Insertion and Loading Characteristics of Three Different Bone-Level Implants

Constance Steiner, Dr Med Dent¹/Matthias Karl, Prof Dr Med Dent¹/Tanja Grobecker-Karl, Dr Med Dent¹

**Purpose:** While primary stability still constitutes an important factor for implant success, high levels of insertion torque resulting from bone compression are controversial and may constitute a co-factor in peri-implant bone loss. **Materials and Methods:** Adhering to the manufacturers’ protocols for medium-quality bone, implant surgery was performed in polyurethane foam blocks equipped with strain gauges attached to the buccal aspect. Following insertion and attachment of provisional abutments, oblique loading was performed. The following parameters were recorded for three different implant types (Straumann Bone Level Tapered [BLT], MIS V3 [V3], Dentsply Sirona Astra TX [ASTRA]): maximum insertion and removal torque, maximum strain during insertion and loading, and implant stability before and after loading (resonance frequency analysis [RFA]). Statistical analysis was based on analysis of variance (ANOVA), Tukey honest significant difference test, and Pearson’s product moment correlation (α = .05). **Results:** Maximum insertion torque (59.9 ± 4.94 Ncm) was recorded for BLT followed by V3 and ASTRA (P < .01 for all comparisons). Maximum removal torque (43.7 ± 9.69 Ncm) was also recorded for BLT, but the pairwise comparisons reached significance only for BLT vs ASTRA (P < .01) and V3 vs BLT (P = .03). Implant stability differed among groups only after loading, where the pairwise comparison between BLT and ASTRA reached significance (P = .02). Maximum strain during insertion was caused by BLT reaching 19,482.62 µm/m, whereas ASTRA implants only caused 6,169.84 µm/m. Strain development during insertion differed significantly among groups (P < .05 for all comparisons). Maximum strain during loading was observed in V3 (646.44 ± 204 µm/m), while only a nonsignificant difference existed between ASTRA and BLT. Insertion torque correlated significantly with strain development (r = 0.68; P < .01), implant stability after loading (r = 0.46; P = .01), and removal torque (r = 0.54; P < .01). Also, implant stability after loading correlated with removal torque (r = 0.86; P < .01). **Conclusion:** Different implant designs and surgical protocols result in varying levels of bone compression. Implants with a triangular shape do not seem to solve this problem. Int J Oral Maxillofac Implants 2020;35:560–565. doi: 10.11607/jomi.7770

**Keywords:** implant insertion torque, removal torque, resonance frequency analysis, strain development

---

High levels of implant insertion torque and corresponding high levels of implant stability are still considered a prerequisite for immediate loading.¹ Specific implant designs with a tapered geometry in the cervical part creating pressure on cortical bone²,³ as well as modifying surgical protocols by undersizing implant osteotomies⁴,⁵ have been advocated in this context.

Contradictory findings on the impact of high insertion torque levels can be found in the literature.⁶⁻⁹ A retrospective clinical study revealed negative marginal bone responses when excessive insertion torque had been applied and demanded the assessment of bone quality for optimizing the surgical protocol.⁶ Similarly, another clinical trial comparing the performance of implants placed with high and low insertion torques revealed greater bone remodeling and soft tissue recession in implants placed with high torque levels.⁷ This seems to be in line with a prospective clinical study showing that only minimal marginal bone loss occurred in implants placed with low insertion torques after a 1-year observation period.⁸ On the contrary, a recent report on implants placed with an average insertion torque of 76.1 ± 20.8 Ncm did not show any negative effects with respect to survival and bone loss.⁹

Several animal studies have been conducted for elucidating the effect of high insertion torque on peri-implant bone healing. Cha and coworkers showed that high insertion torques resulted in high levels of interfacial stress and strain, causing microfractures in peri-implant bone, ultimately leading to increased bone resorption.¹ Similarly, a reduced speed of new bone formation combined with a high speed of marginal bone loss has been shown when excessive undersizing of an osteotomy was applied.¹⁰ Other studies revealed a reduction in crestal bone-to-implant contact during early healing following an underdrilling protocol,¹¹ and even slight underpreparation of implant sockets has been
shown to compromise osseointegration of immediately loaded implants.\(^5\) On the contrary, however, Rea and coworkers found similar amounts of osseointegration irrespective of the insertion torque applied to implants placed in dog mandibles.\(^4\)

Prior to evaluating the biologic implications of peri-implant bone strain resulting from implant insertion, it was the goal of this in vitro study to evaluate the insertion characteristics and primary stability of three current implant designs.

**MATERIALS AND METHODS**

Implant surgery for three different bone-level implant systems (Table 1, Fig 1, groups ASTRA, BLT, V3) was simulated in polyurethane foam material consisting of a trabecular portion covered by a cortical layer with a thickness of 3 mm (Solid Rigid polyurethane foam 10 pcf/40 pcf, Sawbones). Strain gauges were positioned on the buccal surface of the bone surrogate materials next to the osteotomy with the sensing elements oriented horizontally for recording deformation of the material.

Prior to evaluating the biologic implications of peri-implant bone strain resulting from implant insertion, it was the goal of this in vitro study to evaluate the insertion characteristics and primary stability of three current implant designs.

**MATERIALS AND METHODS**

Implant surgery for three different bone-level implant systems (Table 1, Fig 1, groups ASTRA, BLT, V3) was simulated in polyurethane foam material consisting of a trabecular portion covered by a cortical layer with a thickness of 3 mm (Solid Rigid polyurethane foam 10 pcf/40 pcf, Sawbones). Strain gauges were positioned on the buccal surface of the bone surrogate materials next to the osteotomy with the sensing elements oriented horizontally for recording deformation of the material.

Prior to evaluating the biologic implications of peri-implant bone strain resulting from implant insertion, it was the goal of this in vitro study to evaluate the insertion characteristics and primary stability of three current implant designs.

**MATERIALS AND METHODS**

Implant surgery for three different bone-level implant systems (Table 1, Fig 1, groups ASTRA, BLT, V3) was simulated in polyurethane foam material consisting of a trabecular portion covered by a cortical layer with a thickness of 3 mm (Solid Rigid polyurethane foam 10 pcf/40 pcf, Sawbones). Strain gauges were positioned on the buccal surface of the bone surrogate materials next to the osteotomy with the sensing elements oriented horizontally for recording deformation of the material.

Prior to evaluating the biologic implications of peri-implant bone strain resulting from implant insertion, it was the goal of this in vitro study to evaluate the insertion characteristics and primary stability of three current implant designs.

**Table 1** Description of the Implant Systems Used in This Study and the Sequence of Drills as Recommended in the Manufacturer-Specific Guidelines for Medium-Quality Bone

<table>
<thead>
<tr>
<th>Implant system</th>
<th>Surgical protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group BLT</strong></td>
<td></td>
</tr>
<tr>
<td>Straumann Bone Level Tapered</td>
<td>Needle drill 1.6 mm</td>
</tr>
<tr>
<td>4.1 mm × 12 mm</td>
<td>BLT Pilot drill 2.2 mm</td>
</tr>
<tr>
<td>(Institut Straumann)</td>
<td>BLT drill 2.8 mm</td>
</tr>
<tr>
<td></td>
<td>BLT drill 3.5 mm</td>
</tr>
<tr>
<td><strong>Group V3</strong></td>
<td></td>
</tr>
<tr>
<td>MIS V3</td>
<td>Spade marking drill</td>
</tr>
<tr>
<td>3.9 mm × 11.5 mm</td>
<td>Pilot drill 2.4 mm</td>
</tr>
<tr>
<td>(MIS Implants, Minden, Germany)</td>
<td>Step drill 3.0 mm</td>
</tr>
<tr>
<td></td>
<td>Form drill (until marking)</td>
</tr>
<tr>
<td><strong>Group ASTRA</strong></td>
<td></td>
</tr>
<tr>
<td>ASTRA OsseoSpeed TX</td>
<td>Round bur</td>
</tr>
<tr>
<td>4.0 mm × 13 mm</td>
<td>Spiral drill 2.0 mm</td>
</tr>
<tr>
<td>(Dentsply Implants Manufacturing)</td>
<td>Spiral drill 3.2 mm</td>
</tr>
<tr>
<td></td>
<td>Spiral drill 3.7 mm</td>
</tr>
</tbody>
</table>

All implants were inserted and removed with the drill speed set at 25 rpm.

**Fig 2 (left)** Insertion of a BLT implant into an osteotomy created in laminated polyurethane foam simulating alveolar bone. A strain gauge was positioned on the buccal aspect of the bone with the sensing elements oriented horizontally for recording deformation of the material.

**Fig 3 (right)** A provisional cylinder was attached to the implant shoulders and used for loading the implants placed in bone surrogate material. A universal testing machine applied a vertical force while strain development on the buccal aspect of bone was recorded.

© 2020 BY QUINTESSENCE PUBLISHING CO, INC. PRINTING OF THIS DOCUMENT IS RESTRICTED TO PERSONAL USE ONLY. NO PART MAY BE REPRODUCED OR TRANSMITTED IN ANY FORM WITHOUT WRITTEN PERMISSION FROM THE PUBLISHER.
resonance frequency analysis (RFA) was used for quantifying primary implant stability in the mesial-distal and the buccal-lingual direction. Simulating immediate loading protocols, abutments for provisional restorations with a standardized lever arm of 9.0 mm extending from the implant shoulder were torque tightened on the implants, and the specimens were positioned in a universal testing machine (Z020, Zwick/Roell) at an angle of 30 degrees relative to the long axis of the implants and loaded statically with a maximum force of 50 N (Fig 3). Following secondary measurements of implant stability by means of RFA, the implants were removed with the same equipment described earlier recording maximum removal torque.12,13

Statistical analysis comparing maximum insertion torque, primary and secondary implant stability, removal torque, and strain development during implant insertion and loading was based on analysis of variance (ANOVA). For pairwise comparison of means, the Tukey honest significant difference test was applied. In addition, the dataset was checked for potential correlations among parameters using Pearson’s product moment correlation test. The level of significance was set at \( \alpha = .05 \) for all statistical operations conducted.

Table 2 Mean Values and Standard Deviations Recorded for All Parameters Evaluated in This In Vitro Study

<table>
<thead>
<tr>
<th>Implant system</th>
<th>Astra</th>
<th>BLT</th>
<th>V3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum insertion torque (Ncm)</td>
<td>30.2 (1.65)</td>
<td>59.9 (4.94)</td>
<td>45.2 (4.45)</td>
</tr>
<tr>
<td>ISQ initial</td>
<td>61.9 (5.03)</td>
<td>63.7 (7.15)</td>
<td>64.8 (1.81)</td>
</tr>
<tr>
<td>Maximum strain, insertion (µm/m)</td>
<td>6,169.84 (1,685.22)</td>
<td>19,482.62 (8,121.13)</td>
<td>12,785.10 (3,053.91)</td>
</tr>
<tr>
<td>Maximum strain, loading (µm/m)</td>
<td>574.25 (179.63)</td>
<td>557.30 (176.96)</td>
<td>646.44 (204.00)</td>
</tr>
<tr>
<td>ISQ postloading</td>
<td>61.7 (5.12)</td>
<td>66.8 (4.31)</td>
<td>64.1 (2.02)</td>
</tr>
<tr>
<td>Maximum removal torque (Ncm)</td>
<td>28.1 (1.54)</td>
<td>43.7 (9.69)</td>
<td>35.5 (6.11)</td>
</tr>
<tr>
<td>Removal torque / insertion torque (%)</td>
<td>93.1</td>
<td>72.9</td>
<td>78.5</td>
</tr>
</tbody>
</table>
RESULTS

Mean values and standard deviations for all parameters determined during the experiment are given in Fig 4 and Table 2.

Both mean maximum insertion (59.9 ± 4.94 Ncm) and removal torque (43.7 ± 9.69 Ncm) were recorded for BLT implants followed by V3 and ASTRA. While the differences among groups were pronounced for mean maximum insertion torque, these had leveled off to some extent for mean maximum removal torque. ASTRA implants showing the lowest values for mean maximum insertion (30.2 ± 1.65 Ncm) and removal torque (28.1 ± 1.54 Ncm) maintained the highest percentage of torque applied (93.1%), while only a minor difference between BLT and V3 existed with respect to this parameter. ANOVA revealed significant differences between implant groups with respect to insertion torque, and all pairwise comparisons were statistically significant as well (P < .01 for all comparisons). Similarly, ANOVA indicated significant differences for the parameter removal torque, but the pairwise comparisons reached significance only for BLT vs ASTRA (P < .01) and V3 vs BLT (P = .03).

Primary implant stability as determined by RFA measurements ranged from 61.9 for ASTRA to 64.8 for V3. After loading, values ranging from 61.7 for ASTRA to 66.8 for BLT were observed. Significant differences in implant stability were indicated by ANOVA only in the condition after loading, where the pairwise comparison between BLT and ASTRA reached significance (P = .02).

Mean maximum strain during insertion was caused by BLT reaching 19,482.62 µm/m, whereas ASTRA implants only caused 6,169.84 µm/m. Torque (Fig 5a) and strain (Fig 5b) development during implant insertion showed characteristics specific for each implant type used. In BLT implants, a continuous increase in strain and torque development occurred during insertion, reaching its maximum when the implant was fully seated. ASTRA implants reached a plateau phase at approximately 50% of insertion, followed by a second increase in both insertion torque and strain development. MIS implants showed maximum strain development when the most coronal portion of the round implant part

© 2020 BY QUINTESSENCE PUBLISHING CO, INC. PRINTING OF THIS DOCUMENT IS RESTRICTED TO PERSONAL USE ONLY. NO PART MAY BE REPRODUCED OR TRANSMITTED IN ANY FORM WITHOUT WRITTEN PERMISSION FROM THE PUBLISHER.
passed the cortical layer. During insertion of the triangular part of the implant, strain development on buccal bone increased and decreased depending on the position of the implants’ maxima. Strain development during insertion differed significantly among groups based on ANOVA, and all pairwise comparisons were significant as well (BLT vs ASTRA, \( P < .01 \); V3 vs ASTRA, \( P = .02 \); V3 vs BLT, \( P = .02 \)).

The mean loading magnitude exerted onto the implants ranged from 48.8 to 49.6 N, with no significant difference among groups indicated by ANOVA. Hence, this variable was considered as being constant. During loading of the implants, mean maximum strain development (Fig 6) was observed in V3 implants (646.44 ± 204 µm/m), while only a very minor difference existed between ASTRA and BLT. Consequently, neither ANOVA nor the pairwise comparisons revealed any significant difference.

Only few correlations were found among the parameters evaluated considering all three implant types. Insertion torque correlated significantly with strain development (\( r = 0.68; P < .01 \)), implant stability after loading (\( r = 0.46; P = .01 \)), and removal torque (\( r = 0.54; P < .01 \)). Also, implant stability after loading correlated with removal torque (\( r = 0.86; P < .01 \)).

**DISCUSSION**

High levels of implant insertion torque have been considered as being advantageous for achieving osseointegration. Recent research applying a biologic approach has provided evidence that the use of drills as well as compression of alveolar bone causes cell death in the surrounding of an osteotomy. Hence, modern implant designs try not only to minimize bone trauma during osteotomy preparation, but also to minimize peri-implant strain development during insertion. With measurement of insertion and removal torque as well as primary implant stability and peri-implant strain development, this experiment attempted to compare different implant designs.

Increasing strain development during insertion of the BLT implant indicates that primary stability mostly results from compression of cortical bone, which may have negative side effects during healing and may be a co-factor for bone loss frequently observed in the initial phase of healing. A similar but less-pronounced effect was also seen for ASTRA implants. Inserting the round portion of the MIS V3 implant also leads to bone compression, while during insertion of the triangular part, compression of buccal bone only happens when the implant maxima coincide with the buccal aspect. As expected from mechanical principles, maximum mean insertion torque and strain were recorded for BLT implants, followed by MIS V3 and ASTRA.

While it is generally accepted that primary implant stability is a prerequisite for achieving osseointegration, it is unknown how an adequate level of primary stability can be defined. Traditionally, high levels of insertion torque have been considered to be desirable, while a significant body of literature reporting clinical data, meanwhile, exist showing that comparably low levels of insertion torque may also result in good long-term performance.

Resonance frequency measuring stiffness of an implant has been applied both before and after loading, but it hardly allowed for expression of significant differences between implant systems, which was also due to measurement variation. Given the use of a well-standardized bone surrogate material and applying manufacturer-specific drill protocols for medium-quality bone, it had been expected that implant stability would not differ between groups. Also, the fact that insertion torque did not correlate with primary implant stability had been expected, as the two measurement modalities evaluate different parameters. The measurement after loading was carried out with the sole purpose of showing that the implants had been loaded within the elastic limits, and this measurement may not be compared with clinical measurements of secondary implant stability following osseointegration.

Maximum mean removal torque was observed in BLT implants, while no significant difference existed between MIS V3 and ASTRA. However, expression of removal torque in the form of percent insertion torque for ASTRA implants reached 93.1%, while only 72.9% and 78.5% of the insertion torque were required for removing BLT and V3 implants, respectively. It might have been expected that the triangular shape of V3 implants combined with the surgical protocol undersizing the osteotomy would lead to a clamping force following the elastic relaxation of bone, thereby maintaining a high torque level. Surprisingly, this triangular design did not lead to a reduction of strain during loading compared to implants with a conventionally round design. It may also be speculated that BLT and V3 required a lower percent of the insertion torque for implant removal, as the bone surrogate material was plastically deformed, while for ASTRA, the compression of the material was within its elastic limits.

In addition to obvious limitations in simulating the behavior of alveolar bone using polyurethane foam, the specifics of the strain gauge technique have to be considered when interpreting this study. Maximum care was taken to properly align the sensing elements of the strain gauges parallel to the occlusal surface of the bone surrogate material and to position all implants with a standardized buccal wall thickness. Due to the sensitivity of the measurement technique applied with minor positional deviations having an impact.
on the absolute readings, strain development should only be interpreted on a relative scale. Optical three-dimensional (3D) deformation analysis might have constituted an alternative analyzing technique. Potentially positioning errors of the specimens as well as the nonuniform structure of polyurethane foam, however, appear to be variables that can hardly be controlled with such a setup. Currently, the findings presented can hardly be transferred into a clinical setting. While this study was intended to create awareness of potentially harmful aspects of high implant insertion torque, further studies are needed for linking strain measurements with the risk of bone damage.

**CONCLUSIONS**

Current implant designs show specific torque and strain signatures during insertion that may impact marginal bone level changes during healing. From a purely mechanical perspective, triangular implant shapes seem to not reduce strain during insertion and loading. Based on the correlation observed between strain measurements and insertion torque, the latter may be used for assessing the risk of bone damage in a clinical setting.

**ACKNOWLEDGMENTS**

The authors wish to thank Dr. Friedrich Graef, Professor emeritus, Department of Mathematics, University of Erlangen-Nuremberg for statistical data analysis. The authors reported no conflicts of interest related to this study.

**REFERENCES**