Accuracy of Mechanical Torque-Limiting Devices for Dental Implants

Thesis

Presented in Partial Fulfillment of the Requirements for the Degree Master of Science in
the Graduate School of The Ohio State University

By

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2014

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Abstract

Statement of Problem: A common complication in implant dentistry is the unintentional implant screw loosening. The critical factor in the prevention of screw loosening is the delivery of the appropriate target torque value. Mechanical torque-limiting devices (MTLD) are the most frequently recommended devices by the implant manufacturers to deliver the target torque value to the screw. Two types of MTLDs are available: friction-style and spring-style. Limited information is available regarding the influence of device type, sterilization and clinical use on the accuracy of MTLDs.

Purpose: The purpose of this study was to determine the accuracy of MTLDs when they are brand new, after sterilization and after clinical use.

Materials and Methods: This study was divided in three parts. In Part I, five MTLDs from six different dental implant manufacturers (Astra Tech/Dentsply, Zimmer Dental, Biohorizons, Biomet 3i, Straumann (ITI) and Nobel Biocare) (n=5 per manufacturer) were selected to determine their accuracy in delivering target torque values preset by their manufacturers. All torque-limiting devices were new and there were three manufacturers for the friction-style and three manufacturers for the spring-style. The procedure of target torque measurement was performed 10 times for each device and a digital torque gauge (Chatillon Model DFS2-R-ND) was used to record the

measurements. In part II, all MTLDs (N=30) used in Part I were sterilized following manufacturers' recommendations. The sterilization procedure was repeated 100 times and all MTLDs were retested as described in Part I. In part III, 27 MTLDs which have been in clinical service at the Ohio State University College of Dentistry were collected. 13 were friction-style and 14 were spring-style. A total of 6 different dental implant companies were represented (Astra Tech, Zimmer Dental, Biomet 3i, Straumann, Nobel Biocare and Thommen Medical) and all MTLDs had been in use for at least 6 months without being recalibrated and were all tested as described in Part I to determine their accuracy in delivering target torque values. Statistical analysis used nonparametric tests to determine the accuracy of the MTLDs in delivering target torque values and Bonferroni post hoc tests were used to assess pairwise comparisons.

Results: In Part I, friction-style and spring-style MTLDs median absolute difference between delivered torque values and target torque values were not significantly different ($P>0.05$). In part II, there was a significant difference within the spring-style MTLDs before and after sterilization ($P<0.05$). In part III, after clinical service, spring-style MTLDs were significantly more accurate than friction-style MTLDs ($P<0.05$).

Conclusions: Within the limitations of this study, it can be concluded that there is no difference between the accuracy of new friction-style MTLDs and new spring-style MTLDs. After 100 cycles of steam sterilization, spring-style MTLDs were significantly more accurate than friction-style MTLDs. However, all MTLDs fell within $\pm 10\%$ of the

target torque value before and after sterilization. In clinical service, spring-style MTLDs were more accurate than friction-style MTLDs. Some friction-style MTLDs delivered high torque values and did not fall within $\pm 10\%$ of the target torque value.

Dedication

This thesis is dedicated to my wonderful husband Nicholas, the love of my life and to my parents for their endless love, encouragement and support.

Acknowledgments

I would like to express my very great appreciation my committee members, Dr. Burak Yilmaz, Dr. Edwin McGlumphy and Dr. Ben Chien for sharing their knowledge and for their useful and constructive recommendations. I wish to acknowledge the help and assistance of Dr. Frank Beck in the development and the interpretation of the statistics of this study. Finally, I would like to offer my special thanks to Terri Pierce and Victoria Rexford for their every day support.

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Chapter 1: Introduction

For patients missing natural dentition, either partially dentulous or edentulous, the use of osseointegrated implants have been a successful long-term solution. Implant restorations are not problem-free. Several implant complications can be seen as: fracture of prosthesis resin, fracture of frameworks, wear of denture teeth and veneer material chipping.¹ Additionally, a common complication in implant dentistry is the unintentional implant screw loosening.²⁻⁵ Loose screws may lead to further complications like screw fracture, non-retrievable fragments and, in some cases, removal of implants.⁵ To provide optimal treatment with implant restorations, it is essential to understand the screw mechanics and why screws come loose. Multiple causes have been attributed to screw loosening: inadequate torque delivery⁶, embedment relaxation⁶, inadequate prosthesis fit, poorly machined components, excessive loading, screw design and restoration design.^{7,8} When two parts are tightened together by a screw, like the abutment and the implant or the crown and the implant, this unit is referred to as a *screw joint*.⁷ The forces attempting to separate the parts of the screw joint are called *joint separating forces* and the forces keeping the components together are called the *clamping force*.⁷ Screw loosening will happen when the joint separating forces are greater than the clamping force. Then, to prevent screw losing, clamping force should be maximized and the joint separating forces should be minimized. Tightening the screw produces the initial clamping force and the clamp load is proportional to the tightening torque. When the torque is applied to the

screw, friction between opposing threads increase, elongation of the screw occurs, producing a clamping force between the screw head and its seat.⁹ The force or tension developed within the screw created by the applied torque is called the *preload* and is equal in magnitude to the clamping force.⁷ Undertorquing the screws can lead to screw loosening, fracture of the screw and failure of the screw and possibly failure of the prosthesis.^{7,10,11} On the other hand, overtorquing the screw can produce a screw fracture by creating a permanent deformation to the screw shank, stripping of the screw threads, screw loosening and fracture of the components.^{7,10,11} The important factor in the prevention of screw loosening and for providing the appropriate preload to the screw joint is the delivery of the appropriate torque or target value. Preload torque recommendations vary from a range of 10 to 35 Ncm and are determined by different factors: screw material, applied torque, screw head design, abutment material, abutment surface and lubricant.^{7,12} Theoretically, the maximal preload is generated in the screw joint just before torsional fracture of the screw occurs. Subsequently, a safety margin is established to minimize the risk of screw fracture during maximizing the preload.⁷

Delivering the accurate torque can be done with the use of torque-limiting devices that can consistently deliver the desired torque.¹³ Handheld, mechanical and electronic torque-limiting devices are available by manufacturer for operators to apply the adequate torque to the screw joint and tightening screws.^{14,15} Handheld screw drivers can present as different designs depending of their manufacturer. They are easy to use, less expensive than electronic or mechanical torque-limiting devices and offer great tactile sensitivity.¹⁴

Dentists commonly use them to initiate the tightening process, however, it was suggested in a previous published article that they should not be for final gold screw tightening, because they deliver insufficient preload to the screw joint.¹⁶ Also, they can be limited in the amount of torque that they can produce and have been shown to be inconsistent with inter-operator and intra-operator variability.¹⁷ Jaarda and Razzoog showed that operators who had little experience were not able to provide the recommended torque and experienced operators tended to generate more than the recommended amount.¹⁸ On the other hand, Kanawati et al. measured the ability of dentists and dental students to hand torque dental implant components and this study did not report significant differences between the two groups and showed a varying degree of hand torquing abilities using handheld screw drivers.¹⁹ Dellenges and Tebrock measured the amount of torque that can be applied to the heads of implants screw using handheld screw drivers in a simulated clinical setting and their result showed that 10 Ncm gold screw can be adequately tightened with hand held screw drivers, however, larger screws which required more than 10 Ncm of torque can not be tightened manually.²⁰ Hill et al. tested the ability of general dentists to generate implant abutment screw preload using handheld screw drivers in a limited access space simulating the mouth. Their results indicated that handheld screw drivers should not be used in the posterior areas of the mouth to establish sufficient preload forces for implant abutment screw and that dental experience did not significantly improve the ability to generate torque with a handheld screw driver.¹² Another study by Goheen et al. evaluated the ability of experienced operators to produce 32 Ncm of torque

with handheld screwdrivers and the data indicated that there was a wide variation in the ability of operators to perceive adequate torquing forces to implant components.²¹

For all the reasons cited above, calibrated mechanical torque-limiting devices are mandatory to produce proper torquing value.^{17,19,21} Results from some studies are in concert in validating the consistency of mechanical torque-limiting devices,^{10,11,14} but many confounding variables associated with sterilization^{22,23} aging¹⁵ and clinical use^{24, 25} were shown to affect the consistency and the accuracy of mechanical torque-limiting devices. Two studies evaluated the effect of sterilization on mechanical torque-limiting devices. Mahshid et al. evaluated the effect of steam sterilization on the accuracy of spring-style mechanical torque-limiting devices. They concluded that 100 cycles of steam sterilization did not affect the accuracy of Nobel Biocare and Straumann ITI mechanical torque-limiting devices, but did affect Biomet 3i torque-limiting devices with more than 10% difference from their target torque values.²² Dellinges and Curtis study showed that steam and chemiclave sterilization increased the range of torque values compared to data recorded before sterilization.²³ Another study did report that aging had an effect on the accuracy of friction-style mechanical torque-limiting devices.¹⁵

Electronic torque-limiting devices are also used for torque application and they consist of a latch-type dental handpiece and is a foot-activated rheostat. To deliver specific preset target torques, the driver is held in the latch of the handpiece.^{9,14} One study by Mitrani et al. evaluated the accuracy of electronic implant torque-limiting devices following time in

clinical use and their results suggested that accuracy did not significantly change over the 5-year period of clinical service.¹³ However, two other studies have demonstrated variation of torque accuracy of electronic torque-limiting devices for implants. Standlee and Caputo showed torque application errors varied from target values by 1% to 165%.⁹ Tan and Nicholls exposed that one electronic torque-limiting devices induce screw preloads that were 67% greater than the desired optimal preload of 300 N in the gold screw and concluded that electronic torque-limiting devices should be regularly recalibrated to ensure optimal output.¹⁶

Mechanical torque-limiting devices are the most frequently recommended devices by the implant manufacturers to deliver the target torque value to the screw during implant clinical procedures.²² Two types of mechanical torque-limiting devices are available on the market: friction-style (toggle-type) and spring-style (beam-type). The friction-style devices are hexagon wrenches with a handle-release mechanism preset by each manufacturer. The mechanism uses a ball detent system to disengage the lever arm at the desired torque preset by the manufacturer. The ball is compressed into a spherical receptor or the detent and a spring is holding the ball in place. When the target torque is applied, the ball moves out of the spherical receptor and the head of the torque flips to the side. This mechanism limits the torque applied to the screw (Figure 1).^{11,15}

Figure 1 Friction-style mechanical torque-limiting device

The spring-style torque-limiting devices, is a ratchet-type mechanism with a premarked incremental scale established by the manufacturer. The operator applies a force to the spring until the desired torque is achieved visually on the scale. The amount of torque can be varied by how far the beam is deflected so multiple torque values can be applied by using the same device (Figure 2).^{11,15}

Figure 2 Spring-style mechanical torque-limiting device

The accuracy of torque-limiting devices has utmost importance for the delivery of adequate amount of torque. However, torque-limiting devices are not problem-free. The manufacturers have recommended recalibration.

Vallee et al. (2008) reported that spring-type mechanical torque-limiting devices are significantly more accurate than those that use friction-style components.¹⁴ Incorrect torque can be delivered to the screw as a result of the age of the device, frequency of use, debris in the operating mechanism and corrosion of the spring in the handle of the torque device (due to steam sterilization) and can provide inappropriate torque values to screw, with errors as large as 455%.²⁴ McCracken et al. showed that torque-limiting devices should be activated slowly, over 4 seconds, when the operator is using a friction-type torque wrench.¹¹

The optimal torque value accuracy of mechanical torque-limiting devices should be within $\pm 10\%$ of target value.^{9,11,15,21,22,25,26} However, Biohorizons (Irvine, CA) specifies that their optimal torque value should be within 5% of the target value and for Straumann (Basel, Switzerland) torque-limiting devices, the precision of the displayed tightening torque is guaranteed ± 2 Ncm.^{27,28}

The specific aim of this study was to determine the accuracy of mechanical torque-limiting devices in delivering target torque values. Specifically, the study was divided into three parts: In Part I, the aim of the study was to compare the accuracy of friction-

style and spring-style mechanical torque-limiting devices for six dental implant manufacturers in delivering target torque values. In Part II, the aim of the study was to investigate effect of steam sterilization on the accuracy of friction-style and spring-style mechanical torque-limiting devices for the same six dental implant manufacturers. In Part III, the aim of this study was to measure the accuracy of mechanical torque-limiting devices for dental implants in clinical service at The Ohio State University College of Dentistry.

The first null hypothesis was that there will be no significant difference between the accuracy of friction-style mechanical torque-limiting devices and spring-style mechanical torque-limiting devices in achieving their target torque values. The second null hypothesis was that there will be no significant difference in the accuracy of the mechanical torque-limiting devices after 100 cycles of steam sterilization. Finally, the third null hypothesis was that there will be no significant difference between the accuracy of friction-style mechanical torque-limiting devices and spring-style mechanical torque-limiting devices to achieve their target torque values in clinical service at The Ohio State University.

Chapter 2: Materials and Methods

Part I

Torque-limiting devices from six different dental implant manufacturers were selected for this study to determine their accuracy in delivering target torque values preset by their manufacturers. The selected six dental implant companies were: Astra Tech/Dentsply (Mannheim, Germany), Zimmer Dental (Dauchingen, Germany), Biohorizons (Irvine, CA), Biomet 3i (Palm Beach Gardens, FL), Straumann (ITI) (Basel, Switzerland) and Nobel Biocare (Göteborg, Sweden). Two types of mechanical torque-limiting devices were used: Friction-style or toggle-type and spring-style or beam-type. All torque-limiting devices were new and there were three manufacturers for the friction-style (Astra Tech/Dentsply, Zimmer Dental and Biohorizons) and three manufacturers for the spring-style (Biomet 3i (3i), Straumann and Nobel Biocare). Five samples of each of the different implant manufacturers were tested for a total sample size of 30 mechanical torque-limiting devices. A power analysis was performed prior to the testing to determine the number of peak torque measurements necessary for each torque-limiting device. The target torque value in Ncm preset by the manufacturers is detailed in the Table 1.

Manufacturer	N	Target Torque Value (Ncm)
Friction-style		
Astra Tech (A1-A5)	5	25
Zimmer Dental (B6-B10)	5	30
Biohorizons (C11-C15)	5	30
Spring-style		
Biomet 3i (D16-D20)	5	35
Straumann (E21-E25)	5	35
Nobel Biocare (F26-F30)	5	35

Table 1 Mechanical torque-limiting devices tested with their target torque value (Ncm)

Each manufacturer was given a letter (A, B, C, D, E, F) and each torque-limiting device was randomly assigned a number and then labeled accordingly: Astra Tech (A1 to A5), Zimmer Dental (B6 to B10), Biohorizons (C11 to C15), Biomet 3i ((D16 to D20), Straumann (E21 to E25) and Nobel Biocare (F26 to F30) (Figure3).

Figure 3 Mechanical torque-limiting devices tested

The sequence for testing all the devices was randomized. A digital torque gauge (Chatillon Model DFS2-R-ND, Ametek, Largo, Fla) was used to measure the peak torque values and they were reported in Ncm (Figure 4).

Figure 4 Digital torque gauge

The digital torque gauge was new and calibrated by the manufacturer to be accurate within $\pm 0.25\%$ of the full scale. For each mechanical torque-limiting device, the appropriate driver insert or screw driver was selected and was clamped in the 3-jaw chuck of the digital torque gauge (Figure 5).

Figure 5 Mechanical torque-limiting device and driver insert clamped in 3-jaw chuck of digital torque gauge

The driver insert or screw driver was connected to the mechanical torque-limiting device and the torque indicator on the gauge was set at zero. The torque gauge was fixed to a counter top with a vice to prevent movement and to improve stability (Figure 6).

Figure 6 The digital gauge fixed with a vice for stability

The operator used one hand to stabilize the driver and the other hand to apply the necessary force to the mechanical torque-limiting device. The operator applied the necessary force to the torque-limiting devices until friction-type devices released at the precalibrated torque value or until the spring-type devices flexed to the precalibrated limit

on the arm of the torque-limiting device. To be consistent, the reference point used with the spring-type devices was the middle of the line of the precalibrated torque value and the operator used dental loupes during the testing. Each torque device was tested by applying a force over a period of four seconds. The operator calibrated himself by practicing 100 repetitions on a mechanical torque-limiting device from each type of mechanism. The mechanical torque-limiting devices used for calibration were not part of this study. Before each measurement, the operator made one trial repetition to ensure the good function of the apparatus and installation. For each device, the peak torque value registered by the digital torque gauge was recorded and the operator was blinded from these values. This procedure was repeated ten times for each mechanical torque-limiting device. All torquing procedures and readings were performed by the same operator.

Part II

All mechanical torque-limiting devices (N=30) used in Part I was prepared for sterilization following the manufacturer recommendations.

Astra Tech recommendations: In preparation to sterilization, dry the parts and moderately lubricate the functional areas. Reassemble the wrench and operate the torque and ratchet mechanisms to check their functioning. Remove any traces of lubricant from the outer surface of the wrench. Wrap up the wrench prior to sterilization. In autoclave: follow sterilization cycles recommended by the manufacturer of the autoclave. We recommend the use of devices equipped with a vacuum pump to minimize the risk of air pockets forming.²⁹

Zimmer Dental recommendations: After use, disassemble the wrench by reducing the torque level until the wrench comes apart. Clean the parts under cool water with a soft brush until no residuals are visible. Ensure all lumens and internal cavities are thoroughly scrubbed. Flush with cool water. Clean the parts in an ultrasonic cleaning bath at a temperature of 40-50°C with enzymatic cleaning solution for 3 minutes. Dry parts with a lint free towel and the wrench head should be dried using sterile, compressed air. Cool down parts at room temperature. Marked areas should be slightly moistened with special care-oil for handpieces. Reassemble wrench. Place the wrench in appropriate packaging for sterilization.³⁰

Biohorizons recommendations: Before initial use and after each procedure, clean the Dynatorq Torque Wrench with a wet towel or disinfectant wipe. Rinse under warm tap water and wide dry. Before sterilization, spray an approved instrument lubricant into the opening at the back of the wrench. The Dynatorq Torque Wrench may be sterilized by steam autoclave. Sterilize for 20 minutes at 135°C (275°F), with the handle in the “broken” position. After sterilization, re-set the torque break in the handle, then manually “break” the torque again to ensure that the wrench is operating correctly.²⁷

Biomet 3i recommendations: Cleaning. Remove the adapter from the head. To remove the head of the wrench from the body, press the recessed area and gently pull the head. The three parts (adapter, head and body) are now ready for cleaning using water, a brush and an autoclave. Autoclave/steam gravity sterilize for 40 minutes at 132-135°C.³¹

Straumann recommendations: Instruments consisting of several parts should be dismantled before cleaning. Disinfect, clean, sterilize and store each component separately.²⁸

Nobel Biocare recommendations: Clean the parts thoroughly. Allow them to dry completely. Sterilize the instrument using a steam autoclave at 135°C for minimum of 5 minutes or according to recommendations from the manufacturer of the autoclave.³²

All torque-limiting devices were packaged in a sterilization envelope as recommended. They were sterilized following the manufacturer instructions and when there were no specifications, they were put through steam autoclave sterilizing cycle (Statim 2000, Toronto, Ontario, Canada) (Figure 7). The sterilization cycle of the Statim 2000 cassette autoclave occurred at 135°C for a sterilization time of 10 minutes and for a total cycle time of 14 minutes. Above mentioned recommendations were followed between each cycle for each system. The sterilization procedure was repeated 100 times^{22,23} and all mechanical torque-limiting devices were retested as described in Part I for 10 consecutive measurements at targeted torque value. The data obtained in Part I were compared to the results obtained after sterilization of Part II.

Figure 7: Statim 2000 Autoclave

Part III

Mechanical torque-limiting devices found in clinical service at the Ohio State University College of Dentistry were collected for the third part of the study. A total of twenty-seven torque-limiting devices were obtained from the Implant Clinic, the Faculty Practice clinic and the Graduate Prosthodontics clinic. Out of 27 torque-limiting devices, 13 were friction-style torque-limiting device and 14 were spring-style. A total of 6 different dental implant companies were represented: Astra Tech (a), Zimmer Dental (b) Biomet 3i (3i) (d), Straumann (e), Nobel Biocare (f) and Thommen Medical USA (g) (Cleveland, Ohio) (Table 2). All the torque-limiting devices had been in use for at least 6 months without being recalibrated and were all tested as described in Part I. The time which in the

mechanical torque-limiting device have been used, the frequency of use, the number of sterilization cycles and the number of recalibration since their purchase were not available.

Manufacturer	N	Target Torque Value (Ncm)
Friction-style		
Astra Tech/Dentsply (a)	6	25
Zimmer Dental (b)	7	30
Spring-style		
Biomet 3i (d)	3	35
Straumann (ITI) (e)	3	35
Nobel Biocare (f)	5	35
Thommen Medical (g)	3	35

Table 2 Mechanical torque-limiting devices tested in Part III

Statistical analyses were performed by using the statistical software (SAS Version 3 Institute Inc. Cary, NC, USA). Absolute differences (raw error values), median absolute, minimum and maximum data between the measured torque value and the target torque value were evaluated before and after sterilization. Also, the percentage deviation ($\text{Perved} = [\text{Absolute difference} / \text{target torque}] \times 100$) was calculated and compared with the target torque value preset by the manufacturers. The assumptions were to analyze the

study using parametric methods, specifically repeated-measures analysis of variance (ANOVA) with a type 1 error rate (α) of 5%, factorial analysis of variance with instrument status (new versus autoclaved), instruments type (friction-style versus spring-style) and manufacturer as the independent variables. The dependent variable was absolute difference between the target torque and the actual torque. One of the primary assumptions of this method was that the dependent variable was normally distributed. In this study, the data collected were not normally distributed. Consequently, the statistical analysis was conducted with nonparametric methods to assess the data. These methods do not require the assumption of normality.

Chapter 3: Results

Part I and Part II

The torque data were collected from the thirty mechanical torque-limiting devices from six different dental implant manufacturers to determine their accuracy in delivering target torque values (Table 3). Table 3 represents the descriptive summary data of mean, standard deviation, minimum and maximum absolute differences between the measured torque, and the targeted torque value for each manufacturer before and after sterilization. Also, the median absolute difference and the percentage deviation of the measured torque value from the targeted torque value are shown in this table.

Type	Status	Manufacturer	N	Median Ncm	Mean Ncm	SD Ncm	Min Ncm	Max Ncm	Perved %
Friction	New	Astratech (A)	50	0.57	1.10	1.48	0.06	7.76	2.28
Friction	New	Zimmer Dental (B)	50	0.71	0.94	0.73	0.06	2.66	2.37
Friction	New	Biohorizons (C)	50	1.33	1.23	0.48	0.04	2.20	4.43
Friction	New	ALL	150	0.91	1.09	0.99	0.04	7.76	
Friction	Auto	Astratech (A)	50	0.56	0.64	0.45	0.02	2.50	2.24
Friction	Auto	Zimmer Dental (B)	50	0.48	0.69	0.51	0.02	1.72	1.60
Friction	Auto	Biohorizons (C)	50	2.04	2.07	0.74	0.02	3.42	6.80
Friction	Auto	ALL	150	0.93	1.14	0.88	0.02	3.42	
Spring	New	Biomet 3i (D)	50	1.37	1.43	0.51	0.02	2.76	3.91
Spring	New	Straumann ITI (E)	50	0.38	0.53	0.51	0.00	1.84	1.09
Spring	New	Nobel Biocare (F)	50	0.89	1.10	0.83	0.02	3.46	2,54
Spring	New	ALL	150	0.97	1.02	0.73	0.00	3.46	
Spring	Auto	Biomet 3i (D)	50	1.06	1.01	0.57	0.06	1.98	1.69
Spring	Auto	Straumann ITI (E)	50	0.62	0.70	0.60	0.00	3.46	3.03
Spring	Auto	Nobel Biocare (F)	50	0.32	0.44	0.38	0.02	1.94	1.77
Spring	Auto	ALL	150	0.59	0.72	0.57	0.00	3.46	0.91

Table 3 Summary data for the accuracy measures of the six manufacturers before and after 100 sterilization cycles

Table 4 represents pairwise comparisons between status of the torque-limiting devices (new versus autoclaved) for the six different manufacturers. In order to adjust for multiple Wilcoxon matched-pairs signed ranks tests, a step-down Bonferroni method of Holm (X22) was used and P values were compared against the significance threshold ($\alpha=0.05$). According to this test, Biohorizons (B), Biomet 3i (D) and Nobel Biocare (F) torque-limiting devices did show significant difference after sterilization process.

Type	Manufacturer	Median New Ncm	Median Autoclaved Ncm	P
Friction-style	Astra Tech (A)	0.57	0.56	0.7884
Friction-style	Zimmer Dental (B)	0.71	0.48	0.3223
Friction-style	Biohorizons (C)	1.33	2.04	<.0001
Spring-style	Biomet 3i (D)	1.37	1.06	0.0049
Spring-style	Straumann ITI (E)	0.38	0.62	0.6358
Spring-style	Nobel Biocare (F)	0.89	0.32	<.0001

Table 4 Post hoc comparisons between status (new versus autoclaved) by manufacturer

Table 5 represents pairwise comparisons among the different group of mechanical torque-limiting device (friction-style new, friction-style autoclaved, spring-style new and spring-style autoclaved) done with multiple Mann-Whitney-Wilcoxon tests. The *P* values were compared against the significance threshold ($\alpha=0.05$). According to Table 5, friction-style autoclaved torques did show significant difference from the spring-style autoclaved torques ($P<0.05$). Additionally, there was a significant difference within the spring-style torque-limiting devices before and after sterilization ($P<0.05$).

Between type:					
	Median Ncm			Median Ncm	P
Spring-style autoclaved	0.59	VS	Friction-style autoclaved	0.93	0.0002
Spring-style new	0.97	VS	Friction-style new	9.91	0.8726
Within type:					
	Median Ncm			Median Ncm	P
Spring-style autoclaved	0.59	VS	Spring-style new	0.97	<.0001
Friction-style autoclaved	0.93	VS	Friction-style new	0,01	0.0921

Table 5 Post hoc comparisons by group

Table 6 represents pairwise comparisons among the different manufacturer of mechanical torque-limiting devices by group (friction-style new, friction-style autoclaved, spring-style new and spring-style autoclaved) done with multiple Mann-Whitney-Wilcoxon tests. The *P* values were compared against the significance threshold ($\alpha=0.05$). According to Table 6, among the friction-style torque-limiting devices, Astra Tech (A) and Zimmer Dental (B) torque-limiting devices were significantly different from the Biohorizons (C) torque-limiting devices before and after sterilization ($P<0.05$). Furthermore, all the spring-style torque-limiting devices were statistically different from each other before sterilization and after sterilization except Straumann (E) torque-limiting devices were not significantly different than Nobel Biocare (F) torque-limiting devices after sterilization.

Group	Comparison (Median Ncm)	<i>P</i>
Friction-style autoclaved	A (0.56) vs B (0.48)	1.0000
Friction-style new	A (0.57) vs B (0.71)	1.0000
Friction-style autoclaved	A (0.56) vs C (2.04)	<.0001
Friction-style new	A (0.57) vs C (1.33)	0.0122
Friction-style autoclaved	B (0.48) vs C (2.04)	<.0001
Friction-style new	B (0.71) vs C (1.33)	0.0344
Spring-style autoclaved	D (1.06) vs E (0.62)	0.0324
Spring-style new	D (1.37) vs E (0.38)	<.0001
Spring-style autoclaved	D (1.06) vs F (0.32)	<.0001
Spring-style new	D (1.37) vs F (0.89)	0.0127
Spring-style autoclaved	E (0.62) vs F (0.32)	0.0608
Spring-style new	E (0.38) vs F (0.89)	0.0013

Table 6 Post hoc comparisons between manufacturers by group

Part III

The torque data from the twenty-seven torque-limiting devices obtained from the Implant Clinic, the Faculty Practice clinic and the Graduate Prosthodontics clinic were collected in the third part of this study. Table 7 represents the descriptive summary data of mean, standard deviation, median, minimum and maximum differences between the measured torque, and the targeted torque value for each manufacturer. Also, the median absolute difference and the percentage deviation of the measured torque value from the targeted torque value are shown in this table. The median absolute difference value was used to make comparisons because the mean absolute difference may not accurately reflect central tendency due to skewing.

Manufacturer	Mean Ncm	SD Ncm	Median Ncm	Min Ncm	Max Ncm	Perdev (%)
Astratech (a)	3.46	5.40	1.39	0.10	22.40	5.56
Zimmer Dental (b)	3.19	2.66	2.57	0.18	14.08	8.57
ALL	3.31	4.14	1.74	0.10	22.40	
Biomet 3i (d)	0.64	0.44	0.64	0.08	1.62	1.83
Straumann (e)	1.23	0.71	1.10	0.02	2.76	3.14
Nobel Biocare (f)	0.80	0.57	0.69	0.06	2.46	1.97
Thommen medical (g)	0.75	0.61	0.54	0.00	2.62	1.54
ALL	0.85	0.62	0.72	0.00	2.76	

Table 7 Summary data for accuracy measurements of six different manufacturers

Table 8 represents pairwise comparisons among the six different manufacturers within each mechanical torque-limiting device type (friction-style and spring-style). Also, Table 8 displays pairwise comparisons between the six manufacturers. In order to adjust for multiple testing using a step-down Bonferroni method of Holm (X16), *P* values were

compared against the significance threshold ($\alpha=0.05$). According to this test, Astra Tech (a) torque-limiting devices did show significant difference from Zimmer Dental (b) torque-limiting devices ($P<0.05$). Biomet 3i (d) torque-limiting devices were statistically different from Straumann (e) ($P<0.05$). Finally, Biomet 3i (d) torque-limiting devices were not significantly different from Nobel Biocare (f) and Thommen Dental (g) torque-limiting devices ($P>0.05$). Additionally, Table 8 shows that spring-style torque-limiting devices are significantly different than friction-style torque-limiting devices regarding their accuracy.

Between type:			
Median Ncm		Median Ncm	<i>P</i>
Spring-style (0.72)	VS	Friction-style (1.74)	0.0000
Within type:			
Comparison			<i>P</i>
a (1.39)	VS	b (2.57)	0.0140
d (0.64)	VS	e (1.10)	0.0052
d (0.64)	VS	f (0.69)	1.0000
d (0.64)	VS	g (0.54)	1.0000
e (1.10)	VS	f (0.69)	0.0261
e (1.10)	VS	g (0.54)	0.0236
f (0.69)	VS	g (0.54)	1.0000

Table 8 Post hoc comparisons among six different manufacturers within and between each torque type

Chapter 4: Discussion

In this study, accuracy of mechanical torque-limiting devices for dental implants was evaluated in detail in three parts. In part I, the data support the acceptance of the first null hypothesis, as there was no significant difference between the accuracy of friction-style torque-limiting devices and spring-style torque-limiting devices in achieving their target torque values. In part II, the data supports the rejection of the second null hypothesis, as there was a significant difference between the accuracy of spring-style torque-limiting devices and friction-style torque-limiting devices after 100 cycles of steam sterilization. Finally, the third null hypothesis was rejected as there was a significant difference between the accuracy of friction-style mechanical torque-limiting devices and spring-style mechanical torque-limiting devices to achieve their target torque values in clinical service at The Ohio State University.

Part I

Vallee et al. evaluated the accuracy of friction-style and spring-style mechanical torque-limiting devices for dental implants. Within the limitations of their study, spring-style torque-limiting devices were significantly more accurate than friction-style torque-limiting devices.¹⁴ Also, Mahshid et al. demonstrated that before steam sterilization, all the tested spring-style mechanical torque-limiting devices stayed within $\pm 10\%$ of the target torque value.²² Our data supports the acceptance of the first null hypothesis, as

there was no significant difference between the accuracy of friction-style torque-limiting devices and spring-style torque-limiting devices in achieving their target torque values. Furthermore, Astra Tech (A) and Zimmer Dental (B) torque-limiting devices were significantly different from the Biohorizons (C) torque-limiting devices before and after sterilization ($P < 0.05$), meaning that Astra Tech (A) and Zimmer Dental (B) torque-limiting devices were significantly more accurate than torque-limiting devices from Biohorizons (C). Also, all the spring-style torque-limiting devices were statistically different from each other before sterilization and after sterilization except Straumann (E) torque-limiting devices were not significantly different than Nobel Biocare (F) torque-limiting devices after sterilization.

Part II

Two studies have evaluated the effect of sterilization on mechanical torque-limiting devices. Mahshid et al evaluated the effect of steam sterilization on the accuracy of spring-style mechanical torque-limiting devices. They concluded that 100 cycles of steam sterilization did not affect the accuracy Nobel Biocare and Straumann ITI mechanical torque-limiting devices, but did affect Biomet 3i torque-limiting devices with more than 10% difference from their target torque values.²² Dellinges and Curtis study showed that steam and chemiclave sterilization increased the range of torque values compared to data recorded before sterilization.²³ In this part of the study, the median applied torque of spring-style and friction-style torque-limiting devices were significantly different after 100 cycles of steam sterilization; spring-type torque-limiting devices are significantly

more accurate than friction-style devices in achieving their torque values after sterilization. The difference between the two types could be explained by the difference in the handling prior to sterilization. In the instructions for use of friction-style torque-limiting devices, the manufacturer recommends the use of lubricant in different moving parts, a procedure that is not recommended for spring-style torque-limiting devices. During the heating process of sterilization, the lubricant can congeal inside the friction-style torque-limiting devices, jamming the action and increasing the applied torque. Looking at each manufacturer separately, Biohorizons (C), Biomet 3i (D) and Nobel Biocare (F) torque-limiting devices did show significant difference after sterilization process. Biomet 3i (D) and Nobel Biocare (F) torque-limiting devices were closer to the target torque value and Biohorizons (C) torque-limiting devices were significantly less accurate after the sterilization process. These results were found to be interesting and may be considered as a manufacturing error. It could also be explained by an intra-operator experience. Even if there was a training phase to learn to adequately perform the procedure, the operator might have likely become more precise delivering the target torque value using spring-style MTLDs. When referring to the percentage deviation all the torque-limiting devices in Part I and Part II fall within $\pm 10\%$ of the target torque value preset by the manufacturers and the difference was not considered clinically relevant. After sterilization, Biohorizons torque-limiting devices did not fall within $\pm 5\%$ of the target value established by the company and for Straumann torque-limiting devices displayed torque values outside the ± 2 Ncm guaranteed by the manufacturer from the target torque values.

Part III

Four studies have evaluated the accuracy of mechanical torque-limiting devices for dental implant following time in clinical service. McCracken et al.¹¹ measured the variability of mechanical torque-limiting devices in clinical service at a US Dental School. They concluded that friction-style and spring-style torque-limiting devices were capable of producing accurate torque values but some friction-style torque-limiting devices delivered unacceptably high torque values. Gutierrez et al.,²⁴ evaluated 35 friction-style torque-limiting devices for their torque delivery accuracy and they collected data on the age since purchase and number of sterilization cycles. Their conclusions were that there was no correlation between the number of sterilizations or the age and torque delivered. Also, corrosion of the spring in friction-style torque-limiting devices can lead to excessively high torque values. Santos et al.²⁵ determined the accuracy of mechanical torque-limiting devices in delivering target torque values in dental offices in Brazil. They evaluated two torque values (20 and 32 Ncm) and found that when 20 Ncm of torque was used, 62.5% of measured values were accurate and for 32 Ncm, only 37.5% of these values were accurate. Finally, Standlee and Caputo²⁶ evaluated the accuracy of Nobel Biocare, Straumann ITI and DynaTorq ITL mechanical torque-limiting devices and concluded that the mean torque values of Straumann ITI and DynaTorq ITL were within $\pm 10\%$ of their target torque values and that Nobel Biocare exhibited the largest variation for target torque values.

This part of the study was performed to determine if a specific group of torque-limiting devices in use at The Ohio State University clinics applied a clinically suitable torque. For the purpose of this study, torque values within $\pm 10\%$ of their target torque value were defined as the level of accuracy of tested torque-limiting devices.

In this part of the study, the median applied torque of spring-style and friction-style torque-limiting devices were significantly different; spring-type torque-limiting devices are significantly more accurate than friction-style devices in achieving their torque values. It should be noted that the range of values produced by the friction-style torque-limiting devices were considerably greater than that of the spring-style torque-limiting devices (22.50 Ncm vs. 2.76 Ncm). The general effect was caused in large part by two friction-style torque-limiting devices that produced high values, one from Astra Tech (a) and one from Zimmer Dental (b). In friction-style torque-limiting devices, corrosion of the spring can lead to excessively high torque delivery because a lack of spring flexibility. These devices were dismantled but no spring corrosion was found. Both torque-limiting devices were removed from clinical service after the testing for calibration. In the friction-style, Astra Tech (a) torque-limiting devices were significantly more accurate than Zimmer Dental (b) torque-limiting devices. In the spring-style, Biomet 3i (d) torque-limiting devices were significantly more accurate than Straumann (e) torque-limiting devices. Also, Straumann (e) torque-limiting devices were significantly more accurate than Nobel Biocare (f) and Thommen Medical (g) torque-limiting devices. Eventhough, spring-style torque-limiting devices were more accurate

than friction-style torque-limiting devices, all torque-limiting devices except for the two above mentioned fell within $\pm 10\%$ of the target torque value preset by the manufacturers and the difference was not considered clinically relevant.

The results of this study data suggest that steam sterilization and clinical use of torque-limiting devices in an institutional environment, like The Ohio State University, may be associated with an increase in torque value from the target torque value preset by the manufacturer. This may be because the heating process congeals the lubricant inside the friction-style torque-limiting devices, jamming the action and increasing the applied torque.¹¹ In private practice setting, more care may be exerted over strict protocols for sterilizing torque-limiting devices, which is more difficult in an institution with multiple residents, clinicians and staff members.¹¹ Generally, manufacturers recommend sterilizing the device in the broken position of the head (for the friction-style) with the use of an approved lubricant between each use.¹¹ The torque-limiting devices tested in this study were taken from three different clinics at The Ohio State University College of Dentistry and those clinics do not have the same protocol for sterilization. In addition, those clinic protocols do not exactly follow the manufacturers' recommendations. The results of the part II of this study seems to be in line with the results obtained from the Part III which reflects clinical settings. Considering that the results obtained in part II and part III were similar regarding the accuracy of mechanical torque-limiting devices within the type, it can be concluded that the sterilization protocol followed in The Ohio State University College of Dentistry clinics did not have an influence on the accuracy

outcome of MTLDs. The results of this study will not apply to every clinical situation, as too many confounding variables associated with sterilization, maintenance, calibration and use exist. Unfortunately, the time torque-limiting device have been used, the frequency of use, the number of sterilization cycles, the sterilization protocol and the number of recalibration and since their purchase were not available for the test devices in Part III of this project.

As explained by McCracken et al., another factor that can influence the results obtained is the mode of action of spring-style and friction-style torque-limiting devices which is uniquely different. The spring-style torque-limiting device applies the pre-calibrated torque value to the screw by using a flexible metal arm. The torque applied depends on the flexibility of this arm and the distance it is pulled away from the body. In contrast, friction-style torque-limiting devices contain multiple moving parts and mechanical moving connections, including a spring and a ball. The literature reports that these parts can become corroded, leading to excessively high torque delivery resulting from stiffness and lack of flexibility.¹¹

Some critiques can be made regarding this study. The number of sample of torque-limiting devices for each different manufacture was relatively small (N=5) and this was due to financial limitations. Also, all MTLDs, (except the one from Biohorizons) can deliver different level of torque values. This study was limited to only one target torque value for each device but could be expanded to different level target torque value to

evaluate if the accuracy of mechanical torque-limiting devices is dependent of the level of torque value.

One of the limitations of part II of this in vitro study was that the mechanical torque-limiting devices are not exposed to aging procedure (multiple applications of torque over a period of time). Also, potential sources of error were introduced in this study and would include the intra-operator error. The mechanism of friction-style torque-limiting devices limits the operator to the preset torque value. When the desired torque is applied, the head of the torque flips to the side and limit the torque applied by the operator. However, with the mechanism of spring-style torque-limiting devices, the operator has to apply a force to the spring until the desired torque is achieved visually on the scale. This operation is sensitive to manual dexterity and is very subjective to the operator. The second potential source of error is introduced in the experiment would by the accuracy of the digital torque gauge itself. The digital torque gauge was calibrated by the manufacturer to be accurate within $\pm 0.25\%$ of the full scale and was verified after the study. With a calibration accuracy of $\pm 0.25\%$, an error of 0.075 Ncm could be expected on a 30 Ncm measurement. However, this error is small and would have been the same for all the different torque-limiting devices. The unfavorable results obtained with Biohorizons torque-limiting devices led the authors investigate potential reasons for this outcome. When the manufacturer information for MTLDs were looked up in detail, it was observed that Zimmer and Biohorizons MTLDs were manufactured by outside

companies and this fact may have an influence on the manufacturing precision and control of the MTLDS.

Also, in this study, the assumptions were to analyze the study using parametric methods, specifically repeated-measures analysis of variance (ANOVA) with a type 1 error rate (α) of 5%, factorial analysis of variance. One of the primary assumptions of this method was that the dependent variable was normally distributed. In this study, the data collected were not normally distributed. Consequently, the statistical analysis was conducted with nonparametric methods to assess the data. These methods do not require the assumption of normality. The major disadvantage is a loss of statistical power; however, because the sample size was relatively large, it helps to compensate for the loss of power. Correspondingly, with nonparametric tests, the median absolute difference value has to be used to make comparisons because the mean absolute difference may not accurately reflect central tendency due to skewing.

Future research should be designed to introduce mechanical torque-limiting devices in clinical service, but with a control of the confounding variables such as sterilization (number of cycles, and sterilization protocols), aging (frequency of clinical use) and maintenance (number of calibration). Also, a similar study could be done with different methods of sterilization (autoclave versus chemiclave). With the consideration of the independent variables and the combined effect of sterilization and aging, guidelines for calibration for mechanical torque-limiting devices could be developed.

Chapter 5: Conclusions

Within the limitations of this in vitro study, following of conclusions were drawn:

Part I

1. There was no significant difference between the accuracy of new friction-style torque-limiting devices and new spring-style torque-limiting devices in achieving their target torque values.
2. Astra Tech (A) and Zimmer Dental (B) friction-style torque-limiting devices from this study were significantly more accurate than torque-limiting devices from Biohorizons (C) torque-limiting devices from this study ($P<0.05$), however, all the torque-limiting devices in Part I fell within $\pm 10\%$ of the target torque value preset by the manufacturers and the difference was not considered clinically relevant.

Part II

1. Spring-style torque-limiting devices were significantly more accurate than friction-style torque-limiting devices from this study after 100 cycles of steam sterilization ($P<0.05$).
2. After 100 cycles of steam sterilization, the data obtained for Biomet 3i (D) and Nobel Biocare (F) torque-limiting devices were closer to the target torque value.

3. Biohorizons (C) torque-limiting devices from this study were significantly less accurate after the sterilization process ($P<0.05$).
4. All torque-limiting devices in Part II fell within $\pm 10\%$ of the target torque value preset by the manufacturers and the difference was not considered clinically relevant.

Part III

1. Spring-style torque-limiting devices were more accurate than friction-style torque-limiting devices tested ($P<0.05$), however, all the torque-limiting devices except for two samples were within $\pm 10\%$ of the target torque value preset by the manufacturers.
2. Torque-limiting devices should be checked and calibrated according to the instructions of the manufacturer.

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Appendix A: Tables

Type	Status	Manufacturer	Label	Target Torque Value (NCm)	Delivered Torque Value (Ncm)	ABSDIFF (Ncm)	PERDEV (%)
Friction	New	Astra Tech	1	25	24.48	0.52	2.12
Friction	New	Astra Tech	1	25	23.94	1.06	4.43
Friction	New	Astra Tech	1	25	23.76	1.24	5.22
Friction	New	Astra Tech	1	25	24.38	0.62	2.54
Friction	New	Astra Tech	1	25	24.12	0.88	3.65
Friction	New	Astra Tech	1	25	23.94	1.06	4.43
Friction	New	Astra Tech	1	25	23.84	1.16	4.87
Friction	New	Astra Tech	1	25	24.20	0.80	3.31
Friction	New	Astra Tech	1	25	23.88	1.12	4.69
Friction	New	Astra Tech	1	25	23.96	1.04	4.34
Friction	New	Astra Tech	2	25	24.60	0.40	1.63
Friction	New	Astra Tech	2	25	24.76	0.24	0.97
Friction	New	Astra Tech	2	25	24.82	0.18	0.73
Friction	New	Astra Tech	2	25	24.68	0.32	1.30
Friction	New	Astra Tech	2	25	24.60	0.40	1.63
Friction	New	Astra Tech	2	25	24.74	0.26	1.05
Friction	New	Astra Tech	2	25	24.26	0.74	3.05
Friction	New	Astra Tech	2	25	24.66	0.34	1.38
Friction	New	Astra Tech	2	25	24.72	0.28	1.13
Friction	New	Astra Tech	2	25	24.58	0.42	1.71
Friction	New	Astra Tech	3	25	24.56	0.44	1.79
Friction	New	Astra Tech	3	25	24.42	0.58	2.38
Friction	New	Astra Tech	3	25	24.44	0.56	2.29
Friction	New	Astra Tech	3	25	24.70	0.30	1.21
Friction	New	Astra Tech	3	25	25.14	0.14	0.56
Friction	New	Astra Tech	3	25	25.10	0.10	0.40
Friction	New	Astra Tech	3	25	24.66	0.34	1.38
Friction	New	Astra Tech	3	25	25.10	0.10	0.40
Friction	New	Astra Tech	3	25	26.86	1.86	6.92
Friction	New	Astra Tech	3	25	25.10	0.10	0.40
Friction	New	Astra Tech	4	25	27.96	2.96	10.59
Friction	New	Astra Tech	4	25	25.06	0.06	0.24
Friction	New	Astra Tech	4	25	27.14	2.14	7.89
Friction	New	Astra Tech	4	25	25.08	0.08	0.32
Friction	New	Astra Tech	4	25	26.52	1.52	5.73

Continued

Table 9 Raw data for the accuracy measures of the six manufacturers before and after 100 sterilization cycles (Part I and II)

Table 9 continued

Friction	New	Astra Tech	4	25	26.52	1.52	5.73
Friction	New	Astra Tech	4	25	27.66	2.66	9.62
Friction	New	Astra Tech	4	25	25.82	0.82	3.18
Friction	New	Astra Tech	4	25	32.76	7.76	23.69
Friction	New	Astra Tech	4	25	25.36	0.36	1.42
Friction	New	Astra Tech	4	25	27.50	2.50	9.09
Friction	New	Astra Tech	5	25	26.46	1.46	5.52
Friction	New	Astra Tech	5	25	25.82	0.82	3.18
Friction	New	Astra Tech	5	25	25.46	0.46	1.81
Friction	New	Astra Tech	5	25	25.48	0.48	1.88
Friction	New	Astra Tech	5	25	26.82	1.82	6.79
Friction	New	Astra Tech	5	25	25.08	0.08	0.32
Friction	New	Astra Tech	5	25	25.14	0.14	0.56
Friction	New	Astra Tech	5	25	26.74	1.74	6.51
Friction	New	Astra Tech	5	25	27.56	2.56	9.29
Friction	New	Astra Tech	5	25	31.76	6.76	21.28
Friction	New	Zimmer Dental	6	30	30.72	0.72	2.34
Friction	New	Zimmer Dental	6	30	30.60	0.60	1.96
Friction	New	Zimmer Dental	6	30	30.70	0.70	2.28
Friction	New	Zimmer Dental	6	30	32.66	2.66	8.14
Friction	New	Zimmer Dental	6	30	30.14	0.14	0.46
Friction	New	Zimmer Dental	6	30	30.44	0.44	1.45
Friction	New	Zimmer Dental	6	30	30.06	0.06	0.20
Friction	New	Zimmer Dental	6	30	31.56	1.56	4.94
Friction	New	Zimmer Dental	6	30	32.20	2.20	6.83
Friction	New	Zimmer Dental	6	30	30.34	0.34	1.12
Friction	New	Zimmer Dental	7	30	31.24	1.24	3.97
Friction	New	Zimmer Dental	7	30	31.28	1.28	4.09
Friction	New	Zimmer Dental	7	30	31.20	1.20	3.85
Friction	New	Zimmer Dental	7	30	31.68	1.68	5.30
Friction	New	Zimmer Dental	7	30	32.24	2.24	6.95
Friction	New	Zimmer Dental	7	30	32.48	2.48	7.64
Friction	New	Zimmer Dental	7	30	32.28	2.28	7.06
Friction	New	Zimmer Dental	7	30	31.70	1.70	5.36
Friction	New	Zimmer Dental	7	30	31.86	1.86	5.84
Friction	New	Zimmer Dental	7	30	30.98	0.98	3.16

Continued

Table 9 continued

Friction	New	Zimmer Dental	8	30	30.54	0.54	1.77
Friction	New	Zimmer Dental	8	30	30.22	0.22	0.73
Friction	New	Zimmer Dental	8	30	30.40	0.40	1.32
Friction	New	Zimmer Dental	8	30	29.54	0.46	1.56
Friction	New	Zimmer Dental	8	30	29.86	0.14	0.47
Friction	New	Zimmer Dental	8	30	29.68	0.32	1.08
Friction	New	Zimmer Dental	8	30	29.88	0.12	0.40
Friction	New	Zimmer Dental	8	30	29.82	0.18	0.60
Friction	New	Zimmer Dental	8	30	29.94	0.06	0.20
Friction	New	Zimmer Dental	8	30	30.20	0.20	0.66
Friction	New	Zimmer Dental	9	30	30.08	0.08	0.27
Friction	New	Zimmer Dental	9	30	30.38	0.38	1.25
Friction	New	Zimmer Dental	9	30	30.38	0.38	1.25
Friction	New	Zimmer Dental	9	30	30.44	0.44	1.45
Friction	New	Zimmer Dental	9	30	30.32	0.32	1.06
Friction	New	Zimmer Dental	9	30	30.32	0.32	1.06
Friction	New	Zimmer Dental	9	30	30.60	0.60	1.96
Friction	New	Zimmer Dental	9	30	30.36	0.36	1.19
Friction	New	Zimmer Dental	9	30	30.58	0.58	1.90
Friction	New	Zimmer Dental	9	30	30.92	0.92	2.98
Friction	New	Zimmer Dental	10	30	31.34	1.34	4.28
Friction	New	Zimmer Dental	10	30	31.18	1.18	3.78
Friction	New	Zimmer Dental	10	30	31.30	1.30	4.15
Friction	New	Zimmer Dental	10	30	31.24	1.24	3.97
Friction	New	Zimmer Dental	10	30	31.68	1.68	5.30
Friction	New	Zimmer Dental	10	30	31.26	1.26	4.03
Friction	New	Zimmer Dental	10	30	31.24	1.24	3.97
Friction	New	Zimmer Dental	10	30	32.22	2.22	6.89
Friction	New	Zimmer Dental	10	30	31.26	1.26	4.03
Friction	New	Zimmer Dental	10	30	30.74	0.74	2.41
Friction	New	Biohorizons	11	30	29.34	0.66	2.25
Friction	New	Biohorizons	11	30	29.12	0.88	3.02
Friction	New	Biohorizons	11	30	28.58	1.42	4.97
Friction	New	Biohorizons	11	30	28.38	1.62	5.71
Friction	New	Biohorizons	11	30	28.60	1.40	4.90
Friction	New	Biohorizons	11	30	29.10	0.90	3.09

Continued

Table 9 continued

Friction	New	Biohorizons	11	30	28.90	1.10	3.81
Friction	New	Biohorizons	11	30	28.74	1.26	4.38
Friction	New	Biohorizons	11	30	28.58	1.42	4.97
Friction	New	Biohorizons	11	30	28.62	1.38	4.82
Friction	New	Biohorizons	12	30	29.96	0.04	0.13
Friction	New	Biohorizons	12	30	29.54	0.46	1.56
Friction	New	Biohorizons	12	30	29.40	0.60	2.04
Friction	New	Biohorizons	12	30	29.18	0.82	2.81
Friction	New	Biohorizons	12	30	29.04	0.96	3.31
Friction	New	Biohorizons	12	30	28.98	1.02	3.52
Friction	New	Biohorizons	12	30	28.64	1.36	4.75
Friction	New	Biohorizons	12	30	28.66	1.34	4.68
Friction	New	Biohorizons	12	30	29.26	0.74	2.53
Friction	New	Biohorizons	12	30	29.52	0.48	1.63
Friction	New	Biohorizons	13	30	28.24	1.76	6.23
Friction	New	Biohorizons	13	30	28.38	1.62	5.71
Friction	New	Biohorizons	13	30	28.26	1.74	6.16
Friction	New	Biohorizons	13	30	28.16	1.84	6.53
Friction	New	Biohorizons	13	30	28.68	1.32	4.60
Friction	New	Biohorizons	13	30	27.96	2.04	7.30
Friction	New	Biohorizons	13	30	28.10	1.90	6.76
Friction	New	Biohorizons	13	30	28.30	1.70	6.01
Friction	New	Biohorizons	13	30	27.80	2.20	7.91
Friction	New	Biohorizons	13	30	28.06	1.94	6.91
Friction	New	Biohorizons	14	30	29.10	0.90	3.09
Friction	New	Biohorizons	14	30	29.26	0.74	2.53
Friction	New	Biohorizons	14	30	29.38	0.62	2.11
Friction	New	Biohorizons	14	30	28.90	1.10	3.81
Friction	New	Biohorizons	14	30	29.16	0.84	2.88
Friction	New	Biohorizons	14	30	29.26	0.74	2.53
Friction	New	Biohorizons	14	30	29.00	1.00	3.45
Friction	New	Biohorizons	14	30	29.40	0.60	2.04
Friction	New	Biohorizons	14	30	28.66	1.34	4.68
Friction	New	Biohorizons	14	30	29.52	0.48	1.63
Friction	New	Biohorizons	15	30	28.08	1.92	6.84
Friction	New	Biohorizons	15	30	28.48	1.52	5.34

Continued

Table 9 continued

Friction	New	Biohorizons	15	30	28.78	1.22	4.24
Friction	New	Biohorizons	15	30	28.42	1.58	5.56
Friction	New	Biohorizons	15	30	28.56	1.44	5.04
Friction	New	Biohorizons	15	30	28.26	1.74	6.16
Friction	New	Biohorizons	15	30	28.44	1.56	5.49
Friction	New	Biohorizons	15	30	28.78	1.22	4.24
Friction	New	Biohorizons	15	30	28.64	1.36	4.75
Friction	New	Biohorizons	15	30	28.58	1.42	4.97
Spring	New	Biomet 3i	16	35	36.18	1.18	3.26
Spring	New	Biomet 3i	16	35	36.52	1.52	4.16
Spring	New	Biomet 3i	16	35	36.98	1.98	5.35
Spring	New	Biomet 3i	16	35	36.56	1.56	4.27
Spring	New	Biomet 3i	16	35	37.48	2.48	6.62
Spring	New	Biomet 3i	16	35	36.90	1.90	5.15
Spring	New	Biomet 3i	16	35	36.34	1.34	3.69
Spring	New	Biomet 3i	16	35	34.98	0.02	0.06
Spring	New	Biomet 3i	16	35	37.10	2.10	5.66
Spring	New	Biomet 3i	16	35	35.50	0.50	1.41
Spring	New	Biomet 3i	17	35	36.34	1.34	3.69
Spring	New	Biomet 3i	17	35	36.32	1.32	3.63
Spring	New	Biomet 3i	17	35	37.76	2.76	7.31
Spring	New	Biomet 3i	17	35	36.64	1.64	4.48
Spring	New	Biomet 3i	17	35	36.36	1.36	3.74
Spring	New	Biomet 3i	17	35	36.38	1.38	3.79
Spring	New	Biomet 3i	17	35	36.34	1.34	3.69
Spring	New	Biomet 3i	17	35	36.40	1.40	3.85
Spring	New	Biomet 3i	17	35	36.50	1.50	4.11
Spring	New	Biomet 3i	17	35	36.72	1.72	4.68
Spring	New	Biomet 3i	18	35	36.52	1.52	4.16
Spring	New	Biomet 3i	18	35	36.34	1.34	3.69
Spring	New	Biomet 3i	18	35	37.02	2.02	5.46
Spring	New	Biomet 3i	18	35	36.56	1.56	4.27
Spring	New	Biomet 3i	18	35	36.88	1.88	5.10
Spring	New	Biomet 3i	18	35	36.30	1.30	3.58
Spring	New	Biomet 3i	18	35	36.02	1.02	2.83
Spring	New	Biomet 3i	18	35	36.72	1.72	4.68

Continued

Table 9 continued

Spring	New	Biomet 3i	18	35	37.10	2.10	5.66
Spring	New	Biomet 3i	18	35	36.26	1.26	3.47
Spring	New	Biomet 3i	19	35	36.00	1.00	2.78
Spring	New	Biomet 3i	19	35	36.76	1.76	4.79
Spring	New	Biomet 3i	19	35	35.78	0.78	2.18
Spring	New	Biomet 3i	19	35	36.30	1.30	3.58
Spring	New	Biomet 3i	19	35	36.38	1.38	3.79
Spring	New	Biomet 3i	19	35	36.76	1.76	4.79
Spring	New	Biomet 3i	19	35	36.18	1.18	3.26
Spring	New	Biomet 3i	19	35	36.08	1.08	2.99
Spring	New	Biomet 3i	19	35	35.24	0.24	0.68
Spring	New	Biomet 3i	19	35	36.96	1.96	5.30
Spring	New	Biomet 3i	20	35	36.08	1.08	2.99
Spring	New	Biomet 3i	20	35	36.02	1.02	2.83
Spring	New	Biomet 3i	20	35	36.24	1.24	3.42
Spring	New	Biomet 3i	20	35	36.94	1.94	5.25
Spring	New	Biomet 3i	20	35	36.04	1.04	2.89
Spring	New	Biomet 3i	20	35	36.24	1.24	3.42
Spring	New	Biomet 3i	20	35	36.68	1.68	4.58
Spring	New	Biomet 3i	20	35	37.08	2.08	5.61
Spring	New	Biomet 3i	20	35	35.64	0.64	1.80
Spring	New	Biomet 3i	20	35	36.26	1.26	3.47
Spring	New	Straumann	21	35	34.94	0.06	0.17
Spring	New	Straumann	21	35	34.26	0.74	2.16
Spring	New	Straumann	21	35	34.90	0.10	0.29
Spring	New	Straumann	21	35	34.84	0.16	0.46
Spring	New	Straumann	21	35	34.86	0.14	0.40
Spring	New	Straumann	21	35	35.16	0.16	0.46
Spring	New	Straumann	21	35	34.74	0.26	0.75
Spring	New	Straumann	21	35	35.08	0.08	0.23
Spring	New	Straumann	21	35	34.62	0.38	1.10
Spring	New	Straumann	21	35	34.62	0.38	1.10
Spring	New	Straumann	22	35	34.16	0.84	2.46
Spring	New	Straumann	22	35	34.92	0.08	0.23
Spring	New	Straumann	22	35	34.36	0.64	1.86
Spring	New	Straumann	22	35	34.54	0.46	1.33

Continued

Table 9 continued

Spring	New	Straumann	22	35	34.34	0.66	1.92
Spring	New	Straumann	22	35	35.02	0.02	0.06
Spring	New	Straumann	22	35	34.20	0.80	2.34
Spring	New	Straumann	22	35	34.18	0.82	2.40
Spring	New	Straumann	22	35	34.62	0.38	1.10
Spring	New	Straumann	22	35	34.26	0.74	2.16
Spring	New	Straumann	23	35	34.46	0.54	1.57
Spring	New	Straumann	23	35	34.50	0.50	1.45
Spring	New	Straumann	23	35	33.32	1.68	5.04
Spring	New	Straumann	23	35	34.52	0.48	1.39
Spring	New	Straumann	23	35	33.44	1.56	4.67
Spring	New	Straumann	23	35	33.50	1.50	4.48
Spring	New	Straumann	23	35	34.74	0.26	0.75
Spring	New	Straumann	23	35	35.18	0.18	0.51
Spring	New	Straumann	23	35	34.34	0.66	1.92
Spring	New	Straumann	23	35	34.62	0.38	1.10
Spring	New	Straumann	24	35	34.12	0.88	2.58
Spring	New	Straumann	24	35	35.10	0.10	0.28
Spring	New	Straumann	24	35	35.18	0.18	0.51
Spring	New	Straumann	24	35	35.14	0.14	0.40
Spring	New	Straumann	24	35	35.16	0.16	0.46
Spring	New	Straumann	24	35	35.04	0.04	0.11
Spring	New	Straumann	24	35	35.28	0.28	0.79
Spring	New	Straumann	24	35	35.00	0.00	0.00
Spring	New	Straumann	24	35	35.16	0.16	0.46
Spring	New	Straumann	24	35	34.56	0.44	1.27
Spring	New	Straumann	25	35	33.32	1.68	5.04
Spring	New	Straumann	25	35	34.88	0.12	0.34
Spring	New	Straumann	25	35	34.62	0.38	1.10
Spring	New	Straumann	25	35	33.34	1.66	4.98
Spring	New	Straumann	25	35	33.90	1.10	3.24
Spring	New	Straumann	25	35	33.16	1.84	5.55
Spring	New	Straumann	25	35	33.74	1.26	3.73
Spring	New	Straumann	25	35	34.42	0.58	1.69
Spring	New	Straumann	25	35	35.02	0.02	0.06
Spring	New	Straumann	25	35	34.98	0.02	0.06

Continued

Table 9 continued

Spring	New	Nobel Biocare	26	35	35.28	0.28	0.79
Spring	New	Nobel Biocare	26	35	37.94	2.94	7.75
Spring	New	Nobel Biocare	26	35	34.92	0.08	0.23
Spring	New	Nobel Biocare	26	35	36.06	1.06	2.94
Spring	New	Nobel Biocare	26	35	35.82	0.82	2.29
Spring	New	Nobel Biocare	26	35	36.72	1.72	4.68
Spring	New	Nobel Biocare	26	35	37.04	2.04	5.51
Spring	New	Nobel Biocare	26	35	36.08	1.08	2.99
Spring	New	Nobel Biocare	26	35	35.86	0.86	2.40
Spring	New	Nobel Biocare	26	35	36.04	1.04	2.89
Spring	New	Nobel Biocare	27	35	35.26	0.26	0.74
Spring	New	Nobel Biocare	27	35	35.86	0.86	2.40
Spring	New	Nobel Biocare	27	35	35.98	0.98	2.72
Spring	New	Nobel Biocare	27	35	35.96	0.96	2.67
Spring	New	Nobel Biocare	27	35	36.10	1.10	3.05
Spring	New	Nobel Biocare	27	35	35.92	0.92	2.56
Spring	New	Nobel Biocare	27	35	35.84	0.84	2.34
Spring	New	Nobel Biocare	27	35	36.08	1.08	2.99
Spring	New	Nobel Biocare	27	35	35.74	0.74	2.07
Spring	New	Nobel Biocare	27	35	35.26	0.26	0.74
Spring	New	Nobel Biocare	28	35	36.52	1.52	4.16
Spring	New	Nobel Biocare	28	35	37.06	2.06	5.56
Spring	New	Nobel Biocare	28	35	36.36	1.36	3.74
Spring	New	Nobel Biocare	28	35	37.36	2.36	6.32
Spring	New	Nobel Biocare	28	35	37.06	2.06	5.56
Spring	New	Nobel Biocare	28	35	37.38	2.38	6.37
Spring	New	Nobel Biocare	28	35	37.64	2.64	7.01
Spring	New	Nobel Biocare	28	35	38.46	3.46	9.00
Spring	New	Nobel Biocare	28	35	37.26	2.26	6.07
Spring	New	Nobel Biocare	28	35	37.62	2.62	6.96
Spring	New	Nobel Biocare	28	35	35.94	0.94	2.62
Spring	New	Nobel Biocare	29	35	34.80	0.20	0.57
Spring	New	Nobel Biocare	29	35	35.36	0.36	1.02
Spring	New	Nobel Biocare	29	35	34.92	0.08	0.23
Spring	New	Nobel Biocare	29	35	35.32	0.32	0.91
Spring	New	Nobel Biocare	29	35	35.46	0.46	1.30

Continued

Table 9 continued

Spring	New	Nobel Biocare	29	35	35.82	0.82	2.29
Spring	New	Nobel Biocare	29	35	36.62	1.62	4.42
Spring	New	Nobel Biocare	29	35	36.54	1.54	4.21
Spring	New	Nobel Biocare	29	35	35.76	0.76	2.13
Spring	New	Nobel Biocare	30	35	34.42	0.58	1.69
Spring	New	Nobel Biocare	30	35	35.66	0.66	1.85
Spring	New	Nobel Biocare	30	35	35.70	0.70	1.96
Spring	New	Nobel Biocare	30	35	35.32	0.32	0.91
Spring	New	Nobel Biocare	30	35	34.20	0.80	2.34
Spring	New	Nobel Biocare	30	35	34.98	0.02	0.06
Spring	New	Nobel Biocare	30	35	34.84	0.16	0.46
Spring	New	Nobel Biocare	30	35	36.00	1.00	2.78
Spring	New	Nobel Biocare	30	35	35.02	0.02	0.06
Spring	New	Nobel Biocare	30	35	34.14	0.86	2.52
Friction	Autoclaved	Astra Tech	1	25	23.94	1.06	4.43
Friction	Autoclaved	Astra Tech	1	25	23.98	1.02	4.25
Friction	Autoclaved	Astra Tech	1	25	24.34	0.66	2.71
Friction	Autoclaved	Astra Tech	1	25	23.42	1.58	6.75
Friction	Autoclaved	Astra Tech	1	25	24.04	0.96	3.99
Friction	Autoclaved	Astra Tech	1	25	23.58	1.42	6.02
Friction	Autoclaved	Astra Tech	1	25	23.82	1.18	4.95
Friction	Autoclaved	Astra Tech	1	25	24.62	0.38	1.54
Friction	Autoclaved	Astra Tech	1	25	24.12	0.88	3.65
Friction	Autoclaved	Astra Tech	1	25	24.26	0.74	3.05
Friction	Autoclaved	Astra Tech	2	25	24.64	0.36	1.46
Friction	Autoclaved	Astra Tech	2	25	24.44	0.56	2.29
Friction	Autoclaved	Astra Tech	2	25	24.58	0.42	1.71
Friction	Autoclaved	Astra Tech	2	25	24.48	0.52	2.12
Friction	Autoclaved	Astra Tech	2	25	24.80	0.20	0.81
Friction	Autoclaved	Astra Tech	2	25	24.96	0.04	0.16
Friction	Autoclaved	Astra Tech	2	25	24.58	0.42	1.71
Friction	Autoclaved	Astra Tech	2	25	24.92	0.08	0.32
Friction	Autoclaved	Astra Tech	2	25	24.66	0.34	1.38
Friction	Autoclaved	Astra Tech	2	25	24.34	0.66	2.71
Friction	Autoclaved	Astra Tech	3	25	24.66	0.34	1.38
Friction	Autoclaved	Astra Tech	3	25	24.66	0.34	1.38

Continued

Table 9 continued

Friction	Autoclaved	Astra Tech	3	25	24.38	0.62	2.54
Friction	Autoclaved	Astra Tech	3	25	25.70	0.70	2.72
Friction	Autoclaved	Astra Tech	3	25	23.94	1.06	4.43
Friction	Autoclaved	Astra Tech	3	25	26.34	1.34	5.09
Friction	Autoclaved	Astra Tech	3	25	24.24	0.76	3.14
Friction	Autoclaved	Astra Tech	3	25	24.64	0.36	1.46
Friction	Autoclaved	Astra Tech	3	25	25.84	0.84	3.25
Friction	Autoclaved	Astra Tech	3	25	24.36	0.64	2.63
Friction	Autoclaved	Astra Tech	4	25	25.14	0.14	0.56
Friction	Autoclaved	Astra Tech	4	25	24.98	0.02	0.08
Friction	Autoclaved	Astra Tech	4	25	24.96	0.04	0.16
Friction	Autoclaved	Astra Tech	4	25	27.50	2.50	9.09
Friction	Autoclaved	Astra Tech	4	25	25.54	0.54	2.11
Friction	Autoclaved	Astra Tech	4	25	25.50	0.50	1.96
Friction	Autoclaved	Astra Tech	4	25	24.70	0.30	1.21
Friction	Autoclaved	Astra Tech	4	25	24.76	0.24	0.97
Friction	Autoclaved	Astra Tech	4	25	24.74	0.26	1.05
Friction	Autoclaved	Astra Tech	4	25	24.62	0.38	1.54
Friction	Autoclaved	Astra Tech	5	25	25.90	0.90	3.47
Friction	Autoclaved	Astra Tech	5	25	24.60	0.40	1.63
Friction	Autoclaved	Astra Tech	5	25	24.44	0.56	2.29
Friction	Autoclaved	Astra Tech	5	25	25.92	0.92	3.55
Friction	Autoclaved	Astra Tech	5	25	25.26	0.26	1.03
Friction	Autoclaved	Astra Tech	5	25	23.94	1.06	4.43
Friction	Autoclaved	Astra Tech	5	25	24.26	0.74	3.05
Friction	Autoclaved	Astra Tech	5	25	24.24	0.76	3.14
Friction	Autoclaved	Astra Tech	5	25	24.32	0.68	2.80
Friction	Autoclaved	Astra Tech	5	25	24.54	0.46	1.87
Friction	Autoclaved	Zimmer Dental	6	30	30.20	0.20	0.66
Friction	Autoclaved	Zimmer Dental	6	30	30.48	0.48	1.57
Friction	Autoclaved	Zimmer Dental	6	30	30.46	0.46	1.51
Friction	Autoclaved	Zimmer Dental	6	30	29.98	0.02	0.07
Friction	Autoclaved	Zimmer Dental	6	30	30.08	0.08	0.27
Friction	Autoclaved	Zimmer Dental	6	30	29.72	0.28	0.94
Friction	Autoclaved	Zimmer Dental	6	30	30.16	0.16	0.53
Friction	Autoclaved	Zimmer Dental	6	30	29.84	0.16	0.54

Continued

Table 9 continued

Friction	Autoclaved	Zimmer Dental	6	30	30.38	0.38	1.25
Friction	Autoclaved	Zimmer Dental	6	30	29.92	0.08	0.27
Friction	Autoclaved	Zimmer Dental	7	30	31.62	1.62	5.12
Friction	Autoclaved	Zimmer Dental	7	30	31.36	1.36	4.34
Friction	Autoclaved	Zimmer Dental	7	30	31.34	1.34	4.28
Friction	Autoclaved	Zimmer Dental	7	30	31.26	1.26	4.03
Friction	Autoclaved	Zimmer Dental	7	30	31.12	1.12	3.60
Friction	Autoclaved	Zimmer Dental	7	30	31.08	1.08	3.47
Friction	Autoclaved	Zimmer Dental	7	30	31.04	1.04	3.35
Friction	Autoclaved	Zimmer Dental	7	30	30.92	0.92	2.98
Friction	Autoclaved	Zimmer Dental	7	30	30.88	0.88	2.85
Friction	Autoclaved	Zimmer Dental	7	30	30.48	0.48	1.57
Friction	Autoclaved	Zimmer Dental	8	30	31.12	1.12	3.60
Friction	Autoclaved	Zimmer Dental	8	30	29.82	0.18	0.60
Friction	Autoclaved	Zimmer Dental	8	30	29.78	0.22	0.74
Friction	Autoclaved	Zimmer Dental	8	30	30.72	0.72	2.34
Friction	Autoclaved	Zimmer Dental	8	30	30.34	0.34	1.12
Friction	Autoclaved	Zimmer Dental	8	30	30.78	0.78	2.53
Friction	Autoclaved	Zimmer Dental	8	30	29.96	0.04	0.13
Friction	Autoclaved	Zimmer Dental	8	30	30.20	0.20	0.66
Friction	Autoclaved	Zimmer Dental	8	30	30.28	0.28	0.92
Friction	Autoclaved	Zimmer Dental	8	30	30.40	0.40	1.32
Friction	Autoclaved	Zimmer Dental	9	30	30.20	0.20	0.66
Friction	Autoclaved	Zimmer Dental	9	30	30.48	0.48	1.57
Friction	Autoclaved	Zimmer Dental	9	30	30.04	0.04	0.13
Friction	Autoclaved	Zimmer Dental	9	30	30.40	0.40	1.32
Friction	Autoclaved	Zimmer Dental	9	30	30.82	0.82	2.66
Friction	Autoclaved	Zimmer Dental	9	30	30.74	0.74	2.41
Friction	Autoclaved	Zimmer Dental	9	30	30.32	0.32	1.06
Friction	Autoclaved	Zimmer Dental	9	30	30.04	0.04	0.13
Friction	Autoclaved	Zimmer Dental	9	30	30.30	0.30	0.99
Friction	Autoclaved	Zimmer Dental	9	30	30.34	0.34	1.12
Friction	Autoclaved	Zimmer Dental	10	30	31.72	1.72	5.42
Friction	Autoclaved	Zimmer Dental	10	30	31.58	1.58	5.00
Friction	Autoclaved	Zimmer Dental	10	30	31.28	1.28	4.09
Friction	Autoclaved	Zimmer Dental	10	30	31.30	1.30	4.15

Continued

Table 9 continued

Friction	Autoclaved	Zimmer Dental	10	30	31.38	1.38	4.40
Friction	Autoclaved	Zimmer Dental	10	30	31.20	1.20	3.85
Friction	Autoclaved	Zimmer Dental	10	30	31.16	1.16	3.72
Friction	Autoclaved	Zimmer Dental	10	30	30.94	0.94	3.04
Friction	Autoclaved	Zimmer Dental	10	30	31.16	1.16	3.72
Friction	Autoclaved	Zimmer Dental	10	30	31.52	1.52	4.82
Friction	Autoclaved	Biohorizons	11	30	28.50	1.50	5.26
Friction	Autoclaved	Biohorizons	11	30	28.30	1.70	6.01
Friction	Autoclaved	Biohorizons	11	30	27.72	2.28	8.23
Friction	Autoclaved	Biohorizons	11	30	28.20	1.80	6.38
Friction	Autoclaved	Biohorizons	11	30	27.94	2.06	7.37
Friction	Autoclaved	Biohorizons	11	30	28.50	1.50	5.26
Friction	Autoclaved	Biohorizons	11	30	28.24	1.76	6.23
Friction	Autoclaved	Biohorizons	11	30	28.10	1.90	6.76
Friction	Autoclaved	Biohorizons	11	30	28.00	2.00	7.14
Friction	Autoclaved	Biohorizons	11	30	29.00	1.00	3.45
Friction	Autoclaved	Biohorizons	12	30	27.80	2.20	7.91
Friction	Autoclaved	Biohorizons	12	30	28.24	1.76	6.23
Friction	Autoclaved	Biohorizons	12	30	27.66	2.34	8.46
Friction	Autoclaved	Biohorizons	12	30	27.96	2.04	7.30
Friction	Autoclaved	Biohorizons	12	30	27.90	2.10	7.53
Friction	Autoclaved	Biohorizons	12	30	27.88	2.12	7.60
Friction	Autoclaved	Biohorizons	12	30	27.76	2.24	8.07
Friction	Autoclaved	Biohorizons	12	30	27.50	2.50	9.09
Friction	Autoclaved	Biohorizons	12	30	27.84	2.16	7.76
Friction	Autoclaved	Biohorizons	12	30	28.18	1.82	6.46
Friction	Autoclaved	Biohorizons	13	30	29.12	0.88	3.02
Friction	Autoclaved	Biohorizons	13	30	28.32	1.68	5.93
Friction	Autoclaved	Biohorizons	13	30	28.32	1.68	5.93
Friction	Autoclaved	Biohorizons	13	30	29.78	0.22	0.74
Friction	Autoclaved	Biohorizons	13	30	28.46	1.54	5.41
Friction	Autoclaved	Biohorizons	13	30	28.54	1.46	5.12
Friction	Autoclaved	Biohorizons	13	30	27.50	2.50	9.09
Friction	Autoclaved	Biohorizons	13	30	28.14	1.86	6.61
Friction	Autoclaved	Biohorizons	13	30	29.98	0.02	0.07
Friction	Autoclaved	Biohorizons	13	30	27.32	2.68	9.81

Continued

Table 9 continued

Friction	Autoclaved	Biohorizons	14	30	27.82	2.18	7.84
Friction	Autoclaved	Biohorizons	14	30	27.92	2.08	7.45
Friction	Autoclaved	Biohorizons	14	30	28.20	1.80	6.38
Friction	Autoclaved	Biohorizons	14	30	27.96	2.04	7.30
Friction	Autoclaved	Biohorizons	14	30	28.20	1.80	6.38
Friction	Autoclaved	Biohorizons	14	30	27.98	2.02	7.22
Friction	Autoclaved	Biohorizons	14	30	28.50	1.50	5.26
Friction	Autoclaved	Biohorizons	14	30	28.70	1.30	4.53
Friction	Autoclaved	Biohorizons	14	30	27.74	2.26	8.15
Friction	Autoclaved	Biohorizons	14	30	28.38	1.62	5.71
Friction	Autoclaved	Biohorizons	15	30	27.16	2.84	10.46
Friction	Autoclaved	Biohorizons	15	30	26.92	3.08	11.44
Friction	Autoclaved	Biohorizons	15	30	26.82	3.18	11.86
Friction	Autoclaved	Biohorizons	15	30	26.86	3.14	11.69
Friction	Autoclaved	Biohorizons	15	30	26.92	3.08	11.44
Friction	Autoclaved	Biohorizons	15	30	26.62	3.38	12.70
Friction	Autoclaved	Biohorizons	15	30	26.98	3.02	11.19
Friction	Autoclaved	Biohorizons	15	30	26.58	3.42	12.87
Friction	Autoclaved	Biohorizons	15	30	26.76	3.24	12.11
Friction	Autoclaved	Biohorizons	15	30	26.74	3.26	12.19
Spring	Autoclaved	Biomet 3i	16	35	36.98	1.98	5.35
Spring	Autoclaved	Biomet 3i	16	35	36.08	1.08	2.99
Spring	Autoclaved	Biomet 3i	16	35	36.64	1.64	4.48
Spring	Autoclaved	Biomet 3i	16	35	36.52	1.52	4.16
Spring	Autoclaved	Biomet 3i	16	35	34.94	0.06	0.17
Spring	Autoclaved	Biomet 3i	16	35	36.70	1.70	4.63
Spring	Autoclaved	Biomet 3i	16	35	36.08	1.08	2.99
Spring	Autoclaved	Biomet 3i	16	35	35.54	0.54	1.52
Spring	Autoclaved	Biomet 3i	16	35	36.84	1.84	4.99
Spring	Autoclaved	Biomet 3i	16	35	36.64	1.64	4.48
Spring	Autoclaved	Biomet 3i	17	35	36.20	1.20	3.31
Spring	Autoclaved	Biomet 3i	17	35	36.32	1.32	3.63
Spring	Autoclaved	Biomet 3i	17	35	35.32	0.32	0.91
Spring	Autoclaved	Biomet 3i	17	35	35.22	0.22	0.62
Spring	Autoclaved	Biomet 3i	17	35	36.28	1.28	3.53
Spring	Autoclaved	Biomet 3i	17	35	35.78	0.78	2.18

Continued

Table 9 continued

Spring	Autoclaved	Biomet 3i	17	35	35.78	0.78	2.18
Spring	Autoclaved	Biomet 3i	17	35	36.60	1.60	4.37
Spring	Autoclaved	Biomet 3i	17	35	35.82	0.82	2.29
Spring	Autoclaved	Biomet 3i	17	35	35.40	0.40	1.13
Spring	Autoclaved	Biomet 3i	18	35	35.50	0.50	1.41
Spring	Autoclaved	Biomet 3i	18	35	36.10	1.10	3.05
Spring	Autoclaved	Biomet 3i	18	35	35.50	0.50	1.41
Spring	Autoclaved	Biomet 3i	18	35	36.10	1.10	3.05
Spring	Autoclaved	Biomet 3i	18	35	35.98	0.98	2.72
Spring	Autoclaved	Biomet 3i	18	35	36.92	1.92	5.20
Spring	Autoclaved	Biomet 3i	18	35	36.44	1.44	3.95
Spring	Autoclaved	Biomet 3i	18	35	36.74	1.74	4.74
Spring	Autoclaved	Biomet 3i	18	35	36.68	1.68	4.58
Spring	Autoclaved	Biomet 3i	18	35	36.20	1.20	3.31
Spring	Autoclaved	Biomet 3i	19	35	35.16	0.16	0.46
Spring	Autoclaved	Biomet 3i	19	35	35.60	0.60	1.69
Spring	Autoclaved	Biomet 3i	19	35	36.98	1.98	5.35
Spring	Autoclaved	Biomet 3i	19	35	36.04	1.04	2.89
Spring	Autoclaved	Biomet 3i	19	35	35.12	0.12	0.34
Spring	Autoclaved	Biomet 3i	19	35	34.86	0.14	0.40
Spring	Autoclaved	Biomet 3i	19	35	34.76	0.24	0.69
Spring	Autoclaved	Biomet 3i	19	35	35.44	0.44	1.24
Spring	Autoclaved	Biomet 3i	19	35	35.56	0.56	1.57
Spring	Autoclaved	Biomet 3i	19	35	35.30	0.30	0.85
Spring	Autoclaved	Biomet 3i	20	35	35.70	0.70	1.96
Spring	Autoclaved	Biomet 3i	20	35	36.64	1.64	4.48
Spring	Autoclaved	Biomet 3i	20	35	36.52	1.52	4.16
Spring	Autoclaved	Biomet 3i	20	35	35.74	0.74	2.07
Spring	Autoclaved	Biomet 3i	20	35	36.44	1.44	3.95
Spring	Autoclaved	Biomet 3i	20	35	35.86	0.86	2.40
Spring	Autoclaved	Biomet 3i	20	35	36.46	1.46	4.00
Spring	Autoclaved	Biomet 3i	20	35	35.58	0.58	1.63
Spring	Autoclaved	Biomet 3i	20	35	35.58	0.58	1.63
Spring	Autoclaved	Biomet 3i	20	35	36.20	1.20	3.31
Spring	Autoclaved	Straumann	21	35	34.00	1.00	2.94
Spring	Autoclaved	Straumann	21	35	35.64	0.64	1.80

Continued

Table 9 continued

Spring	Autoclaved	Straumann	21	35	34.74	0.26	0.75
Spring	Autoclaved	Straumann	21	35	34.68	0.32	0.92
Spring	Autoclaved	Straumann	21	35	35.20	0.20	0.57
Spring	Autoclaved	Straumann	21	35	34.54	0.46	1.33
Spring	Autoclaved	Straumann	21	35	35.30	0.30	0.85
Spring	Autoclaved	Straumann	21	35	34.60	0.40	1.16
Spring	Autoclaved	Straumann	21	35	35.22	0.22	0.62
Spring	Autoclaved	Straumann	21	35	34.36	0.64	1.86
Spring	Autoclaved	Straumann	22	35	34.04	0.96	2.82
Spring	Autoclaved	Straumann	22	35	34.80	0.20	0.57
Spring	Autoclaved	Straumann	22	35	34.52	0.48	1.39
Spring	Autoclaved	Straumann	22	35	34.72	0.28	0.81
Spring	Autoclaved	Straumann	22	35	34.28	0.72	2.10
Spring	Autoclaved	Straumann	22	35	34.88	0.12	0.34
Spring	Autoclaved	Straumann	22	35	34.74	0.26	0.75
Spring	Autoclaved	Straumann	22	35	35.26	0.26	0.74
Spring	Autoclaved	Straumann	22	35	34.58	0.42	1.21
Spring	Autoclaved	Straumann	22	35	35.62	0.62	1.74
Spring	Autoclaved	Straumann	23	35	34.78	0.22	0.63
Spring	Autoclaved	Straumann	23	35	34.38	0.62	1.80
Spring	Autoclaved	Straumann	23	35	33.76	1.24	3.67
Spring	Autoclaved	Straumann	23	35	34.28	0.72	2.10
Spring	Autoclaved	Straumann	23	35	34.68	0.32	0.92
Spring	Autoclaved	Straumann	23	35	33.82	1.18	3.49
Spring	Autoclaved	Straumann	23	35	34.20	0.80	2.34
Spring	Autoclaved	Straumann	23	35	33.80	1.20	3.55
Spring	Autoclaved	Straumann	23	35	33.56	1.44	4.29
Spring	Autoclaved	Straumann	23	35	34.72	0.28	0.81
Spring	Autoclaved	Straumann	24	35	36.28	1.28	3.53
Spring	Autoclaved	Straumann	24	35	37.00	2.00	5.41
Spring	Autoclaved	Straumann	24	35	38.46	3.46	9.00
Spring	Autoclaved	Straumann	24	35	34.82	0.18	0.52
Spring	Autoclaved	Straumann	24	35	35.90	0.90	2.51
Spring	Autoclaved	Straumann	24	35	35.84	0.84	2.34
Spring	Autoclaved	Straumann	24	35	35.48	0.48	1.35
Spring	Autoclaved	Straumann	24	35	36.32	1.32	3.63

Continued

Table 9 continued

Spring	Autoclaved	Straumann	24	35	36.58	1.58	4.32
Spring	Autoclaved	Straumann	24	35	35.66	0.66	1.85
Spring	Autoclaved	Straumann	25	35	34.84	0.16	0.46
Spring	Autoclaved	Straumann	25	35	34.32	0.68	1.98
Spring	Autoclaved	Straumann	25	35	33.78	1.22	3.61
Spring	Autoclaved	Straumann	25	35	35.52	0.52	1.46
Spring	Autoclaved	Straumann	25	35	35.00	0.00	0.00
Spring	Autoclaved	Straumann	25	35	34.14	0.86	2.52
Spring	Autoclaved	Straumann	25	35	33.88	1.12	3.31
Spring	Autoclaved	Straumann	25	35	34.32	0.68	1.98
Spring	Autoclaved	Straumann	25	35	35.12	0.12	0.34
Spring	Autoclaved	Straumann	25	35	34.88	0.12	0.34
Spring	Autoclaved	Nobel Biocare	26	35	35.16	0.16	0.46
Spring	Autoclaved	Nobel Biocare	26	35	34.98	0.02	0.06
Spring	Autoclaved	Nobel Biocare	26	35	34.82	0.18	0.52
Spring	Autoclaved	Nobel Biocare	26	35	35.32	0.32	0.91
Spring	Autoclaved	Nobel Biocare	26	35	35.22	0.22	0.62
Spring	Autoclaved	Nobel Biocare	26	35	35.70	0.70	1.96
Spring	Autoclaved	Nobel Biocare	26	35	35.08	0.08	0.23
Spring	Autoclaved	Nobel Biocare	26	35	35.30	0.30	0.85
Spring	Autoclaved	Nobel Biocare	26	35	35.08	0.08	0.23
Spring	Autoclaved	Nobel Biocare	26	35	35.36	0.36	1.02
Spring	Autoclaved	Nobel Biocare	27	35	35.10	0.10	0.28
Spring	Autoclaved	Nobel Biocare	27	35	34.84	0.16	0.46
Spring	Autoclaved	Nobel Biocare	27	35	36.08	1.08	2.99
Spring	Autoclaved	Nobel Biocare	27	35	34.76	0.24	0.69
Spring	Autoclaved	Nobel Biocare	27	35	34.38	0.62	1.80
Spring	Autoclaved	Nobel Biocare	27	35	35.38	0.38	1.07
Spring	Autoclaved	Nobel Biocare	27	35	35.12	0.12	0.34
Spring	Autoclaved	Nobel Biocare	27	35	34.78	0.22	0.63
Spring	Autoclaved	Nobel Biocare	27	35	34.84	0.16	0.46
Spring	Autoclaved	Nobel Biocare	27	35	34.72	0.28	0.81
Spring	Autoclaved	Nobel Biocare	28	35	36.06	1.06	2.94
Spring	Autoclaved	Nobel Biocare	28	35	35.82	0.82	2.29
Spring	Autoclaved	Nobel Biocare	28	35	35.54	0.54	1.52
Spring	Autoclaved	Nobel Biocare	28	35	36.16	1.16	3.21

Continued

Table 9 continued

Spring	Autoclaved	Nobel Biocare	28	35	35.80	0.80	2.23
Spring	Autoclaved	Nobel Biocare	28	35	35.08	0.08	0.23
Spring	Autoclaved	Nobel Biocare	28	35	35.68	0.68	1.91
Spring	Autoclaved	Nobel Biocare	28	35	35.80	0.80	2.23
Spring	Autoclaved	Nobel Biocare	28	35	35.70	0.70	1.96
Spring	Autoclaved	Nobel Biocare	28	35	35.48	0.48	1.35
Spring	Autoclaved	Nobel Biocare	29	35	35.96	0.96	2.67
Spring	Autoclaved	Nobel Biocare	29	35	35.22	0.22	0.62
Spring	Autoclaved	Nobel Biocare	29	35	34.84	0.16	0.46
Spring	Autoclaved	Nobel Biocare	29	35	35.16	0.16	0.46
Spring	Autoclaved	Nobel Biocare	29	35	36.94	1.94	5.25
Spring	Autoclaved	Nobel Biocare	29	35	35.40	0.40	1.13
Spring	Autoclaved	Nobel Biocare	29	35	34.90	0.10	0.29
Spring	Autoclaved	Nobel Biocare	29	35	35.56	0.56	1.57
Spring	Autoclaved	Nobel Biocare	29	35	35.62	0.62	1.74
Spring	Autoclaved	Nobel Biocare	29	35	35.56	0.56	1.57
Spring	Autoclaved	Nobel Biocare	30	35	34.80	0.20	0.57
Spring	Autoclaved	Nobel Biocare	30	35	34.38	0.62	1.80
Spring	Autoclaved	Nobel Biocare	30	35	35.28	0.28	0.79
Spring	Autoclaved	Nobel Biocare	30	35	34.06	0.94	2.76
Spring	Autoclaved	Nobel Biocare	30	35	35.12	0.12	0.34
Spring	Autoclaved	Nobel Biocare	30	35	34.52	0.48	1.39
Spring	Autoclaved	Nobel Biocare	30	35	35.02	0.02	0.06
Spring	Autoclaved	Nobel Biocare	30	35	34.56	0.44	1.27
Spring	Autoclaved	Nobel Biocare	30	35	34.88	0.12	0.34
Spring	Autoclaved	Nobel Biocare	30	35	34.68	0.32	0.92

Type	Status	Manufacturer	Label	Target Torque Value (Ncm)	Delivered Torque Value (Ncm)	ABSDIFF (Ncm)	PERDEV (%)
Friction	Autoclaved	Astra Tech	1	25	22.46	2.54	11.31
Friction	Autoclaved	Astra Tech	1	25	23.24	1.76	7.57
Friction	Autoclaved	Astra Tech	1	25	23.18	1.82	7.85
Friction	Autoclaved	Astra Tech	1	25	24.36	0.64	2.63
Friction	Autoclaved	Astra Tech	1	25	24.00	1.00	4.17
Friction	Autoclaved	Astra Tech	1	25	23.26	1.74	7.48
Friction	Autoclaved	Astra Tech	1	25	23.58	1.42	6.02
Friction	Autoclaved	Astra Tech	1	25	23.22	1.78	7.67
Friction	Autoclaved	Astra Tech	1	25	24.24	0.76	3.14
Friction	Autoclaved	Astra Tech	1	25	23.08	1.92	8.32
Friction	Autoclaved	Astra Tech	2	25	22.88	2.12	9.27
Friction	Autoclaved	Astra Tech	2	25	23.94	1.06	4.43
Friction	Autoclaved	Astra Tech	2	25	23.26	1.74	7.48
Friction	Autoclaved	Astra Tech	2	25	22.62	2.38	10.52
Friction	Autoclaved	Astra Tech	2	25	28.28	3.28	11.60
Friction	Autoclaved	Astra Tech	2	25	22.82	2.18	9.55
Friction	Autoclaved	Astra Tech	2	25	25.56	0.56	2.19
Friction	Autoclaved	Astra Tech	2	25	23.36	1.64	7.02
Friction	Autoclaved	Astra Tech	2	25	23.40	1.60	6.84
Friction	Autoclaved	Astra Tech	2	25	23.54	1.46	6.20
Friction	Autoclaved	Astra Tech	3	25	33.34	8.34	25.01
Friction	Autoclaved	Astra Tech	3	25	37.24	12.24	32.87
Friction	Autoclaved	Astra Tech	3	25	36.94	11.94	32.32
Friction	Autoclaved	Astra Tech	3	25	39.12	14.12	36.09
Friction	Autoclaved	Astra Tech	3	25	38.60	13.60	35.23
Friction	Autoclaved	Astra Tech	3	25	39.08	14.08	36.03
Friction	Autoclaved	Astra Tech	3	25	42.68	17.68	41.42
Friction	Autoclaved	Astra Tech	3	25	42.06	17.06	40.56
Friction	Autoclaved	Astra Tech	3	25	47.40	22.40	47.26
Friction	Autoclaved	Astra Tech	3	25	42.16	17.16	40.70
Friction	Autoclaved	Astra Tech	4	25	24.84	0.16	0.64
Friction	Autoclaved	Astra Tech	4	25	25.64	0.64	2.50
Friction	Autoclaved	Astra Tech	4	25	27.46	2.46	8.96
Friction	Autoclaved	Astra Tech	4	25	26.46	1.46	5.52
Friction	Autoclaved	Astra Tech	4	25	26.30	1.30	4.94

Continued

Table 10 Raw data for the accuracy measures of the six manufacturers in clinical service at OSU (Part III)

Table 10 continued

Friction	Autoclaved	Astra Tech	4	25	26.06	1.06	4.07
Friction	Autoclaved	Astra Tech	4	25	26.00	1.00	3.85
Friction	Autoclaved	Astra Tech	4	25	26.50	1.50	5.66
Friction	Autoclaved	Astra Tech	4	25	25.26	0.26	1.03
Friction	Autoclaved	Astra Tech	4	25	26.60	1.60	6.02
Friction	Autoclaved	Astra Tech	5	25	23.94	1.06	4.43
Friction	Autoclaved	Astra Tech	5	25	23.92	1.08	4.52
Friction	Autoclaved	Astra Tech	5	25	24.48	0.52	2.12
Friction	Autoclaved	Astra Tech	5	25	26.74	1.74	6.51
Friction	Autoclaved	Astra Tech	5	25	25.14	0.14	0.56
Friction	Autoclaved	Astra Tech	5	25	23.96	1.04	4.34
Friction	Autoclaved	Astra Tech	5	25	24.82	0.18	0.73
Friction	Autoclaved	Astra Tech	5	25	25.80	0.80	3.10
Friction	Autoclaved	Astra Tech	5	25	26.36	1.36	5.16
Friction	Autoclaved	Astra Tech	5	25	24.90	0.10	0.40
Friction	Autoclaved	Astra Tech	6	25	24.10	0.90	3.73
Friction	Autoclaved	Astra Tech	6	25	25.66	0.66	2.57
Friction	Autoclaved	Astra Tech	6	25	24.00	1.00	4.17
Friction	Autoclaved	Astra Tech	6	25	25.24	0.24	0.95
Friction	Autoclaved	Astra Tech	6	25	24.26	0.74	3.05
Friction	Autoclaved	Astra Tech	6	25	24.10	0.90	3.73
Friction	Autoclaved	Astra Tech	6	25	24.20	0.80	3.31
Friction	Autoclaved	Astra Tech	6	25	24.64	0.36	1.46
Friction	Autoclaved	Astra Tech	6	25	25.32	0.32	1.26
Friction	Autoclaved	Astra Tech	6	25	25.32	0.32	1.26
Friction	Autoclaved	Zimmer Dental	7	30	31.30	1.30	4.15
Friction	Autoclaved	Zimmer Dental	7	30	31.62	1.62	5.12
Friction	Autoclaved	Zimmer Dental	7	30	30.94	0.94	3.04
Friction	Autoclaved	Zimmer Dental	7	30	31.30	1.30	4.15
Friction	Autoclaved	Zimmer Dental	7	30	31.54	1.54	4.88
Friction	Autoclaved	Zimmer Dental	7	30	31.62	1.62	5.12
Friction	Autoclaved	Zimmer Dental	7	30	31.54	1.54	4.88
Friction	Autoclaved	Zimmer Dental	7	30	31.24	1.24	3.97
Friction	Autoclaved	Zimmer Dental	7	30	31.12	1.12	3.60
Friction	Autoclaved	Zimmer Dental	7	30	31.62	1.62	5.12
Friction	Autoclaved	Zimmer Dental	8	30	24.42	5.58	22.85

Continued

Table 10 continued

Friction	Autoclaved	Zimmer Dental	8	30	25.86	4.14	16.01
Friction	Autoclaved	Zimmer Dental	8	30	24.42	5.58	22.85
Friction	Autoclaved	Zimmer Dental	8	30	24.54	5.46	22.25
Friction	Autoclaved	Zimmer Dental	8	30	27.42	2.58	9.41
Friction	Autoclaved	Zimmer Dental	8	30	25.00	5.00	20.00
Friction	Autoclaved	Zimmer Dental	8	30	25.32	4.68	18.48
Friction	Autoclaved	Zimmer Dental	8	30	24.98	5.02	20.10
Friction	Autoclaved	Zimmer Dental	8	30	25.32	4.68	18.48
Friction	Autoclaved	Zimmer Dental	8	30	27.04	2.96	10.95
Friction	Autoclaved	Zimmer Dental	9	30	33.42	3.42	10.23
Friction	Autoclaved	Zimmer Dental	9	30	32.28	2.28	7.06
Friction	Autoclaved	Zimmer Dental	9	30	33.00	3.00	9.09
Friction	Autoclaved	Zimmer Dental	9	30	32.64	2.64	8.09
Friction	Autoclaved	Zimmer Dental	9	30	32.44	2.44	7.52
Friction	Autoclaved	Zimmer Dental	9	30	32.56	2.56	7.86
Friction	Autoclaved	Zimmer Dental	9	30	32.66	2.66	8.14
Friction	Autoclaved	Zimmer Dental	9	30	32.72	2.72	8.31
Friction	Autoclaved	Zimmer Dental	9	30	31.66	1.66	5.24
Friction	Autoclaved	Zimmer Dental	9	30	32.26	2.26	7.01
Friction	Autoclaved	Zimmer Dental	10	30	31.12	1.12	3.60
Friction	Autoclaved	Zimmer Dental	10	30	30.80	0.80	2.60
Friction	Autoclaved	Zimmer Dental	10	30	30.90	0.90	2.91
Friction	Autoclaved	Zimmer Dental	10	30	30.82	0.82	2.66
Friction	Autoclaved	Zimmer Dental	10	30	30.18	0.18	0.60
Friction	Autoclaved	Zimmer Dental	10	30	30.86	0.86	2.79
Friction	Autoclaved	Zimmer Dental	10	30	31.34	1.34	4.28
Friction	Autoclaved	Zimmer Dental	10	30	30.96	0.96	3.10
Friction	Autoclaved	Zimmer Dental	10	30	30.70	0.70	2.28
Friction	Autoclaved	Zimmer Dental	10	30	30.56	0.56	1.83
Friction	Autoclaved	Zimmer Dental	11	30	28.94	1.06	3.66
Friction	Autoclaved	Zimmer Dental	11	30	29.64	0.36	1.21
Friction	Autoclaved	Zimmer Dental	11	30	38.32	8.32	21.71
Friction	Autoclaved	Zimmer Dental	11	30	36.12	6.12	16.94
Friction	Autoclaved	Zimmer Dental	11	30	34.60	4.60	13.29
Friction	Autoclaved	Zimmer Dental	11	30	28.80	1.20	4.17
Friction	Autoclaved	Zimmer Dental	11	30	30.40	0.40	1.32

Continued

Table 10 continued

Friction	Autoclaved	Zimmer Dental	11	30	28.92	1.08	3.73
Friction	Autoclaved	Zimmer Dental	11	30	28.48	1.52	5.34
Friction	Autoclaved	Zimmer Dental	11	30	28.22	1.78	6.31
Friction	Autoclaved	Zimmer Dental	12	30	36.18	6.18	17.08
Friction	Autoclaved	Zimmer Dental	12	30	35.98	5.98	16.62
Friction	Autoclaved	Zimmer Dental	12	30	35.68	5.68	15.92
Friction	Autoclaved	Zimmer Dental	12	30	38.92	8.92	22.92
Friction	Autoclaved	Zimmer Dental	12	30	37.30	7.30	19.57
Friction	Autoclaved	Zimmer Dental	12	30	36.98	6.98	18.88
Friction	Autoclaved	Zimmer Dental	12	30	37.72	7.72	20.47
Friction	Autoclaved	Zimmer Dental	12	30	44.08	14.08	31.94
Friction	Autoclaved	Zimmer Dental	12	30	41.00	11.00	26.83
Friction	Autoclaved	Zimmer Dental	12	30	31.88	1.88	5.90
Friction	Autoclaved	Zimmer Dental	13	30	32.10	2.10	6.54
Friction	Autoclaved	Zimmer Dental	13	30	32.80	2.80	8.54
Friction	Autoclaved	Zimmer Dental	13	30	32.44	2.44	7.52
Friction	Autoclaved	Zimmer Dental	13	30	32.86	2.86	8.70
Friction	Autoclaved	Zimmer Dental	13	30	32.74	2.74	8.37
Friction	Autoclaved	Zimmer Dental	13	30	32.74	2.74	8.37
Friction	Autoclaved	Zimmer Dental	13	30	32.78	2.78	8.48
Friction	Autoclaved	Zimmer Dental	13	30	33.12	3.12	9.42
Friction	Autoclaved	Zimmer Dental	13	30	33.00	3.00	9.09
Friction	Autoclaved	Zimmer Dental	13	30	32.96	2.96	8.98
Spring	Autoclaved	Biomet 3i	14	35	35.36	0.36	1.02
Spring	Autoclaved	Biomet 3i	14	35	35.30	0.30	0.85
Spring	Autoclaved	Biomet 3i	14	35	36.20	1.20	3.31
Spring	Autoclaved	Biomet 3i	14	35	34.84	0.16	0.46
Spring	Autoclaved	Biomet 3i	14	35	35.64	0.64	1.80
Spring	Autoclaved	Biomet 3i	14	35	34.60	0.40	1.16
Spring	Autoclaved	Biomet 3i	14	35	35.20	0.20	0.57
Spring	Autoclaved	Biomet 3i	14	35	35.28	0.28	0.79
Spring	Autoclaved	Biomet 3i	14	35	36.00	1.00	2.78
Spring	Autoclaved	Biomet 3i	14	35	36.46	1.46	4.00
Spring	Autoclaved	Biomet 3i	15	35	36.26	1.26	3.47
Spring	Autoclaved	Biomet 3i	15	35	34.34	0.66	1.92
Spring	Autoclaved	Biomet 3i	15	35	34.38	0.62	1.80

Continued

Table 10 continued

Spring	Autoclaved	Biomet 3i	15	35	34.32	0.68	1.98
Spring	Autoclaved	Biomet 3i	15	35	35.12	0.12	0.34
Spring	Autoclaved	Biomet 3i	15	35	34.74	0.26	0.75
Spring	Autoclaved	Biomet 3i	15	35	34.86	0.14	0.40
Spring	Autoclaved	Biomet 3i	15	35	35.14	0.14	0.40
Spring	Autoclaved	Biomet 3i	15	35	34.80	0.20	0.57
Spring	Autoclaved	Biomet 3i	15	35	35.82	0.82	2.29
Spring	Autoclaved	Biomet 3i	16	35	35.72	0.72	2.02
Spring	Autoclaved	Biomet 3i	16	35	36.62	1.62	4.42
Spring	Autoclaved	Biomet 3i	16	35	35.70	0.70	1.96
Spring	Autoclaved	Biomet 3i	16	35	35.64	0.64	1.80
Spring	Autoclaved	Biomet 3i	16	35	35.94	0.94	2.62
Spring	Autoclaved	Biomet 3i	16	35	36.08	1.08	2.99
Spring	Autoclaved	Biomet 3i	16	35	35.76	0.76	2.13
Spring	Autoclaved	Biomet 3i	16	35	35.08	0.08	0.23
Spring	Autoclaved	Biomet 3i	16	35	36.28	1.28	3.53
Spring	Autoclaved	Biomet 3i	16	35	35.40	0.40	1.13
Spring	Autoclaved	Straumann	17	35	34.50	0.50	1.45
Spring	Autoclaved	Straumann	17	35	33.50	1.50	4.48
Spring	Autoclaved	Straumann	17	35	34.44	0.56	1.63
Spring	Autoclaved	Straumann	17	35	32.48	2.52	7.76
Spring	Autoclaved	Straumann	17	35	34.82	0.18	0.52
Spring	Autoclaved	Straumann	17	35	34.16	0.84	2.46
Spring	Autoclaved	Straumann	17	35	33.06	1.94	5.87
Spring	Autoclaved	Straumann	17	35	34.10	0.90	2.64
Spring	Autoclaved	Straumann	17	35	33.80	1.20	3.55
Spring	Autoclaved	Straumann	17	35	34.04	0.96	2.82
Spring	Autoclaved	Straumann	18	35	35.64	0.64	1.80
Spring	Autoclaved	Straumann	18	35	34.08	0.92	2.70
Spring	Autoclaved	Straumann	18	35	35.84	0.84	2.34
Spring	Autoclaved	Straumann	18	35	34.98	0.02	0.06
Spring	Autoclaved	Straumann	18	35	34.22	0.78	2.28
Spring	Autoclaved	Straumann	18	35	33.34	1.66	4.98
Spring	Autoclaved	Straumann	18	35	35.56	0.56	1.57
Spring	Autoclaved	Straumann	18	35	35.84	0.84	2.34
Spring	Autoclaved	Straumann	18	35	36.52	1.52	4.16

Continued

Table 10 continued

Spring	Autoclaved	Straumann	18	35	33.90	1.10	3.24
Spring	Autoclaved	Straumann	19	35	33.18	1.82	5.49
Spring	Autoclaved	Straumann	19	35	32.24	2.76	8.56
Spring	Autoclaved	Straumann	19	35	33.40	1.60	4.79
Spring	Autoclaved	Straumann	19	35	33.16	1.84	5.55
Spring	Autoclaved	Straumann	19	35	33.52	1.48	4.42
Spring	Autoclaved	Straumann	19	35	32.82	2.18	6.64
Spring	Autoclaved	Straumann	19	35	33.90	1.10	3.24
Spring	Autoclaved	Straumann	19	35	34.62	0.38	1.10
Spring	Autoclaved	Straumann	19	35	33.84	1.16	3.43
Spring	Autoclaved	Straumann	19	35	32.34	2.66	8.23
Spring	Autoclaved	Nobel Biocare	20	35	34.22	0.78	2.28
Spring	Autoclaved	Nobel Biocare	20	35	33.44	1.56	4.67
Spring	Autoclaved	Nobel Biocare	20	35	33.46	1.54	4.60
Spring	Autoclaved	Nobel Biocare	20	35	33.08	1.92	5.80
Spring	Autoclaved	Nobel Biocare	20	35	34.20	0.80	2.34
Spring	Autoclaved	Nobel Biocare	20	35	32.56	2.44	7.49
Spring	Autoclaved	Nobel Biocare	20	35	34.18	0.82	2.40
Spring	Autoclaved	Nobel Biocare	20	35	33.68	1.32	3.92
Spring	Autoclaved	Nobel Biocare	20	35	33.98	1.02	3.00
Spring	Autoclaved	Nobel Biocare	20	35	33.72	1.28	3.80
Spring	Autoclaved	Nobel Biocare	21	35	35.16	0.16	0.46
Spring	Autoclaved	Nobel Biocare	21	35	34.84	0.16	0.46
Spring	Autoclaved	Nobel Biocare	21	35	35.66	0.66	1.85
Spring	Autoclaved	Nobel Biocare	21	35	36.24	1.24	3.42
Spring	Autoclaved	Nobel Biocare	21	35	35.06	0.06	0.17
Spring	Autoclaved	Nobel Biocare	21	35	35.10	0.10	0.28
Spring	Autoclaved	Nobel Biocare	21	35	35.60	0.60	1.69
Spring	Autoclaved	Nobel Biocare	21	35	34.30	0.70	2.04
Spring	Autoclaved	Nobel Biocare	21	35	36.08	1.08	2.99
Spring	Autoclaved	Nobel Biocare	21	35	35.56	0.56	1.57
Spring	Autoclaved	Nobel Biocare	22	35	34.56	0.44	1.27
Spring	Autoclaved	Nobel Biocare	22	35	34.40	0.60	1.74
Spring	Autoclaved	Nobel Biocare	22	35	34.10	0.90	2.64
Spring	Autoclaved	Nobel Biocare	22	35	34.86	0.14	0.40
Spring	Autoclaved	Nobel Biocare	22	35	34.80	0.20	0.57

Continued

Table 10 continued

Spring	Autoclaved	Nobel Biocare	22	35	34.56	0.44	1.27
Spring	Autoclaved	Nobel Biocare	22	35	34.78	0.22	0.63
Spring	Autoclaved	Nobel Biocare	22	35	34.76	0.24	0.69
Spring	Autoclaved	Nobel Biocare	22	35	34.46	0.54	1.57
Spring	Autoclaved	Nobel Biocare	22	35	34.80	0.20	0.57
Spring	Autoclaved	Nobel Biocare	23	35	33.98	1.02	3.00
Spring	Autoclaved	Nobel Biocare	23	35	32.54	2.46	7.56
Spring	Autoclaved	Nobel Biocare	23	35	34.14	0.86	2.52
Spring	Autoclaved	Nobel Biocare	23	35	33.84	1.16	3.43
Spring	Autoclaved	Nobel Biocare	23	35	34.06	0.94	2.76
Spring	Autoclaved	Nobel Biocare	23	35	33.70	1.30	3.86
Spring	Autoclaved	Nobel Biocare	23	35	33.56	1.44	4.29
Spring	Autoclaved	Nobel Biocare	23	35	35.40	0.40	1.13
Spring	Autoclaved	Nobel Biocare	23	35	33.58	1.42	4.23
Spring	Autoclaved	Nobel Biocare	23	35	34.34	0.66	1.92
Spring	Autoclaved	Nobel Biocare	24	35	34.90	0.10	0.29
Spring	Autoclaved	Nobel Biocare	24	35	35.84	0.84	2.34
Spring	Autoclaved	Nobel Biocare	24	35	35.68	0.68	1.91
Spring	Autoclaved	Nobel Biocare	24	35	35.32	0.32	0.91
Spring	Autoclaved	Nobel Biocare	24	35	34.76	0.24	0.69
Spring	Autoclaved	Nobel Biocare	24	35	35.52	0.52	1.46
Spring	Autoclaved	Nobel Biocare	24	35	33.90	1.10	3.24
Spring	Autoclaved	Nobel Biocare	24	35	34.90	0.10	0.29
Spring	Autoclaved	Nobel Biocare	24	35	33.96	1.04	3.06
Spring	Autoclaved	Nobel Biocare	24	35	34.56	0.44	1.27
Spring	Autoclaved	Thommen	25	35	34.80	0.20	0.57
Spring	Autoclaved	Thommen	25	35	34.78	0.22	0.63
Spring	Autoclaved	Thommen	25	35	34.50	0.50	1.45
Spring	Autoclaved	Thommen	25	35	33.50	1.50	4.48
Spring	Autoclaved	Thommen	25	35	34.10	0.90	2.64
Spring	Autoclaved	Thommen	25	35	34.08	0.92	2.70
Spring	Autoclaved	Thommen	25	35	34.06	0.94	2.76
Spring	Autoclaved	Thommen	25	35	34.74	0.26	0.75
Spring	Autoclaved	Thommen	25	35	34.54	0.46	1.33
Spring	Autoclaved	Thommen	25	35	34.56	0.44	1.27
Spring	Autoclaved	Thommen	26	35	34.44	0.56	1.63

Continued

Table 10 continued

Spring	Autoclaved	Thommen	26	35	33.56	1.44	4.29
Spring	Autoclaved	Thommen	26	35	33.08	1.92	5.80
Spring	Autoclaved	Thommen	26	35	33.76	1.24	3.67
Spring	Autoclaved	Thommen	26	35	33.20	1.80	5.42
Spring	Autoclaved	Thommen	26	35	34.28	0.72	2.10
Spring	Autoclaved	Thommen	26	35	34.04	0.96	2.82
Spring	Autoclaved	Thommen	26	35	34.18	0.82	2.40
Spring	Autoclaved	Thommen	26	35	32.38	2.62	8.09
Spring	Autoclaved	Thommen	26	35	33.98	1.02	3.00
Spring	Autoclaved	Thommen	27	35	34.86	0.14	0.40
Spring	Autoclaved	Thommen	27	35	34.48	0.52	1.51
Spring	Autoclaved	Thommen	27	35	35.00	0.00	0.00
Spring	Autoclaved	Thommen	27	35	35.20	0.20	0.57
Spring	Autoclaved	Thommen	27	35	35.18	0.18	0.51
Spring	Autoclaved	Thommen	27	35	35.42	0.42	1.19
Spring	Autoclaved	Thommen	27	35	35.56	0.56	1.57
Spring	Autoclaved	Thommen	27	35	35.42	0.42	1.19
Spring	Autoclaved	Thommen	27	35	35.10	0.10	0.28
Spring	Autoclaved	Thommen	27	35	35.48	0.48	1.35