Polygonal Area of Prosthesis Support with Straight and Tilted Dental Implants in Edentulous Maxillae

Stefan Wentaschek, DMD, MSc¹/Karl Martin Lehmann, DMD, PhD²/Herbert Scheller, DMD, PhD³/Gernot Weibrich, MD, DMD, PhD²/Nikolaus Behneke, DMD, PhD²

Purpose: The aim of this in vitro study was to assess the increase in the polygonal area of implant-retained prosthesis supports in edentulous maxillae with the use of tilted distal implants compared with the use of straight distal implants, using a variety of implant lengths. Materials and Methods: A total of 25 DICOM datasets of atrophic edentulous maxillae were provided. Bone augmentations in the molar region had to be avoided. Two straight reference implants were virtually inserted in the anterior region. Two additional implants were placed far distally on both sides (4 groups: [1] straight, 12-mm length; [2] straight, 10 mm; [3] straight, 8 mm; [4] tilted, 12–16 mm). The resulting implant-supported polygon was measured for each of the 4 groups using three-dimensional planning software. Results: The mean sagittal depth of the supported polygon in Group 1 was 9.9 mm (standard deviation [SD] 4.4) on the right and 10.2 mm (SD 4.4) on the left, and it was 33.7 mm (SD 5.8) in width. For Group 2, the mean sagittal depth was 11.5 mm (SD 5.0) on the right and 11.9 mm (SD 4.7) on the left, and the width was 35.2 mm (SD 5.6). The measurements for Group 3 were 13.8 mm (SD 4.9) deep on the right, 13.8 mm (SD 5.1) deep on the left, and 37.0 mm (SD 5.4) in width. For Group 4, the depth was 15.8 mm (SD 4.9) on the right and 16.4 mm (SD 5.8) on the left, and the width was 39.0 mm (SD 5.1). Conclusion: The area of implant-retained prosthesis support can be enlarged by the use of tilted implants (12 to 16 mm in length, 42 to 45 degrees) compared to the use of straight 8-mm implants (resulting increase: about 15%). Int J Prosthodont 2016;29:245–252. doi: 10.11607/ijp.4310

Many patients with atrophic edentulous maxillae seek implant-retained prostheses. Because of the risks of possible complications,¹,² long treatment time, and high costs,³ bone augmentation procedures must be avoided in some patients. For this reason, implants often cannot be inserted in the molar region and extended cantilevers could be necessary to provide fixed prostheses with the needed masticatory units.⁴ These cantilever extensions lead to extra-axial strain of the implants.

In contrast to this initial concept, the use of removable implant-retained prostheses stabilized on implants only in the frontal area of edentulous jaws has been performed clinically to replace posterior teeth in lateral atrophic maxillae.⁵ But an increased implant-retained prosthesis support area is also beneficial for the kinetics of these prosthesis constructions.

One possible strategy to avoid bone augmentation in distal areas with reduced bone volume involves inserting implants with an intraosseous length of < 8 mm. Even with the use of short implants, a residual bone height of 6 to 7 mm is required; however, especially in the atrophic lateral maxilla, this possibility can be limited for various reasons.³ Using tilted implants to rehabilitate edentulous maxillae has been proposed as an alternative to bone grafting.⁶ This approach aims to place implants of conventional length while increasing the polygonal area of prosthesis support and reducing the cantilever length solely with the use of a tilted implant. Tilted implant surgery proximal to the sinus floor was initially performed with direct visualization after fenestration of the maxillary sinus, but the establishment of guided, three-dimensional (3D) planned implantation has simplified this technique, and it is now much more widely used.³ Increasing the interimplant distance by using tilted implants most likely depends on alternative treatment methods, especially the length of the chosen straight implant.

¹Assistant Professor, Department of Prosthetic Dentistry, University Medical Center of the University of Mainz, Mainz, Germany.
²Associate Professor, Department of Prosthetic Dentistry, University Medical Center of the University of Mainz, Mainz, Germany.
³Medical Director, Department of Prosthetic Dentistry, University Medical Center of the University of Mainz, Mainz, Germany.

Correspondence to: Dr Stefan Wentaschek, Department of Prosthetic Dentistry, University Medical Center of the University of Mainz, Augustusplatz 2, 55131 Mainz, Germany. Fax: +49-6131 17 5517. Email: stefan.wentaschek@unimedizin-mainz.de

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For clinical treatment, the theoretic mathematical increase in a supported area is of limited use. What is most meaningful to the clinician is how far distal the implant-retained prosthesis support can be. Because of the shape of the upper jaw, a more distal implant position should also result in an increased transversal interimplant distance.

The mean enlargement of the polygonal prosthesis support area using tilted implants as an alternative to straight implants remains unknown. Therefore, the aim of this study was to evaluate the increase in the polygonal prosthesis support area from using tilted distal implants in edentulous maxillae compared with straight distal implants of varying lengths.

Materials and Methods

**DICOM Data**

DICOM datasets of 25 edentulous maxillae with limited posterior ridge dimensions were included in this study (15 women, 10 men, mean age: 63.2 years [range: 39 to 82 years; standard deviation (SD): 11.1 years]).

Anonymized cone-beam computed tomography (CBCT) data were provided from the Department of Radiology of the Dental Clinic of the University Medical Center in Mainz, Germany. The DICOM datasets existed prior to this study and were created independently of this investigation for implant planning.

Twenty CBCT images were produced using a dental Volumetric Tomography KaVo 3D eXam unit (KaVo Dental) with a resolution of 0.25 mm. Five scans, all with a resolution of 0.16 mm, were recorded using a 3D Accuitomo FP unit (J. Morita).

All CBCT scans were captured for 3D planning of template-guided implantation using the SKYplanX 6.1 program (Bredent). In this system, three radiopaque markers must be mounted in the scanning pattern used in the CBCT scan. The radiopaque markers were mounted vertical to the occlusal plane of the scanning pattern and were all parallel to one another. The radiologic images of the three markers were covered with orientation screens in the software to calibrate the system. SKYplanX offers the ability to measure distances and angles and to insert auxiliary lines.

**Inclusion Criteria**

The inclusion criteria for the DICOM data were as follows:

1. The CBCT was captured with an intraoral template with radiopaque teeth and radiopaque markers. The markers were oriented perpendicular to the occlusal plane to allow determination of the implant axis.
2. Patients showed reduced bone volume in the molar region of the maxilla that would not allow the placement of dental implants of at least 8 mm in length without bone augmentation.
3. Placement of an implant distal to the two reference implants in the anterior region with an angulation of 42 to 45 degrees to the z-axis, an implant length of at least 12 mm, and bone all around the implant was feasible on both sides. There was a minimum distance of 1 mm from all bone-limiting structures, such as the maxillary sinus.
4. Placement of an implant 12 mm in length distal to the two reference implants in the anterior region with no angulation to the occlusal plane in the sagittal direction was feasible on both sides. Angulation of these implants up to 15 degrees in the centrolateral orientation was allowed.

Of the 3D plannings performed by the authors, 25 met these criteria and were consecutively selected for this study.

**Virtual Implant Placement and Measurement Technique**

Two reference implants were virtually positioned in the maxillary lateral incisor region (SKYplanX, Bredent). Additionally, two mesiodistal upright implants with lengths of 12 mm, 10 mm, and 8 mm (Groups 1, 2, and 3, respectively) were virtually inserted distally to the reference implants. In Group 4, two distally tilted implants of 12 to 16 mm in length and with an inclination of 42 to 45 degrees were positioned (Fig 1).

There were straight and tilted orientations between the implant axis and the occlusal plane in the mesiodistal direction. Each implant was virtually positioned in the posterior maxilla as far distal as possible without bone grafting.

After validation of the measuring tool of the 3D planning software (see below), the differences in the polygonal prosthesis support areas were measured in the sagittal and transverse planes for all four groups ([1] straight, 12 mm; [2] straight, 10 mm; [3] straight, 8 mm; [4] tilted, 12–16 mm) (Fig 2).

**Validation of the Virtual Measurement**

To validate the measurement tool of the 3D design program, 50 virtual measurements were taken and compared with the corresponding true measurements on the appropriate templates. Measurements were taken of the outer maximum distance between the radiologic shadows of the radiopaque markers.
The condition for virtually measuring the distance between two markers was that they had to appear as far as possible at the same time when scrolling through the reproductions of the horizontal sections. This restriction ensured that the markers were perpendicular to the cutting plane and that the measurement was taken at a location comparable to the measurement on the true template at the same point. The 7-mm-high markers were attached in the template by a reference plate according to the manufacturer’s recommendations, which ensured that the markers were parallel to each other. The distance between the two markers was therefore equal over their entire height provided that the measurements were taken in a single plane and thus were comparable with measurements taken in a different plane. In principle, it is possible that the plane spanned by the three markers of the template is not parallel to the plane of the section in which the distance was measured; however, the connection line between two markers in this plane could be parallel to the sectional plane. A virtual measurement was only made if this was confirmed by visual inspection. All measurements were first made two-dimensionally in a horizontal section and then reconstructed in the 3D reproduction. The measurements were compared with actual and electronic measurements on the corresponding templates. These were performed with an electronic digital caliper (Powertec Tools). The caliper was recalibrated after each measurement (Fig 3).

**Statistical Analysis**

Statistical analysis was performed using SPSS 15.0 (SPSS).

**Validation of the Measuring Tool**

The mean value, SD, minimum, and maximum of the true and virtual measurements were evaluated using confidence intervals (CI) and descriptive statistics.
The measured values were tested for normal distribution with the Kolmogorov-Smirnov goodness-of-fit test. When the values were found to be normally distributed, the differences in the mean values were evaluated for significance using the $t$ test for dependent samples.

The null hypothesis was that there would be significant differences between the virtual and the true measurements of the same distances. The alternative hypothesis was that the differences in the measurement results would be purely random. A significance level of 5% was determined as the probability of error for accepting the alternative hypothesis. $P < .05$ was considered statistically significant, and a probability of error of 5% was also used for the confidence level.

### Study Data

The collected data were divided into four groups. The values measured for the distally tilted implants were compared with those for the straight 12-mm, 10-mm, and 8-mm implants. The virtual measurement values were evaluated using descriptive statistics such as mean value, SD, minimum, and maximum. Additionally, box plots were prepared for the four implant groups and compared with one another.

### Results

#### Validation of the Measuring Tool

The results of the measurements that were made to validate the 3D design program’s measuring tool are listed in Table 1.

The Kolmogorov-Smirnov goodness-of-fit test revealed no significant deviations from normality for either the true ($P = .13$) or the virtual ($P = .2$) measurements.

Comparison of the mean values using the $t$ test for dependent samples revealed no significant differences between the true and the virtual measurements ($P = .75$).

#### Study Data

The resulting implant lengths and insertion angles (inclination to the occlusal plane) for the angulated distal implants in Group 4 are shown in Table 2.
The mean transversal distance between the reference implants was 13.8 mm (SD 3.4 mm; min 6.9 mm, max 20.9 mm).

The measured sagittal depths of the polygonal implant-retained prosthesis support areas in the groups with nonangled implants of 12 mm, 10 mm, and 8 mm in length (Groups 1, 2, and 3, respectively) and with tilted implants (Group 4) sagittal to the reference implants are shown in Fig 4.

The measured transversal widths of the two distal implants in each of the four groups are shown in Fig 5.

**Discussion**

For treatment planning in implant dentistry, CBCT is used. In the images acquired using this technique, bone structures are visible and can be measured. These plans are typically transmitted to the surgical environment using templates. To check the precision of the measurement tool used in this study, distances were measured virtually with the planning software and compared with the corresponding true measurements on the template. The virtual measurements differed at most by 0.6 mm (1.15%) from the true measurements. The results of this study are consistent with results from other studies in which the measurement accuracy in CBCT images was analyzed under comparable conditions. Therefore, the method used here appears sufficiently accurate to analyze the question that was posed.

Compared with the typical planned strategy of using a straight 12-mm implant positioned as far distally as the anatomical structures allow, a straight implant of 8 or 10 mm in length can be positioned (in the same patient) in at least the same mesiodistal position. However, because of the reduced implant length, it can generally be placed in a more distal location. A tilted implant of at least 12 mm in length and 45 degrees inclination could at least theoretically require a more mesial placement than a straight implant of 8 or 10 mm in length, but this did not occur in any of the 25 patients examined. The patient-related differences between the four groups therefore always changed in the same direction, thus statistical comparisons of these means always revealed significant differences for these four groups. For this reason, except for the descriptive statistics and the box plots, no further statistical test was performed on the study data.

In the present study, the approximate mean sagittal depth of the supported polygon was 10 mm in Group 1; 12 mm in Group 2; 14 mm in Group 3; and 16 mm in Group 4, respectively, with the appropriate enlargement of the width. In an in vivo study, Krekmanov et al reported a mean increase of 9.3 mm in the mesiodistal aspect of the maxillary support area with implant angulation of 30 to 35 degrees. Those results indicate a 50% improvement in the mesiodistal aspect over the results of this study when comparing Groups 1 and 4 (a gain of approximately 6 mm) despite the reduced angulation of the tilted implants (30 to 35 degrees; in this study, 42 to 45 degrees). This difference might be caused by Krekmanov et al’s use of some anteriorly tilted tuber implants if a patient had sufficient bone in this area.
In a retrospective study of the All on Four concept in the maxilla, Malo et al reported that with angulation of the distal implants, it was possible to position the implant shoulder in the region of the second premolar or the first molar rather than in the canine or first premolar regions. In our study, approximately 6 mm of sagittal depth could be attained with tilted implants compared with 12-mm straight implants, which corresponds—in prosthetic terms—to nearly the width of one premolar.

The clinical benefits that might be achieved by enlarging the support area with the angulation of the distal implants could be interpreted in different ways:

1. If the cantilever length depends on the sagittal depth of the support polygon, for example with a load arm-to-lever arm ratio of 1 to 1, at a mean depth of an average maxillary dental arch, a resulting implant-supported fixed bridge could additionally replace a complete molar. Fig 6 illustrates how far an implant-supported denture can be extended if the cantilever is expanded distally to the same depth as the support polygon.

2. If the goal of treatment is insertion of an implant-supported fixed bridge up to a certain extent, for example to replace the first molar, the enlargement of the support polygon results in a significant improvement of the load arm-to-lever arm ratio at a distal load of the cantilever.

For both approaches, the increased depth of the support polygon depends on the length of the straight implant with which the tilted implant is compared. For example, compared with a short, straight implant, the angulation can only achieve a slight enlargement of the support polygon. However, a much longer implant could be inserted. Compared with similar long, straight implants, a much larger support polygon can be achieved with tilted implants. The possible biomechanical effects of these differences in implant-supported bridges were evaluated in different studies. The enlargement of the support polygon and the possible shortening of the cantilever extensions achieved at high implant length can lead to a significant reduction of the stresses in the peri-implant bone and in the framework of a prosthesis with splinted implants.

In the present study, tilted implants (mean length: 15 mm) reached an approximately 2-mm-deeper support polygon compared with straight implants 8 mm in length and this represents an increase of about 15%. Nevertheless, these two approaches may be functionally comparable in some patients. Recent reviews have shown that implants shorter than 10 mm are not inferior to longer implants regarding bone loss or even survival rate. However, longer implants could achieve a higher primary stability, and tilted longer implants can use the existing cortical bone to a greater extent and seem to be especially suitable for...
of studies. It must be considered that the clinical analysis was performed due to the low number of studies found.

On the other hand, tilted implants might have the disadvantage that they are more difficult to insert. Therefore, computer-guided implant planning and navigated insertion are often used, which increases the effort.

In summary, if sufficient bone volume is available to house a short implant (8 mm) in the posterior maxillary region for a similar polygonal support as a longer tilted implant, from a clinical view longer tilted implants might have advantages. This is especially the case for immediate loading protocols in edentulous jaws. Short implants are more suitable with conventional loading protocols because of the reduced surgical effort.

Systematic reviews comparing the changes in the crestal bone levels and survival rates of axially versus tilted implants show sometimes no differences and sometimes slight, not significant trends or small but slightly significant differences primarily in favor of axial implants but perhaps not to a clinically relevant degree. Even for tilted implants the loss rate in the maxilla is higher than that in the mandible. In an examination of the maxilla in a recent meta-analysis by Chrzanovic et al, a significant difference in survival rate between axial and tilted implants was found.

The authors of all three reviews warn that the rather low level of evidence of the included studies should be taken into consideration as no randomized studies were found.

Only three out of eight articles that were included in the review by Monje et al reported on biomechanical complications. There was no evidence that these occur more often at tilted implants, but no statistical analysis was performed due to the low number of studies. It must be considered that the clinical performance of tilted implants includes the performance of the angled abutments that are most often used. They should compensate for the implant axis and allow a screw connection vertical to the occlusal plane and an impression on the abutment level with more parallel copings. These abutments are generally fixed with screws, and the preload of this screw has to withstand the extra-axial load. Thus, screw loosening is one of the most common technical complications of tilted implants.

In the current study, implants 12 to 16 mm in length and tilted at 42 to 45 degrees increased the support polygon in the anterior–posterior spread about 15% more than straight implants 8 mm in length. Thus, they can shorten cantilever extensions more and can better improve the lever arm-to-load arm ratio for extra-axial loads. This seems to be more meaningful for peri-implant stress than the implant inclination.

Conclusions

The data from this study demonstrate that in edentulous maxillae, increased sagittal and transverse interimplant distances, and thus a more distal placement of the implant-abutment interface with resulting increases in the polygonal implant-retained prosthesis support area, can be achieved using tilted implants in the posterior maxilla if bone grafting needs to be avoided. The implant-retained prosthesis support area can be enlarged by reducing the implant length for distal implants, but even compared with 8-mm straight implants it can be further enlarged in edentulous maxillae by using tilted implants.

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References

Literature Abstract

Tooth Loss and Obstructive Sleep Apnea Signs and Symptoms in the US Population

This cross-sectional study aimed to evaluate the association between tooth loss and obstructive sleep apnea (OSA) signs and symptoms. A total of 7,305 subjects aged older than 25 years were included. Using sleep disorder questionnaires, 20.3% were classified as high risk for OSA. Mean number of teeth lost was 8.1. The authors found that the relationship between tooth loss and high risk of OSA was strongest in adults aged younger than 50 years and attenuated at older age; no association was found in adults aged 65 years and older. Risk for OSA was elevated with number of teeth lost: 25% for 5 to 8 missing teeth, 36% for 9 to 31 missing teeth, and 61% for edentulous patients. No specific type of tooth loss distinguished people who were high risk for OSA. In addition, subjects with a higher number of posterior occlusal contacts had significant protection against OSA risk. The authors suggested future longitudinal studies in association with OSA overnight sleep tests.

Email: anne_sanders@unc.edu — Huong Nguyen, USA