Assessment of Implant Stability of Patients With and Without Radiotherapy Using Resonance Frequency Analysis

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The purpose of this study was to clinically monitor the stability of dental implants in patients with and without a history of radiotherapy, using resonance frequency analysis over 1 year. The stability of patients with 80 implants was monitored with resonance frequency analysis (Ostell Mentor) over 1 year. Data were assessed with Mann-Whitney U test and correlation analysis. Irradiated maxillary implants showed statistically lower values than the mandibular implants at a significant level (P < .05).

Key Words: RFA, implant, radiotherapy, dental prosthesis

INTRODUCTION

Implant-supported prosthetic treatment of oral cancer patients is a challenging procedure because of several factors, such as deformed soft and hard tissue, xerostomia, and impaired muscular function. When the oral physiological factors, insufficient approaches, patient motivation, and tumor prognosis are taken into consideration, realistic outcomes for this particular patient population can be limited. Because of the anatomical insufficiencies that lead to a lack of support and stability, the use of conventional prostheses is limited in most of these patients; therefore, implant-supported prostheses are often regarded as indispensable. However, irradiation is an important factor that might have a negative impact on the success of implants in this group of patients. Several long-term studies have analyzed the factors that can affect implant survival following radiotherapy and evaluated the outcomes of the prosthodontic treatments on these particular patients. Although survival rates of irradiated implants were found to be lower than that of the implants placed in healthy patients, these implants were still accepted as advantageous.

Primary implant stability plays a key role in achieving osseointegration, and various methods have been introduced for the assessment of stability and the degree of osseointegration following implant placement. These methods include histological and histomorphometric evaluations, percussion tests, removal torque analysis, pull- and push-through tests, and the resonance frequency analysis (RFA) technique.

Resonance frequency analysis as a reliable and accurate indicator for determining implant stability is itself a bending test in which a very slight bending force is applied on the implant. A resonance frequency analyzer has been developed to clinically monitor the stability of intraoral and extraoral implants. After attachment of the transducer to the implant, measurements are made using a stylus. It shows the implant stability quotient (ISQ) value in its graphic display panel. The ISQ value refers to the stability and stiffness at the implant-tissue interface (osseointegration). This value is scaled from 1 to 100. Values greater than 50 are considered as osseointegrated.

At present, there are fewer data related to the implant survival rate in irradiated patients by using RFA. Therefore, the purpose of this study was to evaluate implant stability using the RFA technique. The null hypothesis was that the RFA measurements obtained for the comparison of patients with and without radiotherapy history over 1 year showed no significant differences.

MATERIALS AND METHODS

Study population

A total of 80 patients were included in the study. Patients were grouped into 2 study groups of 20 patients each, composed of mandibular and maxillary implants with radiotherapy history and 2 control groups composed of non-irradiated patients. Subjects were excluded if they had a systemic or local disease affecting their immune system other than cancer, infection,
current pregnancy or lactation, or history of antibiotic therapy within the past 3 months in order to eliminate the possible infections. Because of risks related to healing, heavy smokers (more than 10 cigarettes per day) were excluded from the study. The study group inclusion criteria were history of head and neck radiation therapy up to 72 Gy prior to implant placement.

As the aim was to analyze the stability of implants over 1 year, data obtained within 1 year were collected and analyzed.

**Implant placement**

ITI implants (Straumann AG, Basel, Switzerland) were used for the study. Placement of implants in surgical or grafted areas was avoided in case the patients were mandibullectomy or maxillectomy cases. In irradiated patients, all implants were placed within the radiation field after a minimum of 6 months following radiation therapy. In all patients, whether or not they were irradiated, the implants were allowed to osseointegrate for 3 months in the mandible and 6 months in the maxilla. Intraoral and panoramic radiographs were taken before the surgery, and the amount of bone, morphology, and skeletal relationships were evaluated. The available bone height, width, and length were calculated. Diagnostic casts were obtained, and surgical stents were fabricated accordingly. All patients underwent periodontal therapy, and oral hygiene instructions were given.

A crestal flap was elevated, and the implants were placed. Irradiated patients were prescribed an antibiotic regimen (amoxicillin 500 mg, 3 times per day, for 7 days) to minimize the risk of osteoradionecrosis.

After osseointegration, impression copings were fitted into the implant, perpendicular to the mesiodistal axis as recommended by the manufacturer. Results were displayed graphically and represented as an ISQ (1–100) value. The ISQ values were obtained 3 times and averaged. To evaluate the stability level periodically, 1-stage surgery was performed.

To evaluate implant stability values, measurements were made at the 1st, 7th, and 14th day; 3rd, 4th, and 6th month; and 1st year for each of the mandibular implants and at the 1st, 7th, and 14th day; 6th week; 6th and 7th months; and 1st year for maxillary implants.

Following a healing time of 3 months in the mandible and 6 months in the maxilla, implants were loaded. Occlusal adjustments were made to eliminate the lateral loadings. To observe the implants after loading, abutments and superstructures that permitted unscrewing were used.

**Statistical analysis**

Implant stability levels were assessed with descriptive statistical techniques and correlation analysis, and the results were tested by significance tests of the Mann-Whitney U test (difference between 2 means and proportions) at significance levels ($P \leq .05$) that refer to a confidence level of 95% or higher. The coefficients of correlation were tested at the level of significance of $P \leq .05$ and also for several coefficients at $P \leq .01$. Data were analyzed using SPSS version 17.0 for Windows (SPSS Inc, Chicago, Ill.).

**RESULTS**

A total of 80 subjects were recruited into the present study. Four groups were conducted as follows: 20 patients undergoing radiotherapy and having mandibular implants (13 men and 7 women; mean age, 51.6 years [SD, 9.09]), 20 patients undergoing radiotherapy and having maxillary implants (6 men and 14 women; mean age, 63.05 years [SD, 7.27]), 20 control patients with mandibular implants (11 men and 9 women; mean age, 43.35 years [SD, 15.93]), and 20 control patients with maxillary implants (12 men and 8 women; mean age, 53.5 years [SD, 15.21]). A percentage of the difference between men and women is seen as 2 times. The difference between men and women in the 4 groups was not significant ($P = .12$). There was a statistically insignificant difference between the irradiated and non-irradiated groups ($P = .37$).

Means and standard deviations for each examination period are listed in Table 1. As the ISQ values were statistically

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**Table 1**

<table>
<thead>
<tr>
<th>Examination Period</th>
<th>Mandibular Implants</th>
<th>Maxillary Implants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Study</td>
</tr>
<tr>
<td>First day</td>
<td>68.45 ± 9.561</td>
<td>62.4 ± 7.089</td>
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<tr>
<td>First week</td>
<td>60.05 ± 6.908</td>
<td>52.1 ± 5.077</td>
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<tr>
<td>Second week</td>
<td>59.05 ± 6.303</td>
<td>49.25 ± 3.323</td>
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<tr>
<td>Third month (loading)</td>
<td>67.95 ± 6.645</td>
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</tr>
<tr>
<td>Fourth month</td>
<td>62.15 ± 6.132</td>
<td>55 ± 3.742</td>
</tr>
<tr>
<td>Sixth month</td>
<td>70.7 ± 7.349</td>
<td>63.65 ± 5.715</td>
</tr>
<tr>
<td>Sixth month (loading)</td>
<td>70.7 ± 7.349</td>
<td>63.65 ± 5.715</td>
</tr>
<tr>
<td>Seventh month</td>
<td>75.75 ± 6.536</td>
<td>67.3 ± 7.197</td>
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</tbody>
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compared before and after loading, significant differences were observed in both the mandible and the maxilla \((P < .001)\). As a result of this analysis, postloading ISQ values for the control and study groups were statistically higher than preloading values. Similar results were obtained for the irradiated patients at the level of significance as well \((P < .001\); Table 2).

Postloading ISQ values of control groups for the maxilla and mandible were significantly higher than the values of irradiated patients at the level of significance, respectively \((P < .02\) and \(P < .001\); Table 1). This significant result is valid for the ISQ values of the maxillary and mandibular control and study groups at the time of loading \((P < .001\); Table 2).

Using the Mann-Whitney \(U\) test and considering the baseline values (first day), no significant difference was observed in the control and study groups of mandibles, whereas all the remaining periods, including the loading period, showed significant differences in both patient groups \((P \leq .001)\). Maxillary implants were compared, and significant differences were observed in all of the test periods except for the seventh month, which was only 1 month after loading (Tables 1 and 2).

Correlation analyses were done to evaluate whether there were any relationships between control and study groups of mandible and maxilla on the basis of observation periods. No significant relationship was observed between the loading and 1-year ISQ values of mandibular control groups \((P > .05)\). On the contrary, a significant correlation \((P < .05)\) with a relationship strength of \(+65\%\) was observed in the study group. As the same analyses were performed for comparing the loading and 1-year values of the maxilla, strong and significant relationships were observed for both the control \((R = 58.7\%\) and study group \((R = 75.5\%)\). According to these results, significant relations were found between loading and first-year values of the control and study groups \((P < .05)\). It was also analyzed that the relationships were positive and reflected that they moved in the same direction, as loading ISQ first-year values increased (Tables 3 and 4).

**Discussion**

Initial implant stability is a critical issue for the prognosis of the treatment. At the time of implant placement, knowledge of primary stability may serve as a guide for future treatment protocols. This prediction is important, especially in head and neck cancer patients with radiotherapy history.\(^1\)–\(^13\)

Meredith et al\(^{15}\) described several methods for measuring implant stability and osseointegration, such as clinical measurement of cutting resistance, Periotest, and dental fine tester, and concluded that quantitative methods such as RFA as a nondestructive method could be used in clinical research so as to monitor implant stability and provide valuable information.\(^{15}\)–\(^18\) In determining the stability, an ISQ value less than 45 should be taken as a control limit, and in such cases, efforts to increase the stability should be considered.\(^{18}\)–\(^23\)–\(^25\) In our study, Osstell was used as a resonance frequency analyzer to compare the stability levels of implants within 1 year. Implants placed in irradiated mandibles and maxillas were compared with nonirradiated implants. ISQ values measured in various periods were recorded, and results obtained were presented in a numerical form to analyze and compare different observation periods.

In studies reported by Nelson et al\(^7\) and Granstrom,\(^10\) the overall implant survival rate of patients with oral cancer resection was found to be lower than that of noncancer patients. The poor implant survival rate among these patients was due to a higher mortality rate rather than lack of osseointegration. Yerit et al\(^{11}\) stated that irradiated mandibular bone showed significantly lower implant survival in comparison with nonirradiated mandibular bone. Seong et al\(^{34}\) made Osstell measurements immediately after implant placement and found that mandibular implants showed higher initial stability than maxillary implants. In a study performed by Mericske-Stern et al,\(^9\) it was found that all implant failures occurred in the irradiated mandibles rather than maxillary implants under similar circumstances. Granstrom\(^{10}\) evaluated the effects of radiotherapy and found that the highest implant

**Table 2**

<table>
<thead>
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<th>Preloading</th>
<th>Postloading</th>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>69.53</td>
<td>.001</td>
<td>67.95</td>
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<td>Study</td>
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<td>61.98</td>
<td>.001</td>
<td>59.65</td>
</tr>
<tr>
<td>(P)</td>
<td>0.001</td>
<td>0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Maxilla</strong></td>
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<td></td>
</tr>
<tr>
<td>Control</td>
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<tr>
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<tr>
<td>(P)</td>
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**Table 3**

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<tr>
<th>Study Group</th>
<th>First Day</th>
<th>First Week</th>
<th>Second Week</th>
<th>Third Month (Loading)</th>
<th>Fourth Month</th>
<th>Sixth Month</th>
<th>First Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Group</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First day</td>
<td>−.158</td>
<td>.122</td>
<td>.096</td>
<td>.008</td>
<td>−.096</td>
<td>.269</td>
<td>.239</td>
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<tr>
<td>First week</td>
<td>−.133</td>
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<td>.286</td>
<td>.290</td>
<td>.121</td>
<td>−.239</td>
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<td>Second week</td>
<td>−.365</td>
<td>.203</td>
<td>.148</td>
<td>−.009</td>
<td>−.056</td>
<td>−.046</td>
<td>−.072</td>
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<tr>
<td>Third month (loading)</td>
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<td>.227</td>
<td>.029</td>
<td>−.250</td>
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<td>.222</td>
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<td>Fourth month</td>
<td>−.324</td>
<td>−.252</td>
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<tr>
<td>Sixth month</td>
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<td>.138</td>
<td>−.120</td>
<td>.032</td>
<td>.130</td>
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<tr>
<td>First year</td>
<td>−.245</td>
<td>.211</td>
<td>−.092</td>
<td>.362</td>
<td>.187</td>
<td>−.129</td>
<td>.459</td>
</tr>
</tbody>
</table>
failures were in the frontal bone, zygoma, mandible, and nasal maxilla. The lowest implant failures occurred in the maxilla. Similarly, ISQ values of implants showed significant differences in irradiated mandibles, except for the time of implantation. This result confirms that the irradiated mandible loses its compact structure that ordinarily provides better stability.

In both patient groups of this present study, higher ISQ values were obtained by time. Control groups showed higher values than study groups. Irradiated maxillary implants showed lower values than mandibular implants. As loading values and final values were compared, maxillary controls and mandibular study groups demonstrated significant differences.

As the evaluation periods were compared, except for the baseline (first day) values of the mandibular implants, significant differences were observed between the irradiated and non-irradiated mandibles. This could be attributed to the more compact feature of mandibular bone. As the maxillary bone was assessed, no significant difference was observed in the values obtained 1 month after loading. This is postulated to be due to a more spongiose bone characteristic and better blood supply of the maxilla, and loading does not affect or change the values obtained previously.

Previous reports on native bone using RFA have shown a decrease in implant stability in the first month after implant placement, followed by increases in the second and third months, suggesting a process of adaptive bone remodeling around the implant. In our study, baseline values of all the implants were found to decrease within 2 weeks after implantation. After loading, a gradual increase was observed until the first-year values were reached.

Friberg et al\textsuperscript{27} stated that implants with low primary stability showed increased stability over time. During the healing period, the mean ISQ in the mandible and in the maxilla remained stable or slightly increased during the first 4–6 weeks and then started to increase more noticeably.\textsuperscript{26} In most of the studies, an increase in the ISQ values was observed.\textsuperscript{18,23–26} As supported by most of the studies, mandibular implants had a significantly better survival rate than maxillary implants, although long-term survival rates were equivalent.\textsuperscript{5,12,24}

Seong et al\textsuperscript{34} made Osstell measurements immediately after placement and found that mandibular implants had a higher initial stability than maxillary implants. Bischof et al\textsuperscript{11} measured the ISQ values at the time of implant placement and at 1-, 2-, 4-, 6-, 8-, 10-, and 12-week intervals. The ISQ was higher in the mandible than the maxilla. After 3 months, the gain in stability was higher. Results obtained in this present study confirm the findings of Friberg et al\textsuperscript{27}; that the low stability of implants may increase over time.

As the loading values were compared with those obtained at the end of 1 year, it was determined that loading did not have a significant effect on the results obtained at the end of 1 year, which means that the stability level did not change over time as a result of the compact structure of the mandible ($P = .983$). Taking irradiation into consideration, mandibular bone demonstrated significant differences as the loading and 1-year values were compared ($P = .002$). This result indicates that irradiation has a negative effect on the mandible. Controversial results were obtained in the maxilla. Significant differences were observed in healthy patients ($P = .007$), whereas no significant results were obtained in irradiated maxillas ($P = .168$). Maxillary implants have proven to have less stability and can be compromised in the long term. However, in the irradiated maxilla, no significant changes were observed. This may be due to the poorer quality of bone, which was already low at the time of loading. In addition, a richer blood supply in the maxilla is an advantage for supporting an implant in the instance of irradiation. Reduced bone volume, low quality of bone, and excessive occlusal loads are considered when it is decided to load implants immediately.\textsuperscript{23}

We aimed to evaluate the stability levels of implants and observe the changes in ISQ data over 1 year using a numeric value rather than examining the long-term success. Therefore, 1 year of evaluation time that ensured the presence of osseointegration was taken into consideration. In this way, stability measurements of mandibles and maxillas with and without radiotherapy history were compared, and the behavior of the bone-implant interface before and after loading was evaluated.

The amount of lapsed time after irradiation was found to be insignificant both in the mandible and maxilla. Results indicate it is not necessary to wait more than 1 year to obtain higher values. Esser and Wagner\textsuperscript{2} studied 275 dental implants inserted in irradiated mandibles. They found that radiotherapy, age, sex, localization of the implants, and interval between the end of tumor therapy and the time of implantation had no significant effect on osseointegration. Only the time interval between the time of tumor therapy and the abutment operation was noted to be of any great significance. Visch et al\textsuperscript{8} found that survival percentages of implants inserted more than or less than 1 year after irradiation were not significant. In their study of

<table>
<thead>
<tr>
<th>Study Group</th>
<th>First Day</th>
<th>First Week</th>
<th>Second Week</th>
<th>Third Month (Loading)</th>
<th>Fourth Month</th>
<th>Sixth Month</th>
<th>First Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Group</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First day</td>
<td>.279</td>
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<td>.171</td>
<td>-.092</td>
<td>.163</td>
<td>.306</td>
<td>-.086</td>
</tr>
<tr>
<td>First week</td>
<td>-.289</td>
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<td>-.187</td>
<td>-.078</td>
<td>.025</td>
<td>-.024</td>
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</tr>
<tr>
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<td>-.090</td>
<td>-.150</td>
<td>-.170</td>
<td>.012</td>
<td>-.158</td>
</tr>
<tr>
<td>Third month</td>
<td>.197</td>
<td>.044</td>
<td>.087</td>
<td>-.086</td>
<td>-.173</td>
<td>-.087</td>
<td>.074</td>
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<td>.046</td>
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<td>.500</td>
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<td>.320</td>
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<tr>
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<td>.122</td>
<td>-.142</td>
<td>-.264</td>
<td>-.002</td>
<td>-.161</td>
<td>.084</td>
</tr>
</tbody>
</table>

TABLE 4

Result of correlation analysis for the maxilla on the basis of the observation periods

\(P = .082\) \quad \(P = .122\) \quad \(P = .262\) \quad \(P = .090\) \quad \(P = .169\) \quad \(P = .092\) \quad \(P = .150\) \quad \(P = .170\) \quad \(P = .012\) \quad \(P = .158\) \quad \(P = .024\) \quad \(P = .220\) \quad \(P = .046\) \quad \(P = .320\)
mandibular implants, Yerit et al\textsuperscript{11} stated that time of implantation after irradiation showed no statistically significant effect on implant survival. Similarly, Schliephake et al\textsuperscript{13} discovered that previous radiation therapy had no significant effect on survival rates. Parallel to these results, it was found in this study that the time interval since radiotherapy completion does not have any statistically significant effect on the stability of implants.

Most of the studies have demonstrated that rigid fixation of the implant-supported prosthesis appears to minimize prosthenesi-related lesions and complications.\textsuperscript{7,8} In this study, all patients had single-crown restorations without lateral loads to minimize biomechanical failures. Also, screwed abutments were used to be able to make repeated measurements. In most of the studies, it has been demonstrated that the ISQ values were higher. In our study, both irradiated and non-irradiated maxillas and mandibles showed statistically significantly higher ISQ values after loading. Our study has been performed to support the results that were published using numeric data and to determine the stability-level changes with the use of the Oststell mentor.

Evolution of implant stability after loading could not be followed for all implants because most restorations were cemented rather than screw retained, because of the higher costs of screw-retained prostheses. Therefore, to evaluate all of the implants, screw-retained abutments were used. In addition, single-crown restorations were analyzed for standardizing results.

Esser and Wagner\textsuperscript{2} concluded in another study that the success of implants in the irradiated bone is determined after an interval of 18 to 24 months. Therefore, further studies assessing measurements over longer periods of time must be performed for more substantial results.

Within the limitations of this study, it can be concluded that the use of the Osstell as a tool to monitor the variation in the stability of implants over time is a helpful guide in patients with and without radiotherapy. In both maxillary and mandibular implants, a significant difference was seen in the ISQ values of the implants in irradiated and non-irradiated patients. Higher ISQ values were found in mandibular implants compared with those in maxillary implants and also in non-irradiated implants compared with irradiated implants. ISQ values obtained during loading of mandibular implants had no significant effect on the values obtained by the end of 1 year, whereas it was found to be significant with maxillary implants. Finally, implant treatment can be equally effective for patients with radiotherapy history.

**ABBREVIATIONS**

ISO: implant stability quotient
RFA: resonance frequency analysis

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