

The Effect of a Positioning Index on the Biomechanical Stability of Tapered Implant-Abutment Connections

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The biomechanical stability of the implant-abutment connection is critical for the success of implant-supported restorations. This study investigated the effect of a positioning index on the abutment screw preload values of tapered connection implants. Twenty Morse taper implants presenting an internal locking hex received 10 solid and 10 straight screw retained abutments for cemented single-crown restorations. Ten abutments had a positioning index to fit the internal locking hex of the implant (straight), and 10 were locked only by the implant taper (solid). The preload values for each abutment screw after a tightening torque were registered by strain gauges. Prosthetic crowns were placed on each abutment and subjected to mechanical cycling. Detorque forces were applied to each abutment and compared with the initial torque values. Data were statistically analyzed using Kolmogorov-Smirnov and Student *t* tests. The nonindexed group presented higher initial preload ($6.05 \text{ N} \pm 0.95 \text{ N}$) compared with the indexed group ($4.88 \text{ N} \pm 0.92 \text{ N}$; $P < .05$). After cycling, the nonindexed group exhibited less reduction of preload ($13.84\% \pm 6.43\%$) compared with the indexed group ($52.65\% \pm 14.81\%$; $P < .01$). Indexed tapered abutments for single-crown restorations might represent greater biomechanical risk under function.

Key Words: dental implants, Morse taper, positioning index, preload, mechanical cycling

INTRODUCTION

The biomechanical stability of the implant-abutment connection constitutes an important issue regarding restorative success of implant-supported single-tooth restorations.¹ For single-standing restorative situations, a stable union between abutment and implant capable of withstanding the forces generated during function is crucial. Current efforts of several implant manufacturers are aimed at improving connection design to maximize implant-abutment joint stability and thus reduce mechanical restorative failures.^{1,2}

Numerous studies have demonstrated that abutment screw loosening and/or fracture may constitute one of the most common restorative complications in implant dentistry.^{3,4} Screw loosening may represent a significant clinical inconvenience, particularly in situations involving cemented restorations, as it may also lead to patient discomfort caused by an inflammatory response of the adjacent soft tissues and ultimately to marginal bone loss around the implant.⁵

The abutment screw preload, meaning the screw internal tensile force generated when it is submitted to a specific tightening torque, has been pointed out as a key factor in maintaining the integrity of the implant-abutment joint and

consequently the stability of the entire restoration.^{5,6} The magnitude of the preload has been said to be directly related to the amount of applied tightening torque; however, it is also significantly influenced by the screw and abutment connection designs, along with screw material properties and surface roughness.^{6,7} Quantification of the levels of abutment screw preload after tightening may be precisely assessed by strain gauge analysis.

Morse tapered connections have been said to generate a better distribution of the functional loads among the components of the restorative system because of their inner conical design, which produces a stable retention of the abutment by the presence of frictional forces between abutment and implant.^{8,9} Still, to improve abutment positioning on Morse taper implants, some manufacturers have recently introduced internal positioning indexes, adding a new component to the connection system with potential influence on the abutment screw mechanical stability under function.

Based on the limited information in the literature, the present study aims to evaluate the possible influence of a positioning index present in Morse taper connections on the mechanical stability of the implant-abutment joint.

MATERIALS AND METHODS

In this investigation, 20 Morse taper connection implants (3.75 mm × 11 mm) were first selected from multiple batches (Neodent, Curitiba, Brazil). Ten straight and 10 solid screw retained abutments for cemented single-standing restorations

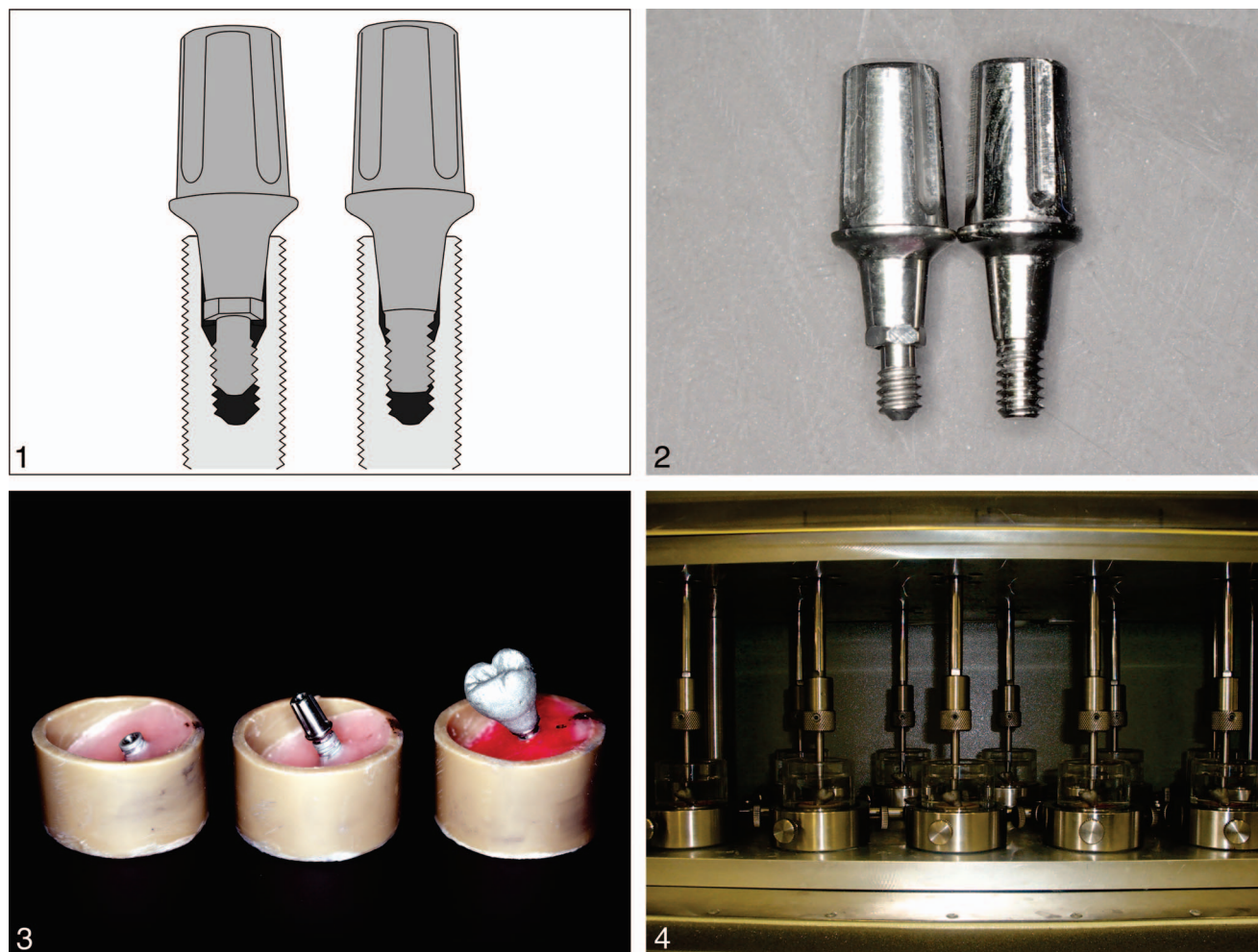
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FIGURES 1–4. **FIGURE 1.** Straight abutment with positioning index (left) in place to fit the internal locking hex of the implant. Solid abutment in place without positioning index (right), evidencing the differences in abutment contact area between both tapered connections. **FIGURE 2.** Details of the straight abutment with positioning index (left) and solid abutment without positioning index (right). **FIGURE 3.** From left to right: implant embedded in acrylic resin, with the abutment in place, and with its respective metal crown in position. **FIGURE 4.** Samples at the mechanical test in the cycling machine.

were chosen and later categorized into 2 groups. The first group of 10 straight abutments (1.5 mm in neck height, 4.5 mm in diameter, 6 mm in body height) presented a positioning hexagonal index located at the abutment neck (Munhão Universal CM Exact, Neodent), whereas the other group consisted of 10 solid abutments without positioning index (Munhão Universal CM, Neodent), locked in position only by the implant taper and presenting the same dimensions (Figures 1 and 2).

All procedures involving specimen assembly and mechanical cycling tests were conducted in accordance with ISO 14.801:2003 for dynamic fatigue tests of endosseous dental implants. The implants were embedded in self-polymerizing acrylic resin (Resina JET, Clássico Ltda, São Paulo, Brazil) at an angle of $30^\circ \pm 2^\circ$, using a positioning device to guide implant placement. Only 8 mm of the total length of each implant was embedded in acrylic resin, leaving 3 mm of uncovered implant surface to simulate marginal bone sauserization as recommended (Figure 3).

The amount of torque for each abutment group was applied in accordance with the implant manufacturer's

instructions. A hex key (\varnothing 0.9 mm) was adapted to a digital axial torque gauge (TSD 150 Torqueleader, MHH Engineering, Bramley, Guilford, Surrey, UK) to apply a tightening torque of 15 Ncm to the straight abutments with a positioning index, whereas another hex key (\varnothing 1.2 mm) was used to apply a torque of 32 Ncm to the solid abutments without the positioning index. The torque gauge was calibrated prior to the experiment in accordance with ISO 6789:2003 and BSEN 26789/1994.

A load cell (Reaccion CTMB-100, Flexar ITX Ltda, São Paulo, Brazil) was used to determine screw preload values after application of the tightening torque. This measuring device consisted of 4 strain gauges (350 ohms) of 5 V each, positioned at opposing sides of the implant joint to eliminate the possible influence of temperature variations and/or tensile forces. Software (PcLab, NOVUS, Porto Alegre, Brazil) was used to record the voltage variations from each strain gauge (mV) as the tightening torque was applied and to convert subsequently each voltage value into Newtons (N).

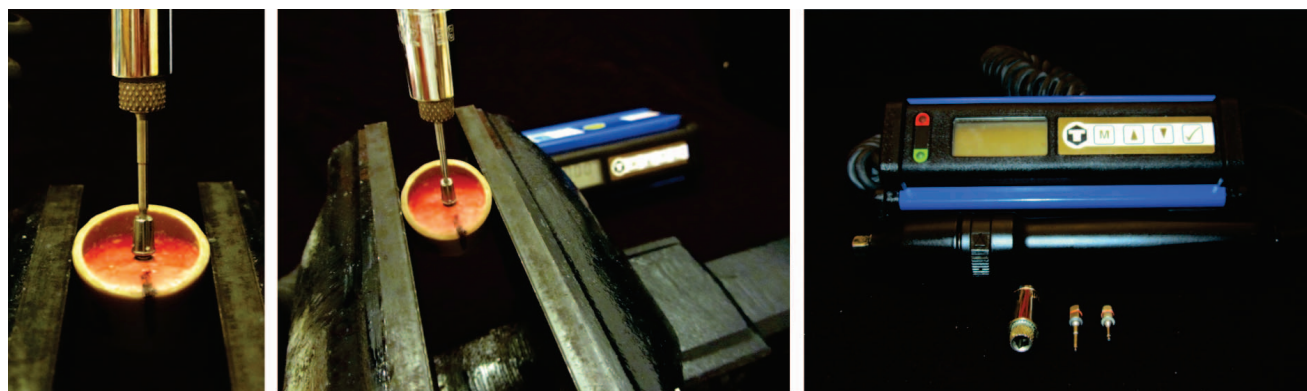


FIGURE 5. Details of the specimens individually placed in a bench vise (left) for application of the removal torque on the abutment screws with a digital torque gauge (right).

Mechanical cycling and removal torque

Twenty nickel-chromium (Jelbond Super, Jelenko, San Diego, Calif) molar crowns were made and placed on all abutments for the mechanical cycling test. Each specimen was then transferred to the cycling machine (ERIOS ER-11000, São Paulo, SP, Brazil), immersed in an isotonic 0.9% saline solution and cycled at 110 N load for 500 000 cycles/1 cycle per second (Figure 4). As recommended by the ISO standards, the loading center for each crown was located at its occlusal surface 11 mm from the implant platform. After this test, the specimens were individually placed in a bench vise, and the removal torque of all abutment screws was performed and recorded using the digital torque gauge (Figure 5). Preload values were assessed by detorque and compared within and between tested groups.

Statistical analysis

Both the absolute difference (initial tightening torque – removal torque) and the relative difference (absolute difference/initial tightening torque) within each group were normally distributed according to the Kolmogorov-Smirnov test.

The absolute and relative differences between the insertion and removal torques between the groups were compared using Student paired *t* test with $P < .05$. The differences in the preload values between groups were also calculated using Student *t* test for independent samples ($P < .05$).

RESULTS

Table 1 shows the initial preload mean values of the abutment screws of each group, indicating a significant difference

Group	n	Mean	SD	P
Nonindexed	10	6.05	0.95	.012*
Indexed	10	4.88	0.92	

* $P < .05$, Student paired *t* test.

between averages of the nonindexed group ($6.05 \text{ N} \pm 0.95 \text{ N}$) compared with the indexed group ($4.88 \text{ N} \pm 0.92 \text{ N}$; $P = .012$).

Analysis of the preload loss revealed significant differences between initial and removal torque values after the cycling test ($P < .001$). Comparison among both groups indicated that the indexed group exhibited a higher preload loss compared with the nonindexed group when considering both the relative difference, in percentage (Table 2), and the absolute difference, in Ncm (Table 3; $P < .05$). In terms of relative preload difference, the nonindexed group exhibited 13.84% of preload loss after mechanical cycling, compared with the indexed group, which presented a preload loss of 52.65% ($P < .001$). Regarding the absolute preload differences, a statistically significant difference was also confirmed between the groups ($P = .002$), where the average torque removal loss for the nonindexed and for the indexed groups were calculated at $4.45 \pm 2.07 \text{ Ncm}$ and $7.96 \pm 2.28 \text{ Ncm}$, respectively.

DISCUSSION

Results from the present investigation indicated a screw preload loss for both analyzed groups following a load simulation test, corroborating other findings reported in the literature,¹⁰ which stated that abutment screws usually undergo preload losses even in the absence of cycling tests. Regarding abutment screw preload, studies indicated that the tightening torque is usually greater than the torque necessary to loosen them,¹¹ although other reports claimed that when conical screws are used, a 10% to 20% greater detorque might be necessary to loosen this type of screw.¹²

After comparing the postcycling removal torque values for both groups, results from the nonindexed group suggest greater biomechanical stability for this type of connection, as a reduced loss of preload in both relative and absolute evaluations was verified. However, differences between the 2 groups become even more evident when relative differences between the tightening and removal torques are compared, although it should be noted that both groups received different initial tightening torque values, in accordance with the implant manufacturer's instructions.

Binon¹³ proposed a classification for commercially

TABLE 2

Relative differences between the initial and removal torques for both groups (%)

Group	n	Mean	SD	P
Nonindexed	10	13.84	6.43	.001*
Indexed	10	52.65	14.81	

*P < .01, Kolmogorov-Smirnov test.

TABLE 3

Absolute differences between the initial and removal torques (Ncm)

Group	n	Mean	SD	P
Nonindexed	10	4.45	2.07	.002*
Indexed	10	7.96	2.28	

*P < .01, Student t test.

available abutment-implant connections. According to this classification, the connections might be categorized according to the degree of fit present between the 2 independent metallic structures. For some connections, under functional load, micromovements among their parts under certain circumstances might be expected, caused by a gap or tolerance between these parts, which are intentionally produced during manufacturing for abutment clinical adaptation and/or fitting. These characteristics may be observed in the indexed group analyzed here. Alternatively, mechanical stability of other connections are based on friction between well-adapted metallic surfaces, in which there is no intentionally projected tolerance between components, leaving independent parts well adapted and securely locked to each other by close contact. Nonindexed Morse taper connections constitute an example of this connection design, in which the abutment turns as a single body, rubbing against the internal walls of the implant and remaining locked under functional loading by the screw preload. According to Binon,¹³ any possible rotational freedom beyond minimum limits among these parts could generate abutment micromovements and thereby produce screw preload loss. The differences found in the present study might be directly related to the differences in micromovements between the groups, as well as to the total area of contact between the tapered metallic surfaces.

Patterson and Johns¹⁴ noted that a possible lack of quality and/or precision in the manufacturing of the implant-abutment connection may prevent these components from entering into close contact with each other. In this scenario, the abutment screw would solely assume the role of maintaining the mechanical stability of the connection. Although the internal design of the straight indexed abutments still presents a defined conical aspect, they also incorporate an internal hex that constitutes the positioning index itself, reducing the tapered area of close contact between metallic surfaces. The micrometric tolerance present between the hexes of the indexed group might have generated a situation in which, once functionally loaded, only this reduced conical portion of the indexed connection became responsible for the mechanical stability of the whole system and thereby caused the verified differences in preload maintenance after cycling between groups.

Regarding initial screw-tightening torque, distinct values were applied to both groups in question. In particular, the nonindexed solid abutments were designed for 32 Ncm of initial torque, whereas the indexed straight abutments received 15 Ncm of initial torque, as recommended by the manufacturer. According to McGlumphy et al,¹⁵ 2 factors are

crucial for the mechanical stability between the implant and the abutment under functional load: the abutment design and the initial screw-tightening torque applied at abutment installation. Jaarda et al¹⁶ corroborated this information, reporting that the constant loosening of abutment screws may be attributed to an insufficient initial torque. However, despite the knowledge that less initial torque may lead to earlier abutment screw loosening under function, levels of torque beyond the manufacturer's recommendations for a particular connection should be avoided, as this excessive torque may lead to screw fracture and/or permanent deformation.¹⁵ Although the indexed group received a lower initial torque, it is important to emphasize that this group demonstrated a significantly inferior mechanical performance when comparing both preload absolute and relative (percentage of preload loss) values.

Weinberg¹⁷ suggested that a minimum of 10 Ncm of screw preload is desirable for a stable performance of the implant-abutment connection under loading. The discussion regarding a nominal quantitative threshold for screw mechanical stability becomes relevant given the results obtained in the current study, in which postcycling detorque forces applied for both the indexed and nonindexed groups revealed absolute differences between initial and removal torques of 7.96 and 4.45 Ncm, respectively. Especially for the indexed group, this finding could represent a challenge, since it indicates a 52.65% of preload loss and points to a lower preload threshold than that recommended by Weinberg to a stable clinical performance. However, it is important to mention that, during the course of the current study, no failures such as abutment screw loosening and/or fracture were observed, although the limitations of an in vitro experiment and the involved number of mechanical cycles should be considered.

The mechanical cycling test performed in this study could be considered as a valuable simulation of clinical conditions. A total of 500 000 cycles with a load of 110 N immersed in saline solution at a frequency of 1 Hz for each specimen were applied. Given that values for the average maximum bite force in the molar region may range between 35 and 330 N and that the chewing frequency in humans has been investigated to be about 1.25 Hz, both the load and frequency applied here might be considered reasonable approximations of the clinical situation.¹⁸ Moreover, the 500 000 cycles applied in this study were determined to simulate approximately 6 months of clinical use of a restoration in an adult patient.¹⁹

The postcycling preload values determined by detorque of the abutment screws indicate an important estimation of the bond strength at the implant-abutment joint. However,

quantitative comparisons between these values and other reported data might be applicable only between similar implant-abutment connections evaluated by the same protocol of measurements. Given that previously published studies on abutment screw preload incorporate different analytical approaches and measurements, it might not be possible to quantitatively compare the findings of the present study with other reported data, which used study designs that may differ substantially from the parameters of the present investigation. However, it might be important to mention that further investigation on the clinical applicability of abutments with similar characteristics of those tested here might be appropriate.

CONCLUSIONS

Within the limitations of this in vitro evaluation, it might be concluded that the presence of a positioning index might negatively affect the biomechanical stability of the tapered abutment screws and therefore their long-term prognosis when applied to single implant-supported cemented restorations.

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