A Long-Term Follow-up Study of Osseointegrated Implants in the Treatment of Totally Edentulous Jaws

Ragnar Adell, DDS, PhD/Bo Eriksson, BSc, PhD/Ulf Lekholm, DDS, PhD/
Per-Ingvar Brånemark, MD, PhD/Torsten Jemt, DDS, PhD

This study reviews the long-term outcome of prostheses and fixtures (implants) in 759 totally edentulous jaws of 700 patients. A total of 4,636 standard fixtures were placed and followed according to the osseointegration method for a maximum of 24 years by the original team at the University of Göteborg. Standardized annual clinical and radiographic examinations were conducted as far as possible. A lifetable approach was applied for statistical analysis. Sufficient numbers of fixtures and prostheses for a detailed statistical analysis were present for observation times up to 15 years. More than 95% of maxillae had continuous prosthesis stability at 5 and 10 years, and at least 92% at 15 years. The figure for mandibles was 99% at all time intervals. Calculated from the time of fixture placement, the estimated survival rates for individual fixtures in the maxilla were 84%, 89%, and 92% at 5 years; 81% and 82% at 10 years; and 78% at 15 years. In the mandible they were 91%, 98%, and 99% at 5 years; 89% and 98% at 10 years; and 86% at 15 years. (The different percentages at 5 and 10 years refer to results for different routine groups of fixtures with 5 to 10, 10 to 15, and 1 to 5 years of observation time, respectively.) The results of this study concur with multicenter and earlier results for the osseointegration method. (INT J ORAL MAXILLOFAC IMPLANTS 1990;5:347-359.)

Key words: Brånemark System□, long-term follow-up, oral implants, osseointegration, total edentulism

More than 200 papers, PhD theses, and monographs have been published to elucidate various aspects of the outcome of the osseointegration method,[1] which was originally introduced for the treatment of total edentulism.[2] The indications for its use have gradually been extended. Load-bearing titanium implants can now be permanently retained almost anywhere in the body where there is vital remodeling bone.[1]

The reliability of any clinical method depends on whether there is (*1*) a sufficiently large body of consecutive patient material, followed continuously; (*2*) an observation period that is long enough; and (*3*) a method that has been unchanged over years with regard to its basic, prognosis-determining characteristics. Additional demands may include that the results be (*1*) reproducible by other independent teams

after adequate training and (*2*) published in recognized scientific journals with a referee system.

Specific criteria for the acceptance of dental implants have been published by NIH.[3,4] More stringent demands were set forth by Albrektsson et al[5] and Shulman et al.[6] The latter authors emphasized the need for adequate statistical methods to be applied in the analyses of implant success rates. These papers constitute a background for the present study.

The marginal reactions at osseointegrated implants (fixtures) have been reviewed clinically, radiographically, histologically, and microbiologically in a series of studies[7-12] as required by Shulman et al.[6]

The aim of this report is to update the survival rates for fixtures and prostheses involved in the treatment of total edentulism after using the osseointegration method for 25 years.

Material and Methods

Material. The study involves 4,636 standard Brånemark System□ fixtures, placed in 759 totally edentulous jaws (ie, a gross mean of six fixtures per jaw) of 700 patients. Of this population, 56.8% were females and 43.2% males. The mean age at the time of fixture placement was 55.3 years (range 19 to 79 years). The majority of patients were referred to the reporting team because of problems with denture retention caused by severe or extreme bone resorption. According to the 15- and 10-year reports,[7,16] the material was divided into four groups (development group and routine groups I, II, and III) designated by time periods of fixture placement (Fig 1).

All fixtures—original as well as additional—were followed from their own time of placement ("year 0" for each individual fixture). The prostheses were also followed from "time 0" of their insertion. The observation times given for prostheses reflect maxillae. Because of the shorter healing periods for mandibular fixtures, mandibular prostheses in this report have observation times approximately 3 months longer than stated.

After appropriate healing, the fixtures were uncovered and provided with abutments to support fixed prostheses. All treatment was performed according to the standardized guidelines published by Brånemark et al.[1]

Fixture lengths varied throughout this study. Fixtures 10 mm in length were used in most development group and routine group I patients. In routine groups II and III, fixtures of different lengths were placed depending on the volume of bone present in each individual site. Abutment-fixture connections different from those of the routine groups were used in early parts of the development group. In this group the number of fixtures placed in each jaw varied considerably and their positions were at times less favorable with regard to the load later imposed by the prostheses. Healing times for fixtures were generally shorter in the development group than in the

routine groups.

During the entire investigation, the fixtures were, however, manufactured in such a way that they had the same biophysical and biochemical surface characteristics. Moreover, they were surgically placed by the same standardized procedure,[1] including pretapping of the sites, through all years. No self-tapping fixtures were included in this follow-up study.

Overviews of the data with respect to jaw and period of fixture placement are given in Tables 1 and 2. Partially edentulous patients or those with bone grafts were excluded, as these results have been reported elsewhere.[13-15] Only patients treated by the original team in Göteborg were included.

Participants in the study must have undergone stage 1 surgery for the placement of fixtures no later than 1 July 1985. For osseointegration to occur, bone requires a minimal healing period of 3 months in the mandible and 6 months in the maxilla with the fixtures isolated and unloaded. The above deadline was consequently necessary to achieve an observation time for prostheses in function of at least 1 year (Fig 2) by the closing date of the study, 1 March 1987.

Withdrawals. Patients were withdrawn from the study for either of two reasons:

1. Fixtures or prostheses that were placed late within the timeframe for each group and could not reach full observation time were withdrawn after their individual maximum observation times had been reached ("scheduled withdrawals"[6]; see column MX in Fig 3).
2. A limited number of patients could not be followed for their full observation periods because of severe illness, change of residence, death, or other reasons as reviewed below. ("withdrawals caused by loss of follow-up"[6]; see column WX in Fig 3).

An analysis was made of patients withdrawn because of loss of follow-up. A total of 143 patients did not appear for the final follow-up visit from 1 January 1986 to 1 March 1987 for the following reasons:

1. Sixty-four patients (44.8% of 143) had died; 18 of these patients belonged to the development group and another 25 to routine group I.
2. Fifty-six patients (39.2%) had, after treatment through the first years in Göteborg and a number of subsequent annual visits, been referred to other centers in Scandinavia closer to home. A retrieval analysis of computer data for these patients gave unreliable results that could not be included in this study.
3. Eight patients (5.6%) were on follow-up programs with extended intervals. Generally, they had an every-second-year recall program, and consequently missed the last follow-up appointment in this study. For several years these patients had demonstrated excellent oral hygiene, stable prostheses, and no

periabutment gingivitis. Their radiographs had shown stable marginal bone height. These patients were exceptions to the requisite of annual follow-up.

4. Four patients (2.8%) were known to be in foreign countries.
5. Three patients (2.1%) reported themselves to be too ill to attend.
6. Three patients (2.1%) were contacted but refused to come.
7. Three patients (2.1%) were not checked.
8. Two patients (1.4%) had moved to unknown addresses.

Data registrations. Basic data comprising identification numbers for each patient, jaw, and fixture were computerized early during the osseointegration project. New patients were continuously added, together with dates for fixture, abutment, and prosthesis insertion, removal, or fracture. Other registrations of information beyond the scope of this investigation were also made. Patients treated before the start of these computerized follow-ups, or not included in the foregoing reports,[7,16] were updated/added on the basis of their clinical records. All patients were continuously followed with regular check-ups, the intention being that every patient should be clinically evaluated at least once every year. Standardized intraoral radiographs,[17] examined by independent specialists, were taken at regular intervals (generally after 1, 3, 5, 7, and 10 years).

Prosthesis stability was checked manually every year. To be considered stable, no saliva was seen moving at the prosthesis abutment connection during attempts to pivot the prosthesis manually. Percussion tests must have given a high-pitched metallic sound with no discomfort to the patient.

In patients whose original fixtures failed, supplementary implants were placed provided that less than two well-spaced and osseointegrated fixtures on each side of the midline remained per jaw. During the healing of supplementary fixtures, patients could usually wear their initial restoration supported by the remaining original fixtures. After the placement of abutments on supplementary fixtures, new prostheses were usually fabricated. The patients did not use a removable denture at any time. Such a series of events was regarded as a continuous prosthesis stability. Likewise, patients using only one prosthesis (framework), even if facings and/or teeth were replaced because of attrition or other type of wear, were considered to have continuously stable prostheses. Patients who temporarily or permanently had to resort to removable conventional dentures were excluded from the group characterized as having continuous prosthesis stability.

Jaws in which all fixtures were lost temporarily also lost continuous prosthesis stability and consequently were not registered as such. The same conditions applied to jaws with a permanent loss of all fixtures. When jaws with a temporary loss of all fixtures later were reoperated, the new fixtures were followed from their new

placement dates.

For fixtures to be recorded as osseointegrated, they must have been stable at the abutment connection operation. At the actual annual check-up it was seen that they were connected to a stable prosthesis as previously described. In all radiographs there was evidence of a direct bone-to-fixture connection with no perifixtural radiolucency. If fixture fracture or perifixtural radiolucent space was suspected, the prosthesis was removed and individual manual fixture mobility tests were performed. At irregular intervals, clinically stable prostheses were also removed for individual fixture mobility checks. Such tests were also performed whenever restorations were removed for prosthetic services. Mobile fixtures were removed, and the sites were curetted and closed. If a fixture had fractured and a sufficiently long apical portion remained, it was repaired, reused,[18] and then registered as stable but fractured.

With or without radiographic examination, annual check-ups could not always be carried out strictly within the predetermined month. However, as far as possible, all patients were checked annually.

Statistical Methods. Statistical analysis involved the construction of lifetables for fixtures and prostheses as well as the study of proportions. The estimated survival rates were constructed according to standard techniques,[19] as suggested by other authors for similar purposes.[6,20,21] A discussion with special relevance to the present report can be found in the paper by Shulman et al.[6] An example of a lifetable for the present study is shown in Fig 3.

The aim of analysis was to estimate a series of "survival" rates (the survival curve), describing how the original cohorts of jaws/prostheses and fixtures were successively reduced as the observation time increased. The time from prosthesis or fixture placement to removal was considered the lifespan (age). To construct the survival rates, conditional risks of prosthesis or fixture removal were estimated for each year of "age." The numerator in such an estimate was the number of events in the age interval. The denominator was the number of prostheses or fixtures that survived and were followed over the full year, plus half the number of fixtures that were withdrawn during the same year.

Log rank tests[22] were used to compare the overall survival rate of prostheses but were not regarded adequate for fixture survivals for reasons given below. Comparisons at specific points in time were made, relating differences to their standard errors.

The survival times of fixtures in the same patient would be expected to be stochastically dependent. Hence, the standard errors based on all fixtures should be too small. Two approaches were used to try to overcome this problem (see Tables 7 to 12). In the first (I), individual lifetables were constructed for each patient and the survival rates at 5, 10, and 15 years were used as observations (that is, one considers

a sample of patients and the standard errors are derived from this sample). In the other approach (II), the Greenwood formula[23] for the standard error of survival rates was modified.[24] A component of variance reflecting the variation in failure risk between patients was then included. The total variance was estimated using the estimated conditional risks for individual patients. Approach II generally gives somewhat larger standard errors than approach I.

Results

In Tables 3 through 8 the results are reviewed with regard to the outcome per jaw, and in Tables 9 through 12 and Figs 4 and 5 with regard to individual fixture results. The tables show the survival percentages for the annual segments of the material that reached 5, 10, and 15 years of "age," while Figs 4 and 5 are based on each annual survival rate for fixtures. The proportions of jaws with continuous prosthesis stability for the full observation period are shown in Tables 3 and 4.

An estimated continuous prosthesis stability was achieved for 95% or more of the maxillae after 5 and 10 years. At 15 years the percentages were at least 92%. For mandibles, 99% of the prostheses remained continuously stable at all time intervals, and for routine group II 100% remained continuously stable.

Eleven patients temporarily lost all maxillary fixtures but later received new fixtures and prostheses. There were seven such patients in the development group, three in routine group I, and one in routine group II. A permanent loss of all maxillary fixtures occurred in nine patients. These failures appeared for five patients in the development group, three in routine group I, and one in routine group II. There were no patients with a temporary loss of all mandibular fixtures. Only three individuals had a permanent loss of all mandibular fixtures. This occurrence implied a permanent return to a conventional denture. One of these patients was in the development group, one in routine group I, and one in routine group III. The patients who permanently lost all fixtures either did not want to undergo another fixture placement operation or had become too old or too ill for such an operation. A temporary or permanent loss of all fixtures implied that such jaws never were registered as having continuous prosthesis stability.

The percentages of jaws in which one fixture placement operation sufficed to rehabilitate the patient are reviewed in Tables 5 and 6. These were consequently the patients without supplementary fixtures to maintain prosthesis stability. At 5 years, 88%, 89%, and 98% of the maxillae were without supplementary fixtures in the routine groups; at 10 years 80% and 89%; and at 15 years 76%. For mandibles in the routine groups, 91%, 97%, and 99% of the jaws did not require supplementary fixtures. At 10 years this was still true for 86% and 96%, and at 15 years for 83% of the jaws.

Individual fixture survival rates calculated from the time of fixture placement are shown in Tables 7 and 8 and Figs 4 and 5. At 5 years, the estimated percentage of

stable and prosthesis-supporting maxillary fixtures was 84% for routine group 1, and 89% and 92% for routine groups II and III. At 10 years, the estimated fixture survival rate exceeded 80%, and at 15 years it was 78% for routine group I. For mandibles, the corresponding estimated survival rates exceeded 90% at 5 years, and they were even more than 95% for routine groups II and III. At 10 years, the survival rates were 89% and 98%, and at 15 years in routine group I they were 86%.

Without regard for specific fixture groups, the following summarizing results were obtained for routine group fixtures when calculated from time of fixture placement. The survival rate for all maxillary (routine group) fixtures was 89% (87;90) at 5 years and 81% (79;83) at 10 years. The survival rate for all mandibular (routine group) fixtures was 97% (97;98) at 5 years and 95% (94;96) at 10 years.

If the abutment connection was assumed to be a starting point for evaluation of fixture survival rates, results were even better according to Tables 9 and 10. They were about 6% improved for maxillary and mandibular fixtures in routine group I, 2% better for routine group II maxillary fixtures, and 1% better for routine group III maxillary fixtures.

The log rank test comparing all annual data (not only at 5, 10, and 15 years) showed no significant differences between the groups for maxillae and mandibles with regard to continuous prosthesis stability (Tables 3 and 4).

Fractures were recorded for less than 5% of the fixtures (Tables 11 and 12). The exception was routine group I maxillary fixtures, which experienced a 13% and 16% fracture rate after 10 and 15 years, respectively.

Discussion

For the edentulous patient, successful, continuous long-term use of a stable prosthesis matters much more than the outcome of individual fixtures. In this study, an estimated continuous prosthesis stability was present for more than 95% of the maxillae at 5 and 10 years in all groups (Table 3) and for at least 92% of the jaws at 15 years. In mandibles, 99% (for routine group II, 100%) had continuous prosthesis stability in all groups at 15 years. These results could be compared with those for fixed prostheses supported by natural teeth, which are about 90% after 5 to 10 years, as reported in studies on this subject.[25-27]

A more academic evaluation of the osseointegration method can be done with the survival rates for individual fixtures as a basis. In contrast to earlier studies,[7,16] in which fixture survival rates were reported based on the time of abutment connection, Tables 7 and 8 and Figs 4 and 5 in this study review the percentages of stable, prosthesis-supporting fixtures from the time of fixture placement. In spite of this more demanding form of presentation using the statistical lifetable approach and extended observation periods, the estimated individual fixture survival rates for the routine groups in this report match and even exceed those reported in 1981.[7] They also concur with those of multicenter studies.[28,29] Finally, the estimated routine

group results satisfy and exceed the theoretic demands proposed by Albrektsson et al [5] for an 85% 5-year and an 80% 10-year individual implant survival rate. The only formal exception to meeting the aforementioned criteria involved maxillary fixtures in routine group I, the estimated survival rates of which were 84% instead of 85% at 5 years. However, at 10 years they were 81%, thus exceeding the 80% limit.

By way of summary, the survival rates for fixtures— being 89% at 5 years (routine groups I, II, III), 81% at 10 years (routine groups I, II), and 78% at 15 years (routine group I only) for all maxillary fixtures, and 97% at 5 years (routine groups I, II, III), 95% at 10 years (routine groups I, II), and 86% at 15 years (routine group I only) for all mandibular fixtures—should be regarded as generalized results of this investigation. Because routine group I still implied some learning of possible limits of the method for the authors, other factors are involved in assessing the survival rates. However, it should be observed that the summarizing results all exceeded the 5-year 85% and 10-year 80% individual implant success rate levels proposed by Albrektsson et al.[5]

When evaluated from the time of abutment connection (Tables 9 and 10), the results were 1% to 6% better in the routine groups, since fixtures that were not osseointegrated during the healing process had been excluded.

The percentages of fractured fixtures were small (Tables 11 and 12). When occurring, they appeared to be more of a historical problem. Reasons for the significantly higher frequency of maxillary fixture fractures in routine group I compared with routine groups II and III and their treatment have been discussed in detail by Adell et al[7] and Lekholm et al.[18] When there was an insufficient length of internal threads for repair, fixtures with fractures in the apical third were sometimes removed regardless of osseointegration status. This fact is relevant when survival rates for maxillary fixtures in routine group I are evaluated.

Except for the survival rates for continuously stable prostheses and the percentages of fractured fixtures, the results of all examinations indicate that better results were achieved in the routine groups compared to the development group. Better results for individual fixture survival rates were also observed when routine groups II and III were compared with the first group. These outcomes were interpreted as following a distinct learning curve. The development group patients were treated during a period when knowledge from experimental animal studies[2] was being successively transformed to the human clinical situation. More total losses of all fixtures in individual patients were observed in the development group than for any of the routine group jaws. This outcome was likely to be related to a desire to test the possible limits of the method and an attempt to help needy but technically difficult patients. During the treatment of patients in the development group, only one fixture length was available. Consequently, it was not always possible to take full advantage of all bone present in a certain fixture site, eg, the canine eminence. In light of present knowledge of adequate load distribution,[30,31] too few or too many

fixtures per jaw were placed at times. Moreover, occasionally they were asked to assume too much cantilever load. The main factor in assessing the mandibular fixture survival rates in this group probably was the reduced healing time during this period.

It can also be concluded from Tables 5 and 6 that more than one fixture placement operation was frequently needed in the development group to maintain prosthesis stability. Increasing experience through the routine groups dramatically decreased the need for reoperation, to become just a few percent for mandibles in routine groups II and III.

Sex or age differences between the groups did not suggest an explanation for the increasingly positive results. Moreover, later routine groups included higher numbers of jaws with minimal amounts of bone left, constituting borderline situations which were not regarded as treatable during the early parts of the osseointegration project. Finally, it should be emphasized that teams in the multicenter studies[28,29] were not required to experience learning periods, as did the authors of this report. Consequently, they were provided with a fully developed method whose potential for success is illustrated by their results.

Except for continuous prosthesis stability, all results indicated somewhat better survival rates for mandibles than for maxillae. As emphasized in other studies,[7,13,14,16] this outcome was frequently the result of a small available bone volume below the nose and between the sometimes expanded maxillary sinus recesses. Buccopalatally, residual bone was often quite thin. Maxillae generally offered very little mechanical resistance during the surgical placement of fixtures. The only cortical reinforcement to initially support the fixtures was frequently the cortical lining of the nose or the maxillary sinus. With these quantitative and qualitative maxillary deficiencies, it is surprising that the survival rates for prostheses and fixtures were so positive. Experience suggests that maxillae should be regarded as difficult for the unexperienced and a challenge for the experienced surgeon and prosthodontist. The higher numbers of mandibles compared to maxillae operated on in routine groups II and III reflect the authors' respect for these challenges. It should be emphasized that the majority of both maxillae and mandibles in this, as well as in the 1981 study,[7] were severely resorbed. Consequently, the jaw bone anatomy in most situations was less than ideal for treatment.

With a mean of 55.3 years (SD 10.6) and a slight predominance of women (56.8%), the age and sex distribution data did not differ significantly from that reported in the 1981 paper.[7] The range for age at the time of fixture placement was expanded from 19 to 79 years of age, indicating an increased range of applicability of the method.

In spite of the fact that a central core of patients comprised the 1981[7] and the present study material, it would be quite misleading to assume that the data

presented herein represents a simple mathematical extension of the 1981 study[7] with longer observation times. There were several reasons for differences in material composition and results:

1. Partially edentulous patients were excluded from the present material, as they have been separately analyzed elsewhere[15]; however, they were included in the 1981 review.[7]
2. Supplementary data to include patients belonging to the development and routine I and II groups were added.
3. Earlier computerized errors were corrected.
4. The lifetable statistical analysis method was regarded as much more accurate[6] than the mean results for 5-year periods as presented 1981.[7]

A team of professional people more or less interested in this kind of long-term study, working with 700 patients for up to 24 years and producing annual data involving approximately 4,600 fixtures, incurred great risks related to the accuracy of recording and tabulating data. A larger number of checks, ie, comparing clinical and computer records and computerized probability tests was carried out during the preparation of this paper. Any subsequent missing data or errors were corrected.

More precise determination as to whether fixtures were osseointegrated could have been achieved if the prostheses were detached annually and individual manual fixture stability tests performed. However, such an approach was regarded as too time-consuming and cumbersome for the patients. Annual detachment of the restorations could furthermore have implied additional wear of components. Actually, such examinations were only carried out randomly at the time of prosthesis adjustments.

The statistical approach used two categories of analysis—jaws and fixtures. The choice of category was not a matter of methodological procedure, but related rather to the objective of the investigation. An extremely small-scale theoretical experiment could have implied that a number of fixtures was placed into one jaw. To obtain a reasonable number of fixtures, multiple jaws were required. Since they were not identical in those characteristics that determined fixture survival, the observations of survival time for fixtures in the same jaw were to some extent stochastically dependent on each other. Two approaches were explored to handle this situation. The second one (II), using a modified variance formula,[23,24] was considered the most reliable alternative. To the authors' knowledge, the problem of stochastically dependent survival times has not been fully dealt with and will be the subject of a forthcoming paper.[24]

Every patient could not be followed for the full observation time as originally scheduled. The loss of patients who died compromised the long-term follow-up, but was regarded as a natural outcome of these patients having reached advanced ages.

Not unexpectedly, they exclusively belonged to the two "oldest" groups. Treated patients who were referred to other centers were not sent back until they had reached a steady state with no treatment anticipated other than annual follow-ups. Consequently, their withdrawal from late follow-ups was not regarded as a compromise to the overall results.

Conclusion

This study indicates that the osseointegration method has been basically unchanged; has a large, consecutively followed body of subject material; and has a sufficiently long observation period. The results have been analyzed as recommended by Shulman[6] and others.[20,21] They parallel and even exceed the demands for dental implantation methods set forth by Albrektsson et al[5] and concur with the outcome of multicenter investigations in which independent teams with long-term experience participated.[26,27]

Based on the reviewed results and numerous other investigations, routine treatment of edentulism with fixed prostheses supported by osseointegrated fixtures appears to be a highly efficient method, giving predictable long-term results in large patient populations.

Acknowledgment

The keen, laborious and most professional contributions by instruction nurse Barbro Svensson, senior programmer Jonny Lindqvist, secretary Christina Wikström, and nurses at the Brånemark Clinic are gratefully acknowledged.

1. Brånemark P-I, Zarb G, Albrektsson T(eds): *Tissue-Integrated prostheses: Osseointegration in Clinical Dentistry*. Chicago, Quintessence Publ Co, 1985.

2. Brånemark P-I, Breine U, Adell R, Hansson BO, Lindström J, Ohlsson Å: Intra-osseous anchorage of dental prostheses. I. Experimental studies. *Scand J Plast Reconstr Surg* 1969;3:81-100.

3. US Department of Health and Human Services: *Dental Implants: Benefit and Risk.* National Institutes of Health—Harvard Consensus Development Conference 1980.

4. US Department of Health and Human Services: National Institutes of Health Consensus Development Conference Statement: *Dental Implants*, 1988.

5. Albrektsson T, Zarb G, Worthington P, Eriksson AR: The long-term efficacy of currently used dental implants: A review and proposed criteria of success. *Int J Oral Maxillofac Implants* 1986;1:11-25.

6. Shulman LB, Rogoff GS, Savitt ED, Kent RL: Evaluation in reconstructive implantology. *Dent Clin North Am* 1986;30:327-349.

7. Adell R, Lekholm U, Rockler B, Brånemark P-I: A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. *Int J Oral Surg* 1981;6:387-416.

8. Adell R, Lekholm U, Rockler B, Brånemark P-I, Lindhe J, Eriksson B, Sbordone L: Marginal tissue reactions at osseointegrated titanium fixtures. I. A 3-year longitudinal prospective study. *Int J Oral Maxillofac Surg* 1986;15:39-52.

9. Adell R, Lindvall AM, Strid KG, Eriksson B, Brånemark P-I, Lekholm U: Marginal bone reactions at osseointegrated fixtures—Variations with surgical technique and radiographic examination methods. A prospective study. *Int J Oral Maxillofac Implants*, submitted for publication, 1990.

10. Cox JF, Zarb G: The longitudinal clinical efficacy of osseointegrated dental implants: A 3-year report. *Int J Oral Maxillofac Implants* 1987;2:91-100.

11. Lekholm U, Adell R, Lindhe J, Brånemark P-I, Eriksson B, Rockler B, Lindvall AM, Yoneyama T: Marginal tissue reactions at osseointegrated titanium fixtures. II. A cross-sectional retrospective study. *Int J Oral Maxillofac Surg* 1986;15:53-61.

12. Lekholm U, Eriksson I, Adell R, Slots J: The condition of the soft tissues at tooth and fixture abutments supporting fixed bridges. A microbiological and histological study. *J Clin Periodontol* 1986;13:558-562.

13. Adell R, Lekholm U, Gröndahl K, Brånemark P-I, Lindström J, Jacobsson M: Reconstruction of severely resorbed edentulous maxillae using osseointegrated

fixtures in immediate autogenous bone grafts. *Int J Oral Maxillofac Implants* 1990;5:233-246.

14. Breine U, Brånemark P-I: Reconstruction of alveolar jaw bone. An experimental and clinical study of immediate and preformed autologous bone grafts in combination with osseointegrated implants. *Scand J Plast Reconstr Surg* 1980;14:23-48.

15. Jemt T, Lekholm U, Adell R: Osseointegrated implants in the treatment of partially edentulous patients. A preliminary study on 876 consecutively placed fixtures. *Int J Oral Maxillofac Implants* 1989;4:211-217.

16. Brånemark P-I, Hansson BO, Adell R, in cooperation with Breine U, Lindström J, Hallén O, Öhman A: Osseointegrated oral implants in the rehabilitation of the edentulous patient. Experience from a 10-year period. *Scand J Plast Reconstr Surg* 1977;11(suppl 16).

17. Strid KG: Radiographic results and Radiographic procedures, in Brånemark P-I, Zarb G, Albrektsson T (eds): *Tissue-Integrated Prostheses. Osseointegration in Clinical Dentistry*. Chicago, Quintessence Publ Co, 1985, pp 187-198, 317-327.

18. Lekholm U, Adell R, Brånemark P-I: Complications, in Brånemark P-I, Zarb C, Albrektsson T (eds): *Tissue-Integrated Prostheses. Osseointegration in Clinical Dentistry*. Chicago, Quintessence Publ Co, 1985, p 239.

19. Colton T: *Statistics in Medicine.* Boston, Little, Brown and Co, 1974.

20. Hansson BO: Success and failure of osseointegrated implants in the edentulous jaw. *Swed Dent J* 1977;1(suppl 1).

21. Schwartz O, Bergman P, Klausen B: Autotransplantation of human teeth. A lifetable analysis of prognostic factors. *Int J Oral Surg* 1985;14:245-258.

22. Kalbfleish JD, Prentice RL: *The Statistical Analysis of Failure Time Data*. New York, Wiley, 1980.

23. Cox DR, Oakes D: *Analysis of Survival Data*. London, Chapman and Hall, 1984, pp 48-51.

24. Eriksson B: On the analysis of survival times for dependent individuals. *Stat Med*, to be submitted, 1991.

25. Izikowitz L: Långtidsprognos för broar med friändssadlar. *Tandläkartidningen* 1984;76: 577- 586.

26. Karlsson S, Hedegård B: Efterundersökning av patienter med större brokonstruktioner. Del II: Klinisk undersökning på patienter behandlade under 1974-1975 av privattandläkare. *Tandläkartidningen* 1984;76: 1425-1434.

27. Nyman S, Lindhe J: A longitudinal study of combined periodontal and prosthetic

treatment of patients with advanced periodontal disease. *J Periodontol* 1979;50:163-169.

28. Albrektsson T: A multicenter report on osseointegrated oral implants. *J Prosthet Dent* 1988;60:75-84.

29. Albrektsson T, Dahl E, Enbom L, Engevall S, Engquist B, Eriksson AR, Feldmann G, Freiberg N, Glantz PO, Kjellman O, Kristersson L, Kvint S, Köndell PÅ, Palmquist J, Werndahl L, Åstrand P: Osseointegrated oral implants. A Swedish multicenter study of 8139 consecutively inserted Nobelpharma implants. *J Periodontol* 1988;59:287-296.

30. Skalak R: Aspects of biomechanical considerations, in Brånemark P-I, Zarb G, Albrektsson T (eds): *Tissue-Integrated Prostheses. Osseointegration in Clinical Dentistry.* Chicago, Quintessence Publ Co, 1985, pp 117-128.

31. Rangert B, Jemt T, Jörneus L: Forces and moments on Brånemark implants. *Int J Oral Maxillofac Implants* 1989;4:241-247.

Table 1 Age and Sex of Patients at Fixture Placement

	Age (years)		Sex	
Group	Mean	SD	Females (%)	Males (%)
Development	53.2	9.5	57.4	42.6
Routine I	53.3	10.3	62.8	37.2
Routine II	53.0	10.6	64.3	35.7
Routine III	57.5	10.6	49.7	50.3
Total	55.3	10.6	56.8	43.2
Mandibles	55.9	9.7	57.9	42.1
Maxillae	51.9	10.4	55.0	45.0

Table 2 Number of Fixtures and Jaws at Time of Fixture Placement

Group (Period of fixture placement)	Maxillae		Mandibles		Total	
	Fixtures	Jaws	Fixtures	Jaws	Fixtures	Jaws
Development (1 July 1965-30 June 1971)	229	33	155	28	384	61
Routine I (1 July 1971-30 June 1976)	524	80	480	83	1004	163
Routine II (1 July 1976-30 June 1981)	394	58	869	143	1263	201
Routine III (1 July 1981-30 June 1985)	642	106	1343	228	1985	334
Total	1789	277	2847	482	4636	759

Table 3 Proportions land 95% confidence intervals) of Maxillae With Continuous Prosthesis Stability 5, 10, and 15 Years after Prosthesis Placement According to Group (period of fixture placement)

	Years after prosthesis placement			
Group	5	10	15	20
Development	100% (90;100)	97% (89;100)	92% (82;100)	*
Routine I	96% (89;1003	95% (87;100)	93% (83;100)	
Routine II	100% (90;100)	98% (85;100)		
Routine III	98% (88;100)			

**Too few observations for statistical analysis.*
No significant differences between groups at any 5-year interval.

Table 4 Proportions (and 95% confidence intervals) of Mandibles With Continuous Prosthesis Stability 5,10, and 15 Years After Prosthesis Placement According to Group (period of fixture placement)

	Years after prosthesis placement			
Group	5	10	15	20
Development	99% (90;100)	99% (88;100)	99% (86,100)	*
Routine I	99% (89;100)	99% (87;100)	99% (85;100)	
Routine II	100% (90;100)	100% (88;100)		
Routine III	99% (91;100)			

**Too few observations for statistical analysis.*
No significant differences between groups at any 5-year interval.

Table 5 Proportions (and 95% confidence intervals) of Maxillae With Only One Fixture Placement Operation 5,10, and 15 Years after Prosthesis Placement According to Group (period of fixture placement)

	Years after prosthesis placement			
Group	5	10	15	20
Development	34%	34%	29%	*
	(13;54)	(11;56)	(7;50)	
Routine I	88%	80%	76%	
	(79;96)	(69;89)	(63;88)	
Routine II	89%	89%		
	(78;98)	(75;100)		
Routine III	98%			
	(90;100)			

**Too few observations for statistical analysis.*
Significant differences were present at 5 years for any of the routine groups versus the development group, at 10 years for routine groups I and II versus the development group, and at 15 years for routine group I versus the development group.

Table 6 Proportions (and 95% confidence intervals) of Mandibles With Only One Fixture Placement Operation 5,10, and 15 years After Prosthesis Placement According to Group (period of fixture placement)

	Years after prosthesis placement			
Group	5	10	15	20
Development	53%	32%	32%	*
	(34;70)	(12;52)	(10;54)	
Routine I	91%	86%	83%	
	(83;99)	(76;97)	(69;98)	
Routine II	97%	96%		
	(89;100)	(87;100)		
Routine III	99%			
	(90;100)			

**Too few observations for statistical analysis.*
Significant differences were present at 5 years for any of the routine groups versus the development group, at 10 years for routine groups I and II versus the development group, and at 15 years for routine group I versus the development group.

Table 7 Proportions (and 95% confidence intervals) of Maxillary Stable Prosthesis Supporting Fixtures 5,10, and 15 Years After Placement of Fixtures According to Group

	Years after fixture placement			
Group	5	10	15	20
Development	55%	46%	44%	*
	I(44;66)	I(34;58)	I(32;56)	
	II(41;69)	II(30;62)	II(26;62)	
Routine I	84%	81%	78%	
	I(79;89)	I(74;88)	I(66;90)	
	II(76;92)	II(73;89)	II(68;88)	
Routine II	89%	82%		
	I(83;95)	I(74;90)		
	II(81;97)	II(72;92)		
Routine III	92%			
	I(87;97)			
	II(86;98)			

**Too few observations for statistical analysis.*
Significant differences were present at 5 years for any of the routine groups versus the development group and for routine group III versus routine group I, at 10 years for routine groups I and II versus the development group, and at 15 years for routine group I versus the development group. I and II refer to different methods of calculating confidence intervals.

Table 8 Proportions (and 95% confidence intervals) of Mandibular Stable Prosthesis Supporting Fixtures 5,10, and 15 Years After Placement of Fixtures According to Group

	Years after fixture placement			
Group	5	10	15	20
Development	75%	64%	61 %	*
	I (65;85)	I (52;76)	I (46;76)	
	II (65;85)	II (45;83)	II (44;78)	
Routine I	91%	89%	86%	
	I (87;95)	I (85;93)	I (79;92)	
	II (86;96)	II (82;96)	II (77;93)	
Routine II	98%	98%		
	I (96;100)	I (95;100)		
	II (96;100)	II (95;100)		
Routine III	99%			
	I (97;100)			
	II (96;100)			

**Too few observations for statistical analysis.*
Significant differences were present at 5 years for any of the routine groups versus the development group and for routine groups II and III versus routine group I, at 10 years for routine groups I and II versus the development group and for routine group II versus routine group I, and at 15 years for routine group I versus the development group. I and II refer to different methods of calculating confidence intervals.

Table 9 Proportions (and 95% confidence intervals) of Maxillary Stable Prosthesis-Supporting Fixtures 5, 10, and 15 Years After Connection of Abutments According to Group

	Years after fixture placement			
Group	5	10	15	20
Development	59%	50%	47%	*
	I(48;70)	I(39;61)	I(37;57)	
	II(44;74)	II(36;64)	II(31;63)	
Routine I	91%	87%	84%	
	I(86;96)	I(80;94)	I(75;93)	
	II(83;99)	II(78;96)	II(70;98)	
Routine II	91%	84%		
	I(85;97)	I(77;91)		
	II(81;99)	II(77;91)		
Routine III	93%			
	I(87;99)			
	II(86;99)			

**Too few observations for statistical analysis.*
Significant differences were present at 5 years for any of the routine groups versus the development group, at 10 years for routine groups I and II versus the development group, and at 15 years for routine group I versus the development group. I and II refer to different methods of calculating confidence intervals..

Table 10 Proportions (and 95% confidence intervals) of Mandibular Stable Prosthesis Supporting Fixtures 5,10, and 15 Years After Connection of Abutments According to Group

	Years after fixture placement			
Group	5	10	15	20
Development	81 %	68%	65%	*
	I (71;91)	I (56;80)	I (50;80)	
	II (70;92)	II (53;82)	II (47;83)	
Routine I	98%	96%	92%	
	I (91;100)	I (92;100)	I (85;99)	
	II (91;100)	II (92;100)	II (84;99)	
Routine II	99%	98%		
	I (97;100)	I (96;100)		
	II (97;100)	II (94;100)		
Routine III	99%			
	I (96;100)			
	II (95;100)			

**Too few observations for statistical analysis.*
Significant differences were present at 5 years for any of the routine groups versus the development group, at 10 years for routine groups I and II versus the development group, and at 15 years for routine group I versus the development group. I and II refer to different methods of calculating confidence intervals.

Table 11 Proportions (and 95% confidence intervals) of Maxillary Fractured Fixtures 5,10 and 15 Years After Placement of Fixtures According to Group

	Years after fixture placement			
Group	5	10	15	20
Development	0%	3%	6%	*
	I (0;5)	I (0;9)	I (1;14)	
	II (0;5)	II (0;9)	II (0;14)	
Routine I	7%	13%	16%	
	I (1;15)	I (5;21)	I (8;24)	
	II (1;15)	II (5;21)	II (8;24)	
Routine II	2%	5%		
	I (0;8)	I (0;11)		
	II (0;8)	II (0;12)		
Routine III	1%			
	I (1;5)			

**Too few observations for statistical analysis.*
Significant differences were present at 5 years for routine groups II and III versus routine group I, and at 10 years for routine group II versus routine group I. I and II refer to different methods of calculating confidence intervals.

Table 12 Proportions (and 95% confidence intervals) of Mandibular Fractured Fixtures 5,10, and 15 Years After Placement of Fixtures According to Group

	Years after fixture placement			
Group	5	10	15	20
Development	0%	I%	3%	*
	I (0;6)	I (0;8)	I (0;12)	
	II (0;6)	II (0;8)	II (0;13)	
Routine I	3%	4%	4%	
	I (0;9)	I (0;10)	I (0;11)	
	II (0;9)	II (0;10)	II (0;12)	
Routine II	I%	I%		
	I (0;6)	I (0;8)		
	II (0;6)	II (0;8)		
Routine III	0%			
	I (0;5)			
	II (0;5)			

**Too few observations for statistical analysis.*
No significant differences between groups at any 5-year interval. I and II refer to different methods of calculating confidence intervals.

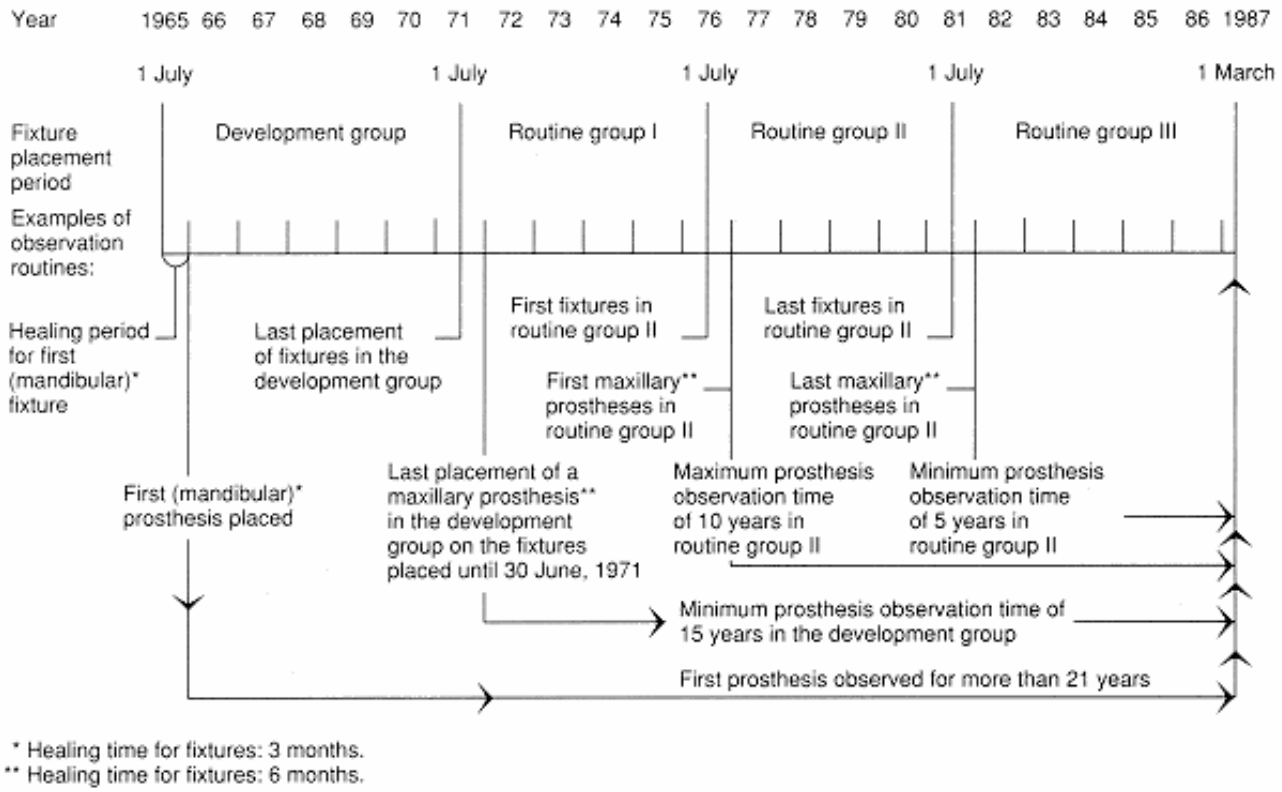
Year
1965 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 1987
1 July
1 July
1 July
1 July
1 March
Fixture placement period
Development group
Routine group I
Routine group II
Routine group III
Examples of observation routines:
Healing period for first (mandibular)* fixture
Last placement of fixtures in the development group
First fixtures in routine group II
Last fixtures in routine group II
First maxillary** prostheses in routine group II
Last maxillary** prostheses in routine group II
First (mandibular)* prosthesis placed
Last placement of a maxillary prosthesis** in the development group on the fixtures placed until 30 June, 1971
Maximum prosthesis observation time of 10 years in routine group II
Minimum prosthesis observation time of 5 years in routine group II
Minimum prosthesis observation time of 15 years in the development group
First prosthesis observed for more than 21 years
* Healing time for fixtures: 3 months.
** Healing time for fixtures: 6 months.

Fig.

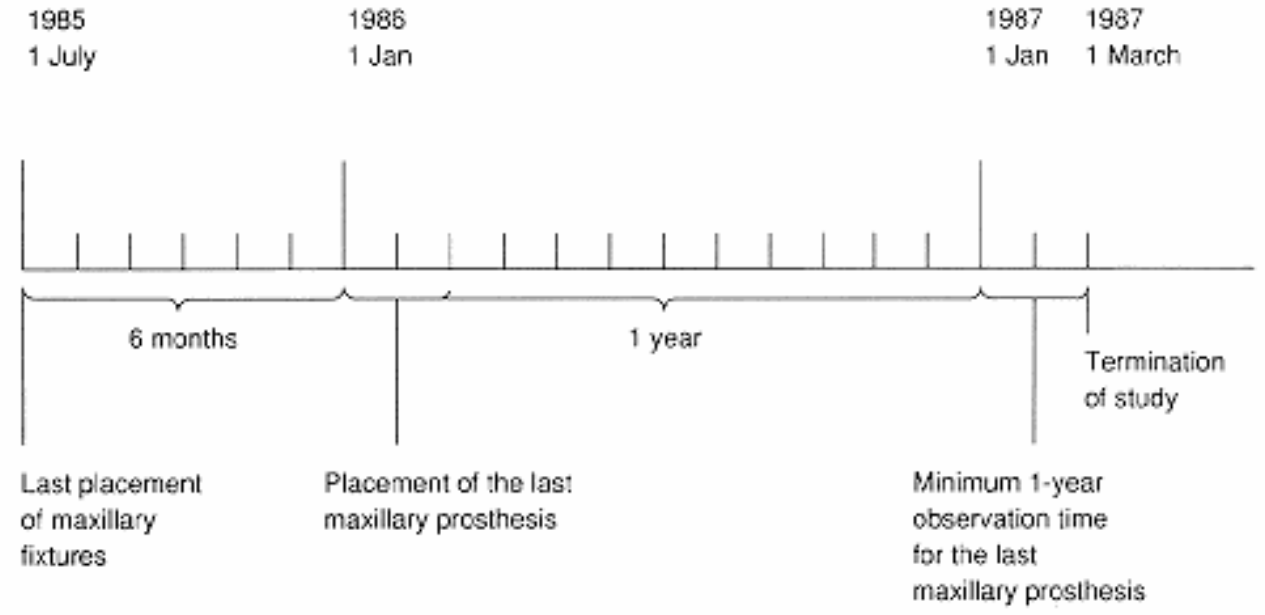
1985
1 July
1986
1 Jan
1987
1 Jan
1987
1 March
6 months
1 year
Termination of study
Last placement of maxillary fixtures
Placement of the last maxillary prosthesis
Minimum 1-year observation time for the last maxillary prosthesis

Fig.

YEAR GROUP		OX	DX	WX	MX	QX	CUM PX
0–1	YR	869	9	0	12	0.0104287	0.989571
1–2	YR	848	3	11	1	0.0035629	0.986045
2–3	YR	833	1	0	0	0.0012005	0.984862
3–4	YR	832	1	8	6	0.0012121	0.983668
4–5	YR	817	1	18	26	0.0012579	0.982431
5–6	YR	772	1	9	133	0.0014265	0.981029
6–7	YR	629	0	6	167	0.0000000	0.981029
7–8	YR	456	2	12	207	0.0057720	0.975367
8–9	YR	235	0	5	154	0.0000000	0.975367
9–10	YR	76	0	0	76	0.0000000	0.975367

Fig. from time of placement in mandibles for routine group ll (maximum observation time 10 years). OX is the number of fixtures present at the beginning of each year. DX is the number of mobile and/or removed fixtures annually. WX is the number of withdrawals because of loss of follow-up, eg, five during the second year; MX is the number of scheduled withdrawals because fixtures could not reach the maximum 10 years of observation time, as not all were placed during the first year. For example, 76 fixtures were placed during the first and 154 during the second year. QX is the proportion of fixtures removed in each interval. CUM PX is the cumulative success rate.

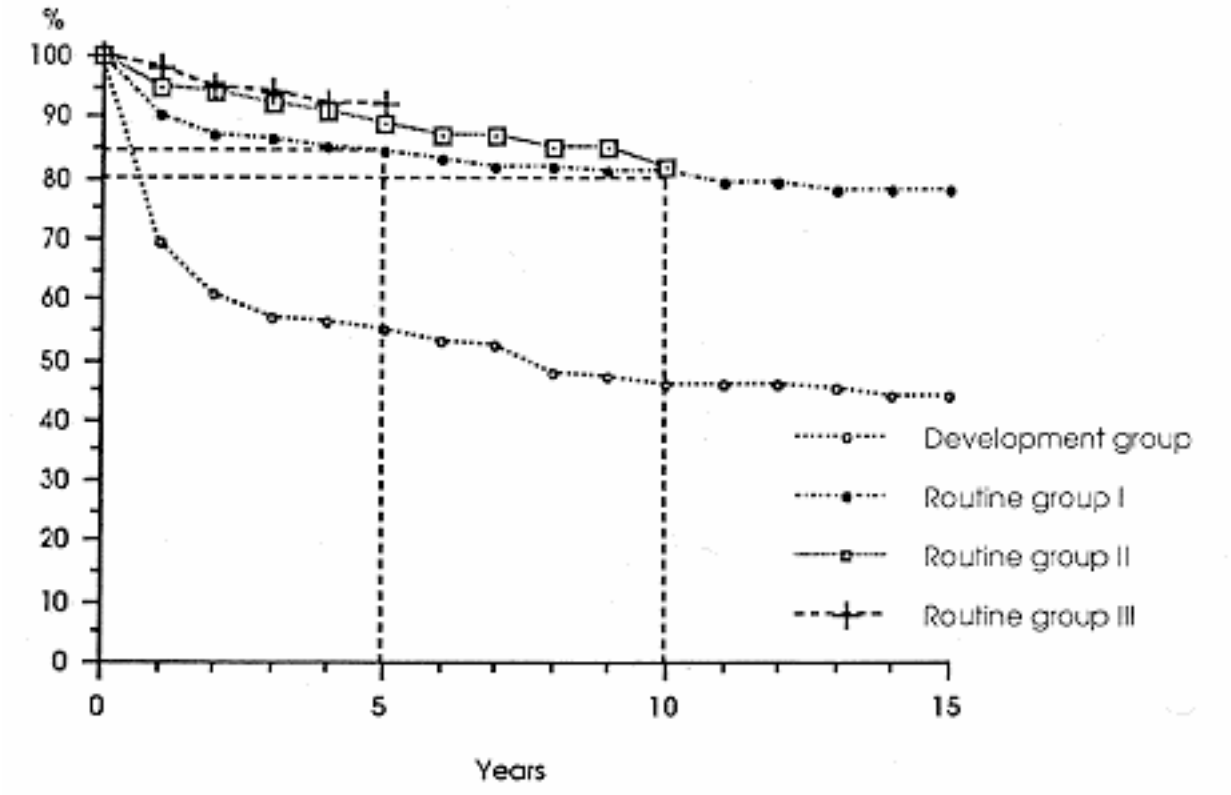

Fig. 4

Annual success rates for individual fixtures in maxillae calculated from time of fixture placement. Five-year 85% and 10-year 80% levels are indicated. Note that the results of all routine groups equal or exceed these levels.

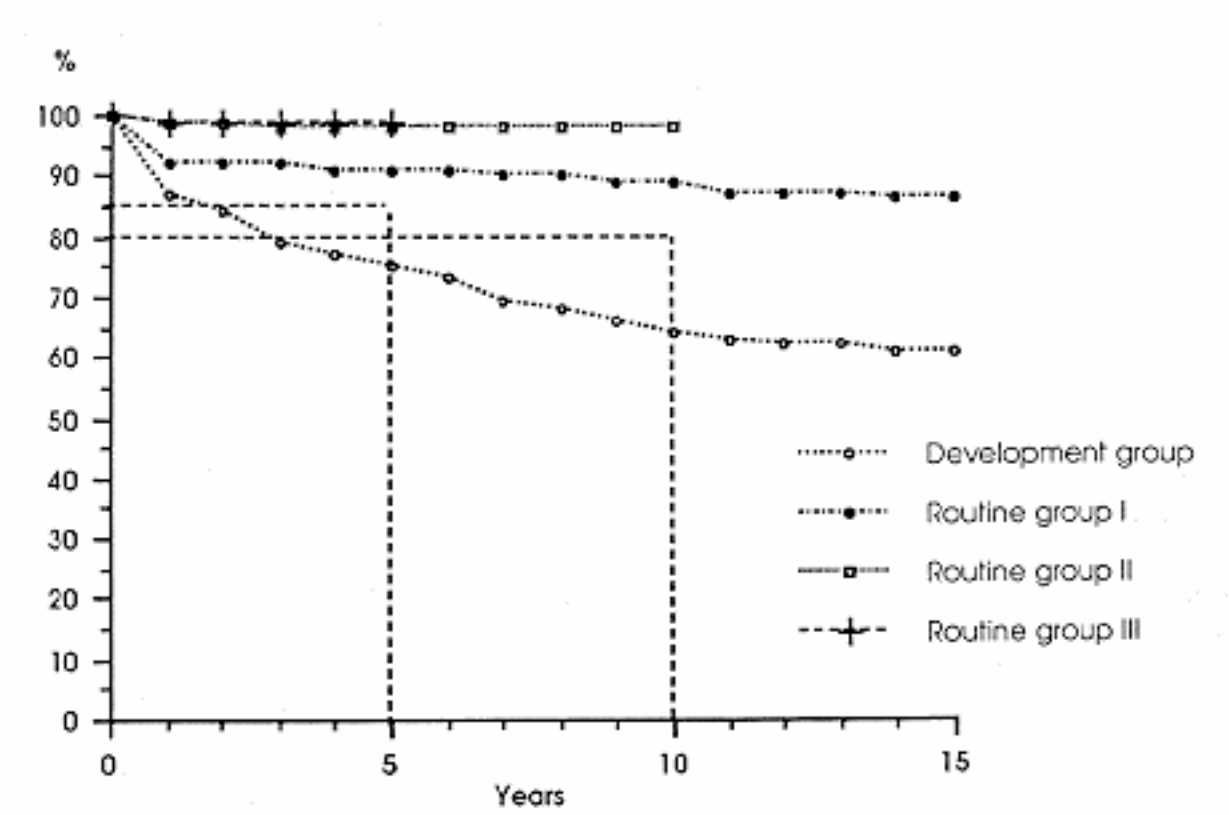

Fig. 5

Annual success rates for individual fixtures in mandibles calculated from time of fixture placement. Five-year 85% and 10-year 80% levels are indicated. Note that the results of all the routine groups considerably exceed these levels.