

Survey of Dental Clinicians for Attitude and Use of Torque-Limiting Devices

Chandur P.K. Wadhwani, BDS, MSD¹/Paul S. Rosen, DMD, MS²/Gang Yang, DMD³/
Wenjie Hu, DDS, PhD³/Todd Schoenbaum, DDS, MS⁴/Tomas Linkevicius, DDS, Dip Pros, PhD⁵/
Shankar Iyer, DDS, MDS⁶/Timothy Hess, DDS, MAGD⁷/
Mathew T. Kattadiyil, BDS, MDS, MS⁸/Kwok-Hung Chung, DDS, PhD⁹

Purpose: The purpose of this study was to survey practicing clinicians and determine if differences existed concerning their use of torque-limiting devices (TLDs) and screw-tightening protocols, comparing this with existing universal industry standards. **Materials and Methods:** A nine-question survey was administered with 428 dentists providing data for three specific areas: (1) demographic information—TLD ownership, device age, frequency of use, and observations of screw loosening; (2) recognition information—calibration, reading measurements of the TLD, and the meaning of preload; (3) usage information—screw-tightening protocols and effect of speed during actioning of the TLD. Data collection was compared with industry standards for use of hand torque tools including ISO-6789 1,2:2017 and related texts pertaining to screw fastener protocols. **Results:** The beam-type TLD was the most popular; however, 33% surveyed used it incorrectly. Most TLDs being used were older than 1 year, with only 6% calibrated. Forty-eight percent observed screw loosening less than once per year, while 44% reported three or more occurrences per year. A similar number used the TLD for implant placement and abutment screw tightening. Screw-tightening protocols varied. Preload was not understood by the majority of those surveyed. **Conclusion:** Dentistry does not appear to adhere to the protocols and standards recommended by other industries that also rely on screw-fastening mechanisms and TLDs. Further education and training appears to be warranted in this area of implant dentistry to reduce the risks of screw-associated complications. *Int J Oral Maxillofac Implants* 2021;36:538–545. doi: 10.11607/jomi.8590

Keywords: abutment screw loosening, calibration, implant screws, preload, screw-tightening, torque-limiting device

¹Private Practice limited to Prosthodontics, Bellevue, Washington; Department of Periodontics, Oregon Health Sciences University, Portland, Oregon, USA.

²Private Practice limited to Periodontics, Yardley, Pennsylvania, and New York, New York; Department of Periodontics, University of Maryland, Baltimore, Maryland, USA.

³Department of Periodontology, Peking University School and Hospital of Stomatology, National Center of Stomatology & National Engineering Laboratory for Digital and Material Technology of Stomatology, Beijing, China.

⁴Dental College of Georgia, Augusta, Georgia, USA.

⁵Private Practice limited to Prosthetics, Vilnius; Institute of Odontology, Faculty of Medicine, Vilnius University, Vilnius, Lithuania.

⁶Private Practice limited to Prosthodontics, Elizabeth, New Jersey; Department of Prosthodontics and Periodontics, Rutgers University, Newark, New Jersey, USA.

⁷Private Practice, Auburn, Washington; Department of Restorative Dentistry, University of Washington, Seattle, Washington, USA.

⁸Advanced Education Program in Prosthodontics, Loma Linda University, Loma Linda, California, USA.

⁹Department of Restorative Dentistry, University of Washington, Seattle, Washington, USA.

Correspondence to: Dr Chandur Wadhwani, 12715 Belred Rd, #201, Bellevue, Washington, 98005, USA. Email: cpkw@uw.edu

Submitted May 9, 2020; accepted January 10, 2021.

©2021 by Quintessence Publishing Co Inc.







Screw fasteners have been developed and used for almost 500 years,^{1,2} with manufacturing standards developed in the 1800s to improve their performance.³ One particular problem with using screws as fasteners is their inadvertent loosening, which is an issue encountered by many engineering industries.⁴ Standardized tightening protocols and specialized tools, such as torque-limiting devices (TLDs), have been developed to reduce this potential risk.⁵ Currently, these types of tools, known as torque wrenches in dentistry, have become an integral part of the armamentarium for tightening screws, especially in implant therapy. Nevertheless, screw loosening is problematic and has been reported as the most frequent prosthetic complication with screw-retained implant prostheses.⁶ Reports have indicated an overall occurrence rate of approximately 4% to 12%, with a large proportion happening within the first year of prosthetic placement.^{7–9}

In light of this high incidence, it would be useful to determine the factors that can contribute to this undesirable event. Some of these factors have been described¹⁰ and include component morphology, materials selection, patient factors (such as bruxism), and screw-tightening protocols; yet, there is sparse

Fig 1 The survey questionnaire.

Implant Torque Wrench Survey: Please CIRCLE answers

1. Which type(s) of torque wrench do you have: (circle – more than one ok!)

A. "Toggle Type" B. "Variable manual" C. "Electric" D. "Beam/Bar Type"




2. How long have you had your torque wrench:
 A. Less than 1 year B. 1–3 years C. Longer than 3 years

3. When do you use it most often: (Circle all apply)
 A. Surgical placement of implant b. Place healing cap
 C. Tighten abutment D. Test Implant integration

4. How often have you seen screw loosening of an implant restoration?
 A. Never B. Very rarely (less than once per year)
 C. Rarely (3–4 year) D. More than 5 times a year

5. Have you ever calibrated the torque wrench?
 A. Yes B. No

6. For a "Beam Type" wrench, 20 Ncm is most accurately represented by:

A. Bar Leading edge at 20 Mark B. Middle bar at 20 Mark C. Trailing edge bar at 20 Mark

7. What is "Preload" of a screw?
 A. Hand tightening of the screw before using torque wrench
 B. Tightening the screw to a predetermined value, then test by lateral chewing
 C. Tension in the screw producing clamping force
 D. Wait time between each tightening event of the screw allowing for settling

8. Does the speed of tightening when using either a bar or a toggle type torque wrench have any effect?
 A. Both B. No
 C. Only on Beam type wrench D. Only on Toggle wrench E. Do not know

9. What is your tightening protocol when using a torque wrench on Final Abutments/Restoration?
 A. Tighten to required value 1 time
 B. Tighten to the required value once, wait a few minutes then re-tighten
 C. Tighten to required value, let patient go, then 1 week later patient returns for re-tightening
 D. Tighten to required torque more than once, no waiting
 E. Tighten to required torque, reverse (loosen), retighten to required torque value

information in the dental literature evaluating if clinicians use or follow any industry standard guidelines, especially when using tools designed to optimize screw tightening. It was presumed that the results would provide an abundance of clinical insight and a valid interpretation of the current standard of care. The purpose of this study was to survey practicing dental clinicians to study their use of TLDs and tightening protocols and

to gauge their understanding of these relative to current universal industry standards.

MATERIALS AND METHODS

A nine-question survey was developed by the authors and administered to various groups of dentists

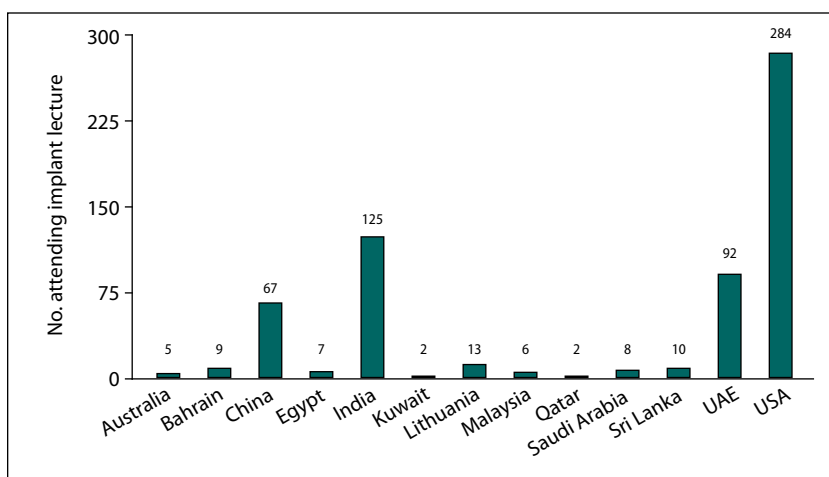


Fig 2 Country of origin and number of attendees presented with questionnaire.

attending either implant-related lectures given by several of the coauthors (C.W., K.H.C., P.R., T.H.) at eight different locations or as an Internet lecture. These lectures occurred during a period beginning on August 15, 2019, and lasting up until April 8, 2020, which coincided with the COVID-19 outbreak. The respondents were asked to voluntarily provide anonymous answers and were informed that all questions were optional and that the survey for the study would take approximately 10 minutes or less. This multiple-choice-question survey (Fig 1) was related to implant TLDs and screw tightening and took approximately 10 minutes or less to complete. The nine questions were divided into three categories: demographic data, recognition information, and usage information.

Demographic Data Collection

Demographic information that was gathered (questions 1 to 4) included the type of torque wrench owned, for how long, how often it was used, and the frequency of screw loosening encountered.

Recognition Information

Questions 5 to 7 centered on calibration of the TLD, reading of the torque number scale, and the meaning of preload of a screw.

Usage Information

Information (questions 8 and 9) on the screw-tightening protocol when using TLDs as well as the effect of tightening speed was collected.

Some of the data collection occurred in two specific countries (United States and China) and some from a multinational lecture given through the Internet, where the polling could not be sorted by country. The questionnaire was translated for the Chinese group; for all others, it was provided in English. All responses were

reviewed by one researcher following the Declaration of Helsinki protocols.¹¹

Data Analysis

The data were organized using Microsoft Excel 2019. The results were calculated as a percentage of the number of respondents answering the questions. The total of the responses for some questions may be more than the number of respondents, as more than one answer selection was allowed, and not all questions were answered by all respondents.

RESULTS

An international cohort of clinicians provided data from the following countries: Australia, Bahrain, China, Egypt, India, Kuwait, Lithuania, Malaysia, Qatar, Saudi Arabia, Sri Lanka, UAE, and the United States (Fig 2).

The survey was filled out by 428 out of a total of 630 attendees, with 202 not wishing to participate, representing a 68% return rate. Of the 428, almost all questions were answered, with the exception of one related to preload, which received only 371 responses.

Demographic Information

Regarding the question on which type of TLD was the most popular, 60% stated the beam-type TLD (Fig 3). With respect to years in service, the majority (43%) claimed their TLD had been used for more than 3 years (Fig 4). Many used the device for more than one procedure, with the respondents providing 804 answers. Most respondents (45%) used TLDs for surgical implant placement, closely followed by placement of the definitive abutment (41%; Fig 5). Regarding the observation of screw loosening, only 8% of respondents reported that they had not seen this (Fig 6).

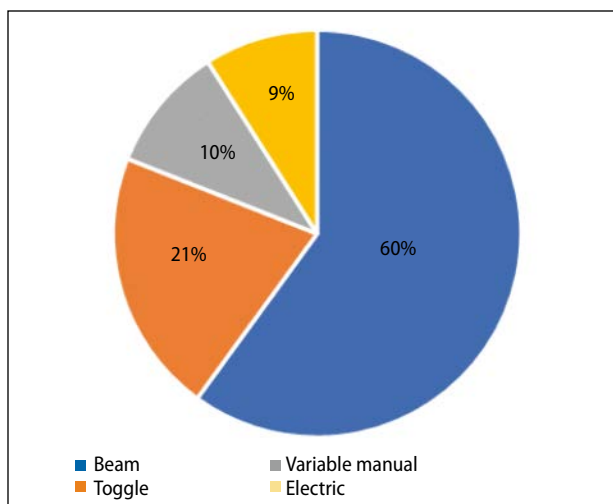


Fig 3 Percentage of the type of TLD possessed by clinicians; some had more than one type. TLD, n = 639; respondents, n = 428.

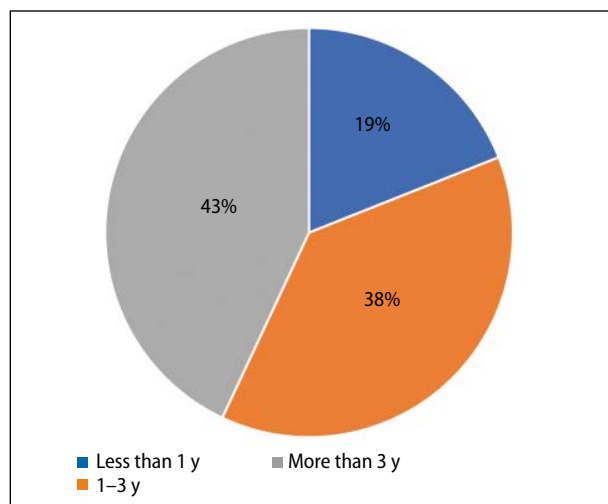


Fig 4 Percentage of the age of TLDs (n = 428).

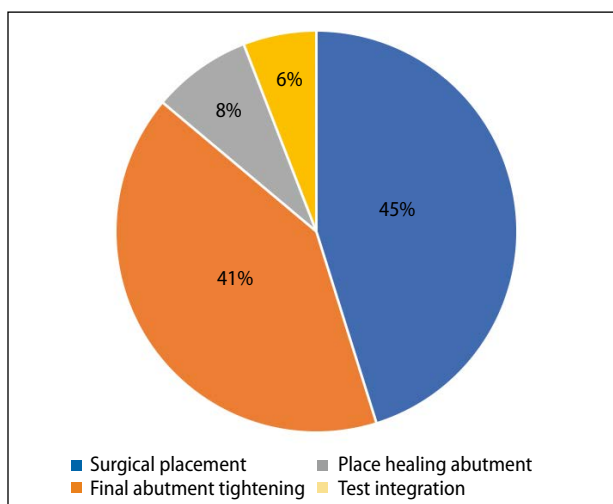


Fig 5 Percentage of procedures where clinicians most often use TLDs (usage, n = 804; respondents, n = 419).

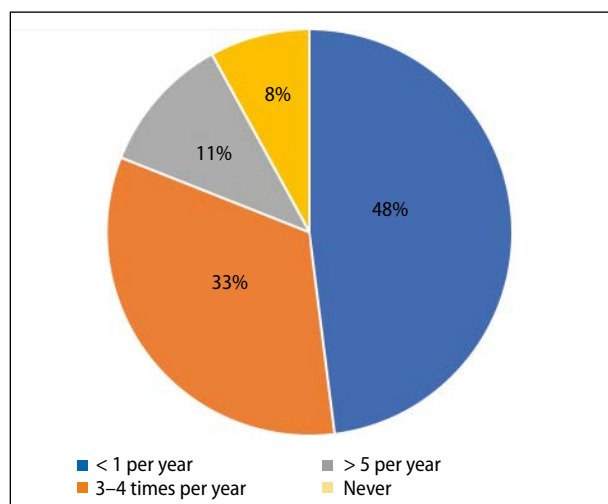


Fig 6 Frequency of screw loosening observed (n = 424).

Recognition Information

Only 25 of the individuals, representing 6% of the responses, had calibrated their TLD (Fig 7). When asked about the beam position relative to the marker arm, 66% had the marker position correct as the central mid-bar (Fig 8). Of the 371 respondents, only 14% appeared to understand the term "preload" and what it referred to. Half of this group related the question to hand tightening, then using a TLD (Fig 9).

Usage Information

Regarding the speed of activation of either the toggle- or beam-type TLD, there were 422 responses, with 58% not knowing if speed of activation affected torque

delivery. Only 5% correctly identified toggle-type TLD being affected by the speed of use (Fig 10). Tightening protocols provided from 427 respondents (50%) reported tightening to the required torque value, waiting a few minutes, then retightening; 22% only tightened the abutment screw once with the TLD (Fig 11).

DISCUSSION

Surveys are an extremely useful tool that allow the assessment of large populations and the establishment of a consensus with relative ease. In the present study, the survey design was focused on both the use of TLDs

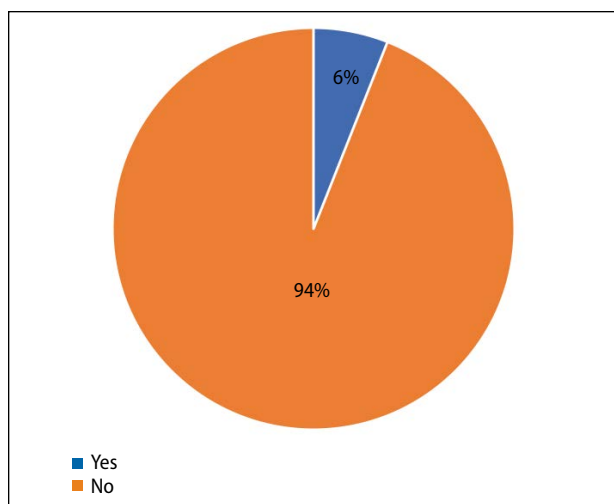


Fig 7 Percentage of respondents who had calibrated their TLDs (n = 424).

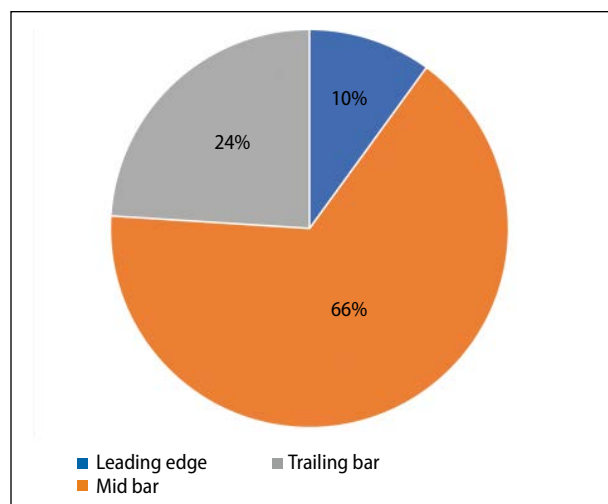


Fig 8 Percentage of respondents regarding correct location to read torque value on beam-type TLD (n = 426).

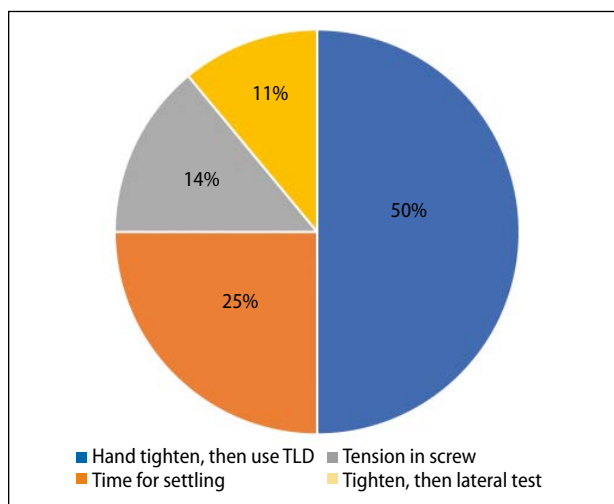


Fig 9 Percentage of respondents' answers to the definition of preload (n = 371).

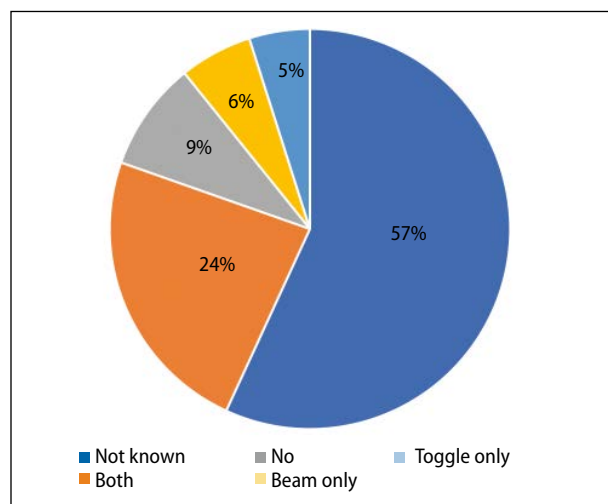


Fig 10 Percentage of respondents regarding the effect of speed when using TLDs (n = 422).

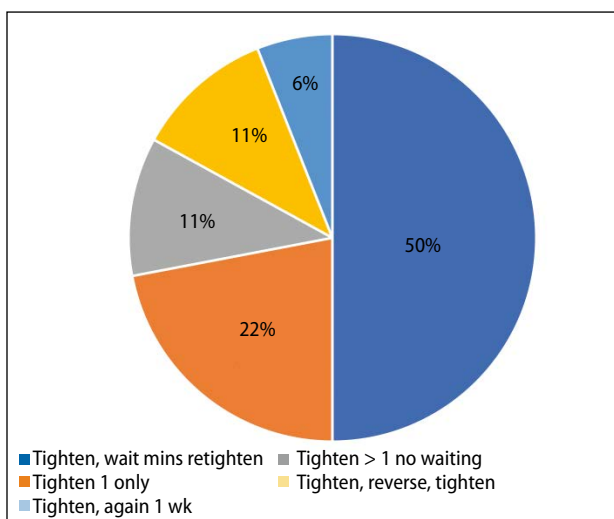


Fig 11 Percentage of respondents regarding screw-tightening protocols (n = 427).

and their protocols. Six hundred thirty clinicians had the opportunity to access the survey, with 428 choosing to participate. The response rate was 68%, which is considered very good.^{12,13}

The initial intent was to offer a written survey to clinicians attending in-person lectures specific to implant dentistry; however, due to in-person restrictions, the survey was later broadcast in a web-based form (GoToWebinar: <https://www.gotomeeting.com/webinar>), given during virtual lectures. This had an added advantage in allowing information to be accumulated from multiple countries.

Surveying a cohort group during a lecture has some advantages in that the groups were attending for specific knowledge for a subject of interest. The list of questions was limited to nine, as this was an initial insight into clinicians' attitudes, with information gleaned intended to be used in further surveys.

The most common device used, based on this survey, was the beam-type TLD. Dentists refer to TLDs somewhat descriptively with terms such as beam- and toggle-type, but they have been classified within the ISO 6789-1:2017 according to their function as either Type I or Type II.¹⁴ The beam-type TLD is considered a Type I “spring” hand torque tool.¹⁴ The term “spring” relates to it working on the concept of a beam-shaped elastic metal, which allows deflection. The torque applied during use is related to its single-load cantilever beam deflection providing a simple device with no moving parts. The toggle-type TLD is considered a Type II hand torque tool.¹⁴ It has moving parts and thus is impacted by cleaning and aging.^{15–17} The toggle-type TLD compares the applied torque to the output torque, usually via a toggle release system based on a frictional component that is often provided by a spiral spring mechanism. Unfortunately, because it uses spring compression, some confusion has resulted when describing this TLD. Some authors have incorrectly named this “spring-type,”¹⁸ when in reality it is a friction-based tool. It is the beam-type that works with an elastic or cantilever spring mechanism.

Routine TLD calibration was reported by only 6% of the respondents. This is a deviation from industrial standards, where it is mandatory for all TLDs as described by ISO 6789-2.¹⁹ The standard stipulates that all TLDs should be calibrated at 12 months or 5,000 cycles, whichever is first, or more frequently if overloaded, after repair, after improper handling, or if ambient conditions during usage or storage are exceeded. This is highly relative to the practice of dentistry, as the effects of cleaning and heat sterilization have been reported to negatively affect the performance of TLDs.^{16,17,20–27} When a TLD is out of calibration, it may result in overdelivering or underdelivering the recommended torque. This deviation has been noted in the literature with TLDs used in clinical practice.^{16,17}

Furthermore, the dental studies on allowable variation do not follow the requirements of ISO 6789-2, relating to maximum permissible variation in target torque.¹⁹ It should be in the order of $\pm 6\%$. Within dental studies on TLDs, there appears to be an arbitrary 10% variation assigned and accepted.^{20–25} An increase in variation from the industry standard of 6% to an arbitrary one of 10% can have an extreme effect on the screw mechanics. Generally, it is considered that most of the applied torque is used to overcome friction, and only about 10% is used to provide tension to the screw providing the preload.²⁶ Thus, a variation from the target that yields too little torque may not be sufficient to provide adequate preload of the screw, and too much torque could result in permanent plastic deformation of the screw.⁵

Calibration usually requires specialized equipment such as electronic torque-measuring devices. However, in some instances, TLD may be checked and sometimes calibrated in-office with easily accessed materials in a simple and economical manner.^{27–29}

Regarding the question of the three reading options from the beam-type TLD, the marker that is present on the middle of the beam is correct. If incorrectly used/read, it will overread the torque when the marker aligns with the lower edge of the beam, and conversely underread with the upper edge of the beam adjacent to the marker point. The beam dimension is also representative of a torque value; in other words, the diameter of the beam must be considered with the reading. Twenty-four percent had the beam at the trailing edge, signifying that greater than the target torque of 20 Ncm would be delivered. Of those that responded, 10% would be short of the target torque if the beam was placed at the leading edge. In the picture provided, the beam diameter represents approximately 5 Ncm from the trailing edge up to the leading edge in Fig 1, image (A). When actioned at lower torque values, it would be 17.5 Ncm to tighten a screw; if the beam is not in the center, then the error in readings could be ± 2.5 Ncm or 13% from the target value. This was the TLD most clinicians possessed, and it accounted for 378 devices from question 1, whereas 391 responded to question 5. This may in part explain why a few did not get this answer correct. However, overall, 34% of clinicians chose the incorrect option.

Actioning speed does affect some TLDs. Because of the effects of inertia and friction on the working parts, the toggle-type device must be actioned in a controlled manner. ISO 6789¹⁴ makes a recommendation on speed of use of the toggle-type (Type II) wrench, recommending a minimum time period for application of torque values. Furthermore, it states a minimum time to increase the torque from 80% of the target value to a target of 0.5 seconds for devices providing < 10 Nm (1,000 Ncm). The dental literature has limited information on this aspect, with only two studies found.^{17,24} Neither of these recommend a minimum time to increase the torque from 80% of the target value to the target itself, but both of these studies did recommend using a “slower” speed. One suggests activation over 4 seconds¹⁷ and the other at 5.2 Ncm/s.²⁴ No other studies appeared to factor in speed of activation as a variable. For the present survey, only 5% of clinicians recognized that speed does have an effect on the toggle-type wrench.

TLDs have multiple uses in implant dentistry, including surgical implant placement as well as screw tightening. The question allowed more than one answer, with 45% of respondents using the TLD to place dental implants and 41% reporting that they used a TLD when

finally restoring the implant. One might infer that some of the respondents may have been surgeons only, and not have been involved in restoring the implant. Healing abutments were tightened by 8% of the respondents using TLD. This has been advocated by some researchers as a way to reduce the risk of microbial contamination of the implant during the healing phase.³⁰ The study also reported that this could not adequately be achieved without the use of a TLD.³⁰

Screw-tightening protocols appear to vary greatly among the group, with differences in the number of torque-tightening events as well as time between successive tightening. The most frequently reported protocol for definitive abutment tightening was to torque to the required value, wait a few minutes, and then retighten. This has been reported in multiple studies in the literature,^{31–35} with a waiting period time of 10 minutes between two tightening events recommended by one source.³⁶ However, scrutinizing this article, it did not use a proper control group with two tightening events, and the sample size was low ($n = 2$) and underpowered. Studies evaluating time intervals between tightening have often assigned arbitrary times to allow for settling of components, which have shown that wait time between tightening makes no difference.^{37,38} The engineering texts also mention settling events, and there is no prescribed waiting period.⁵ However, they do indicate that multiple tightening events should be undertaken during the process to overcome friction due to screw thread and screw seat irregularities.^{5,26}

Screw loosening was observed less than once per year by 48% of respondents, with 33% indicating that they observed this at least three to four times each year. Factors that are associated with this complication would also relate to how frequently implant procedures were undertaken and how many patients were seen with implant restorations as well as the type of restoration. The literature reports a high incidence with single implant crowns and a much lower number with multi-unit restorations.⁶

The final question was designed to understand the general knowledge related to the mechanics of screw joints. “Preload” is a common term used when considering screw joint fasteners.^{5,26} The term has also been incorporated into the dental terminology.³⁹ If the term is understood, one would assume that the clinician understands the process inducing tension into the screw, creating a clamping force that holds the implant joint together. If this term is not well understood, it would suggest that the clinician is unaware that the screw should be tightened within its elastic limits.

Limitations of this survey include the clinical experience of those attending not being recorded as it

related to years in practice, specialist vs general practitioner, and whether the clinician placed implants, restored them, or performed both. The survey only inquired about definitive restorations; it may well be that clinicians also torque provisional restorations where implant manufacturers or clinical direction recommends this. Other limitations include survey respondents in general, where they may not report completely or accurately. The language may also have been a barrier to answering some questions, especially as it is not known how well the multinational group understood English. The clinical implications are that screw-loosening events can be reduced if dentistry follows industry-based standards and dentists improve their understanding of these procedures. Also, with surgical aspects, if the TLD is not calibrated and misread, the implant may not be anchored sufficiently, and failure may result. Given that TLD use and screw-tightening protocols should be universal across all industries, it appears that dental clinicians may require further training and education.

CONCLUSIONS

Within the limitations of this survey, the data suggest that dentistry does not follow universal industrial standards when working with screw fasteners and TLDs, specifically:

- The beam-type TLD is the most popular used for implant procedures, but one-third of clinicians may have been using this type of device incorrectly. The use of the toggle-type wrench is also misunderstood and may not be utilized correctly as recommended by ISO 6789.
- Most of the TLDs of the respondents were more than 1 year old, with only 6% of clinicians calibrating their TLD tools as stipulated by ISO 6789.
- A variety of implant abutment tightening protocols were embraced, many based on arbitrary waiting times between successive tightening.
- TLDs were most frequently used for surgical implant placement and securing the definitive abutment.
- Less than 10% observed no screw loosening, with one-third noting three to four occurrences a year or more.
- Only 14% of clinicians understood the terminology related to screw tightening.

ACKNOWLEDGMENTS

The authors reported no conflicts of interest related to this study.

REFERENCES

- Bickford JH. An Introduction to the Design and Behavior of Bolted Joints, ed 3. Oxford: Taylor and Francis Group, 1995:V.
- Shigley JE. Mechanical Engineering Design. New York: McGraw Hill, 1977: 24–32.
- Smith C. Nuts, Bolts, Fasteners, and Plumbing Handbook. St Paul: Motorbooks, 1990: 40.
- Bickford JH. An Introduction to the Design and Behavior of Bolted Joints, ed 3. Oxford: Taylor and Francis Group, 1995:527–564.
- Bickford JH. An Introduction to the Design and Behavior of Bolted Joints, ed 3. Oxford: Taylor and Francis Group, 1995:261–262.
- Goodacre BJ, Goodacre SE, Goodacre CJ. Prosthetic complications with implant prostheses (2001–2017). *Eur J Oral Implantol* 2018;11(suppl 1):s27–s36.
- Katsavochristou A, Koumoulis D. Incidence of abutment screw failure of single or splinted implant prostheses: A review and update on current clinical status. *J Oral Rehabil* 2019;46:776–786.
- Nithyapriya S, Ramesh AS, Kirubakaran A, Mani J, Raghunathan J. Systematic analysis of factors that cause loss of preload in dental implants. *J Indian Prosthodont Soc* 2018;18:189–195.
- Krishnan V, Thomas CT, Sabu I. Management of abutment screw loosening: Review of literature and report of a case. *J Indian Prosthodont Soc* 2014;14:208–214.
- Huang Y, Wang J. Mechanism of and factors associated with the loosening of the implant abutment screw: A review. *J Esthet Restor Dent* 2019;31:338–345.
- WMA Declaration of Helsinki—Ethical Principles for Medical Research Involving Human Subjects. <https://www.wma.net/policies-post/wma-declaration-of-helsinki-ethical-principles-for-medical-research-involving-human-subjects/>. Accessed 26 April 2020.
- McLeod CC, Klabunde CN, Willis GB, Stark D. Health care provider surveys in the United States, 2000–2010: A review. *Eval Health Prof* 2013;36:106–126.
- Dykema J, Jones NR, Piché T, Stevenson J. Surveying clinicians by web: Current issues in design and administration. *Eval Health Prof* 2013;36:352–381.
- ISO 6789-1:2017. Assembly tools for screws and nuts—Hand torque tools—Part 1: Requirements and methods for design conformance testing and quality conformance testing: Minimum requirements for declaration of conformance. Geneva: International Organization for Standardization, 2017.
- Saboury A, Sadr SJ, Fayaz A, Mahshid M. The effect of aging on the accuracy of new friction-style mechanical torque limiting devices for dental implants. *J Dent (Tehran)* 2013;10:41–50.
- Gutierrez J, Nicholls JI, Libman WJ, Butson TJ. Accuracy of the implant torque wrench following time in clinical service. *Int J Prosthodont* 1997;10:562–567.
- McCracken MS, Mitchell L, Hegde R, Mavalli MD. Variability of mechanical torque-limiting devices in clinical service at a US dental school. *J Prosthodont* 2010;19:20–24.
- Stroosnijder E, Gresnigt MM, Meisberger EW, Cune MS. Loss of accuracy of torque wrenches due to clinical use and cleaning procedure: Short communication. *Int J Prosthodont* 2016;29:253–255.
- ISO 6789-2:2017, Assembly tools for screws and nuts—Hand torque tools—Part 2: Requirements for calibration and determination of measurement uncertainty. Geneva: International Organization for Standardization, 2017.
- Sadr SJ, Fayyaz A, Mahshid M, Saboury A, Ansari G. Steam sterilization effect on the accuracy of friction-style mechanical torque limiting devices. *Indian J Dent Res* 2014;25:352–356.
- L'Homme-Langlois E, Yilmaz B, Chien HH, McGlumphy E. Accuracy of mechanical torque-limiting devices for dental implants. *J Prosthet Dent* 2015;114:524–528.
- Mahshid M, Saboury A, Fayaz A, Sadr SJ, Lampert F, Mir M. The effect of steam sterilization on the accuracy of spring-style mechanical torque devices for dental implants. *Clin Cosmet Investig Dent* 2012;4:29–35.
- Neugebauer J, Petermüller S, Scheer M, Happe A, Faber FJ, Zoeller JE. Comparison of design and torque measurements of various manual wrenches. *Int J Oral Maxillofac Implants* 2015;30:526–533.
- Standlee JP, Caputo AA, Chwu MY, Sun TT. Accuracy of mechanical torque-limiting devices for implants. *Int J Oral Maxillofac Implants* 2002;17:220–224.
- Yilmaz B, L'Homme-Langlois E, Beck FM, McGlumphy E. Accuracy of mechanical torque-limiting devices for dental implants after clinical service. *J Prosthet Dent* 2015;114:378–382.
- Bickford JH. An Introduction to the Design and Behavior of Bolted Joints. Oxford: Taylor and Francis Group, 1995: 179.
- Wadhvani CPK, O'Brien RT, Rosen PS, Chung KH. A technique to validate the accuracy of a beam-type mechanical torque limiting device. *J Prosthet Dent* 2020;124:647–652.
- 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* 2020;123:403–407.
- O'Brien R, Wadhvani CPK, Rosen PS, Chung KH. Validating implant torque limiting devices with a customized tool: A dental technique. *J Prosthet Dent* 2021;125:407–410.
- Bousquet P, Bennasar IC, Tramini P, Jacquemot M, Cuisinier F. Tightening of healing abutments: Influence of torque on bacterial proliferation risk, an in vitro investigation. *Biomed Tech (Berl)* 2014;59:495–500.
- Kim KS, Lim YJ, Kim MJ, et al. Variation in the total lengths of abutment/implant assemblies generated with a function of applied tightening torque in external and internal implant-abutment connection. *Clin Oral Implants Res* 2011;22:834–839.
- Kim KS, Lim YJ. Axial displacements and removal torque changes of five different implant-abutment connections under static vertical loading. *Materials (Basel)* 2020;13:699.
- Sammour SR, Maamoun El-Sheikh M, Aly El-Gendy A. Effect of implant abutment connection designs, and implant diameters on screw loosening before and after cyclic loading: In-vitro study. *Dent Mater* 2019;35:e265–e271.
- Varvara G, Sinjari B, Caputi S, Scarano A, Piattelli M. The relationship between time of retightening and preload loss of abutment screws for two different implant designs: An in vitro study. *J Oral Implantol* 2020;46:13–17.
- 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;9:213–221.
- Siamos G, Winkler S, Boberick KG. Relationship between implant preload and screw loosening on implant-supported prostheses. *J Oral Implantol* 2002;28:67–73.
- Bacchi A, Regalin A, Bhering CL, Alessandretti R, Spazzini AO. Loosening torque of universal abutment screws after cyclic loading: Influence of tightening technique and screw coating. *J Adv Prosthodont* 2015;7:375–379.
- Alnasser AH, Wadhvani CPK, Schoenbaum TR, Kattadiyil MT. Evaluation of implant abutment screw tightening protocols on reverse tightening values: An in vitro study. *J Prosthet Dent* 2021;125:486–490.
- The Glossary of Prosthodontic Terms: Ninth edition. *J Prosthet Dent* 2017;117:e1–e105.