it was a significant factor in the present study, with a lower CSR found in men. Strietzel and colleagues presented a significantly higher failure rate in women.¹¹

Even though the CSR of the older patients (≥ 71) seemed to show higher early failure rates, age-related differences in the CSR were not significant. This finding is similar to the results of Carr and colleagues¹⁷ In contrast, Brocard and colleagues²³ showed the highest CSR for middle-aged patients (40–60: 88.6%) and a

significantly lower CSR for patients older than 60 years (78.1%).

A reason for the higher CSR of 14-mm long implants with a diameter of 3.5 mm in the present study might be that when peri-implantitis occurs, more bone loss must occur before the implant has to be removed. The similar CSRs of 8-, 9.5-, and 11-mm long implants and 3.5- and 4.5-mm diameter implants in the present study show the potential of short- and narrow-diameter implants. In the future, placement of short or smaller diameter implants without bone grafting may be adequate, obviating the need to place larger and/or wider implants in combination with bone grafting procedures. Buser and colleagues reported results for a much shorter observation period (8 years) in which 8-mm long ITI implants (Institut Straumann AG, Basel, Switzerland) had a slightly lower CSR (91.4%) than 10-mm long (93.4%) and 12-mm long (95.0%) implants. This was not significant.²⁴ Carr and colleagues¹⁷ reported that ITI implants with a diameter of 4.8 mm were 3.4 times more likely to fail than 4.1-mm implants. Perry and Lenchewski¹⁹ reported more failures of 3.4-mm Frialit-2 implants (CSR 85%) than 3.8-mm implants (CSR 93.16%), whereas 4.5-, 5.5-, and 6.5-mm implants were in between, after an observation time of 5 years.

Most studies have found significantly higher success rates after 5 to 11 years for implants placed in the mandible, as compared with the maxilla.^{11,21,24,35–40} Differences in bone quality and quantity have been discussed as potential causes for these differences. However, when Naert and colleagues³⁰ followed a similar number

of implants for 12 years, they found no significant differences between the jaws. The differences in CSRs between implants placed in the upper and lower jaw in the present study were not as high as those documented in other studies but were significant (1–3%). However, those differences were the opposite of what has previously been described.

The CSR of implants placed in the maxilla and followed for 204 months (17 years) was higher (94.7%) than the comparable mandibular implants (92.1%), and a significantly higher CSR was found for implants placed in soft- and normal-quality bone than in hard-quality bone. The authors speculate that the higher risk of overheating during preparation of the typically harder mandibular bone may explain the higher rate of early implant failures there. The weaker maxillary bone also enjoys better perfusion and nutrition, and this also may influence osseointegration and implant survival. Other reasons may include the consistent use of condensed implant bed preparation in soft bone to improve primary stability, the AI's progressive screw design, and the experience level of the surgeons.

Failed osseointegration and peri-implant infections were the main reasons for implant failure; early implant loss resulted from both, whereas peri-implantitis caused most of the late implant complications. Mechanical complications (implant or abutment fracture) and overloading occurred rarely (incidence = 0.2%) with overloading tending to occur immediately after delivery of the prosthesis. The risk of mechanical complications rose with the time elapsed after prosthetic insertion. The fact that differences in CSRs for patients classified as bruxers and nonbruxers also rose over time may be directly related to this.

Preventing positioning errors is a prerequisite when comparing multiple panoramic radiographs. Metric evaluations are difficult to reproduce, even with the use of intraoral periapical radiographs, so it is necessary to use radiopaque measurement references. In the present study, the implant dimensions were used as the reference. Even though panoramic radiographs present a lower resolution than intraoral radiographs, the accuracy in metric evaluations was proven to be below 0.1 mm that should be sufficient accurate for a longitudinal study.^{9–11} Evaluation of crestal bone loss was performed chair-side by the examiner, which may be less accurate than methods employing digital measurement. Within those limitations on accuracy, the documented

low rates of peri-implant bone loss (1 mm or less horizontally around 85.7% of the ANKYLOS dental implants and 1 mm or less vertically around 85.2%) after 204 months seem to be very promising. In 1986, Albrektsson and colleagues⁴¹ published a formula under which an implant could be considered a success if after 17 years, 4.7 mm of bone or less was lost around it (1.5 mm in the first year and 0.2 mm per year in succeeding years $[0.2 \text{ times } 16] = 1.5 \text{ mm} + 3.2 \text{ mm} = 4.7 \text{ mm}$). This was confirmed in the 1998 consensus report by Zarb and Albrektsson.⁴² Reasons for the low bone-resorption rate in the present study may include the platform shift incorporated in the design of ANKYLOS implants, as well as the strong morse taper connection, which helps to avoid micromovements under loading conditions.

CONCLUSION

ANKYLOS dental implants placed in edentulous and partially edentulous patients and followed for up to 20 years showed high CSRs (93.3% after 204 months). This was especially true for implants placed in the maxilla and in weak (soft) bone. Short and relatively narrow-diameter implants had CSRs that were similar to those of long and wide ones. Peri-implantitis was the main reason for late implant failures. The low rates of peri-implant crestal bone loss after 204 months (1 mm or less horizontally around 85.7% of the ANKYLOS implants and 1 mm or less vertically around 85.2%) show the potential of the key features in the ANKYLOS design, including the progressive thread design, the wide platform shift, and the morse taper connection.

CONFLICT OF INTEREST

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