To Immediately Load, Expose, or Submerge in Partial Edentulism: A Study of Primary Stability and Treatment Outcome

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Purpose: This study was undertaken to assess the predictive usefulness of preoperative bone density, as measured by computed tomography (CT), and the intraoperative implant stability measures of insertion torque (IT), Periotest values (PTV), and resonance frequency analysis (ie, implant stability quotient [ISQ]) toward developing an algorithm for successful immediate loading, one-step exposure, or submergence of dental implants. Materials and Methods: Consecutively presenting patients requesting immediate loading in areas other than the anterior mandible were analyzed retrospectively. The implants were either immediately loaded, left exposed, or submerged on the basis of preoperative CT bone density and intraoperative primary stability measures. All implants surviving the traditional healing period were verified for osseointegration. Results: Eighteen patients were analyzed retrospectively, and they received 58 implants. Seven implants failed, for a survival rate of 88%. Primary stability measurements at insertion were correlated with one another and with preoperative CT bone density. Preoperative mean bone density for surviving implants was greatest for immediately loaded implants (983 ± 83), lower for exposed implants (803 ± 29), and lowest (480 ± 23) for submerged implants. Bone density was significantly different between submerged implants that failed and those that survived. Mean IT for successful implants was higher than for those that failed. Mean PTVs were lower (ie, better) for successful versus failed implants, although this difference was significant only for submerged implants. Conclusions: In this group of patients, objective measures of bone density by CT, IT, PTV, and ISQ correlated with each other and therefore may provide a useful algorithm for making clinical implant loading decisions. Of the technologies applied in this group of patients, PTV was the most reliable predictor at implant placement of failure to osseointegrate.

Key words: algorithm, bone density, immediate loading, partial edentulism, primary stability, retrospective analysis
these have become two of the more promising alternatives to the original two-stage protocol.

Immediate loading began for full-arch restorations in the anterior mandible as a method to provide patients with a fixed provisional restoration at the time of implant insertion. To maintain predictability in these early cases, eight implants were placed. Three were immediately loaded, and five were left submerged and restored in the traditional fashion. It was anticipated that the three immediately loaded implants would fail after the 3- to 4-month period of osseointegration and the restoration would be supported by the five remaining implants. Surprisingly, the immediately loaded implants osseointegrated, demonstrating it was possible to immediately load an implant. In the mid- to late 1990s, several reports confirmed successful one-step implant placement without immediate loading, and many others confirmed success with immediate loading over the short term, while one reported long-term (10-year) results. All of these early experiments, which incorporated cross-arch splinting of immediately loaded implants in the anterior mandible, showed survival rates that were comparable to those seen with the two-staged approach. Between 1997 and 2001, these techniques were expanded to complete-arch maxillary restorations, with encouraging results. These promising results with full-arch applications led to immediate loading in partially edentulous conditions. However, when partially edentulous patients are treated, fewer implants are used, often in sites with less dense bone (eg, the posterior mandible and maxilla), with little option for cross-arch splinting or the inclusion of “backup implants” to keep in reserve. Even with these obstacles, many authors have reported high success rates with immediate loading in partial edentulism with short-span restorations and single teeth, ushering in a period of refinement in the evolution of immediate loading. In 2004 a meta-analysis of 35 studies consisting of 689 patients with 2,329 implants demonstrated a 10-year survival rate of 96.6%. The patients in these reports were treated by very experienced practitioners using stringent inclusion/exclusion criteria; therefore, these excellent results may not be representative of what can be expected in the general population. In addition, when the partially edentulous patients were analyzed separately, there was a significantly lower survival rate in the posterior maxilla (91.4%) versus the anterior mandible (98.4%); thus, even in experienced hands, lower survival rates for immediate loading have been seen.

Although immediate loading can be applied successfully, the decision on when to put implants into immediate function is still largely made empirically. Consequently, as more implants are loaded immediately, especially in type III and IV bone, and as partially edentulous cases become more popular, increased failure rates can be expected. Accordingly, as immediate loading expands to partial edentulism and complete-arch restorations that use fewer implants provided by less experienced practitioners, it will be beneficial to have objective guidelines indicating when immediate loading can be predictably applied. This will avoid reverting to the unacceptably low survival rates that were seen in the pre-Brånemark era, when failures of one-piece immediately loaded implants were commonplace.

Today, several technologies can be used as outcome predictors for effective immediate loading. In 1987 computed tomography (CT) was introduced for diagnostics in implant dentistry, and in 2001 it was shown that preoperative bone density (as observed through CT) and an interactive software program correlated well with the dentist’s subjective rating of bone quality. In the mid-1990s initial implant stability was related to bone

![Empirical Loading Algorithm](image-url)
density using insertion torque\textsuperscript{36–39} (IT) (also called seating torque or placement torque) as a guide. The Periotest instrument (Medizintechnik Gulden) has been used for evaluation of implant stability since 1986,\textsuperscript{40–43} and more recently, resonance frequency analysis (RFA) has been used to determine when osseointegration has occurred.\textsuperscript{44,45} While these objective measures for assessing bone density and implant stability have been applied individually to evaluate implant status at insertion, they have generally not been used together as an algorithm. Furthermore, threshold values for predicting the success of immediately loaded implants have not been identified.

The present authors have been loading implants immediately since 1986\textsuperscript{5}; however, not every implant placed is loaded immediately, even when the patient requests it. Rather, an empirical algorithm has been used to identify implants that can be safely loaded immediately or exposed or should be submerged. To refine this algorithm, a retrospective analysis of a group of 18 patients who consecutively presented during a 5-year period between 1999 and 2003 and requested immediate loading in sites other than the anterior mandible was undertaken. Its purpose was to assess the predictive usefulness of preoperative CT bone density and the intraoperative implant stability measures of IT, Periotest values (PTVs), and RFA toward developing an evidence-based algorithm for successful immediate loading, exposure, or submergence.

**MATERIALS AND METHODS**

A series of consecutively treated patients who presented between September 1999 and November 2003 requesting immediate loading in areas of the jaws other than the anterior interforaminal region of the mandible were analyzed retrospectively. All patients were in good health, exhibited fixed opposing dentitions, and had had their implants in situ for at least 5 years. Of 252 presenting patients, a total of 18 patients meeting these inclusion criteria received 58 implants, which were either immediately loaded, left exposed with a healing abutment, or submerged according to preoperative and intraoperative criteria of an empirical loading algorithm (Fig 1).

Prior to implant placement, each patient underwent CT scanning (GE LightSpeed or GE HiSpeed, GE Medical Systems). Scans were reformatted (SimPlant 7, Materialise Dental) to determine implant position and mean bone density in Hounsfield units (HU) at each planned implant site.

All 58 implants were placed by the same operator and were cylindric screws. Forty-nine were etched-surface external-hex self-tapping implants (Osseotite, Biomet 3i), six were machined-surface external-hex self-tapping implants (Mark III, Nobel Biocare), and three were sandblasted/acid-etched internal-octagon implants (SLA Standard Plus, Institut Straumann). Sites were prepared according to the manufacturers’ guidelines, except that in type 3 and 4 bone, preparations were undersized through the use of a final twist drill that was 1.25 mm narrower than the diameter of the planned implant. Minimal countersinking was performed to keep the shoulder of the implant in cortical bone. Rarely, the bone was tapped, but when it was necessary in very dense bone, tapping was performed 3 mm short of the prepared site.

The initial stability of implants was measured by IT (DEC500, Nobel Biocare, or Ratchet with Torque Control Device, Straumann USA); PTV at 4 mm above the implant platform, (Periotest, Medizintechnik Gulden); and, when available, RFA (Resonance Frequency Analyzer Model 6, Osstell). The latter instrument became available after nine of the patients in this analysis were treated; therefore, this data point is not available for all patients.

According to the authors’ empirical algorithm (Fig 1), implants were loaded immediately only when they successfully met both preoperative and intraoperative requirements. The preoperative assessment required a CT density at the site of at least 600 HU. All implants that failed to meet this minimum bone density threshold were automatically submerged, although intraoperative data were still recorded. All planned implant sites demonstrating a density above 600 HU were considered and prepared for immediate loading. However, a series of three intraoperative tests were performed, and again, based on empirical determinants of required stability, only implants achieving stability as measured by IT of at least 40 Ncm, PTV of \(-3\) or lower, and an implant stability quotient (ISQ) of at least 65 were actually immediately loaded. Implants that did not meet these criteria were either loaded or submerged using the following criteria. Criteria for implants in a restorative site to be submerged were: IT < 20 Ncm, PTV ≥ –1, or ISQ ≤ 58. Criteria for exposure were an IT between 40 and 20, a PTV between \(-1\) and \(-3\), and, when available, an ISQ between 59 and 65. However, the patient was always given the choice to override the criteria and expose or submerge regardless of intraoperative values as long as the mean preoperative bone density according to the CT was equal to or greater than 600 HU. During this period in the empirical algorithm, single-tooth implants were not considered eligible for immediate loading. However, they could be left exposed with a healing abutment if the implant met the criteria for exposure or immediate loading. According to the empirical algorithm, for immediate loading in complete-arch cases, only half of the implants in a restoration were loaded, and
the remaining adjacent implants were left exposed and unloaded in case of failure of immediately loaded implants. The implants to be loaded were those that demonstrated the best preoperative and intraoperative values.

Immediate loading was accomplished by placement of a prosthetic abutment on the implant and the conversion of a preoperatively prepared removable prosthesis into a fixed screw-retained provisional prosthesis at implant insertion. Exposure was accomplished by placement of a healing abutment at implant insertion, which would extend 1 to 2 mm coronal to the tissue and would be kept out of occlusion. On the basis of preoperative and intraoperative measures, implants were assigned to one of three groups: immediately loaded, exposed (one-stage), or submerged (two-stage).

Except for suture removal after 8 to 14 days, immediately loaded provisional prostheses were not removed for at least 3 months in the mandible and 4 months in the maxilla. At the end of this healing period, immediately loaded restorations and exposed healing abutments were removed and submerged implants were exposed for evaluation. Implant success was determined on the basis of survival, PTV ≤ –1, ISQ ≥ 60, and lack of radiolucency, discomfort, or gingival inflammation. Successful implants were then restored with splinted fixed screw-retained or cement-retained porcelain-fused-to-high-noble-metal/ceramic restorations. Multiple implants were always splinted.

The data were analyzed with statistical software using the unpaired t test and correlation analysis (Statview 5.0, SAS institute).

RESULTS

Eighteen patients meeting the study criteria received 58 dental implants, which were restored with 18 prostheses and were followed for at least 5 years. Fifty-one implants had osseointegrated by 4 to 6 months and 7 implants failed prior to 6 months, for an overall survival rate of 88% (Table 1).

As a result of insertion measures, implants were distributed into three groups. Eight implants in three patients were loaded immediately with three screw-retained splinted fixed restorations. Seven of these implants were successful and one had failed by the end of the healing period. This failure (implant no. 19) occurred in the anterior maxilla (Table 2) as a result of mobility (PTV = 11) during the healing period. Although it remained in function, it was included as a failure in the analysis. Another of these implants (implant no. 5) failed after 5 years and was not included in the early failure rate, since it was felt the failure was not related to the immediate loading. Ten implants were exposed, and all were successful. Forty implants were submerged, and six of these failed.

Table 1 shows the distribution of the implants by patient, size, type, location, insertion data, loading condition, and outcome. The actual stability of implants is categorized into three groups by color. Implants that met the criteria for immediate loading are shown in green, those that met the criteria for exposure are shown in yellow, and those that met the submergence criteria are shown in red. Owing to patient preference and other reasons previously outlined, 12 implants skewed the data by falling into groups not appropriate for their intraoperative values and are shown in orange. Implants were only considered for immediate loading when all measurements were in green for every implant in a prosthesis. If any measurement was in red, submergence was recommended. Patients were sorted by their mean HU for the restorative site (highest to lowest) to demonstrate color trends for loading conditions.

Of the six failures that occurred in the submerged group, five were in the posterior maxilla and one was in the anterior maxilla (Table 2).

Means and ranges of preoperative and intraoperative measurements for the 46 implants with non-skewed data by treatment and outcome are shown in Table 3.

There was a trend for bone density (HU) to decrease from immediately loaded implants to those that were submerged. Preoperative mean bone density for surviving implants was greatest for immediately loaded implants (983 ± 83 HU), followed by exposed implants (803 ± 29 HU) and submerged implants (480 ± 23 HU). There was a significant difference in bone density between submerged implants that failed and those that survived (P = .0077).

With regard to intraoperative measures, mean IT in the immediately loaded group was 44 ± 1 Ncm for successful implants and 40 Ncm for the implant that failed. These values were not markedly different. In the submerged group, mean IT was 24 ± 1 Ncm for successful implants and 20 Ncm for those that failed. The difference was not significant (P = .3031). However, the mean PTV in the immediately loaded group was –4.6 ± 0.4 for successful implants and markedly higher at –3 for the implant that failed. For submerged implants that were successful, the mean PTV was –2 ± 0.3, while for failures in this group it was significantly higher at 0.0 ± 1.0 (P = .0013). RFA measurements are presented in Table 3 for informational purposes only, as too few measurements were available for meaningful analysis.

Correlation analysis between CT bone density and primary stability measures for all implants placed for each criterion was performed, and the results...
Table 1  Detailed Implant Data

<table>
<thead>
<tr>
<th>Patient</th>
<th>1 EX</th>
<th>2 GI</th>
<th>3 MW</th>
<th>4 DI</th>
<th>5 WT</th>
<th>6 SG</th>
<th>7 CD</th>
<th>8 MB</th>
<th>9 JE</th>
<th>10 IC</th>
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<tbody>
<tr>
<td>Mean HU</td>
<td>1,268.0</td>
<td>1,127.6</td>
<td>919.6</td>
<td>907.3</td>
<td>858.8</td>
<td>828.7</td>
<td>798.1</td>
<td>724.0</td>
<td>661.7</td>
<td>633.7</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Implant no.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
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<tbody>
<tr>
<td>Implant size/ surface</td>
<td>4 × 10/0</td>
<td>4 × 10/0</td>
<td>4 × 10/0</td>
<td>4 × 10/0</td>
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<tr>
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<th>#45</th>
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<th>#46</th>
<th>#14</th>
<th>#13</th>
<th>#11</th>
<th>#21</th>
<th>#23</th>
<th>#25</th>
<th>#36</th>
<th>#14</th>
<th>#11</th>
<th>#21</th>
<th>#25</th>
<th>#26</th>
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<tr>
<td>HU</td>
<td>1,314.0</td>
<td>1,221.9</td>
<td>1,051.6</td>
<td>890.2</td>
<td>887.1</td>
<td>996.6</td>
<td>814.9</td>
<td>830.5</td>
<td>887.1</td>
<td>876.7</td>
<td>835.2</td>
<td>846.3</td>
<td>794.9</td>
<td>730.0</td>
<td>772.0</td>
<td>688.0</td>
<td>884.0</td>
<td>661.0</td>
<td>714.4</td>
<td>603.5</td>
<td>683.2</td>
<td>673.9</td>
<td>487.6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| ST | 45 | 45 | 40 | 40 | 45 | 45 | 45 | 30 | 30 | 35 | 30 | 35 | 20 | 25 | 40 | 45 | 30 | 40 | 40 | 20 | 40 | 30 | 30 | 30 | 40 |

| PTV | -5 | -4 | -3 | -3 | -3 | -3 | -3 | -2 | -4 | -5 | -5 | -5 | -3 | -3 | -3 | -3 | -2 | -4 | -3 | -3 | -3 | -2 | -4 | -3 | -2 |

| RFA | 69 | 69 | NA | 72 | 72 | 70 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 68 | NA | NA | NA | NA |

<table>
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<tr>
<th>Loading condition</th>
<th>IL</th>
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<th>IL</th>
<th>EX</th>
<th>EX</th>
<th>EX</th>
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<th>SM</th>
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<tr>
<td>Outcome</td>
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<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
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<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
</tr>
</tbody>
</table>

SLA = SLA surface (Straumann); O = Osseotite (Biomet/3i); M = machined-surface Millik (Nobel Biocare); SM = submerged; S = success; F = failure;
Tooth numbers are FDI system.

*Not immediately loaded (single implant); †late failure; ‡submerged per patient’s request; §exposed per patient’s request; ¶implant too unstable to measure PTV after placement, surgeon decided not to measure PTV.

Table 2  Summary of Implants Placed by Treatment, Location, and Outcome

<table>
<thead>
<tr>
<th>Treatment</th>
<th>No. of patients</th>
<th>No. of implants</th>
<th>Posterior mandible (n = 16)</th>
<th>Anterior maxilla (n = 20)</th>
<th>Posterior maxilla (n = 22)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Successful</td>
<td>Failed</td>
<td>Successful</td>
<td>Failed</td>
</tr>
<tr>
<td>Immediate</td>
<td>3</td>
<td>8</td>
<td>7</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Exposed</td>
<td>5</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Submerged</td>
<td>11</td>
<td>40</td>
<td>34</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>18*</td>
<td>58</td>
<td>51</td>
<td>7</td>
<td>16</td>
</tr>
</tbody>
</table>

*One patient received both immediately loaded and exposed implants.

Table 3  Mean Preoperative and Intraoperative Measurements by Treatment and Outcome for Non-Skewed Implants (n = 46)

<table>
<thead>
<tr>
<th>Treatment/Outcome</th>
<th>Preoperative measurement</th>
<th>Intraoperative measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CT bone density (HU)</td>
<td>IT (Ncm)</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>Mean ± SE</td>
</tr>
<tr>
<td>Immediate loading</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Success</td>
<td>7</td>
<td>983 ± 83</td>
</tr>
<tr>
<td>Failure</td>
<td>1</td>
<td>618</td>
</tr>
<tr>
<td>Exposed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Success</td>
<td>6</td>
<td>803 ± 29</td>
</tr>
<tr>
<td>Failure</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Submerged</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Success</td>
<td>5</td>
<td>268 ± 36*</td>
</tr>
<tr>
<td>Failure</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>46</td>
<td>579 ± 38</td>
</tr>
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</table>

*P = .0077; †P = .0013.

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are shown in Table 4. Preoperative CT bone density correlated with all primary stability measures, confirming its value as a preoperative predictor for immediate loading, exposure, or submergence.

The result of correlation analysis among primary stability measures for all implants placed is shown in Table 5. The strongest correlation was between PTV and RFA (r = 0.78). Correlation between IT and PTV or RFA was not as strong (r = 0.64 and r = 0.59, respectively. It should be noted, as previously stated, that not all implants were measured via RFA.

**DISCUSSION**

This retrospective analysis was undertaken to see whether threshold data could be identified on the basis of outcome for patients treated using an experiential algorithm to decide whether implants could be immediately loaded, exposed, or submerged. The authors examined preoperative CT bone density and intraoperative measures (IT, PTV, and ISQ) to see whether reliable outcome predictors could be identified.

This analysis included only a very small number of patients and implants, and the methods included several uncontrolled variables. Significant among these were the option of patient decision making, which influenced the algorithm, and the selection criteria for groups, which were based only upon the authors’ experience. Although these factors influenced the data, this analysis presents new information of value for designing future studies, which should be conducted with larger numbers of patients. Furthermore, with the current absence of definitive predictive information, these preliminary findings will serve as a valuable adjunct in helping practitioners decide whether immediate loading or one-step exposure could be reasonable alternatives to submergence.

**Table 4** Correlations Between CT Findings and Primary Stability Measures for All Implants

<table>
<thead>
<tr>
<th>Measure</th>
<th>N</th>
<th>Correlation coefficient</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>IT</td>
<td>58</td>
<td>R = .72</td>
<td>&lt; .0001</td>
</tr>
<tr>
<td>PTV</td>
<td>57</td>
<td>R = .70</td>
<td>&lt; .0001</td>
</tr>
<tr>
<td>RFA</td>
<td>18</td>
<td>R = .64</td>
<td>.0036</td>
</tr>
</tbody>
</table>

**Table 5** Correlations Between IT, PTV, and ISQ

<table>
<thead>
<tr>
<th>Measure</th>
<th>N</th>
<th>Correlation coefficient</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>IT and PTV</td>
<td>57</td>
<td>R = .64</td>
<td>&lt; .0001</td>
</tr>
<tr>
<td>IT and ISQ</td>
<td>18</td>
<td>R = .59</td>
<td>.0086</td>
</tr>
<tr>
<td>PTV and ISQ</td>
<td>18</td>
<td>R = .78</td>
<td>&lt; .0001</td>
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In the present group of patients, there was a high failure rate for implants that were left submerged, and one might have expected these implants to be successful since they were protected through submergence. However, these failures occurred in the maxilla and, for the most part, in posterior sites, which are known to have lower osseointegration rates.\textsuperscript{17,30,46,47} In addition, it was surprising that the survival of rough-surfaced implants in low-density bone was not higher, but here, too, there is likely a threshold of bone density where even a rough surface will not guarantee osseointegration.\textsuperscript{48,49}

In this analysis, CT bone density was found to be a valuable planning tool as a predictor for initial implant stability. However, it is limited as a single factor for preoperative determination of loading condition, because there may be differences in bone density between the planned and actual implant positions. To identify the effect that actual implant positional differences may have had on the data, the authors compared the preoperative implant site and postinsertion implant positions via periapical radiographs. While this was only a qualitative judgment, there appeared to be no discernable difference in the mesiodistal dimension. However, there may have been differences buccolingually, which are not identifiable with two-dimensional radiographs. All scans for these patients were done using medical scanners, which were cali-

...bly drilled daily for accuracy of Hounsfield numbers. The more recently introduced cone beam scanners reduce the radiation exposure to the patient but do not produce accurate Hounsfield numbers. Since the HU values for bone density as measured by CT are dependent on the type of scanner, scanning exposure, and reformating programs used,\textsuperscript{50–54} clinicians should correlate the data presented in this analysis with their own data equipment and software when considering using this algorithm.

IT is a frequently used measure of primary stability, but the data regarding IT for immediate loading are variable. Li et al.\textsuperscript{55} in a retrospective study of 690 implants, reported IT values ranging from 20 to 50 Ncm, and successful immediately loaded implants had, on average, a significantly higher IT (44.29 Ncm) than those that failed (38.89 Ncm). Ottoni et al.\textsuperscript{39} found, in a study of 46 single-tooth implants, half of which were immediately loaded, that low survival rates were associated with low IT, and this seemed to be the most important predictor of outcome. They reported that IT above 32 Ncm was needed to achieve osseointegration. Maló et al.\textsuperscript{22,56} in reports of complete-arch restorations with four implants in both the mandible and maxilla, employed underpreparation to achieve IT above 40 Ncm. Wohrle\textsuperscript{19} reported 100% survival for immediately loaded single-tooth implants in the esthetic zone with a minimum IT of 45 Ncm. However, none of these studies reported an analysis of IT. It should be noted that IT can be a subjective measure. For example, drilling units and torque wrenches are limited to preset values, and operators are able to decide when to stop seating/insertion/placement. In the present analysis, the drilling unit and torque wrench were limited to fixed preset values: 20, 30, 40, or 45 Ncm for the drilling unit and 15 or 35 Ncm for the ratchet torque wrench. Therefore, because the instruments would not measure above or below these preset values, the actual measurements might have been slightly higher or lower. In addition, to maintain a conservative approach when in less dense bone and to prevent stripping the implant, seating was stopped when the implant appeared to reach its final position even if the drilling unit or ratchet would have allowed drilling to continue. In these cases the lower value was recorded.

PTVs and ISQs are objective measures, but they, too, can vary. The PTV is dependent on the type of measurement (ie, height above the bone). The higher the measurement point, the higher the PTV.\textsuperscript{40} In this group of patients, the measurement was always made 4 mm above the bone level. The RFA device was not available for nine of the early patients. Therefore, meaningful statistical analysis could not be undertaken, and RFA results are presented for informational purposes only. Furthermore, RFA measurements in these patients were variable, possibly because of differences in the measurement height above bone, the intimacy of bone/implant contact, and use of the first-generation device.

The new third-generation instrument (Osstell ISQ) may offer some improvement. Friberg et al.\textsuperscript{57} comparing rough and machined-surface implants, compared RFA and IT and observed a lack of correlation between these measures. Da Cunha et al.\textsuperscript{58} in another study of 24 immediately loaded implants, found no direct relationship between ISQ and IT. Clearly, there is a need for more clinical research to determine threshold values for these technologies for the prediction of successful osseointegration at implant insertion.

Of the intraoperative measures employed in this analysis, only PTV demonstrated significant differences between those implants that were successful and those that failed. This was apparent within the data for submerged implants, where there were enough failures for statistical analysis. On the basis of these data, PTV appears to be the most reliable of the intraparative technologies used in these patients for predicting failure at the time of implant placement.

The combination of precision of initial bone fit and adequate bone density is essential for effective immediate loading or exposure. In this group of implants, there was variability in terms of initial fit,
the implants were placed with freehand preparation techniques. To improve initial fit, undersizing\textsuperscript{1,5,32} of the site was performed in some but not all of the sites, and this inconsistency may have introduced another important variable that is difficult to account for in these data.

When newer implant designs (now more commonly available than when this study was conducted) are used, initial stability may be improved in poorer-quality bone. However, it cannot be assumed that implant design alone will allow for immediate loading or exposure in less dense bone. The bone quality must still be adequate to resist micromovement during the osseointegration period.\textsuperscript{59} In addition, newer surface technologies may improve the chances of immediate loading or one-step implant placement.\textsuperscript{60}

There was good correlation between preoperative CT, IT, PTV, and RFA, given the limitations of this study. This may lead clinicians to believe that any one of these may serve as an indicator with which to make a clinical decision in the absence of the others. However, since the individual correlations could have been stronger and because not all implants were tested with RFA, it would be preferable to use more than one criterion when deciding to immediately load or expose an implant.

In this analysis, the data were skewed, thereby artificially raising or lowering the means for groups, because 12 implants in seven patients were placed into groups not indicated by the intraoperative primary stability measurements. There were several reasons for this. According to the empirical algorithm, certain patients were given the choice to expose or submerge implants; therefore, a single-tooth implant and half of the implants in a full-arch patient were left exposed and kept in reserve rather than loaded immediately. In addition, some implants were left submerged when one of a group of implants in the restorative site did not meet the immediate loading or exposure criteria but others did. Therefore, to analyze pure intergroup data, those implants responsible for skewing were not included in the analysis between groups. However, all implants were included in the correlation analysis, since the treatment condition had no effect on the relationship of intraoperative criteria.

Derivation of an accurate threshold from these preliminary data is not possible without more research as a result of uncontrolled variables. In addition, the number of immediately loaded implants in this series is simply too small to be able to make unequivocal statements on specific IT values, PTVs, and ISQs as identifiers for loading or exposing implants at insertion.

With these caveats in mind, some predictions based on these data are worthy of discussion. It would appear that the threshold preoperative bone density for immediate loading of implants in multiple-implant restorations is most likely above the 618 HU observed for the failed immediately loaded implant but below the lowest value (722 HU) recorded for the successful immediately loaded implants. Therefore, 725 HU is most likely a reasonably conservative estimate. For IT, the implant that failed was 40 Ncm and the successful implants were between 40 Ncm and 45 Ncm. Accordingly and in agreement with others,\textsuperscript{19,22} a conservative threshold would be 45 Ncm. Ottoni et al. showed,\textsuperscript{38} implants with lower IT were successful, while other authors showed that lower IT values were correlated with higher failure rates following immediate loading.\textsuperscript{55,61} It should be noted that IT values can be deceptive, in that they may be produced with only the coronal one or two threads in cortical bone, whereas the remainder of the implant is seated in more porous cancellous bone. Accordingly, these implants may not be able to withstand micromovements during the healing period. Therefore, an algorithm of the technologies of PTVs and ISQs may be helpful in discriminating this condition. The failed immediately loaded implant showed a PTV of \textasciitilde{}3 while the successful implants had PTVs no higher than \textasciitilde{}4, indicating that \textasciitilde{}4 may be a reasonably conservative threshold. For five of the eight immediately loaded implants with ISQ measurements, the range was 69 to 72, indicating that values above 68 appear to be reasonably predictive for successful immediate loading.

It should be noted that these data for immediate loading result from treatments where each restoration consisted of multiple splinted implants. Therefore, the implants may have acted symbiotically to offset forces that single implant restorations may not be able to withstand. For single teeth to be immediately loaded, increased CT bone density, IT values, and ISQs and decreasing PTVs should be considered.

Since there were no failures among exposed implants, values for exposure in one step in all probability can be: CT of at least 700 HU, IT of at least 20 Ncm, and PTV lower than \textasciitilde{}1. Because there were only two ISQ measurements for one patient (79 and 82) in the exposed group, no predictions for this measure can be made. Implant submergence should be considered for values below 700 HU, below an IT of 20 Ncm, and equal to or higher than a PTV of \textasciitilde{}1. Because so few ISQ measurements were made, no predictions on the basis of ISQ value can be made as to when to submerge.

The values observed in this group of patients may not be transferable to other implant designs and CT scanning procedures.
CONCLUSIONS

Within the limitations of this study, objective measures of bone density by computed tomography and primary stability by insertion torque, Periotest values, and implant stability quotients correlated with each other, and therefore when used together they may provide a valuable algorithm for making clinical implant loading decisions. Of the methods used in this group of patients, the Periotest value was the most reliable predictor at placement of failure of an implant to osseointegrate.

REFERENCES


