



# Accuracy of different electronic torque drivers: A comparative evaluation

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**PURPOSE.** This study aims to evaluate the loosening torque on the implant fixture, and to assess the accuracy of difference electronic torque drivers. **MATERIALS AND METHODS.** Three electronic torque drivers were used to measure the loosening torque on the implant system (AnyOne; MegaGen). The implant fixtures were divided among the 3 electronic torque driver types (W&H, SAESHIN, and NSK group) and 9 for each group. The screws were fastened at the implant fixture by three electronic torque drivers using the tightening torques recommended by the manufacturers of the drivers. After 10 minutes, the screws were again fastened at the implant fixture with equal torque. Then, the loosening torques were measured with an MGT12 torque gauge (MARK-10, Inc.). This measurement procedure was repeated 10 times under loosening torques of 15 Ncm, 25 Ncm, and 35 Ncm. In the statistical analysis, all values of loosening torque were analyzed with the one-way ANOVA and Kruskal-Wallis test ( $\alpha=.05$ ) for comparative evaluation. **RESULTS.** There were significant inter-group differences at loosening torques of 15 Ncm and 25 Ncm ( $P<.05$ ). The accuracy of the NSK driver was the highest, followed by SAESHIN and W&H. There was no significant difference between NSK and W&H at 35 Ncm ( $P>.05$ ). The SAESHIN driver showed the closest loosening torque at 35 Ncm. **CONCLUSION.** The most accurate loosening torques were SAESHIN at 35 Ncm, and NSK at 15 Ncm and 25 Ncm. Since the loosening torque may vary depending on the tightening torques and electronic torque drivers, periodic calibration of the electronic torque driver is recommended. [*J Adv Prosthodont 2019;11:350-7*]

**KEYWORDS:** Accuracy; Loosening torque; Electronic torque driver; Implant fixture

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Received August 4, 2019 / Last Revision October 30, 2019 / Accepted December 10, 2019

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This work was supported by an Industrial Strategic Technology Development Program (10062635, New hybrid milling machine with a resolution of less than 10  $\mu$ m development, using open CAD/CAM S/W integrated platforms for one day prosthetic treatment of 3D smart medical care system) funded by the Ministry of Trade, Industry & Energy (MOTIE, Korea) and Technology Innovation Program (or Industrial Strategic Technology Development Program, 10077743) and the development of the handpiece design for the air turbine and root canal treatment was funded by the Ministry of Trade, Industry & Energy (MOTIE, Korea) and Korea Institute for Advancement of Technology (KIAT) through the National Innovation Cluster R&D program (P0006691).

## INTRODUCTION

Of the various methods for recovering damaged areas due to tooth loss, implant treatment has become standard in the field of dentistry. The concept of implant osseointegration was introduced by Brånemark in 1952, and dental implant treatment became common in fully and partly edentulous patients in 1965.<sup>1</sup> In 1978, it spread globally through the Toronto Convention, and the fields of application have rapidly increased since then. Implant treatment was previously aimed at the recovery of masticatory function, but, with the more recent emphasis on aesthetic recovery, patient satisfaction with implants is similar to that with natural teeth.<sup>2,3</sup>

For the long-term success of the implant, the biological reaction occurring between the implant fixture and the bone during healing and the biomechanical bite force delivered to the surrounding bones through the prosthesis should be considered.<sup>4</sup> The various causes of implant failure include mechanical problems, such as loosening and fracture of abutment screws and prosthesis and abutment fracture due

to metal fatigue;<sup>5-10</sup> and biological problems such as plaque accumulation, osseointegration loss, and osteolysis.<sup>11-14</sup> In general, after implant placement, osseointegration increases over time; however, if bony tissues are weak, osteogenesis of the implant interface is reduced, occasionally leading to osseointegration failure. In such cases, when the prosthesis is installed, osseointegration interface separation may occur due to torsion force by tightening torque and loosening torque.<sup>15</sup>

The clinical survival rate of the implant strongly correlates with stability after insertion. The stability of the implant is assessed by various methods. Typically, the stability is assessed through a biomechanical analysis with hard tissue interface and an interface histological analysis with soft and hard tissues. Biomechanical analysis with hard tissue interface is mainly conducted through physical means. Percussion reaction testing<sup>16</sup> is a simple method that involves hitting the top of an implant with a metal object and listening to vibration sound; the results cannot be quantified and it is difficult to detect decrement of sound quality or amplified resonant frequency. Tooth mobility measurement [Periotest (Siemens AG, Bensheim, Germany)] and Dental Fine Tester<sup>17</sup> use an exclusive handpiece; the reliability of the measured value decreases according to the positions of the abutment and handpiece. The reverse torque test<sup>16,18,19</sup> detects abnormalities by applying counterclockwise torque at 20 Ncm to the implant. This is effective for detecting implant osseointegration failure but causes irreversible deformation in juveniles. Measurements of cutting force, insertion torque, and cutting resistance on insertion<sup>16</sup> do not harm the area of implant placement but assessing bony tissues only on insertion has the disadvantage of being difficult to reproduce. Resonance frequency analysis<sup>20-22</sup> is nondestructive testing of the relationship between the implant and the surrounding bone using electrical vibration. It has a high degree of reproducibility and reliability, but the equipment is expensive and the prosthesis should be removed.

Interface histological analysis with soft and hard tissues is conducted through various imaging methods. Radiologic examination<sup>17,23,24</sup> is commonly used, but standardization is difficult and the limitation of 2D interpretation is a disadvantage. Micro-CT can be used to obtain 3D images of the implant and bone interface, but the examinee is exposed to radioactivity. Histological and histomorphometric analyses are quantitative methods for testing the bones and implants, allowing simultaneous observation of the implant and the surrounding soft and hard tissues; however, as destructive tests, they have limited clinical utility. The pull-out and push-out test<sup>16,25,26</sup> has been used for measuring the shear bond strength of the cylinder-type implant, and the degree of micro-level implant osseointegration can be quantified as biomechanical bond strength.

To investigate the stability of the connection between implant fixture and abutment, various methods for measuring the loosening torque of an abutment screw have been introduced. Loosening torque, one of the indicators of joint stability, is a measure of the full load remaining immediately

before loosening of the abutment screw, affected by the fitness of the implant prosthesis.<sup>27</sup> Elshahawy *et al.*<sup>28</sup> measured the turning force of the loosening of the abutment screw, and Faulkner *et al.*<sup>29</sup> used the Periotest for this purpose. Haack *et al.*<sup>30</sup> measured the full load through the transformation of the screw length, comparing the initial length of the abutment screw and its length after loosening. In addition, Martin *et al.*<sup>31</sup> used a strain gauge to measure full load and loosening torque. Gross *et al.*<sup>32</sup> obtained the value of loosening torque by measuring microleakage of dye at the part of the connection between the abutment and the fixture. This method is simple and appropriate for clinical use, but there was a problem of result distortion due to temperature or corrosion.

The loosening torque can be measured using a torque driver and torque gauge. The devices that apply tightening torque and loosening torque to the implant abutment screw are divided broadly into two types: manual and electronic. The manual devices are further classified as torque wrenches or torque drivers. The existing manual torque wrenches developed by implant companies include a torque-limiting device and a torque-indicating device. The torque-limiting device breaks the handle head component if the input torque value exceeds a critical level. The torque-indicating device has a part in which a graduated arc is marked, which can control the size of the tightening force during use. Manual torque drivers include various forms and methods; for example, a contra-angle torque device has a device that can control the tightening force in the existing contra-angle handpiece.<sup>33</sup>

Manual torque drivers are mainly used in the early tightening process, and experienced clinicians are able to apply appropriate torque values; however, because it is prone to error due to the problem of uniformity according to the user,<sup>34,35</sup> it is not recommended for use in the final abutment screw tightening.<sup>36-39</sup> On the other hand, the electronic torque driver effectively provides even torque, so it has the advantage of not being affected by the environment of use.<sup>40,41</sup> Recently, keeping pace with technological advances in dentistry, manufacturers have developed new electronic torque drivers, and the demand is increasing. With the electronic torque driver, the torque value the practitioner wants is evenly applied to the abutment screw in a digital format, and the torque value can be checked through the LCD screen. Its accuracy and convenience are better than those of the manual devices.

This study was aimed to evaluate the loosening torque that may affect the implant fixture. In this manner, the torque delivered to the implant fixture can be checked when the abutment screw is loosened at the torque recommended by the manufacturer. There are many previous studies that measured loosening torque and removal torque,<sup>42-48</sup> but few studies have measured the delivery of the loosening torque applied to the abutment screw to the implant fixture *in vitro*. The measurement of the loosening torque of the general torque driver can be done as follows: Tightening is performed, and the abutment screw fastened to the implant fix-

ture with the torque driver tip fixed on the torque gauge is manually rotated to measure the loosening torque. However, in this study, the loosening torque was directly applied to the abutment screw fastened to the implant fixture with an electronic torque driver and the torsion force affecting the implant fixture was checked, simultaneously measuring the torque delivered to the implant fixture with a digital torque gauge.

This study was aimed to quantify the torsion force delivered to an implant fixture when an abutment screw is removed through the method of measuring the loosening torque with high reliability in a biomechanical analysis with vital hard tissue interface, using three kinds of electronic torque drivers (W&H, SAESHIN, and NSK) and a digital torque meter (Mark-10, Inc.). The general method of measuring the removal torque<sup>49-58</sup> reflects the degree of osseointegration according to the general characteristics of the implant; however, this study was conducted without calculating interface shear strength, using the same implant system for the three kinds of electronic torque driver.

This objective of this study was to evaluate the loosening torque that may affect the implant fixture and to assess the accuracy of different electronic torque drivers (W&H, SAESHIN, and NSK). The null hypothesis of this study was that there would be no difference in the measured value of torque delivered to the implant fixture when the abutment screw is loosened, among three kinds of electronic torque driver.

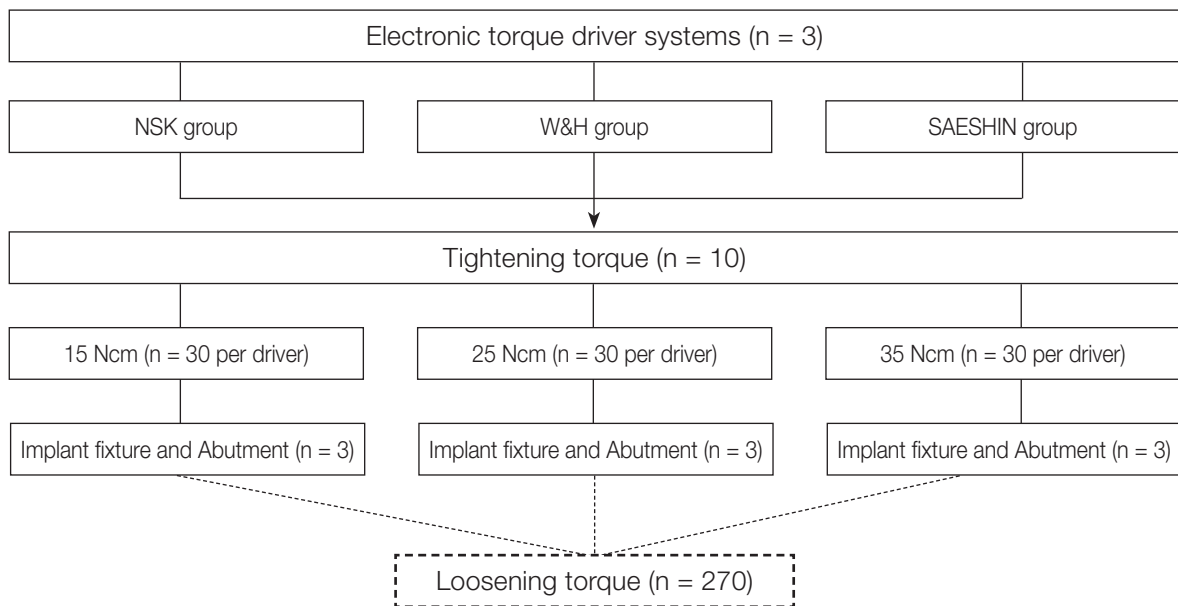
**MATERIALS AND METHODS**

Fig. 1 shows the overall overview of this study. Three kinds

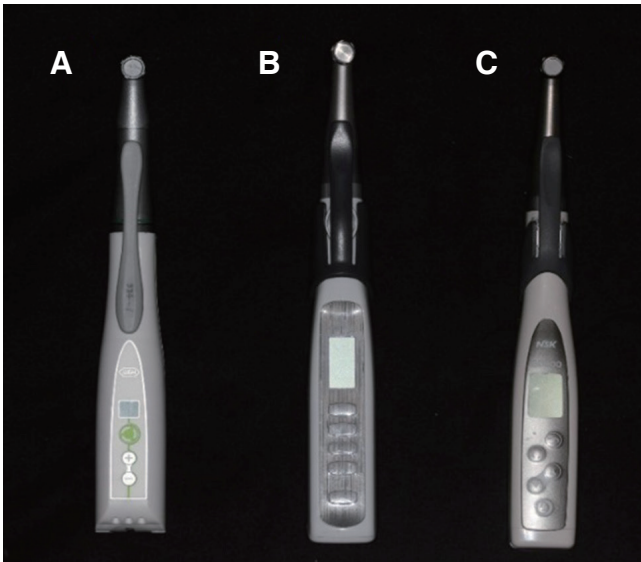
of electronic torque driver systems were used: W&H (IA-400, W&H Co. Ltd., Burmoos, Austria), SAESHIN (TRAUS-MCE30NN, SAESHIN Inc., Daegu, Republic of Korea), and NSK (ISD-900, NSK Co., Tokyo, Japan) (Fig. 2); and a digital-type torque meter: MGT12 (MARK-10, Inc., Copiague, NY, USA) (Fig. 3). Using the fixture and abutment kit (AnyOne, MegaGen, Daegu, Republic of Korea), a uniform implant system allowed objective, quantitative comparison of the numerical data obtained using the three different electronic torque drivers.

A jig that could fix an electronic torque driver and a digital torque meter in the exact location was used (Fig. 3). A total of 27 implant fixtures, abutments, screws, and torque driver tips were used in the experiment. In the MGT12, an implant fixture is fixed with a 3-jaw chuck, and the driver tip of the electronic torque driver is fastened into the hexagonal furrow at the top of the abutment screw to adjust axes X, Y, and Z of the jig. At the same time, the electronic torque driver is fixed by the exclusive holder (Fig. 3, Fig. 4). If the joint between the implant fixture and the electronic torque driver accurately align, the abutment screw can be tightened or loosened.

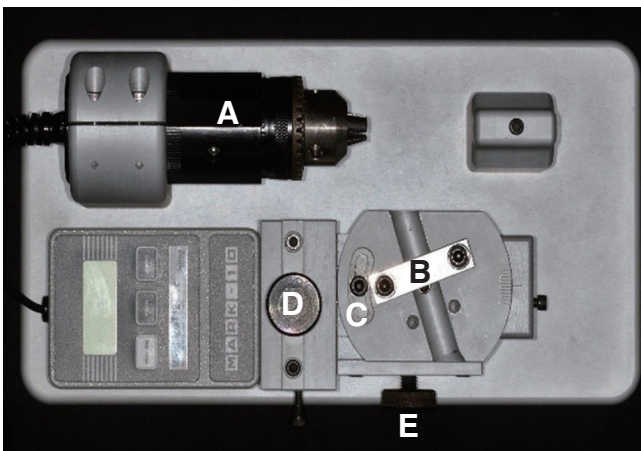
Tightening torque was applied two times and loosening torque was applied one time. The tightening torques of all the electronic torque drivers were 15 Ncm, 25 Ncm, and 35 Ncm. The calibration of drivers was made for the accuracy of an electronic torque driver, and the trueness and repetitive reproducibility of the tightening torque values were tested by using a digital torque gauge. After fastening, the initial tightening torque was applied and after 10 minutes, the same tightening torque was applied; five minutes later, the loosening torque was applied. This process was repeated 10 times



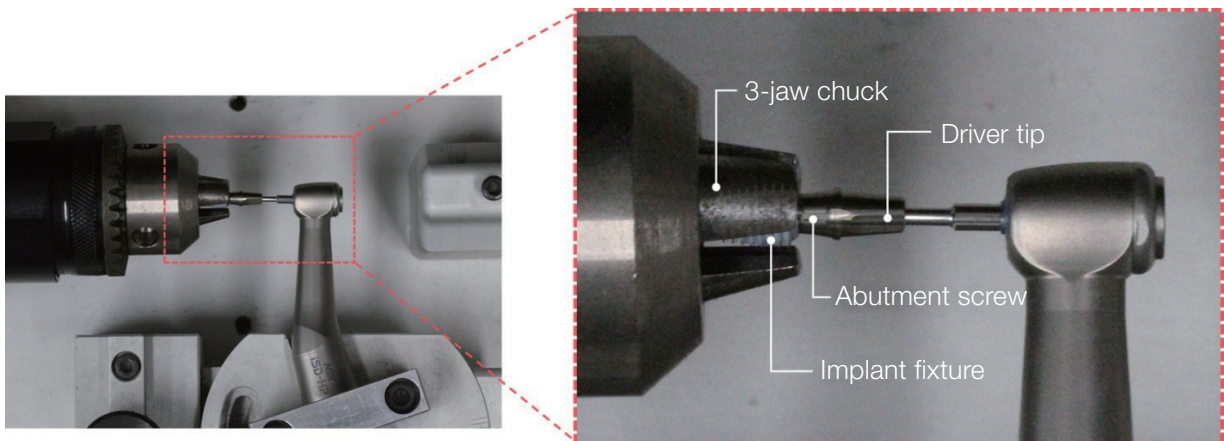
**Fig. 1.** Flow-chart of the study design.



**Fig. 2.** Three kinds of electronic torque driver. (A) W&H, (B) SAESHIN, (C) NSK.



**Fig. 3.** Digital torque gauge and self-developed jig. (A) Digital torque gauge, (B) Electronic torque driver holder, (C) Z-axis alignment, (D) Y-axis alignment, (E) X-axis alignment.



**Fig. 4.** Specimen preparation for loosening torque measurement in digital torque gauge.

per specimen and the loosening torque measurements were recorded, for a total of 270 repetitions (30 times per torques [15, 25, and 35 Ncm] and 90 per electronic torque drivers [NSK, W&H, SAESHIN]) (Fig. 1). A new screw was used for each measurement. All processes of this experiment were conducted by the same investigator (K.S.).

The loosening torque can be measured by digital torque meter, as in Fig. 4. As shown in Fig. 4, if the MGT12 fixes the implant fixture, the 3-jaw chuck is the part where the load is generated when the loosening torque is applied after applying the tightening torque. In this setting, the force applied to the MGT12 is not solely the force applied to the abutment screw; rather, it is the delivered force passing through the implant fixture. From a clinical perspective, the 3-jaw chuck of MGT12 is analogous to the alveolar bone connected to the implant fixture, and the loosening torque applied in this manner can be defined as the stability of osseointegration (that is, the torque delivered to the implant fixture combined with the alveolar bone). From a physical perspective, the loosening torque of the abutment screw generated by the electronic torque driver is larger than the torsion force as energy is lost in the process of delivery to the implant fixture, but the amount of energy lost is negligible, so the loosening torque and torsion force were considered the same.

All statistical processes were analyzed using SPSS for Windows 23.0 (SPSS Inc., Chicago, IL, USA). First, the normal distribution of the data was examined through the Shapiro-Wilk test. For the loosening torque of all electronic torque drivers, the one-way ANOVA ( $\alpha = .05$ ) was performed if there was a homogeneity of the variances and the Tukey test was conducted post hoc. If there was no homogeneity of the variances, the Kruskal-Wallis test was performed and a pairwise test was conducted post hoc.

**RESULTS**

Table 1 and Fig. 5 show the results of loosening torque of different electronic torque drivers. There were statistically significant differences in target torque among the three kinds of electronic torque driver ( $P < .001$ ). The values obtained with the W&H are significantly decreased compared to all target torques. Overall, there were significant differences among the three kinds of drivers at the target torques of 15 Ncm and 25 Ncm. In the system comparisons, the measured value was closest to the target torque in the following order: NSK > SAESHIN > W&H ( $P < .05$ ). At the target torque of 35 Ncm, the SAESHIN driver ( $33.1 \pm 2.4$  Ncm) showed the closest measured value, while there was no significant difference between the NSK ( $30.6 \pm 1.3$  Ncm) and W&H driver ( $31.7 \pm 1.6$  Ncm) ( $P > .05$ ).

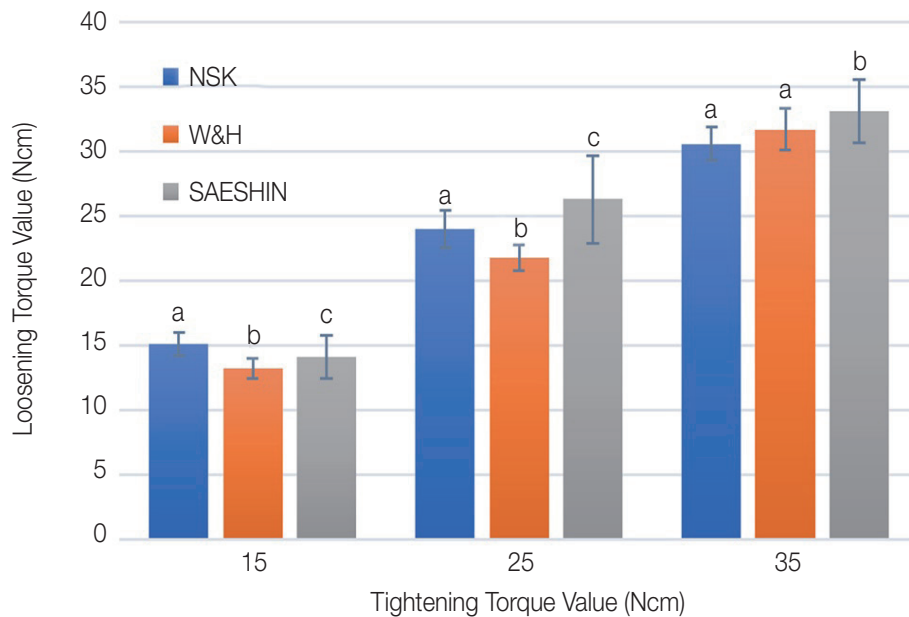
**DISCUSSION**

This study applied tightening torque to a screw fastened to an implant fixture with three kinds of electronic torque drivers at the target torque values of 15 Ncm, 25 Ncm, and 35 Ncm, then applied the loosening torque accordingly, and measured the final delivered torque between the implant fixture and the MGT12 device. The torque measured in this experiment was delivered to the test components in the following order: abutment screw → implant fixture → MGT12. This is clinically equivalent to the loosening torque of the electronic torque driver delivered in the following order: abutment screw → implant fixture → alveolar bone, thereby affecting the osseointegration of the implant fixture with the alveolar bone. In the study published by T. Paepoemsin *et al.*,<sup>49</sup> it was reported that the force of the removal torque was

**Table 1.** Comparison of loosening torque value among digital torque drivers (n = 30)

Tightening torque value (Ncm)	Loosening torque value, Mean ± SD (Ncm)			P
	NSK	W&H	SAESHIN	
15	15.1 ± 0.9 <sup>a</sup>	13.2 ± 0.8 <sup>b</sup>	14.1 ± 1.7 <sup>c</sup>	< .001**
25	24.0 ± 1.4 <sup>a</sup>	21.8 ± 1.0 <sup>b</sup>	26.3 ± 3.4 <sup>c</sup>	< .001*
35	30.6 ± 1.3 <sup>a</sup>	31.7 ± 1.6 <sup>a</sup>	33.1 ± 2.4 <sup>b</sup>	< .001*

Significant by \* One-way ANOVA or \*\* Kruskal-Wallis test;  $P < .05$ . Different letters indicate significant differences;  $P < .05$ .



**Fig. 5.** Comparison of loosening torque value according to the target tightening torque value and torque drivers. Same lowercase letters are not significantly different according to Tukey HSD test and a pairwise test ( $P < .05$ ).

approximately 80% - 90% of the tightening torque recommended by each manufacturer. In our study, the torque delivered to the implant fixture was delivered at the level of approximately 93.7% of the loosening torque.

The results of this study show the feasibility of the method for checking the impact on the implant fixture when the loosening torque is applied to the abutment screw tightened at the target torque. In an *in vitro* test conducted by Stüker *et al.*,<sup>50</sup> for the tightening torque at  $30.07 \pm 0.28$  Ncm, the removal torque was up to  $18.75 \pm 1.89$  Ncm. Further, in an *in vitro* study conducted by Ghanbarzadeh *et al.*,<sup>51</sup> for a one-piece abutment type, the removal torques were  $20.25 \pm 4.46$  Ncm and  $13.16 \pm 2.18$  Ncm for the tightening torques of  $28.8 \pm 4.61$  Ncm and  $16.8 \pm 1.73$  Ncm, respectively. Meanwhile, in an *in vitro* test conducted by Saliba *et al.*,<sup>52</sup> for the tightening torque of 32 Ncm, the removal torque was as high as  $38.62 \pm 6.43$  Ncm. As shown in Table 1, except for the removal torque result as high as  $26.3 \pm 3.4$  Ncm for the tightening torque at 25 Ncm with the SAESHIN electronic torque driver, all had loosening torques lower than the tightening torque.

The tightening torque affects the loosening torque, and the loosening torque is finally delivered to the osseointegration site as a torque between the implant fixture and the alveolar bone. In animal testing using rabbits conducted by Hwang *et al.*,<sup>53</sup> there was a difference in the removal torque according to the time of implant fixture insertion, and the removal torque measured at week 5 was approximately  $16.06 \pm 6.17$  Ncm. In the study reported by Koh *et al.*,<sup>54</sup> when the removal torque was measured on implant fixtures in mongrel dogs, the removal torque was  $71.2 \pm 2.5$  Ncm at week 12, which was the highest value. In animal testing using mice conducted by Yi *et al.*,<sup>55</sup> the removal torque was 30 Ncm at week 2 and 70 Ncm at week 6. Buser *et al.*<sup>56</sup> measured the removal torque of Osseotite implants at weeks 4 and 12, and the values were 62.6 Ncm and 95.7 Ncm, respectively. The longer the implant healing period, the higher the level of osseointegration becomes; therefore, in the early phase, when the removal torque is similar to or lower than the applied abutment tightening torque, it is necessary to pay close attention when loosening the abutment screw. In addition, because osseointegration is poor in some individuals, it is necessary to take precautions, for example, by increasing the healing period, increasing the coherence, or reapplying the tightening torque. Even if the removal torque between the implant fixture and the alveolar bone is higher than the loosening torque, the loosening torque is an element in contrast to the removal torque, so it may have a direct impact on osseointegration. Thus, it is advisable to reduce the frequency of loosening torque addition.

According to results of this study, the tightening torque and loosening torque did show a slight difference (Table 1). The differences in target torques of 15 Ncm were 0.1, -1.8, and -0.9 Ncm in NSK, W&H, and SAESHIN, respectively. The differences in 25 Ncm were -1, -3.2, and 1.3 Ncm in NSK, W&H, and SAESHIN, respectively. The differences in 35 Ncm were -4.4, -3.3, and -1.9 Ncm in NSK, W&H, and

SAESHIN, respectively. At most difference values, the loosening torque was lower than the target torque (tightening torque). Previous study evaluating the accuracy of tightening torques in torque-limiting devices showed lower tightening torques (mean difference of -1.7 to -9.9 Ncm) relative to target torque in all 5 type of torque-limiting devices.<sup>57</sup> Therefore, the lower tightening torque compared to the target torque may cause the lower loosening torque. Low loosening torque can affect stability over time in the oral cavity.<sup>57</sup> Therefore, calibration according to the manufacturer's manual is required for accurate tightening torque.<sup>58</sup> Further study is needed on how low tightening torque affects loosening torque.

The present study has a number of limitations. First, the loosening torque was measured by referring to the torque setting on the electronic torque driver as the target torque without actually measuring the tightening torque. The instrument was calibrated before the experiment, but its use in previous studies may cause low tightening torques,<sup>57</sup> so further research is needed. Second, the loosening torque was measured by fixing the implant fixture to a 3-jaw chuck on the digital torque gauge. Different results can be obtained with implant fixtures placed in the bone in the oral cavity. Finally, it has not been tested in oral conditions. Many intra-oral conditions (functional load, humidity, and temperature) cause the screw to loosen.<sup>59,60</sup> Therefore, the loosening torque before applying the oral condition in this study should be regarded as a relatively high loosening torque. Therefore, further studies require results evaluated under oral conditions.

## CONCLUSION

Within the limitations of this *in vitro* study, all three electronic torque drivers had significant differences in loosening torque values ( $P < .001$ ). The tightening torque and loosening torque did show a slight difference, and most of the loosening torque was lower than the tightening torque. The most accurate loosening torques showed SAESHIN ( $33.1 \pm 2.4$  Ncm) at 35 Ncm, and NSK ( $15.1 \pm 0.9$  Ncm and  $24.0 \pm 1.4$  Ncm) at 15 Ncm and 25 Ncm. Since the loosening torque may vary depending on the tightening torques and electronic torque drivers, periodic calibration of the electronic torque driver is recommended.

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## REFERENCES

1. Brånemark PI. Osseointegration and its experimental background. *J Prosthet Dent* 1983;50:399-410.
2. Sumi T, Braian M, Shimada A, Shibata N, Takeshita K,

- Vandeweghe S, Coelho PG, Wennerberg A, Jimbo R. Characteristics of implant-CAD/CAM abutment connections of two different internal connection systems. *J Oral Rehabil* 2012;39:391-8.
3. Lang LA, Sierralta M, Hoffensperger M, Wang RF. Evaluation of the precision of fit between the Procera custom abutment and various implant systems. *Int J Oral Maxillofac Implants* 2003;18:652-8.
  4. Adell R, Eriksson B, Lekholm U, Brånemark PI, Jemt T. Long-term follow-up study of osseointegrated implants in the treatment of totally edentulous jaws. *Int J Oral Maxillofac Implants* 1990;5:347-59.
  5. Binon PP. The effect of implant/abutment hexagonal misfit on screw joint stability. *Int J Prosthodont* 1996;9:149-60.
  6. Lee WJ, Lim JH, Cho IH. Stress of dental implant abutment screw by the tightening torque. *J Korean Acad Prosthodont* 1998;36:721-37.
  7. Lim JB, Yim SH, Cho IH. The effect of screw hole sealing method on abutment screw loosening in dental implant. *J Korean Acad Prosthodont* 1997;35:767-80.
  8. Cho SM, Lim JH, Cho IH. A study on geometric comparison of four interchangeable implant prosthetic retaining screws and measurement of loosening torque. *J Korean Acad Prosthodont* 1998;36:468-82.
  9. Balshi TJ, Hernandez RE, Pryszyk MC, Rangert B. A comparative study of one implant versus two replacing a single molar. *Int J Oral Maxillofac Implants* 1996;11:372-8.
  10. Kempainen P, Eskola S, Ylipaavaliemi P. A comparative prospective clinical study of two single-tooth implants: a preliminary report of 102 implants. *J Prosthet Dent* 1997;77:382-7.
  11. Cho IH. Biomechanical analysis of implant prosthodontic restorations. *J Korean Dent Assoc* 1993;31:438-43.
  12. Binon PP. The effect of implant/abutment hexagonal misfit on screw joint stability. *Int J Prosthodont* 1996;9:149-60.
  13. Binon PP. Implants and components: entering the new millennium. *Int J Oral Maxillofac Implants* 2000;15:76-94.
  14. Misch CE. Principles for screw-retained prostheses. In: Misch CE. *Contemporary implant dentistry*. 2nd ed., Missouri: CV Mosby, 1999. p. 669-85.
  15. Ivanoff CJ, Sennerby L, Lekholm U. Reintegration of mobilized titanium implants. An experimental study in rabbit tibia. *Int J Oral Maxillofac Surg* 1997;26:310-5.
  16. Ko SM, Park SJ, Kim IS, Song SI, Lee IK. Observation of the change of the dental implant stability and bone density evaluation methods. *J Korean Acad Periodontol* 2009;39:185-92.
  17. Park YS, Yi KY, Lee IS, Jung YC. Correlation between microtomography and histomorphometry for assessment of implant osseointegration. *Clin Oral Implants Res* 2005;16:156-60.
  18. Sennerby L, Dasmah A, Larsson B, Iverhed M. Bone tissue responses to surface-modified zirconia implants: A histomorphometric and removal torque study in the rabbit. *Clin Implant Dent Relat Res* 2005;7:S13-20.
  19. Klokkevold PR, Johnson P, Dadgostari S, Caputo A, Davies JE, Nishimura RD. Early endosseous integration enhanced by dual acid etching of titanium: a torque removal study in the rabbit. *Clin Oral Implants Res* 2001;12:350-7.
  20. Westover L, Faulkner G, Hodgetts W, Raboud D. Comparison of implant stability measurement devices for bone-anchored hearing aid systems. *J Prosthet Dent* 2018;119:178-84.
  21. Friberg B, Sennerby L, Linden B, Gröndahl K, Lekholm U. Stability measurements of one-stage Brånemark implants during healing in mandibles. A clinical resonance frequency analysis study. *Int J Oral Maxillofac Surg* 1999;28:266-72.
  22. Meredith N, Shagaldi F, Alleyne D, Sennerby L, Cawley P. The application of resonance frequency measurements to study the stability of titanium implants during healing in the rabbit tibia. *Clin Oral Implants Res* 1997;8:234-43.
  23. Sennerby L, Wennerberg A, Pasop F. A new microtomographic technique for non-invasive evaluation of the bone structure around implants. *Clin Oral Implants Res* 2001;12:91-4.
  24. Fanuscu MI, Chang TL. Three-dimensional morphometric analysis of human cadaver bone: microstructural data from maxilla and mandible. *Clin Oral Implants Res* 2004;15:213-8.
  25. Brandt J, Bierögel C, Holweg K, Hein W, Grellmann W. Extended push-out test to characterize the failure of bone-implant interface. *Biomed Tech (Berl)* 2005;50:201-6.
  26. Dhert WJ, Verheyen CC, Braak LH, de Wijn JR, Klein CP, de Groot K, Rozing PM. A finite element analysis of the push-out test: influence of test conditions. *J Biomed Mater Res* 1992;26:119-30.
  27. Cibirka RM, Nelson SK, Lang BR, Rueggeberg FA. Examination of the implant-abutment interface after fatigue testing. *J Prosthet Dent* 2001;85:268-75.
  28. Elshahawy W, Ajlouni R, Ajlouni K, Sadakah A. Failure torque of ceramic neck titanium implant. *J Prosthet Dent* 2018;119:432-6.
  29. Faulkner MG, Wolfaardt JF, Chan A. Measuring abutment/implant joint integrity with the Periostest instrument. *Int J Oral Maxillofac Implants* 1999;14:681-8.
  30. Haack JE, Sakaguchi RL, Sun T, Coffey JP. Elongation and preload stress in dental implant abutment screws. *Int J Oral Maxillofac Implants* 1995;10:529-36.
  31. Martin WC, Woody RD, Miller BH, Miller AW. Implant abutment screw rotations and preloads for four different screw materials and surfaces. *J Prosthet Dent* 2001;86:24-32.
  32. Gross M, Abramovich I, Weiss EI. Microleakage at the abutment-implant interface of osseointegrated implants: a comparative study. *Int J Oral Maxillofac Implants* 1999;14:94-100.
  33. Kim DG, Park CJ, Cho LR. Comparative analysis of the implant torque controller. *J Dent Rehabil Appl Sci* 2012;28:27-36.
  34. Jaarda MJ, Razzoog ME, Gratton DG. Providing optimum torque to implant prostheses: a pilot study. *Implant Dent* 1993;2:50-2.
  35. Goheen KL, Vermilyea SG, Vossoughi J, Agar JR. Torque generated by handheld screwdrivers and mechanical torquing devices for osseointegrated implants. *Int J Oral Maxillofac Implants* 1994;9:149-55.
  36. Tan KB, Nicholls JL. The effect of 3 torque delivery systems on gold screw preload at the gold cylinder-abutment screw joint. *Int J Oral Maxillofac Implants* 2002;17:175-83.
  37. Vallee MC, Conrad HJ, Basu S, Seong WJ. Accuracy of fric-

- tion-style and spring-style mechanical torque limiting devices for dental implants. *J Prosthet Dent* 2008;100:86-92.
38. Dellinges MA, Tebrock OC. A measurement of torque values obtained with hand-held drivers in a simulated clinical setting. *J Prosthodont* 1993;2:212-4.
  39. Gross M, Kozak D, Laufer BZ, Weiss EI. Manual closing torque in five implant abutment systems: an in vitro comparative study. *J Prosthet Dent* 1999;81:574-8.
  40. Jaarda MJ, Razzoog ME, Gratton DG. Providing optimum torque to implant prostheses: a pilot study. *Implant Dent* 1993;2:50-2.
  41. Tan KB, Nicholls JI. The effect of 3 torque delivery systems on gold screw preload at the gold cylinder-abutment screw joint. *Int J Oral Maxillofac Implants* 2002;17:175-83.
  42. Johansson CB, Sennerby L, Albrektsson T. A removal torque and histomorphometric study of bone tissue reaction to commercially pure titanium and vitallium implant. *Int J Oral Maxillofac Implants* 1991;6:437-41.
  43. Johansson CB, Albrektsson T. A removal torque and histomorphometric study of commercially pure niobium and titanium implants in rabbit bone. *Clin Oral Implants Res* 1991;2:24-9.
  44. Klokkevold PR, Nishimura RD, Adachi M, Caputo A. Osseointegration enhanced by chemical etching of the titanium surface. A torque removal study in the rabbit. *Clin Oral Implants Res* 1997;8:442-7.
  45. Buser D, Nydegger T, Hirt HP, Cochran DL, Nolte LP. Removal torque values of titanium implants in the maxilla of miniature pigs. *Int J Oral Maxillofac Implants* 1998;13:611-9.
  46. Buser D, Nydegger T, Oxland T, Cochran DL, Schenk RK, Hirt HP, Snétivy D, Nolte LP. Interface shear strength of titanium implants with a sandblasted and acid-etched surface: a biomechanical study in the maxilla of miniature pigs. *J Biomed Mater Res* 1999;45:75-83.
  47. Inadome T, Hayashi K, Nakashima Y, Tsumura H, Sugioka Y. Comparison of bone-implant interface shear strength of hydroxyapatite-coated and alumina-coated metal implants. *J Biomed Mater Res* 1995;29:19-24.
  48. Ellingsen JE, Johansson CB, Wennerberg A, Holmén A. Improved retention and bone-to-implant contact with fluoride-modified titanium implants. *Int J Oral Maxillofac Implants* 2004;19:659-66.
  49. Paepoemsin T, Reichart PA, Chaijareenont P, Strietzel FP, Khongkhunthian P. Removal torque evaluation of three different abutment screws for single implant restorations after mechanical cyclic loading. *Oral Implantol (Rome)* 2016;9:213-21.
  50. Stüker RA, Teixeira ER, Beck JC, da Costa NP. Preload and torque removal evaluation of three different abutment screws for single standing implant restorations. *J Appl Oral Sci* 2008;16:55-8.
  51. Ghanbarzadeh J, Rajabzadeh M, Nakhaei M, Rajatihaghi H, Tayarani Najjaran N. Torque removal evaluation of screw in one-piece and two-piece abutments tightened with a handheld screwdriver. *J Dent Mater Tech* 2013;3:11-5.
  52. Saliba FM, Cardoso M, Torres MF, Teixeira AC, Lourenço EJ, Telles Dde M. A rationale method for evaluating unscrewing torque values of prosthetic screws in dental implants. *J Appl Oral Sci* 2011;19:63-7.
  53. Hwang YJ, Cho JH, Lee CH. Investigation of osseointegration according to the healing time after having iatrogenic mobility of implant fixtures. *J Korean Acad Prosthodont* 2010;48:308-14.
  54. Koh YH, Kim YJ, Chung HJ. Bone healing around screw-shaped titanium implants with three different surface topographies. *J Korean Acad Periodontol* 2001;31:41-55.
  55. Yi YA, Park YB, Choi H, Kim SJ, Kim KM, Oh S, Shim JS. The evaluation of osseointegration of dental implant surface with different size of TiO<sub>2</sub> nanotube in rats. *J Nanomater* 2015;2:1-10.
  56. Buser D, Nydegger T, Hirt HP, Cochran DL, Nolte LP. Removal torque values of titanium implants in the maxilla of miniature pigs. *Int J Oral Maxillofac Implants* 1998;13:611-9.
  57. Albayrak H, Gumus HO, Tursun F, Kocaagaoglu HH, Kilinc HI. Accuracy of torque-limiting devices: A comparative evaluation. *J Prosthet Dent* 2017;117:81-6.
  58. Wadhvani CPK, O'Brien R, Rosen PS, Chung KH. Testing and calibrating the mechanical-type toggle torque wrenches used in implant dentistry: A dental technique. *J Prosthet Dent* 2019 Aug 2. pii: S0022-3913(19)30342-7.
  59. Kreissl ME, Gerds T, Mueche R, Heydecke G, Strub JR. Technical complications of implant-supported fixed partial dentures in partially edentulous cases after an average observation period of 5 years. *Clin Oral Implants Res* 2007;18:720-6.
  60. Sananez A, Lefebvre C, Looney S, Baker P, Mettenburg D, Rueggeberg FA. In vitro mechanical analysis of complete-arch mandibular implant-supported fixed prostheses abutment screws after cyclic loading. *J Prosthet Dent* 2015;113:432-9.