Clinical applications of angled abutments — a literature review

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Dental implants have been proven to be an effective way of restoring the masticatory ability to completely or partially edentulous patients. But when clinicians deal with undesirable implant orientation caused by poor bone conditions, an angled abutment is often the treatment of choice for prosthetic restorations. A search of articles related to the success rate, stress analysis, and bone response to loading of angled abutments was performed in order to understand the rationale for their current clinical applications. Evidence shows that the clinical performance of angled abutments is comparable to that of straight abutments with respect to both soft-tissue responses and general survival rates. However, in vitro studies of stress/strain analyses of angled abutments can only agree that stress/strain levels increase as abutment angulation increases. Three analytical techniques including the photo elastic technique, strain gauge analysis, and finite element analysis have been applied for analyzing angled abutments. Further comparative studies are required using these three techniques because some quantitative aspects are still inconclusive such as how much stress is introduced upon a certain degree of abutment angulation. (Chin Dent J, 24(1): 15-20, 2005)

Key words: dental implant, angled abutment, survival rate, literature review, stress analysis.

Implant prostheses often offer a more-predictable treatment course than traditional restorations. It was proven that osseointegrated implants can successfully be used to restore the completely or partially edentulous patients with long-term success. But in some real clinical situations, severely resorbed bone may result in inappropriate implant alignment, which can cause disparities between the implant long axis and the abutment long axis. Under such circumstances, difficulties will be certainly encountered in future prosthesis fabrication. Two options are available to overcome such problems: the angled implant and the angled abutment. As early as 1990 Kallus et al. demonstrated prototype angled abutments of the Branemark (Nobel Biocare, Göteborg, Sweden) implant system. The advent of angled abutments has simplified the management of situations when implant placements are suboptimal. Gelb et al. presented 3 cases restored with pre-angled abutments to fulfill the esthetic demands and functional objectives of patients. Until the present time, no thorough review of the information on angled abutments can be found in the literature which can elaborate both the efficacy and biomechanical mechanisms of this treatment modality.

Dentists understand the risks involved when restored prostheses are subjected to non-axial loading. It has always been recommended to direct occlusal loads as close to the long axis of the fixture as possible. However, it is known that the loading on angled abutments is mostly off-axis, which raises the concern of how angled abutments generally perform with such an unfavorable loading regimen. The purposes of this article were to determine the general clinical success rate of angled abutments through a literature review, to understand the current methodology used to analyze the stress and strain of
bone, and to review the responses of the bone toward the loading around implants restored with angled abutments.

**Clinical performance**

In the early design of angled abutments which is published by Kallus et al.6, a prototype of an angled abutment was introduced. Because of the lack of diversity of shoulder height and form in the early developed Branemark angled abutments, such concerns as with the soft-tissue health induced by misfitting between the soft-tissue thickness and abutment shoulder heights were encountered. Other than the minor aforementioned shortcomings, 14 patients showed favorable results in improved esthetics and structural integrity with prosthetic reconstruction. An animal study with histological observations of angled abutments was done by Celletti et al.10. In their study, 20 implants (3i, Implant Innovations, Palm Beach, FL, USA) were placed in 2 subhuman primates and were later restored with 25° and 35° angled abutments. After 1 year in service, they discovered that the quality of the osseointegration proved to be histologically excellent either in both the straight and angled abutments.

**Soft-tissue performance**

A retrospective study investigated the possible peri-implant mucosal complications around angled abutments11. In that study, 421 Branemark implants placed in 71 patients were restored with angled abutments or a combination of angled and straight abutments (209 angled abutments and 212 straight abutments). The overall gingival problems in the areas around the angled abutments were comparable or lower than those with standard abutments. Another soft-tissue evaluation of angled abutment was done by Eger et al.12. In that study, 81 implants (56 restored with angled abutments, 25 with straight abutments) in 24 patients were evaluated for the parameters of probing depth, gingival level, gingival index, and mobility. The final data revealed no significant differences between angled and straight abutments for any of the clinical variables measured, and no significant difference was found in gingival inflammation or implant mobility between the two groups as well.

**Overall success rate**

In a study by Balshi et al.11, the cumulative survival rates for angled abutments were 94.8% and 94.1% for the maxilla and mandible respectively. These are comparable to those of straight abutments which were 91.3% in the maxilla and 97.4% in the mandible. Sethi et al. reported a 5-year mean survival probability of 98.6% and a 10-year survival probability of 98.2% with a 95% confidence interval for angled abutments13, 14. In their observations, 3101 implants restored with angled abutments ranging from 0° to 45° were included. They reported that the magnitude of the angles did not significantly influence the survival rate. A comparison chart is listed for all of the reviewed survival analyses (Table 1).

**Stress analysis**

Due to the unfavorable loading direction that angled abutments have, it is important to understand

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**Table 1. Comparison chart for survival rates**

<table>
<thead>
<tr>
<th>Duration of evaluation (years)</th>
<th>Balshi et al.11</th>
<th>Sethi et al.13</th>
<th>Sethi et al.14</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of angled abutments reviewed</td>
<td>3</td>
<td>5</td>
<td>14</td>
</tr>
<tr>
<td>No. of straight abutments reviewed</td>
<td>209</td>
<td>2261</td>
<td>3101</td>
</tr>
<tr>
<td>Abutment angulation evaluated</td>
<td>30°</td>
<td>0°~45°</td>
<td>0°~45°</td>
</tr>
<tr>
<td>Supported prosthesis type</td>
<td>fixed prostheses</td>
<td>fixed and removable prostheses</td>
<td>fixed and removable prostheses</td>
</tr>
<tr>
<td>Success rate of angled abutments</td>
<td>maxilla, 94.8% mandible, 94.1%</td>
<td>survival probability of &gt; 98.6%</td>
<td>mean survival probability of &gt; 97.5%</td>
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</table>
Angled abutments

the stresses transferred through various abutment angulations to the surrounding bone, through which we can prevent less-than-ideal stress transfer conditions. Current techniques employed to evaluate the biomechanical loads on implants consist of photoelastic stress analysis, finite element analysis, and strain-gauge analysis. Two studies conducted by Clelland et al. used both photoelastic analysis and a strain gauge technique. Abutment angulations of 0°, 15°, 25°, 30°, and 35° (0°, 15°, and 20° for the study published in 1993) were tested with 178 N applied along the long axis. The stresses obtained from the photoelastic fringe order conversion showed a significant increase as abutment angulation increased. The highest fringe order was found near the implant apex, which indicated the highest stress concentration. Strain gauge values were also obtained from a point 4 mm away from the implant surface. The compressive stresses and tensile stresses were calculated from the strain gauge readings and subsequently converted to compressive stress and tensile stresses of the bone by Hooke’s law. Results showed that all converted bone strain data were within the physiological zone as proposed by Frost. A comparison of strain gauge data and the photoelastic fringe order data also showed consistency between these two analytical methods.

Another study conducted to test the stress distribution on the bone-implant interface for different abutment angulations by means of photoelastic and strain gauge analyses was carried out by Brosh et al. In that study, three strain gauges were attached to the implants surface on each side and then embedded in a photoelastic resin. Abutment angulations of 0°, 15°, and 25° were tested with a loading of up to 350 N along the implant long axis. Photoelastic models were similarly prepared without strain gauges attached and then loaded with 100, 200, and 300 N. The results of the strain gauge models showed that the loading side had significant higher strain response to force (SRF) (instead of using strain data, they used SRF, which is strain produced per loading unit) than those on the contralateral side. The results showed significantly higher SRFs when abutment angulation was increased. On the implant surface, the more apical the location was, the smaller was SRF ratio which was generated. By comparing the data obtained from the photoelastic model, they found that strain measurement distribution data showed a pronounced decrease in value along the implant compared to those of photoelastic models. The discrepancies were more pronounced when the influence of abutment angulation was compared. They concluded that when the abutment angulation increased, stress and strain increased, and the comparison between the two analytical techniques could only be made qualitatively rather than quantitatively due to tendencies of the discrepancies in the stresses/strains to increase. The conclusions concerning comparisons of the two techniques were not compatible with Clelland et al.’s. data published in 1993.

<table>
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<th></th>
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<tbody>
<tr>
<td>0°, 15°, 20°</td>
<td>0°, 15°, 25°</td>
<td></td>
</tr>
<tr>
<td>Loading magnitude (N)</td>
<td>178</td>
<td>0-300 (for the strain gauge model)</td>
</tr>
<tr>
<td>Loading direction</td>
<td>along the abutment long axis</td>
<td>along the implant long axis</td>
</tr>
<tr>
<td>Implant size (mm)</td>
<td>3.8 × 10</td>
<td>4 × 13</td>
</tr>
<tr>
<td>Strain gauge location</td>
<td>4 mm away from the implant surface</td>
<td>on the implant surface, loading and contralateral side</td>
</tr>
<tr>
<td>Conclusions about the effect of increasing abutment angulation</td>
<td>significant increase in stresses and strains as abutment angulation increases</td>
<td>stresses and strains (SRF) increase as abutment angulation increases</td>
</tr>
<tr>
<td>Conclusions about the comparison of the two study techniques</td>
<td>strain gauge data provided results consistent with the visual interpretation of fringe order</td>
<td>strain gauge measurements showed more-pronounced changes than did the photoelastic analysis</td>
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</table>
Since both Brosh et al.’s study and Clelland et al.’s study were mainly aimed at the two analytical techniques for angled abutments, a comparison table of related issues is made for these two studies (Table 2).

The only 3-dimensional finite element analysis of angled abutments was done by Clelland et al. A premaxilla model was developed through a computed tomographic scan of a dry human skull. A simulated implant was subsequently inserted. The elastic properties of the cancellous bone were calculated from density values determined from related CT numbers. The model was loaded with 178 N along the abutment axis and analyzed. The results showed that peak stress/strain values generally increased as abutment angulation increased. These data qualitatively substantiated the results from the strain gauge and photoelastic studies. However the amounts of increment were not quite the same between the different analytical techniques. Further studies are required.

**Bone response to biomechanical loading**

In 1892, Wolff observed that “every change in the form and function of bone or of their function alone is followed by certain definite changes in their internal architecture and in their external conformation, in accordance with mathematical laws”. This is Wolff’s law. At that time, not much was understood about the mechanisms responsible for this effect, until 1987, when mechanostat theory made a connection between mechanical loading and the responses of the bone. This theory postulated some threshold data about which the bone’s physiological modeling and remodeling responses accordingly can be switched on or off. Long-term implant interfaces can only be maintained through these dynamic modeling and remodeling processes. More time and studies are required to test the validity of the mechanostat theory. However, the threshold data from the mechanostat theory (Table 3) can be used as references when performing stress/strain analyses around implant/bone interfaces. The finite element analytical data for angled abutments in the premaxilla area were compared with mechanostat theory threshold by Clelland et al. The peak compressive strains (1950 microstrains) and peak tensile strains (1500 microstrains for 20° angled abutments) were reported to be within the threshold of the adapted window and the mild overload window in the mechanostat theory. According to Frost, the strain level in the adapted window tends to conserve bone, maintain its strength, and prevent a osteopenia; likewise, strain levels in the mild overload zone can add and strengthen bone.

**DISCUSSION**

In one study which implants placed in subhuman primates were loaded for 1 year, Celletti et al. demonstrated that the quality of osseointegration was so excellent that overloading can only cause abutment screw breakage rather than loss of bone or failure of the implants. Using histological examinations, they found that “no osteoblasts or osteoclasts were present in the bone adjacent to the implants”, leading them to the conclusion that no active remodeling had taken place. This finding is inconsistent with the theory that long-term implant interfaces can only be maintained through dynamic modeling and remodeling processes. This should apply to angled abutments as well.

Other types of failure related to angled abutments in reviewed articles included fracture of the occlusal material, fracture in parts of the framework, loosening or fracture of abutment screws, and loss of osseointegration. Most of the articles claiming high success/survival rates did not take abutment screw loosening, occlusal material, or framework fracture into account in calculating the success/survival rates. These complications might not

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**Table 3. Threshold windows for the mechanostat theory**

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<thead>
<tr>
<th>Strain range (microstrain)</th>
<th>Description</th>
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<tr>
<td>&lt; 50</td>
<td>Bone is weakened by active remodeling</td>
</tr>
<tr>
<td>50 – 1500</td>
<td>Bone is conserved and strength is maintained</td>
</tr>
<tr>
<td>1500 – 3000</td>
<td>Modeling bone strengthening</td>
</tr>
<tr>
<td>&gt; 3000</td>
<td>Unrepaired microdamage begin to accumulate</td>
</tr>
<tr>
<td>&gt; 25000</td>
<td>Exceeds bone’s fracture strength</td>
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</table>
eventually lead to implant failure, but can still frustrate both dentists and patients and should be major concerns from a biomechanical point of view. Careful examination and documentation of such events to be included in future success/survival analyses are essential.

The most tapered pre-angled abutment reviewed was 45°. It was stated that the magnitude of the angle did not influence the survival rate. However, 3-D finite element data showed that a 45° angle of loads on an implant tripled the compressive stress. They also increased tensile stresses from almost zero to 4000 Psi in the bone. No other in vitro stress/strain data were found for such an extreme angle. Clinical application of angled abutments with such angulation should be used with great caution before the scientific evidence approves its feasibility.

When off-axis loading is applied to an implant, the magnitude of the stress will be increased 3 times or more. Hoshaw et al. also reported that overloading can cause bone loss around the implant neck. Other studies showed that excessive stresses may cause implant failure, component fracture, and/or crestal bone loss around the implant neck. It may seem dangerous to use angled abutments which maybe subjected to off-axis loading. However, with all the clinical successes and survival rate from the articles in this review, it seemed reasonable to assume that stress distributions around the bone surrounding implants restored with angled abutments are favorable or at least comparable to those of straight abutments, even though the loading mechanisms of angled abutments in anterior teeth and posterior teeth differ in terms of force direction and magnitude. Most of the success/survival rate analyses in the literature combined anterior and posterior data together, which renders it impossible to determine the exact performance of anterior angled abutments.

Researchers have tried to analyze stress/strain distributions generated from angled abutments with different analytical techniques. We only know that stresses and strains increase as the abutment angulation increases. There is no general consensus about how much stresses/strains increase with regard to the unit increase in abutment angulation to date. Further studies are required for clarification.

When comparing finite element analytical data with those of animal studies or to the threshold data from mechanostat theory, it should be noted that finite element analysis makes a lot of assumptions during model construction, parameter selection, and load simulation. All those can reduce the credibility of the resultant data. In order to make the model meaningful, validation of finite element models can be done by using the data from strain-gauge analysis as suggested by Brosh et al.

In the reviewed finite element study done for angled abutments, loading was applied along the long axis of the abutments in the anterior maxilla area. However, the real loading condition for anterior teeth is mostly at a certain angle toward the long axis of the abutments/restorations. Stresses/strains generated through such loading may be more detrimental to the surrounding bone since it is more off-axis. When future finite element analytical studies are conducted, this factor should be considered and carefully designed.

CONCLUSIONS

Based on the literature reviewed, several conclusions can be drawn.

1. The clinical performance of angled abutments is comparable to that of straight abutments.
2. The stresses/strains generated through off-axis loading increase as the abutment angulation increases, but there is no consensus as to what extent of angle increase will cause implant or bone failure. The data from mechanostat theory are used in the literature as a certain threshold reference to predict possible bone failure.
3. Off-axis loads are said to be detrimental to the surrounding bone. However, the clinical performances of angled abutments have mostly been satisfactory. Further studies are needed to clarify the discrepancies between the favorable clinical success/survival rates and the unfavorable in vitro biomechanical research data.

REFERENCES


