Influence of Connections and Surfaces of Dental Implants on Marginal Bone Loss: A Retrospective Study Over 7 to 19 Years

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Purpose: This retrospective study compared the long-term outcomes of dental implants according to type of connection and surface. Materials and Methods: Multiunit restorations were classified as follows: an external connection with a turned surface, an external connection with an anodized surface, or an internal connection with a fluoride-modified surface. Patients who were followed up for longer than 7 years after implant loading were included in the study. Cumulative implant survival rates and the amounts of marginal bone loss were calculated by reviewing dental records and radiographs. Only implants that survived until the last follow-up visit were included in the analysis of marginal bone loss. Statistical analyses were performed to detect between-group differences at the significance level of .05. Results: Sixty-nine patients with 261 bone-level implants were included. The average follow-up duration was 15.2 years in the external turned group, 10.6 years in the external anodized group, and 9.9 years in the internal fluoride-modified group. There was no significant between-group difference in the cumulative survival rate ($P = .439$) despite eight implant failures (six in the external turned group and two in the internal fluoride-modified group). The mean (SD) marginal bone loss values at the last follow-up were 0.47 mm (0.67), 0.87 mm (1.07), and 0.23 mm (0.58) in the external turned, external anodized, and internal fluoride-modified groups, respectively. After adjusting for follow-up duration, there was significantly less marginal bone loss in the external turned group than in the external anodized group ($P < .001$) and in the internal fluoride-modified group than in the external anodized group ($P < .001$). No significant difference in marginal bone loss was found between the external turned and internal fluoride-modified groups ($P = .44$). Conclusion: The implant-abutment connection structure is an important contributor to the maintenance of the level of marginal bone surrounding the implant. Implant surface characteristics are another contributor to marginal bone resorption. Int J Oral Maxillofac Implants 2020;35:1195–1202. doi: 10.11607/jomi.8450

Keywords: bone resorption, dental implant-abutment design, dental implants, retrospective studies, surface properties

Dental implants are widely used to replace missing teeth and should have predictable long-term outcomes given the continuing increase in life expectancy.1–3 In order for a dental implant to function properly in the oral cavity over a long period, there should be no implant-related biologic or mechanical complications.4,5 Maintenance of a stable marginal bone level around the implant is important for long-term survival and success of the implant.6 The peri-implant marginal bone level is influenced by patient-related biologic factors, such as the gingival biotype, supracrestal tissue attachment,7 accumulation of inflammatory cells around the implant-abutment interface,8 and occlusal status.9 Furthermore, the properties of the dental implant itself, such as the implant-abutment interface and the surface properties of the implant, may affect the marginal bone height.2,10 Although various types of implants are commercially available, the implant connection system can be broadly classified according to the type of implant-abutment interface: external or internal.11 External-connection implants, more precisely, external hexagon butt-joint-connection implants, have been used since the development of screw-shaped implants, typically with the structure of a standard external hexagon on the implant platform. Internal-connection implants have connections of various shapes, including internal grooves, trilobes, and internal conical connections.6 Unlike external hexagon connections, internal conical connections, more precisely, internal friction-interfaced
connections, have been reported to reduce microgaps and leakage, which can lead to complications from bacterial colonization of the connection; however, it has been reported that gap and leakage cannot be eliminated completely.12,13

The early screw-shaped implants had a turned (also known as machined) surface without any modification. However, most of the dental implants used today have a modified surface.14 Animal studies have shown that as the surface roughness of the implant increases, the bone-to-implant contact ratio improves and the removal torque of the implant also increases,15 which decreases the dip in stability that occurs during early osseointegration, allowing for immediate placement16 and immediate loading.17 However, the modified implant surface may not allow long-term stability of the peri-implant bone. A recent systematic review of studies with at least 5 years of follow-up reported that peri-implant bone loss was significantly less with implants that had an unmodified surface than with implants with a modified rough surface.18

In this retrospective clinical study, the marginal bone loss around dental implants containing external hexagon connections was measured and compared with that around those with internal conical connections. Data were collected for external hexagon implants with a turned surface, external hexagon implants with a modified surface, and internal conical implants with a modified surface. The aim of the study was to evaluate the long-term effects of type of implant connection and type of surface on peri-implant marginal bone loss. The null hypotheses were that there would be no difference in marginal bone loss between external and internal implant-abutment connections or between implants with unmodified and modified surfaces.

MATERIALS AND METHODS

Study Design and Selection Criteria

The dental records and radiographic data for patients who received implant-supported fixed dental prostheses at the Department of Prosthodontics, Seoul National University Dental Hospital, were retrospectively reviewed. The study protocol was approved by the institutional review board of Seoul National University Dental Hospital (IRB number: ERI20007) and performed in compliance with the STROBE guidelines.19

The treatment period, implant system, and type of prosthesis were classified to reflect the developmental history of titanium dental implants as follows: an implant system with an external hexagon connection and a turned surface (Brånemark, Nobel Biocare), used from January 1999 to December 2000 (external turned group); an implant system with the same external hexagon connection and an anodized surface (TiUnite, Brånemark, Nobel Biocare), loaded from January 2006 to December 2006 (external anodized group); and an implant system with an internal conical connection and a fluoride-modified surface (OsseoSpeed, Astra Tech, Dentsply), loaded from January 2007 to December 2008 (internal fluoride-modified group). Splinted multiunit implants for partially edentulous patients with follow-up for longer than 7 years after loading were included. The external-connection groups included only patients who had a screw-retained-type prosthetic restoration, and the internal-connection group included only patients with a cement-retained type of prosthesis. Single-unit implant restorations were excluded, as were external hexagon-connection implants without radiographic records immediately after loading or 1 year later. Patients without dental records containing implant information were also excluded.

Analysis of Marginal Bone Level

Only implants that survived until the last follow-up were included in the marginal bone level analysis. Panoramic radiographs obtained immediately after implant loading (baseline), 1 year after loading, and at the last follow-up visit were retrieved. Implants in the internal fluoride-modified group rarely had radiographs available at the baseline and 1 year after loading, so measurements were only available for the last follow-up visit. These radiographs were digitized in JPG format and used to evaluate marginal bone around the implants. An experienced observer (J.H.L.) not otherwise
involved in treatment of the patients measured marginal bone loss on the radiographs using ImageJ software (National Institutes of Health). The distance from the implant platform to the marginal bone level was defined as marginal bone loss. The actual marginal bone loss values were calculated using the expression ratios of the true and radiographically measured lengths of the investigated implants. The marginal bone loss values were measured on both the mesial and distal sides of the implants. The mean values between the mesial and distal data for each implant were documented for analysis. Implants that did not survive were excluded from radiographic measurement and any further statistical analysis.

Statistical Analysis
Implant survival was investigated by Kaplan-Meier curve analysis. The cumulative survival rate was calculated for each implant group. Differences between the survival curves were analyzed using the log-rank test.

The distribution of marginal bone loss was highly positively skewed, with many near-zero values observed. The Shapiro-Wilk test showed that the distribution was not normal (P < .001). Therefore, nonparametric analysis methods were mainly adopted. The descriptive statistics are expressed as the mean, SD, and median. The Kruskal-Wallis and Wilcoxon rank sum tests were used to compare the marginal bone loss between the three implant groups at each time point as appropriate. When post hoc multiple comparisons were needed, the Wilcoxon rank sum test was used to compare mean marginal bone loss values for all pairs with adjustment using the Bonferroni correction method. Differences in marginal bone loss between the different time points were assessed by the Wilcoxon signed rank test. Overall changes across the three time points within each group were analyzed using the Friedman test. Exploratory parametric repeated-measures analysis of variance was performed to test for a difference in the trend of marginal bone loss between the external hexagon-connection groups across time. Furthermore, analysis of covariance was used to examine the marginal bone loss values at the last follow-up visit to compare differences according to the surface treatment (external turned and external anodized groups) and connection type (internal fluoride-modified and external anodized groups) under adjustment for differences in duration of follow-up. The statistical analysis was performed using R software (version 3.6.1, R Foundation for Statistical Computing), based on a significance level of .05.

RESULTS
The analysis included data for 261 implants in 69 patients (31 men, 38 women). Table 1 shows the patient demographics. At the time of implant loading, the mean patient age was 55.1 ± 8.1 years. The external turned, external anodized, and internal fluoride-modified groups, respectively, included 19 patients with 105
implants, 20 patients with 70 implants, and 30 patients with 86 implants. The mean overall follow-up duration was 12.2 ± 3.1 (range: 7.1 to 19.4) years but varied from group to group (external turned group, 15.2 years; external anodized group, 10.6 years; and internal fluoride-modified group, 9.9 years).

Overall, eight implants failed in four patients during the observation period. Four implants in the external turned group were found to be fractured between 10 and 18 years of follow-up. Another two implants in the external turned group and two implants in the internal fluoride-modified group were removed because of loss of osseointegration between 6 and 14 years of follow-up. Kaplan-Meier implant survival analysis with stratification by implant group revealed that 6 of 105 implants in the external turned group failed, with a cumulative survival rate of 98.1% by 13 years of follow-up and 88.9% by 19 years of follow-up, while all 70 implants in the external anodized group survived, with a cumulative survival rate of 100.0%. Furthermore, 2 of 86 implants failed in the internal fluoride-modified group, with a cumulative survival rate of 97.7% by 11 years of follow-up. There was no significant difference in the cumulative survival rate between the implants when stratified by group ($P = .439$; Fig 2).

Table 2 shows the descriptive statistics for marginal bone loss. At the last follow-up visit, the mean (SD) marginal bone loss values were 0.47 mm (0.67), 0.87 mm (1.07), and 0.23 mm (0.58) in the external turned, external anodized, and internal fluoride-modified groups, respectively. A significant difference in marginal bone loss was found between the groups only for the final measurements at the last follow-up visit ($P < .001$) but not at baseline and 1 year after loading ($P > .05$). At the last follow-up visit, the marginal bone loss was significantly greater in the external hexagon connection (external turned and external anodized) groups than in the internal conical connection group ($P < .001$). There was a significant difference in the trend of changes from baseline to the final measurement between the external turned and external anodized groups ($P = .003$).

### Table 1 Patient Demographics and Implant Features

<table>
<thead>
<tr>
<th></th>
<th>External turned</th>
<th>External anodized</th>
<th>Internal fluoride-modified</th>
<th>Mean</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients, n</td>
<td>19</td>
<td>20</td>
<td>30</td>
<td></td>
<td>69</td>
</tr>
<tr>
<td>Male, n (%)</td>
<td>11 (57.9)</td>
<td>6 (30)</td>
<td>14 (46.7)</td>
<td>31</td>
<td>44.9</td>
</tr>
<tr>
<td>Female, n (%)</td>
<td>8 (42.1)</td>
<td>14 (70)</td>
<td>16 (53.3)</td>
<td></td>
<td>55.1</td>
</tr>
<tr>
<td>Age, y $^a$</td>
<td>50.9 ± 7.3</td>
<td>55.7 ± 7.7</td>
<td>57.3 ± 8.0</td>
<td>55.1 ± 8.1</td>
<td></td>
</tr>
<tr>
<td>Implants, n</td>
<td>105</td>
<td>70</td>
<td>86</td>
<td></td>
<td>261</td>
</tr>
<tr>
<td>Maxilla, n (%)</td>
<td>39 (37.1)</td>
<td>39 (53.4)</td>
<td>44 (51.2)</td>
<td>122</td>
<td>46.2</td>
</tr>
<tr>
<td>Mandible, n (%)</td>
<td>66 (62.9)</td>
<td>31 (46.6)</td>
<td>42 (48.8)</td>
<td></td>
<td>53.8</td>
</tr>
<tr>
<td>Follow-up, y</td>
<td>15.2 ± 2.7</td>
<td>10.6 ± 1.6</td>
<td>9.9 ± 0.8</td>
<td>12.2 ± 3.1</td>
<td></td>
</tr>
<tr>
<td>Patients with failures, n (%)</td>
<td>3 (15.8)</td>
<td>0</td>
<td>1 (3.3)</td>
<td>4</td>
<td>5.7</td>
</tr>
<tr>
<td>Male, n (%)</td>
<td>3 (27.3)</td>
<td>0</td>
<td>1 (7.1)</td>
<td></td>
<td>12.9</td>
</tr>
<tr>
<td>Female, n (%)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Failed implants, n (%)</td>
<td>6 (5.7)</td>
<td>0</td>
<td>2 (2.3)</td>
<td>8</td>
<td>3.1</td>
</tr>
<tr>
<td>Maxilla, n (%)</td>
<td>0</td>
<td>0</td>
<td>2 (4.5)</td>
<td></td>
<td>1.6</td>
</tr>
<tr>
<td>Mandible, n (%)</td>
<td>6 (9.1)</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>4.3</td>
</tr>
</tbody>
</table>

The data are presented as the number (percentage) or the mean ± SD. $^a$When implants were loaded. External turned group = external hexagon connection with a turned surface; external anodized group = external hexagon connection with an anodized surface; internal fluoride-modified group = internal conical connection with a fluoride-modified surface; n = number of measurements.
Table 2  Descriptive Statistics for Marginal Bone Loss

<table>
<thead>
<tr>
<th>Group</th>
<th>n (%)</th>
<th>Baseline</th>
<th>After 1 y</th>
<th>Last follow-up visit</th>
<th>After 1 y–baseline</th>
<th>Last follow-up visit–after 1 y</th>
<th>Overall change</th>
<th>Difference in change between groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>External turned</td>
<td>99 (37.4)</td>
<td>0.02 (0.02), 0.0</td>
<td>0.19 (0.47), 0.00</td>
<td>0.47 (0.67), 0.21b</td>
<td>&lt; .001†</td>
<td>&lt; .001†</td>
<td>&lt; .001†</td>
<td>&lt; .001†</td>
</tr>
<tr>
<td>External anodized</td>
<td>70 (26.4)</td>
<td>0.01 (0.06), 0.00</td>
<td>0.33 (0.53), 0.00</td>
<td>0.87 (1.07), 0.51b</td>
<td>&lt; .001†</td>
<td>&lt; .001†</td>
<td>&lt; .001†</td>
<td>&lt; .001†</td>
</tr>
<tr>
<td>Internal fluoride-modified</td>
<td>84 (33.2)</td>
<td>–</td>
<td>–</td>
<td>0.23 (0.58), 0.00a</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>P value</td>
<td>–</td>
<td>.175†</td>
<td>.161†</td>
<td>&lt; .001§</td>
<td>.190†</td>
<td>.085§</td>
<td>.024†</td>
<td>–</td>
</tr>
</tbody>
</table>

The marginal bone loss data are presented as the mean (SD), median. The superscript letters a and b indicate a significant between-group difference in the mean value. Significant results are reported in bold. The Wilcoxon rank sum test was used to compare the means for all pairs with adjustment using the Bonferroni correction method. †Wilcoxon signed rank test; ††nonparametric Wilcoxon rank sum test; §nonparametric Kruskal-Wallis test; ¶Friedman test; °repeated-measures analysis of variance. External turned group = external hexagon connection with a turned surface; external anodized group = external hexagon connection with an anodized surface; internal fluoride-modified group = internal conical connection with a fluoride-modified surface; n = number of measurements.

Fig 3  (Left) Comparison of marginal bone loss (mm) according to the surface treatment (turned vs anodized) in the external hexagon connection groups at the last follow-up visit. The data are shown as the mean (error bar: 95% confidence interval) after adjusting for follow-up duration by analysis of covariance. The covariates that appear in the model are calculated for 13.3 years of follow-up. *Significant difference, P < .05.

Fig 4  (Right) Comparison of marginal bone loss (mm) according to type of connection (external vs internal) in the modified surface groups at the last follow-up visit. The data are shown as the mean (error bar: 95% confidence interval) after adjusting for follow-up duration by analysis of covariance. The covariates that appear in the model are calculated for 10.2 years of follow-up. *Significant difference, P < .05.

Analysis of covariance revealed a significant difference in marginal bone loss between the external turned and external anodized groups at the last follow-up visit (P < .001). After approximately 13.3 years of follow-up, the marginal bone loss in the external turned group was estimated to be 0.68 mm less than that in the external anodized group (Fig 3). The marginal bone loss in the internal fluoride-modified group was estimated to be 0.62 mm smaller than that in the external anodized group after 10.2 years (P < .001; Fig 4). In comparison with the external turned and internal fluoride-modified groups, marginal bone loss in the external anodized group was estimated to be 0.38 mm (95% CI: 0.21 to 0.54) and 0.33 mm (95% CI: 0.14 to 0.52), respectively, after 12.8 years of follow-up; the difference was not statistically significant (P = .44).

DISCUSSION

Both null hypotheses of this study were rejected. After adjusting for the different follow-up durations, the marginal bone loss was significantly greater for the external-connection implants than for the internal-connection implants when comparing the two groups with modified surfaces. In the external-connection groups, the modified surface showed significantly more bone loss than the nonmodified surface. However, in all three groups, the average amount of marginal bone loss was less than 1 mm. The 10-year cumulative implant survival rate was 97.7% or higher in all three groups with no significant between-group difference.

The results of this retrospective study are consistent with those of four recent systematic reviews comparing...
the effects of internal and external connections on marginal bone loss.\textsuperscript{6,11,21,22} All these reviews reported significantly less bone loss for internal connections than for external connections.\textsuperscript{6,11,21,22} Two of the reviews reported high survival rates for both internal- and external-connection implants with no significant difference between the two types.\textsuperscript{11,22}

Nevertheless, most of the studies included in the aforementioned systematic reviews had less than 5 years of follow-up, and only two reported long-term results.\textsuperscript{23,24} The studies that included more than 12 years of follow-up reported no significant difference in marginal bone loss between internal and external connections.\textsuperscript{23,24} However, none of those studies controlled for the difference in surface roughness between the external-connection groups, which included Brånemark implants with a turned surface, and the internal-connection groups, which included Astra-Tech implants with a TiO\textsubscript{2}-blasted surface.\textsuperscript{23,24} In the present study, the external-connection implants were divided into a turned surface group and an anodized surface group to control for any bias originating from the difference in surface roughness. Like two of the aforementioned studies,\textsuperscript{23,24} no significant difference in marginal bone loss was found between the group with an external connection and a turned surface and the group with an internal connection and a modified surface during long-term follow-up. In contrast, there was a significant difference in marginal bone loss in the long term between the external anodized (external connection, modified surface) and internal fluoride-modified (internal connection, modified surface) groups. The results of this study can be considered meaningful given the paucity of relevant long-term clinical studies.

In all the systematic reviews,\textsuperscript{6,11,21,22} the platform-switching design of the internal connections was speculated to be the bigger contributor to the lower marginal bone loss compared with the external connections. This is because the effect of an internal connection without platform switching on marginal bone loss was reported to be similar to that of an external connection without platform switching in a previous study.\textsuperscript{6} In the present study, marginal bone loss may have been significantly lower in the internal fluoride-modified group than in the group with the Brånemark implant as a result of the platform-switching design used for the Astra-Tech implant.

Destruction of the soft tissue seal around the implant-abutment connection due to the difference in micromobility of the abutment may also cause more bone resorption around the external connection than around the internal connection. The stability of the implant-abutment connection is important in terms of the soft tissue seal on the abutment, which prevents pocket formation and invasion by bacteria.\textsuperscript{10,11} In an implant with the external hexagon connection, the "hex" structure, which is just 0.7 mm in height, was originally a device that was connected to a mouter to insert the screw-shaped implant into the bone. Therefore, micromobility is detected in the external hexagon connection when masticatory force is applied to the superstructure.\textsuperscript{25} This micromobility causes breakage of the soft tissue seal and loosening of the abutment screw that maintains the stability of the implant-abutment connection, leading to marginal bone loss around the implant and potential implant failure.\textsuperscript{10,26,27} The internal conical connection is mainly dependent on friction between the implant and the abutment for maintenance of the stability of the connection, so it is different from the external hexagon connection, which depends entirely on screw retention.\textsuperscript{28} Given that friction contributes to the stability of the connection despite screw loosening, this type of connection is advantageous for maintenance of the soft tissue seal and is important in prevention of marginal bone loss.\textsuperscript{10,14,29}

Another major factor in the prevention of marginal bone loss is the implant surface characteristics.\textsuperscript{30–32} In the present study, the external turned and external anodized groups were compared to determine the effect of surface characteristics on marginal bone loss around an implant while excluding the confounding effect of implant-abutment connections. Titanium surfaces microroughened by anodic oxidation (TiUnite, Nobel Biocare) or a blasted surface treated with fluoride (OsseoSpeed, Astra Tech, Dentsply) have been widely used and investigated over a long period of time.\textsuperscript{33–35} Generally, modified titanium surfaces show more bone healing activity around dental implants than turned surfaces made of commercially pure titanium.\textsuperscript{32,36} However, clinically, bone responds to not only the implant surface but also a number of other factors, including distribution of load from superstructures to the implant and interaction between soft tissues and abutments.\textsuperscript{10,37} Furthermore, turned or machined titanium surfaces have shown high clinical success rates in the long term, although modified surfaces are reportedly superior in terms of the early bone response in both animal and human studies.\textsuperscript{38–40} In the present study, when comparing two types of implants with different surfaces but of the same brand, the amount of bone loss around a modified surface was significantly greater than that around a nonmodified surface. This finding is consistent with the results of several previous studies and is thought to reflect colonization by microorganisms as a result of increased surface roughness.\textsuperscript{41,42} However, if it is possible to prevent the rough surface from being exposed to microorganisms, it would be advantageous to use a rough surface rather than a turned surface because of the more biocompatible bone response.\textsuperscript{38–40} A previous systematic review reported that
careful interpretation is needed. Only patients who of the present study need to be confirmed in prospec-

to perform, although an inspiring and informative in-
nection with a turned surface would be difficult
faces. A prospective study using the internal conical
connection has been used with modified sur-
faces. A prospective study using the internal conical
connection with a turned surface would be difficult
to perform, although an inspiring and informative in-
vestigation with such a design has been published re-
cently. Therefore, in the present study, the data were
analyzed by assuming that the marginal bone level
would be affected more by the connection structures
than by the surface characteristics of the implant. The
internal fluoride-modified group showed significantly
less bone loss than the external turned group at the last
follow-up visit in this study. However, the significance
of this between-group difference disappeared after the
marginal bone loss value was adjusted for the observa-
tion period. Further research is needed to confirm this
finding.

This study retrospectively divided multiunit implant
restorations into three groups to analyze the influence
of type of implant connection and type of surface on
marginal bone loss in the long term. Only one brand of
implant per group was included, excluding single-unit
implant restorations, to minimize the impact of con-
founding factors. The restoration method was also kept
consistent within each implant group to control for the
impact of differences in the prosthetic methods used.
The relatively long follow-up duration in the turned
surface group resulting from the historical differences
in implant development was adjusted for by statisti-
cal methods. However, this study has some limitations
because of its retrospective design. In particular, the
restorative methods used were not matched between
the groups. The internal-connection group, unlike the
external-connection groups, included restoration with
a cement-retained type of prosthesis. This may have
led to inflammation or bone loss due to residual ce-
ment in the internal-connection group. The results
of the present study need to be confirmed in prospec-
tive studies in the future. In addition, high survival rates
were found in all three groups in this study. However,
careful interpretation is needed. Only patients who
were followed up for more than 7 years were included
to evaluate the long-term effects of marginal bone loss.
Therefore, failure of the implant in patients who have
been followed up for less than 7 years has not been
evaluated. Moreover, some of the patients may have
experienced early failure or complications outside of
the hospital in which they were originally treated.
Therefore, the actual success rate may not be as high as
suggested by the results of this study. Furthermore, the
analysis of marginal bone loss included only survival of
implants until the final follow-up period, so its findings
should also be interpreted with caution.

CONCLUSIONS

Even though all three implant groups in this study
showed high survival rates with no significant between-
group differences during long-term follow-up, external-
connection implants lost 0.62 mm more marginal bone
after 10.2 years of follow-up than internal-connection
implants. Furthermore, when compared with the same
brand of external-connection implant, it was estimated
that the modified surface would show 0.68 mm more
marginal bone resorption after 13.3 years than the
nonmodified surface. The structure of the implant-
abutment connection may be a key factor in the break-
age of the soft tissue seal, which heralds the beginning
of marginal bone loss. Furthermore, the implant surface
characteristics may be important in the progression of
marginal bone loss. Given that the connection and sur-
face of the implant can affect the marginal bone loss
around the implant, development and clinical applica-
tion of an implant system that takes these findings into
account will be needed.

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