

The Use of Angulated Abutments in Implant Dentistry: Five-Year Clinical Results of an Ongoing Prospective Study

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A total of 2,261 2-stage implants was placed in 467 patients in combination with angled abutments ranging from 0 to 45 degrees. These were observed over a period of up to 96 months, with a mean observation time of 28.8 months. Single and multiple teeth were replaced and restored using angled abutments. For patients who contributed multiple survival data, the data were considered dependent. Therefore, a mean survival estimation was performed. With a certainty of 95%, an estimated mean survival rate better than 98.6% after a 5-year observation period was calculated. The statistical comparison of 2 independent, randomized implant groups (with abutments angled between 0 and 15 degrees and between 20 and 45 degrees) by means of a log-rank test showed a probability of 0.84 (P value) that the survival functions are the same for both groups. Good esthetic and functional outcomes were observed. (INT J ORAL MAXILLOFAC IMPLANTS 2000;15:801-810)

Key words: dental abutments, osseointegrated dental implants, survival analysis

The placement of endosseous dental implants has become an increasingly common practice. Some implants, especially some oral implants of the past, are poorly documented or have not been followed up for an adequate time period.¹ It is important to use an implant system that is adequately supported by clinical reports. Well-documented implant systems such as the Brånemark (Nobel Biocare, Göteborg, Sweden) or Frialit-2 (Friadent, Mannheim, Germany) show high success rates. For follow-ups of more than 5 years, the Brånemark System has shown success rates of 85% to 100% in the maxilla and 93% to 99% in the mandible.^{2,3} The Frialit-2 implant system has shown success rates of 97.6% when used for single-tooth replacement and 98.8% in immediate postextraction applications.⁴ Comparable success

rates have also been found by several other studies and different dental implant systems.⁵⁻¹³

To date, there have been no long-term published studies that have assessed the effect of non-axial loading on the bone supporting the implants. The anatomy of the jaws and the morphology of the residual ridges determine the orientation and angulation of implant placement. Similarly, the position and morphology of the teeth are determined by esthetic and functional considerations. In the majority of situations, there is a difference between the long axis of the implant and the long axis of the planned tooth replacement.

The purpose of this article was to present preliminary results of the clinical long-term behavior of implants restored using a broad range of angulated abutments.

MATERIALS AND METHODS

The study was designed prospectively and was performed at the Centre for Implant and Reconstructive Dentistry, London, United Kingdom. Since March 1991, 467 patients (55% female) have been included in the study. These patients were provided with a total of 2,261 implants to replace missing

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Table 1 Distribution of Implants Placed According to Location and Gender

Gender/Arch	No. of arches	No. of implants placed
Female		
Maxilla	194	831
Mandible	111	420
Male		
Maxilla	168	680
Mandible	80	330
Total	553	2261

teeth with fixed restorations or to provide support and retention for removable prostheses. The patient group comprised 256 females and 211 males with an age range from 17 to 83 years at the date of implant surgery. The mean age was 49.6 years. The distribution of implants placed is given in Table 1.

The implants used were custom-made, parallel-sided, commercially pure titanium screws with a machined surface. The implants had an internal hex and thread to provide positive location and a means of securing the abutment to the implant. The machined pre-angled abutments had an external hex to orient to the implant and a screw to secure them to the implant. These were manufactured from titanium alloy at angles ranging from 0 to 45 degrees in 5-degree increments.

Patient Selection

All patients at the Implant Centre who chose dental implants as a treatment option, or patients who were referred for implant treatment to the Centre for Implant and Reconstructive Dentistry, were included in the study if there were no contraindications for implant treatment.

Treatment Procedure

The treatment procedure included a diagnostic phase, a pre-implant surgical phase for augmentation if necessary, a surgical phase for the placement and exposure of the implants in 2 stages, and a prosthetic phase. A maximum number of implants of the largest possible dimension was placed in each arch according to the surgical protocol summarized below.

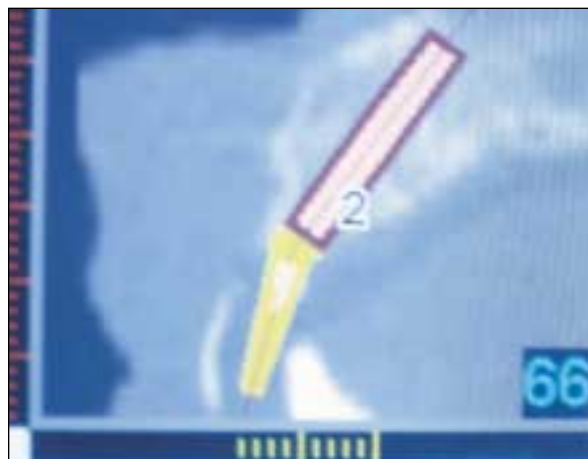


Fig 1 Cross-sectional image of a CT scan showing a maxillary implant, in the planning stage, positioned between the labial and palatal cortical plates. With the pre-angled abutment attached, it lies within the prosthetic envelope defined by the radiopaque marker on the labial surface and the mandibular incisor. The abutment therefore emerges within the space allocated for the restoration.

Diagnostic Protocol. Clinical examination was carried out to assess the status and the periodontal tissues of any remaining teeth. Clinical examination also included assessment of occlusal and parafunctional status and the soft tissues, including attached gingiva, muscle attachments, and the lip line.

Radiographic examination was carried out for all patients, including an orthopantomograph and other radiographs as required. Periapical radiographs were taken for assessment of detail, lateral cephalographs for the assessment of bone width in the midline and facial profile, and computed tomographic (CT) scans for the assessment of bone volume and quality in patients requiring multiple implants, particularly in the posterior mandible. Furthermore, CT scans were used for the assessment of abutment angulation (Fig 1).

A diagnostic preview (via an arrangement of teeth in wax) was used to establish the most esthetically pleasing and functionally viable tooth position. A diagnostic template was fabricated over the plaster duplicate of the preview to outline the prosthetic envelope within which the abutment must fit.¹⁴ Where inadequate bone was present, a variety of procedures were used to augment the region, either prior to the placement of implants or at the time of implant placement.

Implant Surgery. Implant Placement. Access to the bony ridge was obtained using remote incisions whenever possible. Remote palatal incisions were used in the maxilla, and remote buccal incisions were used in the mandible. The implant sites were



Fig 2a Implants in situ, placed using a diagnostic template to identify the site for the implant osteotomy. Implant angulation is determined anatomically, with the implants placed between the cortical plates.

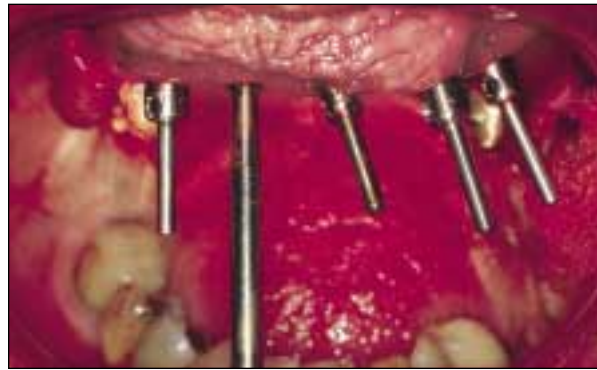


Fig 2b Zero-degree try-in abutments are inserted into the implants, demonstrating the divergent angulation of the abutments. This is caused by the morphology of the maxilla, whose base forms a smaller arc than the alveolar crest.

selected and a diagnostic template was used whenever appropriate. The treatment procedure was modified on the basis of bone quality and jaw shape according to Lekholm and Zarb.¹⁵

Osteotomies were prepared within the available bone and between the labial and palatal cortical plates. Internally irrigated osteotomy burs were used in the mandible and maxilla at speeds ranging from 1,000 to 2,000 RPM. Sterile saline was delivered by an internal cannula to the cutting edges of the burs.¹⁶ The burs were used to create the osteotomy atraumatically and precisely and as a gauge to measure the depth of the osteotomy. The diameter of the osteotomy was enlarged incrementally using gradually wider burs matched to the implant diameters.

Bone taps were used in types 1 and 2 bone for all implant diameters and in type 3 bone for 4.5-mm- and 5.5-mm-diameter implants, because of the increased torque required for implant placement. Socket formers were used in the maxilla, either by themselves or in conjunction with ridge expanders and/or osteotomy burs, depending on the clinical situation. In types 3 and 4 bone socket formers that matched the implant diameter were used to create the osteotomy. For thin maxillary ridges, socket formers were used in conjunction with ridge expanders to widen narrow maxillary ridges.¹⁷ Osteotomy burs were used to determine depth and prepare the apical area in dense bone. In the posterior maxilla, where limited bone height was present, socket formers were used to raise the sinus floor to create height, using sinus floor manipulation.¹⁸⁻²¹ This was done in conjunction with osteotomy burs.

Abutment Alignment and Selection. Abutment alignment and selection were carried out during first-stage surgery (implant placement) using try-in



Fig 2c Correctly angled try-in abutments in place, showing parallelism and alignment, which will facilitate the prosthetic restoration.

abutments ranging from 0 to 45 degrees in 5-degree increments.²² The try-in abutments corresponded to definitive abutments and were used in conjunction with the diagnostic template (Figs 2 and 3). Restorative angles and plane of orientation were evaluated for the screw-retained abutments (or angled healing abutments) so that pre-machined definitive abutments would be available at second-stage surgery. The restorative angle and orientation were noted on the patient record form and data sheet. The wound was closed; the primary provisional prosthesis was then modified to compensate for any alteration in the gingival contours and fitted.

Implant Exposure. This procedure was carried out 6 months after implant placement for both mandibular and maxillary implants. The implant was exposed and the cover screw was removed. The pre-angled abutments that were selected at the time of implant placement were seated (Fig 4), and the



Fig 3a A try-in abutment at first-stage surgery for a single-tooth replacement is selected to fit within the prosthetic envelope as outlined by the diagnostic template.



Fig 3b Multiple try-in abutment positions are verified for mesiodistal and buccopalatal alignment using a diagnostic template. This is to ensure adequate space for prosthetic reconstruction.



Fig 4 Occlusal view of multiple definitive abutments attached at second-stage surgery. These lie within the space allocated for each tooth of the restoration (as verified by the template) and can be seen to be aligned with each other.

angle and orientation of the abutments were confirmed using the template. The height of each abutment was also assessed using the template and the patient's occlusion and was modified if necessary.

The fixing screw was inserted through the correctly aligned and seated abutment and tightened to 32 Ncm, using counter torque applied via artery forceps. Primary stability of the implant was confirmed by percussion and the absence of turning when rotational forces were applied to the implant while tightening the screw. The hex hole of the screw was filled with wax, and the screw access hole was sealed with a glass-ionomer cement. Implant sites were allowed to heal for a period of 4 weeks prior to the fabrication of definitive restorations.

Transitional Restorations. Transitional restorations were fabricated from acrylic resin to provide the patients with esthetic and functional restorations, fitted at the time of abutment attachment. The design of the restoration was based on the diagnostic

preview or try-in and allowed the transfer of tooth form and position. The restorations were fabricated hollow to receive the abutment and were relined at the time of exposure. In a limited number of patients, pre-angled healing abutments were used; on these occasions, the provisional restoration was appropriately modified for the transitional period.

Prosthetic Phase. Fixed restorations were fabricated as single crowns supported by 1 implant, or as a prosthesis supported by multiple implants using splinted crowns. Most fixed restorations were cement-retained and were fabricated using conventional laboratory protocol for conventional cement-retained restorations. Thirty-eight implants supported connected restorations, and 2 single crowns used lateral fixation screws for supplementary retention. One restoration was fabricated for screw retention and was supported by 6 implants.

For removable restorations, a variety of protocols was used. A total of 24 implants was placed for the retention of dentures; 1 implant failed and was subsequently replaced. Removable prostheses were retained using ball attachments, bar and clips, and attachments mounted on bars.

Implants used to stabilize traditional removable prostheses primarily provided retention. Thus, these prostheses were supported by both implants and soft tissues. Four implants in the maxilla and 2 in the mandible were used for the retention of these prostheses. The number of stages varied considerably, depending upon the mechanism used for retention.

Patient Recall. Follow-up of patients after prosthetic restoration was performed according to the protocol given in Table 2. Radiographs were normally obtained after implant placement, 1 week after loading, at 6, 12, 18, and 24 months after placement of the definitive prosthetic restoration,

and annually thereafter. To assess bone levels, periapical radiographs were taken using the long-cone technique and Rinn paralleling system (RinnXCP film holders, Rinn Corporation, Elgin, IL). When periapical radiographs did not provide an accurate result, orthopantomographs provided a radiographic overview (Planmeca PM 2002 CC Proline panoramic x-ray, Planmeca Oy, Helsinki, Finland).

Clinical assessment involved visual examination, recording of clinical parameters (bleeding on probing, pocket depth, and implant mobility), as well as occlusal examination in centric relation and during lateral excursions. Patient feedback and any complications were addressed as appropriate. When necessary, oral hygiene instructions were given to ensure that a plaque-free environment could be maintained. The ideal aid to oral hygiene was selected based on access. This was confirmed by plaque disclosure at each visit, and the technique was modified until the appropriate level of hygiene was achieved.

Calculations and Statistics

All calculations were carried out using a personal computer. The data were transferred into a database format (Microsoft Access, Microsoft, Redmond, WA). Statistical analyses were performed with a statistical program (JMP, SAS Institute Inc, Cary, NC).

Because some patients contributed multiple survival data, dependent information from the data could not simply be excluded.²³ Therefore, a mean survival estimation according to Aalen et al²⁴ was performed using SAS software (SAS Institute Inc).

To compare survival estimates according to the Kaplan-Meier method, a 1-implant-per-patient selection, supported by a randomization procedure, was performed to obtain independent information from the data.²⁵ This was performed as follows: for each patient who contributed multiple survival data, only 1 implant was chosen for survival analysis. In situations where 1 or more of a patient's implants failed, only 1 of the failures was considered for analysis. Either the failed implant that was placed first or, in cases where several failed implants were placed at the same time, only 1 of the failures was chosen by computerized randomization. In cases where none of the implants had failed thus far, only the implant that was placed first was considered for analysis. A computerized randomization was performed when several implants had been placed at the same time. This data selection was considered as worst-case selection. Survival curves were then compared using the log-rank test.²⁶

Table 2 Follow-up Protocol

Time since loading	Procedure
1 week	Clinical assessment Baseline radiographs Oral hygiene instruction
1 month	Clinical assessment
3 months	Clinical assessment Oral hygiene instructions
6 months	Clinical assessment Radiographs Oral hygiene instructions
12 months	Clinical assessment Radiographs Oral hygiene instructions
18 months	Clinical assessment Radiographs Oral hygiene instructions
24 months	Clinical assessment Radiographs Oral hygiene instructions
Every 2-3 years	Prosthesis removed for assessment of individual implants

RESULTS

Patients Lost to Follow-up

There were 467 patients with a total of 2,261 implants included in the study. Eighty-one patients (17.3%) with a total of 379 implants (16.8%) were lost to follow-up. Fifty-five patients (11.8%) were referred patients who did not attend the recall program and were monitored by their referring dentist. Fourteen patients (3%) did not comply with requests to attend for monitoring, 8 patients (1.7%) moved away from the area and were unable to attend regularly, and 4 patients (0.8%) are deceased. The reasons for loss of follow-up are summarized in Table 3.

Intraoperative Complications

In the posterior mandible, no damage to the inferior dental nerve (IDN) took place because the depth of the osteotomy was measured to be 2 mm clear of the IDN. When implants were placed in the anterior mandible, the mental foramen was exposed and the osteotomies prepared so that the completed osteotomy was at least 3 mm anterior to the foramen.

Placement of implants in the maxilla involved the engagement of the opposing cortical plate whenever possible. In a small but unrecorded number of osteotomy preparations, the nasal or sinus floor was inadvertently perforated. The implant length that was selected reached only to 1.0 mm below the point at which the perforation took place. Therefore, no

Table 3 Patients Lost to Follow-up

Reason for loss	No. of patients
Referred patients not attending recall	55 (11.8%)
Non-compliance	14 (3%)
Patient moved away	8 (1.7%)
Deceased	4 (0.8%)
Total	81 (17.3%)

implants were placed into the sinus or the nasal floor, and no adverse consequences were noted.

Because of the protocol concerning the anatomic placement of implants between the cortical plates, very few incidences of dehiscence through the labial or cortical plates were noted. These were not recorded and were not considered significant.

Postoperative Complications

Infection originating from the cover screw dead space did occur. Twelve implants were treated by removing the cover screw and, while irrigating the internal hex and thread, introducing an antibiotic (gentamicin) and reinserting the cover screw. This led to uneventful healing.

Soft tissue breakdown was seen, which led to premature exposure of 15 implants. The implants that were prematurely exposed were treated by uncovering the implants and attaching healing abutments, which were left unloaded for the remainder of the 6-month healing period. None of the implants treated in this way failed.

Implant Loss

A total of 2,261 implants was placed between March 1991 and May 1999; of these, 38 implants failed during the observation period, and 2,223 remain in situ. Twelve implants failed prior to exposure because of infection, and 16 implants failed at exposure. Three implants failed before prosthetic treatment could be started as a result of excessive bone loss around the implants. The cause for this has not been determined. Two implants failed prior to completion of the restorative phase. Five implants were lost after the completion of the restorative phase, but 3 of these implants were successfully replaced and connected to the existing prosthesis. Two implants were not replaced, but the restorations continue to function, since the implants were considered unnecessary for the long-term survival of the restorations.

Frequency of Implant Lengths and Diameters

Figure 5 depicts the frequency of different implant lengths used. The majority of the implants (92%)

were more than 10 mm long. Figure 6, depicting the frequency of diameters used, demonstrates that the majority of implants used were 3.75 mm in diameter. A disproportionately small number of 5.5-mm implants were used because they were only recently introduced to the practice (1997).

Frequency of Abutment Angulations

The entire range of angles available was used and is depicted in Fig 7. The majority of the angles used ranged between 5 and 30 degrees (2,039 or 90.2%). A small number (222 or 9.8%) of 0-, 35-, 40-, and 45-degree abutments were also used. This enabled a greater number of patients to be treated without compromise of ideal implant placement according to available anatomic conditions.

There were no implant or abutment failures associated with the use of angled abutments. Furthermore, there was no incidence of screw loosening associated with angled abutments. The use of angled abutments allowed restorations to be parallel and aligned with each other. Cement-retained prostheses could be fabricated for these patients, which furthermore allowed them to be connected together, providing cross-arch splinting as well as facilitating the management of failed implants.

Survival Analysis

The duration of observation since placement of the implants was between 0 and 96 months, with a mean observation time of 28.8 months. Figure 8 depicts the distribution of implants with regard to time since placement. Fifty percent (median) of all implants were placed within 21.6 months prior to the last observation. In addition, the box plot shows the 25% quartile (9.9 months) and the 75% quartile (41.7 months).

Figure 9 depicts the mean survival estimation following placement, according to Aalen et al.²⁴ For each patient who contributed multiple survival data, the data were considered dependent. After an observation time of 60 months (5 years) after placement, the calculated 95% confidence interval of the mean survival estimation according to Aalen et al.²⁴ was 99% ($\pm 0.4\%$). Therefore, with a certainty of 95%, the mean survival probability after 5 years can be considered better than 98.6%.

Figure 10 depicts the survival analysis of 2 selected groups of implants. A total of 467 implants was selected according to the aforementioned "worst-case" selection procedure. The survival analysis according to Kaplan-Meier of implants with abutment angulation of more than 15 degrees ($n = 219$) was compared with implants restored with abutments that were angulated at 0 to 15 degrees

Fig 5 Frequency of implant lengths used in the patient population.

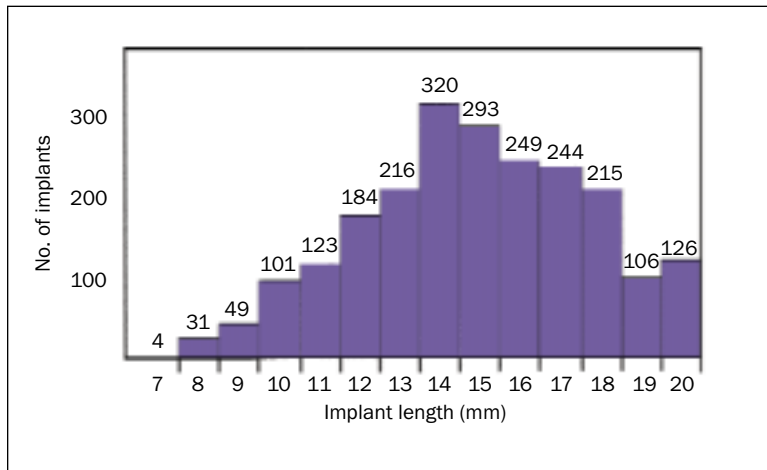


Fig 6 Frequency of implant diameters used.

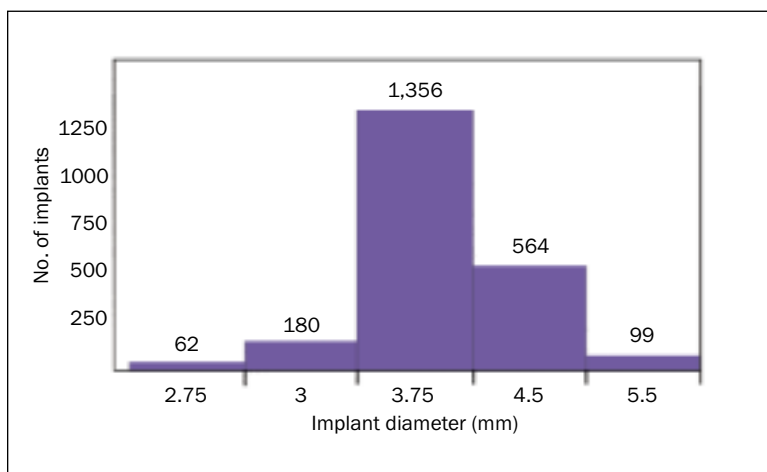
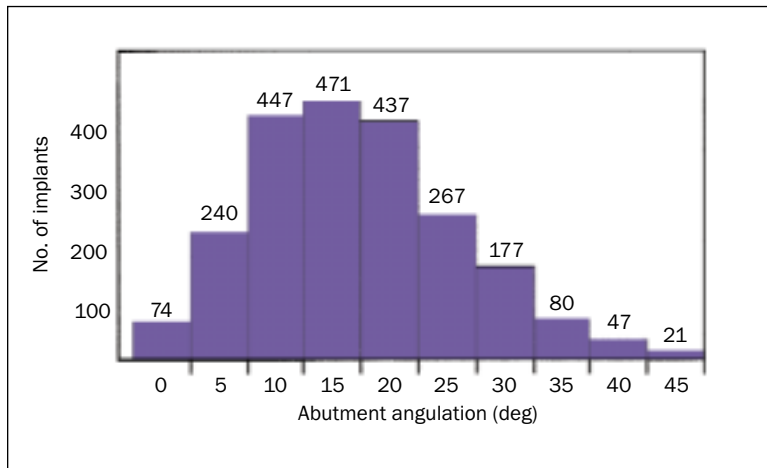


Fig 7 Frequency of abutment angulations used.



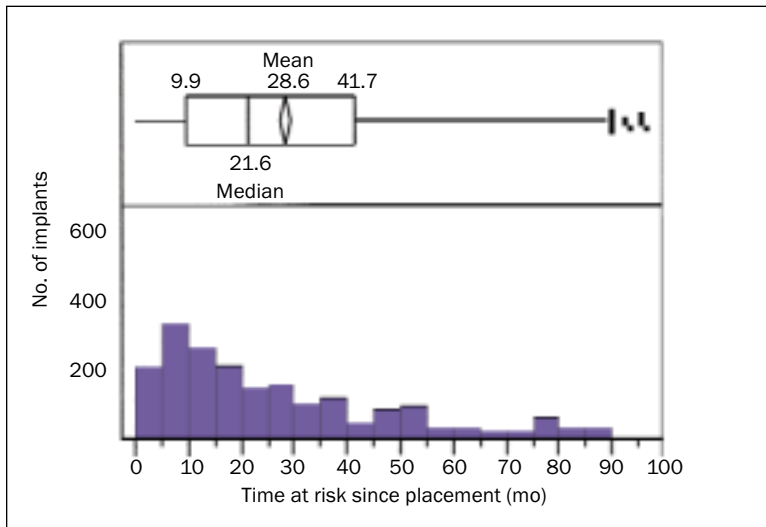


Fig 8 Distribution of implants according to time since placement (histogram and box plot with 25% and 75% quartiles).

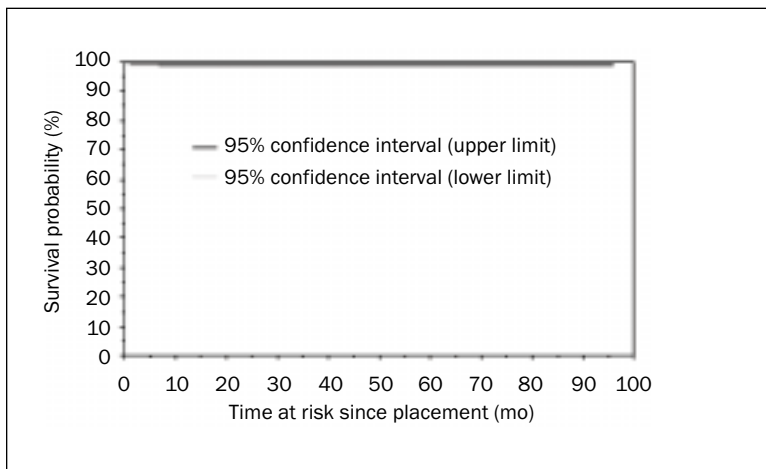


Fig 9 Mean survival estimation according to Aalen et al.²⁴

(n = 248). Statistical comparison of the groups by means of a log-rank test showed a probability of 0.84 (*P* value) that the survival functions are the same for both groups.

DISCUSSION

Historically, the need to change the abutment angle has been recognized, as a result of the difference in angulation between the bone available for implant placement and the long axis of the planned restoration. However, there have been concerns expressed about the adverse effect of non-axial forces on the survival of implants. These have been investigated by means of photoelastic studies as well as 3-dimensional finite element computer simulations.²⁷⁻²⁹ However, these in vitro investigations do not address the biological response of bone to functional loads.

Goodship and coworkers have demonstrated the capacity of bone to remodel in response to strain.³⁰ To date, no long-term studies have been published that have assessed the effect of non-axial loading on the bone supporting the implants or on the component parts transmitting these forces to the supporting bone.^{31,32}

The results of this study demonstrate that there seems to be no difference in the survival of implants based on the use of angulated abutments ranging from 0 to 45 degrees. Balshi et al have also demonstrated that the survival of implants loaded via 30-degree abutments is not significantly different from implants loaded via straight abutments.³¹ As demonstrated by the present results, the survival of implants loaded via angulated abutments is comparable to other reported studies in which angulated abutments were not used or addressed.²⁻¹³

The protocol that was used for this study involved the placement of implants anatomically within the available bone, irrespective of the angle between the long axis of the implant and proposed prosthetic crown. This approach served several purposes:

- It enabled implants of a greater dimension (length and diameter) to be placed.
- It enabled a greater number of patients to be treated.
- It avoided surgical compromise by allowing the implants to be placed between the cortical plates, thus preventing perforations and dehiscences.
- It allowed the perimucosal site to be placed more anatomically and facilitated restoration esthetically, functionally, and phonetically.
- It improved the efficiency of the treatment by reducing treatment planning and clinical and laboratory time.
- It improved access for oral hygiene.

The abutments were selected at first-stage surgery, which reduced the number of component parts required. Alignment of each implant hex and abutment at this stage made it possible to overcome many of the difficulties associated with the laboratory correction of non-aligned implants and abutments. The planning of treatment was greatly simplified, since complex surgical templates based on CT scans to guide the osteotomy preparation did not need to be fabricated.^{33,34}

Most importantly, there appeared to be a comparable high survival rate and an esthetic and functional outcome that was consistently achieved. This may be attributable to the improved biomechanics that result from the use of angled pre-machined abutments, which are selected and aligned to lie within the prosthetic envelope to facilitate the restorative phase. Cement-retained restorations could be fabricated, which are technically easier to fabricate than stress-inducing screw-retained restorations.³⁵⁻³⁷

Because of the mean observation time of 29 months, less than half of the 2,261 placed implants could be considered for the calculation of the survival probability after 5 years. These factors may contribute to the high survival rate of 98.6% after a 5-year observation period considering the 95% confidence interval of the mean survival estimation according to Aalen et al ($99 \pm 0.4\%$). Additionally, as a result of the lack of events (failures) after 35 months, the estimated success rate after 5 years must be considered preliminary.

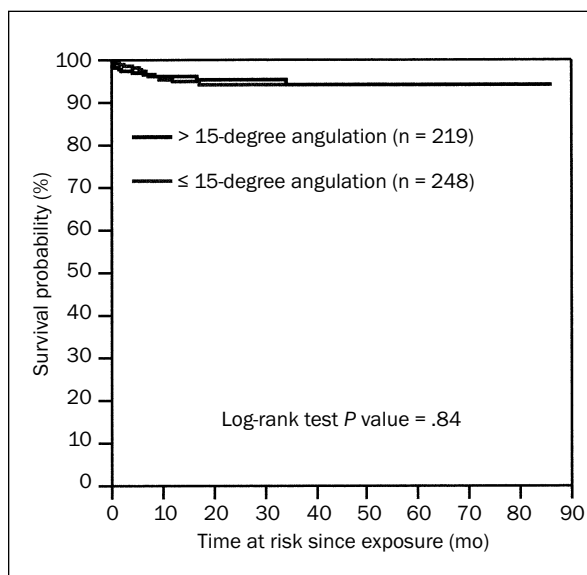


Fig 10 Survival analysis according to Kaplan-Meier. Selected groups are compared according to abutment angulation.

CONCLUSION

Angulated abutments may be used without compromising the long-term survival of implants. Treatment planning can be facilitated and implant placement can be carried out without surgical compromise. The fabrication of restorations utilizes conventional restorative procedures. Good esthetic and functional outcomes can be easily achieved using the protocol outlined.

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