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# Biomechanical characterization of narrow diameter dental implants

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## Introduction

Narrow diameter implants (NDIs) are designed for placement in locations where placement of the larger diameter implants is not feasible due to anatomical limitations. For example, narrow diameter implants may be utilized in areas with narrow spaces between adjacent teeth, between convergent teeth roots, or in narrow ridge situations. Additionally, narrow diameter implants can be used to replace small teeth including the lateral maxillary and mandibular incisors. Because of the anterior placement of NDIs, aesthetic considerations are also crucial for the design of narrow diameter implants.

Several studies have been conducted to assess the effectiveness of narrow diameter implants. For instance, an evaluation of 316 NDIs followed over a 10-year period demonstrated a cumulative survival rate of 92.3% without any implant fractures.<sup>1</sup> Similarly, another study examined 510 implants with diameters ranging from 3.0 to 3.5 mm from multiple implant systems.<sup>2</sup> Only three of the implants were lost, demonstrating a survival rate of 99.4%. In general, these long-term studies have shown that small diameter implants can exhibit survival rates on par with those of wider diameter implants, suggesting that narrow diameter implants can be a promising treatment option for situations in which large diameter implants are contraindicated.

Despite promising results, NDIs have several potential disadvantages that could limit their use. In particular, biomechanical risk factors must be carefully analyzed prior to using NDIs clinically.<sup>3</sup> Studies have shown that implants with smaller diameters have decreased mechanical properties,<sup>4</sup> suggesting that fatigue testing is advisable for NDIs to reduce the risk of fracture in clinical practice. Additionally, mathematical simulation of stress distributions around implants demonstrated that implant diameter has a larger influence on mechanics than implant length.<sup>5</sup> Both theoretical and experimental studies suggest that thorough mechanical characterization should be conducted for NDIs.

Another crucial consideration is primary stability, which has been considered important for facilitating osseointegration of dental implants.<sup>6</sup> Because NDIs have smaller surface areas than larger-diameter implants, the diminished contact with bone could potentially reduce primary stability. Wider-diameter implants have been proposed to gain primary stability in cases where low-density bone is common.<sup>7</sup> To ensure that NDIs have sufficient primary stability, tests such as insertion torque can be conducted. Additionally, torsional mechanical testing can demonstrate whether NDIs have

sufficient strength to withstand insertion torque. These tests, along with data from fatigue testing, can reduce the risk of mechanical failure in clinical applications.

To characterize the biomechanics of narrow diameter implants, Zimmer Eztetic™ 3.1 x 13 mmL, Astra Tech OsseoSpeed™ EV 3.0 x 13mmL, BioHorizons® Laser-Lok® 3.0 x 12mmL, and NobelActive® 3.0 x 13mmL implants were examined. The objective of the study was to assess the insertion torque, torsional yield strength, and fatigue properties of each implant.

## Methods

### Fatigue

Samples were potted in Dycal cement (Dentsply, Milford, DE, USA). Abutments were assembled with the corresponding implants and then tightened to the torque values specified in the respective Instructions for Use. Then test caps were adhered to the abutments to ensure that all implant systems experienced similar load distributions. Fatigue testing was conducted per ISO 14801 at a temperature of 20°C ± 5°C. Loads were applied at 14 Hz and varied between a peak load and 10% of the peak load. Per ISO 14801, each implant was tested for 5 million cycles, which is intended to simulate the functional loading of dental implants. Fatigue curves were generated to compute the endurance limit for each implant system.

### Insertion Torque

Artificial bone substrate (Sawbones, Vashon Island, WA, USA) with a 3mm 50 pcf cortical layer and a 30 pcf core was selected to simulate dense bone. This substrate was sectioned into test pieces approximately 0.8 inch wide by 0.8 inch long and 0.8 inches tall. Based on the respective manufacturer's dense bone drilling protocol, an appropriate osteotomy was created in each piece of artificial bone substrate. Implant drivers and artificial bone substrate pieces were secured in custom-designed fixtures. After the implant was aligned with the osteotomy, a Bionix Electromechanical Torsion System (MTS, Eden Prairie, MN) was used to rotate the implant at 8 rpm until the implant was flush with the top surface of the bone substrate. 5 implants from each manufacturer were tested. The maximum insertion torque values were recorded for each implant using the Bionix System.

### Torsional Yield Strength

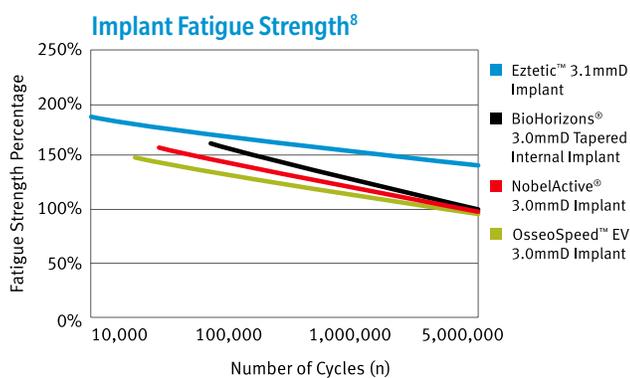
Implants were potted in 3M Scotch-Weld Epoxy (3M, St. Paul, Minneapolis, USA) and allowed to cure for 48 hours. Fixtures were designed to hold the potted implants and corresponding implant drivers. After ensuring that the driver was aligned with the potted implant, a Bionix

Electromechanical Torsion System (MTS, Eden Prairie, MN) was used to rotate the implant via its corresponding driver at 10 degrees/minute until the implant-driver assembly failed. Torque versus rotation curves were recorded for each sample and analyzed per ISO 13498 to calculate the yield stress for each sample.

## Results

### Fatigue

Per ISO 14801, fatigue curves were generated for all implant types by testing at 14 Hz for 5 million cycles, which simulates the functional loading of a dental implant. All implant systems had equivalent endurance limits other than Zimmer, which exhibited an endurance limit that was 43% higher than that of Astra Tech, Nobel, and BioHorizons implants (Figure 1). Nobel, Astra Tech, and BioHorizons implants had failures of the implant and screw. Zimmer implants exhibited screw and implant failures at the potting level.<sup>8</sup>

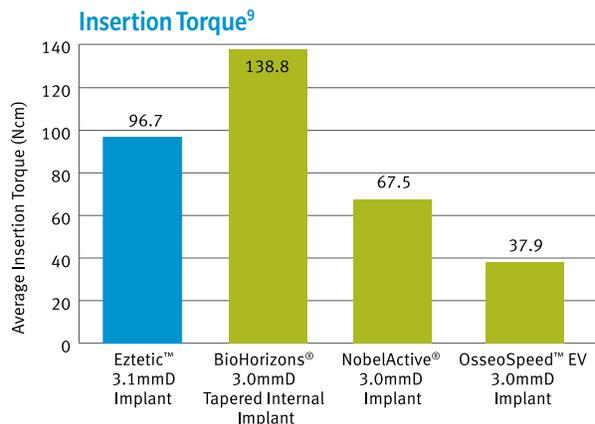


All Products were tested in increments of 5 Lbs.

**Figure 1:** Endurance limits for narrow implants (n=11). Fatigue testing conducted per ISO 14801 demonstrated that at 5 million cycles Zimmer implants had an endurance limit that was 43% higher than that of Astra Tech, Nobel, and BioHorizons implants.

### Insertion Torque

Peak torque values were recorded during insertion of the implants into artificial bone substrate. The average insertion torque for each implant brand was calculated. All implants were fully seated and did not exhibit any failures.<sup>9</sup> Insertion torque values were  $96.7 \pm 4.1$ ,  $138.8 \pm 4.9$ ,  $67.5 \pm 6.1$ , and  $37.9 \pm 1.6$ , N-cm for Zimmer, BioHorizons, Nobel, and Astra Tech, respectively (Figure 2).<sup>9</sup> Insertion torque values for the Zimmer implants were 43% higher and 154% higher than the Astra Tech and Nobel implants, respectively.<sup>9</sup>

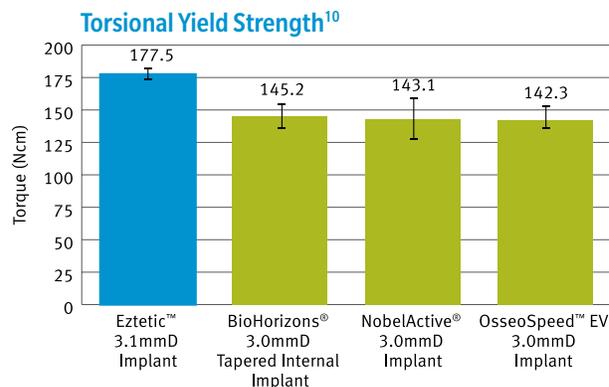


Benchtop engineering test utilizing a dense bone substrate.<sup>9</sup>

**Figure 2:** Average insertion torque for narrow diameter implants (n=5). Insertion torque testing in artificial bone substrate demonstrated that Zimmer implants had an insertion torque that was 43% higher and 154% higher than the Astra Tech and Nobel implants, respectively. Data are reported as mean  $\pm$  standard deviation.

### Torsional Yield Strength

Torque testing was conducted until the implant and/or driver failed. Results were quantified using the yield strength, which was calculated per ISO 13498. Torsional yield strength values were  $177.5 \pm 4.9$ ,  $145.2 \pm 10.5$ ,  $143.1 \pm 17.4$ , and  $142.3 \pm 7.1$ , N-cm for Zimmer, BioHorizons, Nobel, and Astra Tech, respectively (Figure 3).<sup>10</sup> The yield strength for the Zimmer implant was 24%, 23%, and 22% higher than that of Astra Tech, Nobel, and BioHorizons, respectively.<sup>10</sup> Both Nobel and Astra Tech failed at the implant and driver interface.<sup>10</sup> Zimmer implants failed at the potting level and BioHorizons implants failed at the interface wall.<sup>10</sup>



Benchtop engineering test utilizing the implants and their corresponding drivers.<sup>17</sup>

**Figure 3:** Torsional yield strength values for narrow diameter implants (n=6). Connection strength testing conducted per ISO 13498 demonstrated that Zimmer implants had yield strength values that were 24%, 23%, and 22% higher than that of BioHorizons, Nobel, and Astra Tech, respectively. Data are reported as mean  $\pm$  standard deviation.

## Discussion

The objective of the study was to assess the insertion torque, torsional yield strength, and fatigue properties of NDIs from Zimmer, Astra Tech, BioHorizons, and Nobel. Data demonstrated that Zimmer implants had the highest fatigue endurance limit and the highest torsional yield strength. Additionally, Zimmer implants had higher insertion torque values than Nobel and Astra Tech implants.

Fatigue testing is crucial for assessing the effectiveness of implant design, particularly for NDIs<sup>3</sup>. Studies of stress distributions indicate that narrow diameters increase the stress that the implant experiences.<sup>11, 12</sup> These increased stresses could increase the risk of fatigue failure,<sup>13</sup> highlighting the importance of fatigue strength for NDIs. In this study, fatigue testing data showed that the Zimmer implant had greater fatigue strength than Astra Tech, Nobel, and BioHorizons implants. These results suggest that the design of the Zimmer implant enables it to withstand the stresses applied during fatigue testing and ultimately have a reduced likelihood of component fracture. Significantly greater fatigue properties are particularly important for NDIs because studies have shown that smaller implant diameters can reduce the fatigue strength of dental implants.<sup>14</sup>

Torsion testing results showed that the Zimmer implant had the highest yield strength. The higher yield strength of the Zimmer implant could be explained by differences in the design of the implant and/or driver, which enabled the implant-driver assembly to withstand greater stresses prior to yielding. Because higher torsional yield strength could reduce the likelihood of failures during any abnormally high torque applications, higher yield strength results are preferable. Additionally, the yield strength should be significantly higher than the corresponding insertion torque to reduce the chance of failure during insertion.

Insertion torque data supplemented fatigue testing results by showing potential differences in the primary stability of the implants. The results of this study suggest that the Astra Tech and Nobel implants might have lower primary stability than the Zimmer implants. Low insertion torque values, which indicate lower primary stability, can suggest an increased risk of implant failure.<sup>15</sup> Lower insertion torque results could have important implications, particularly in anterior areas where aesthetics is of concern, because primary stability plays an important role in deciding whether an implant can be immediately provisionalized or loaded.<sup>16</sup> However, a high insertion torque that approaches torsional yield strength could be detrimental because it could increase the risk of failure during insertion. The BioHorizons insertion torque was 95.5% of the yield strength while the Zimmer insertion torque was 54.5% of the yield strength. The high insertion torque of the Zimmer implants, which did not approach the yield strength, indicates a reduced risk of implant failure during insertion and an increased likelihood of achieving primary stability.

Several factors could contribute to the higher mechanical properties observed for the Zimmer implants. The geometry of the implant and precise machining of the implant could make it more resistant to failure and increase its fatigue strength. By potentially enabling the implant to more effectively bear loads, the design of the double friction-fit connection could also contribute to the high mechanical integrity of the Zimmer implant. In addition, the Zimmer implant is made using a titanium alloy, which is stronger than commercially pure titanium materials also used in dental applications.<sup>17</sup> These design factors could play a role in the high fatigue strength,

torsional yield strength, and insertion torque exhibited by the Zimmer implant.

## Conclusions

Biomechanical characterization is crucial for assessing NDIs because smaller implant diameters can result in decreased mechanical integrity<sup>3</sup>. Results of this study demonstrated that Zimmer implants had a higher fatigue endurance limit and higher torsional yield strength than Astra Tech, BioHorizons, and Nobel implants. Additionally, Zimmer implants had higher insertion torque values than Nobel and Astra Tech implants. Collectively, these results suggest that the Zimmer implant

will have better primary stability, torsional strength, and resistance to fatigue failure than the other narrow diameter implants.

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