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UNIFORMED SERVICES UNIVERSITY OF THE HEALTH SCIENCES

POSTGRADUATE DENTAL COLLEGE
NAVAL POSTGRADUATE DENTAL SCHOOL
8955 WOOD ROAD
BETHESDA, MARYLAND 20889



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Name of Candidate: Jeremiah J. Sparks
Master of Science Degree
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THESIS/MANUSCRIPT APPROVED:

DATE:

IMAMURA.GLEN.M
ASAO.1088288510

Digitally signed by
IMAMURA.GLEN.MASAO.10882
88510
Date: 2022.06.21 12:29:45 -04'00'

6/21/22

Glen M. Imamura
RESEARCH DEPARTMENT, NAVAL POSTGRADUATE DENTAL SCHOOL
Committee Chairperson

YU.STACY.LEEF
UNG.1501497211

Digitally signed by
YU.STACY.LEEFUNG.15014972
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Date: 2022.06.22 13:31:29 -04'00'

6/22/22

Stacy I. Yu
PROGRAM DIRECTOR, PROSTHODONTICS DEPARTMENT, NAVAL POSTGRADUATE
DENTAL SCHOOL Committee Member

PETRICH.ANTO
N.1237342093

Digitally signed by
PETRICH.ANTON.1237342093
Date: 2022.06.21 14:53:33 -04'00'

6/21/22

ANTON PETRICH
PROSTHODONTICS DEPARTMENT, NAVAL POSTGRADUATE DENTAL SCHOOL
Committee Member

ANGLED CHANNEL ABUTMENT SCREW REVERSE TORQUE VALUES
FOLLOWING MECHANICAL CYCLING

by

Jeremiah J. Sparks
Lieutenant Commander, Dental Corps
United States Navy

A thesis submitted to the Faculty of the
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ABSTRACT

Angled Channel Abutment Screw Reverse Torque Values Following Mechanical Cycling

Jeremiah Jason Sparks, DDS, 2022

Thesis directed by: Dr. Glen Imamura
Professor (ret), Research Department
Naval Postgraduate Dental School

Introduction: Screw-retained implant restorations employ an angled screw channel (ASC) to allow access from a more favorable, and/or esthetic location. Retention screw insertion torque is applied at an angle greater than 0° . Theoretically, this should diminish the amount of realized screw torque due to the angle of force application. **Objective:** To compare reverse torque values (RTV) of abutment screws tightened to manufacturer's recommended value from 3 different angles (0° , 10° , and 20°) following off-angled, cyclic load testing. **Methods:** Thirty-one implant abutments/screws (MIST IC S-Link) and implants (BIOMET 3i 4.1mm Osseotite external hex) were divided into 3 angulation groups (0° , 10° , and 20°) with sample sizes of 11, 10, and 10 respectively. Customized 3D printed mounts for a chewing simulator (SD Mechatronik, Feldkirchen-Westerham) were fabricated in ABS plastic and designed to hold the implant long axis at 50° to the applied load. Samples were assembled, secured into custom mounts, and prepared for testing in a random order. Angulation guides (0° , 10° , and 20°) were used to direct a 20Ncm insertion torque to abutment screws using an adjustable torque wrench (Zimmer

Biomet) and appropriate hexalobular driver. Torque was reapplied 10 minutes after initial application. A cyclic load (50N, 250,000X) was applied (3mm dia cobalt chrome ball) to lingual of the abutments. Immediately following testing, the digital torque gauge was used to measure RTV at 0° to the long axis of all samples. RTVs were compared using analysis of variance (ANOVA) $\alpha=0.05$. **Results:** ANOVA found no significant difference in post-cyclical mean RTVs values (13.5Ncm/0°, 12.6Ncm/10° and 13.2Ncm/20°) between angulation groups ($p=0.31$). All post-cycle mean RTVs were less when compared to the applied initial torque (20Ncm). **Conclusion:** This randomized *in vitro* study found abutment screw driver insertion angle did not significantly influence mean screw RTVs between groups. All RTVs were less than manufacturer's recommended torque (20Ncm).

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
RTV	Reverse Torque Value
3D	3-Dimensional

CHAPTER 1: Introduction

Five- and 10-year success rates of single implant restorations have been documented to equal or surpass that of conventional fixed dental prostheses for the replacement of missing teeth¹. Restoring clinicians have two options, screws, or cement, for retaining these restorations on their abutments². Each method of retention has different indications. Cement retention is indicated in cases of implant prosthetic malposition or to preserve an intact occlusal surface. Screw retained restorations are indicated in cases where the implant position is ideal or there is inadequate interocclusal space³. The disadvantages of each method have been well documented. Cement retention increases the risk of peri-implantitis related to the presence excess subgingival cement and screw retained restorations have the potential to undergo failure due to screw loosening⁴.

Malpositioned implants typically warrant restoration using a cement retained restoration to compensate for positional discrepancies. However, some clinicians desire ease of retrievability and the decreased risk of soft tissue complications afforded by a screw retained restoration^{4, 5}. Screw-retention of off angled implants can result in several post-operative complications to include an unaesthetic outcome, occlusal interference, or compromised restorative material thickness⁶. To minimize these complications the angulated screw channel has been developed⁵.

Manufacturers make claims that screw channel restorative implants do not experience degradation in applied torque value at the implant abutment interface. Recently published research does not support this position. Hu et al (2019) concluded

that the reverse torque values (RTVs) of dental implant abutment screws torqued using a hexalobulated abutment screw driver in an angled screw channel are lower than the initial torque of 35Ncm across three different angulations. Limitations of this study include the need for documented calibration of the torque wrench within one year of use, the use of implant analogs instead of implants, and using a single implant analog for each test group. Additionally, there was no attempt to replicate conditions found in the oral cavity, i.e., thermal or mechanical cycling, prior to measuring RTVs⁷.

The purpose of this study was to evaluate RTVs of abutment screws tightened to manufacturer's recommended torque value from three different angles (0°, 10° and 20°) following cyclic off-angled load testing. The null hypothesis states there will be no differences between RTVs of abutment screws tightened from these three different angles following repetitive off angle loading.

CHAPTER 2: Materials and Methods

This study was submitted to the Walter Reed Military Medical Center and determined to be non-human use. Sample size requirements were based on Hu et al. (2019) that demonstrated a mean difference of ~ 1 - 2 Ncm when comparing RTVs of 0° , 10° , and 20° angled channel abutment screws. The proposed study aims to validate this comparison using a technical approach that addressed design limitations identified by Hu et al. A minimum of 10 evaluable samples in each of three angulation groups (30 samples total) were required to detect a desired difference of ~ 1.6 Ncm between two groups, assuming a common standard deviation of 1 Ncm, with 80% power and a Bonferroni corrected alpha of $0.05/3$. Allowing for $\sim 10\%$ of samples to be identified as unevaluable/invalid, the study could include up to twelve samples in each angulation group (36 total).

Thirty two machined abutment screws (iMilling, reference #SC3IO, Chantilly, VA, USA), thirty two 4.1mm S-Link abutments (iMilling, reference #SL3IO41) that allow angle correction up to 20 degrees, and thirty two 4.1 mm implants (Biomet 3i Osseotite external hex) were divided into 3 angulation groups (0° , 10° , and 20°) with a sample size of $n=11$, $n=11$, and $n=10$ for the 0° , 10° , and 20° groups respectively. (Figure 1.).

A random numbers generator was used to randomize the numbers from 1-32. Each number was assigned to one sample. Samples were assembled for testing in groups of four in sequential order beginning with numbers 1-4. Implants were embedded in 3-Dimensional (3D) printed ABS plastic sample holders (Figure 2.) and secured using auto-polymerizing methyl methacrylate (Alike, GC America, Alsip, IL, USA). The sample

holders were designed to test up to 4 samples. A 3D printed ABS plastic jig was fabricated to secure the sample holders for the application of torque (Figure 3.).

Abutment screws in each group were hand tightened using a hexalobulated abutment screw driver (Angled Square Driver 3i Long, iMilling, reference #ALD3IL) to hold abutments to implants (Figure 4.). Three 3D angulation guides (Dental LT Clear, Formlabs, Somerville, MA), one for each angulation were printed to verify specified insertion angulation. They were positioned on each abutment prior to applying final insertion torque (Figure 5.). All screws were torqued to manufacturer's recommended torque of 20Ncm using the hexalobulated screw driver in a manual restorative torque wrench (Zimmer Biomet, Carlsbad, CA, USA, reference #TWR). See Figure 6. This was verified accurate with a digital torque (Tohnichi Torque Gauge, model BTGE50CN-G, Buffalo Grove, IL, USA). See Figure 7. Ten minutes after the initial torque, each screw was re-torqued to 20Ncm with the manual torque wrench. The assembled samples were mounted in the chewing simulator (SD Mechatronik, Feldkirchen-Westerham). See Figure 8. A round tipped (3mm diameter), milled cobalt chromium antagonist was attached to the chewing simulator's movable load applying metallic rod (Figure 9.). A 50N load was applied at a 50° offset from vertical for 250,000 cycles at a rate of 1.3 Hz.

Post cycling the assembled mounted samples were placed in the ABS plastic jig and secured with a bench top vice grip to measure reverse torque. A standard hexagon implant abutment screw driver was secured in the digital torque gauge and a RTV of each sample was measured in Ncm from the 0 degrees position parallel to the implant (Figure 10.). The same primary investigator performed the entire experiment.

RTVs were calculated and compared using one-way analysis of variance (ANOVA). All statistical analyses were performed using R statistical software.

CHAPTER 3: Results

Table 1 lists the measured RTVs of each sample and the mean RTV for each angulation group. The 0° group had the highest mean RTV ($13.51 \pm 1.28\text{Ncm}$), and the 10° group had the lowest mean RTV ($12.63 \pm 1.56\text{Ncm}$), with the 20° group averaging $13.28 \pm 1.12\text{Ncm}$ RTV. The ANOVA showed no significance between groups ($p=0.31$). All three groups measured below the initially applied torque of 20Ncm. Figure 11 graphically represents the findings.

Table 1. Reverse torque values of implant abutment screws

Sample	0° RTV (Ncm)	10° RTV (Ncm)	20° RTV (Ncm)
1	12.80	13.70	13.95
2	15.70	1.60*	13.05
3	14.50	12.55	14.25
4	14.90	15.50	13.75
5	12.90	14.10	15.15
6	14.55	12.90	13.20
7	13.40	12.30	13.05
8	12.70	12.05	13.25
9	11.25	11.75	11.80
10	13.30	9.80	11.30
11	12.60	11.60	
Mean	13.51 ± 1.28	12.63 ± 1.56	13.28 ± 1.12

CHAPTER 4: Discussion

The implant abutment interface of an external connection, screw retained, single unit prosthesis can be defined as a screw joint, with two parts tightened together by an abutment screw.⁸ When torque is applied to the abutment screw, a force called preload is generated⁹. This resulting force will cause the screw to elongate under tension and create a clamping force between the implant and the abutment.¹⁰ Preload and clamping force are equivalent in magnitude.⁸

In the text, “Introduction to the Design and Behavior of Bolted Joints”, John H. Bickford described the loosening sequence of screw joints as a two-stage process. It begins with a slow, progressive loss of preload, likely due to the application of cyclic forces, such as mastication, breaking down the intimate contact of the clamped surfaces and ends with micro-motion at the implant abutment interface, connection instability, and screw loosening.¹¹

In this study, 1 sample in the 10° group demonstrated a recorded RTV of 1.6Ncm. As a statistical outlier, it was not included in the analysis of the data to prevent inappropriately skewing the analysis. The null hypothesis was accepted because no significant difference in mean abutment screw RTVs was found between groups, as demonstrated by the 0.31 p-value. However, each group demonstrated greater than 30% loss of the applied torque, with the 0°, 10°, and 20° groups having a 32.5%, 36.9%, and 33.6% decrease in torque, respectively.

The type of implant abutment connection may be related to the measured loss of torque. According to Huang and Wang (2019), external connection two-piece implant systems have an advantage in orientation of the abutment and anti-rotation. However, the

contact surface area of the parts is limited by the short height and diameter of the hexagon used to join the parts together. This makes the external hexagon implant systems vulnerable to micromotion and instability.¹² Kitagawa et al. (2005) used nonlinear dynamic analysis to determine that when compared to internal connection implant systems, external hex type connections had greater linear and rotational movement.¹³ This supports that the choice of connection system may have contributed to the lower RTV findings.

The off-angled access may have been a factor in the measured results. Swamidass et al (2021) compared RTVs between straight line access screws and angulated screw channels across five different groups after cyclic loading.¹⁴ From that study it was concluded that straight line screw access channels performed comparably to angulated screw access channels with regards to percentage of reduction in RTVs post cycling but that angulated screw access channels from manufacturer's with lower manufacturer recommended torque values experienced a higher percentage of torque loss¹⁴. It has been reported that during mastication an average bending moment of 24 to 27Ncm is applied to the contacting surface between opposing teeth¹⁵. With an initially applied torque of 20Ncm followed by 50N off-angled cyclical loading, the observation of decreased RTVs found in this study are not abnormal.

In this study the system selected had a lower manufacturer's recommended torque value, 20Ncm, instead of other implant-abutment systems that use a higher recommended torque value. The lower initial applied torque of 20Ncm decreased the preload or clamping force at the abutment implant interface and therefore require less cyclic force to degrade the contact of the implant abutment interface.

Limitations of this study include lack of a 0° control group using a standard hexagon driver, not measuring reverse torque values prior to cycling to establish a control from which to calculate the percentage of torque lost due to applying a cyclical load, and not thermal cycling each sample to simulate the oral environment more closely.

CHAPTER 5: Conclusions

Based on the findings of this in vitro study, the following conclusions were drawn:

1. The degree of applied torque angulation did not significantly influence mean screw RTVs between groups.
2. All RTVs were less than manufacturer's recommended torque, 20Ncm.



Figure 1. Assembled Sample.

The gold colored MIST S-Link abutment was secured to the Osseotite titanium external hex implant with the abutment screw. The shorter abutment side is visible to the right, allows for angulated access. The screw head is visible on the top right.

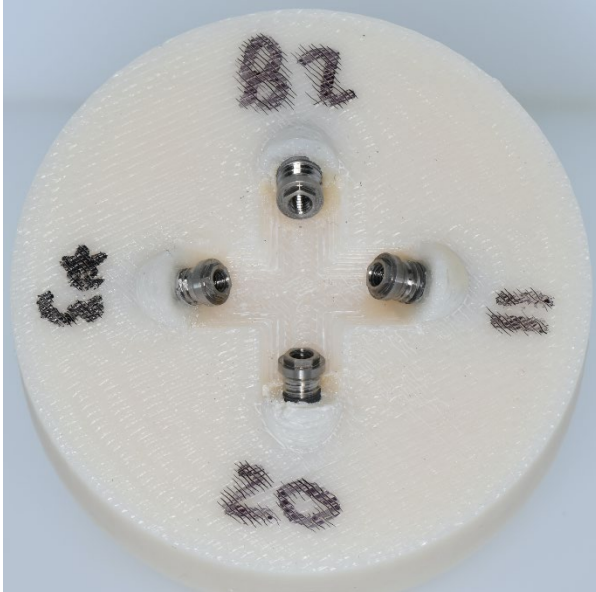


Figure 2. Embedded Implants.

Four randomized Osseotite titanium external hex implants were embedded in a 3D printed ABS plastic sample holder and secured using auto-polymerizing methyl methacrylate. The implants were orientated with a 50 degree offset from the vertical axis to simulate the relationship of the anterior incisors.

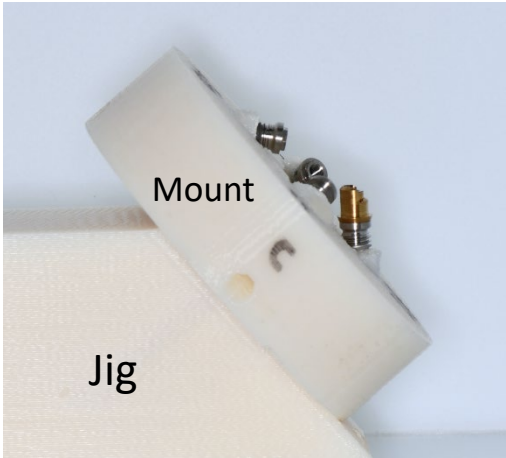


Figure 3. Implant and Abutment Mounted in the Sample Holder (Lateral View). The 3D printed ABS plastic sample mount was placed in the plastic jig to facilitate the initial application of torque and the later measurement of reverse torque to the abutment screw. The Osseotite titanium external hex implant with the MIST S-Link abutment is visible in this figure.



Figure 4. Hexagon Driver and Hexalobulated Driver.

A standard hexagon implant abutment screw driver is on the left. The rounder hexalobulated driver used for angled screw channel access torquing is on the right.

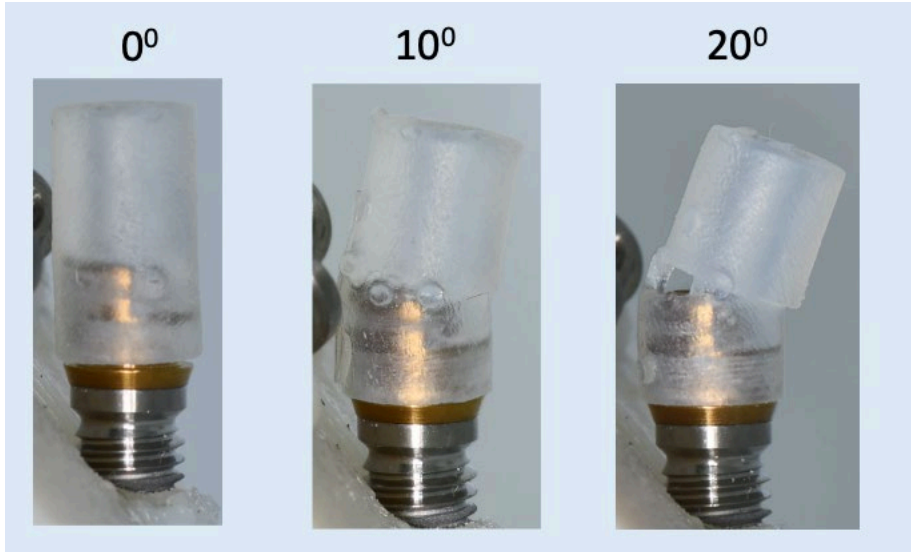


Figure 5. Samples with Angulation Sleeves.

Three 3D angulation guides, one for each tested angulation, are attached to assembled secured samples. They were positioned on each abutment prior to applying initial and final insertion torque.



Figure 6. Torque Wrench Action at 20 Ncm.

The assembled secured sample with the mount in the jig was torqued to 20Ncm with the angulation guide in place. The Zimmer Biomet adjustable manual restorative torque wrench demonstrated a breaking action when the set torque value was applied to the abutment screw, as demonstrated in the figure.



Figure 7. Tonichi Torque Gauge.

Interface of the digital torque gauge displaying a measured value of 14.50Ncm.



Figure 8. Four Samples Mounted in the Chewing Simulator.

Four assembled torqued samples secured in the SD Mechatronik CS-4 chewing simulator. The 3mm cobalt chromium antagonist is engaged equally across each sample.

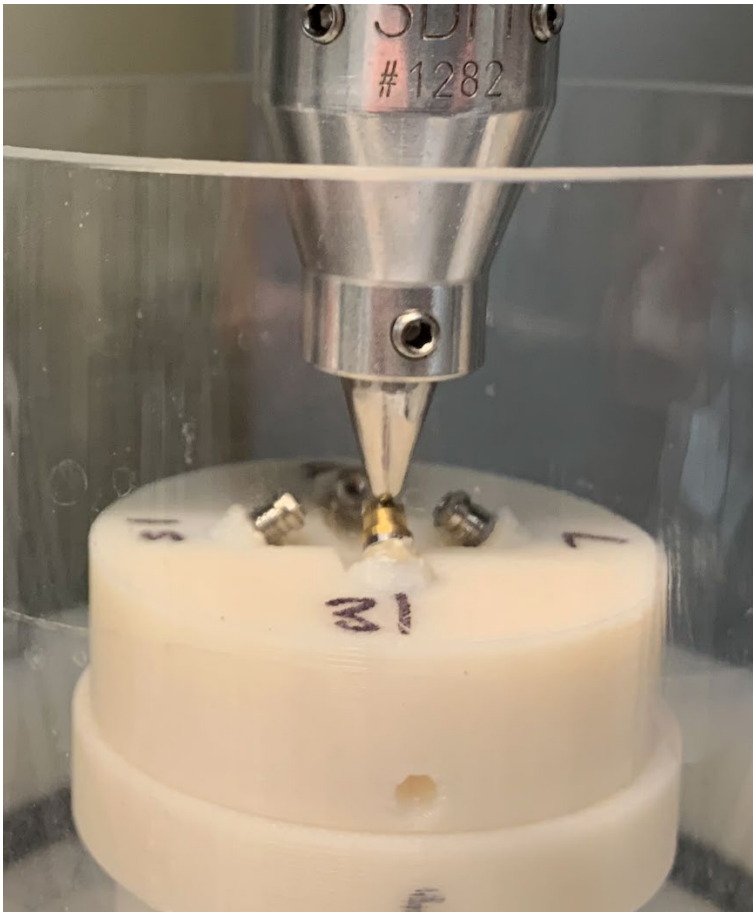


Figure 9. Test Sample Mounted in the Chewing Simulator.

Single assembled torqued sample secured in the SD Mechatronik CS-4 chewing simulator. The 3mm cobalt chromium antagonist was engaged prior to initiating mechanical cyclic loading.

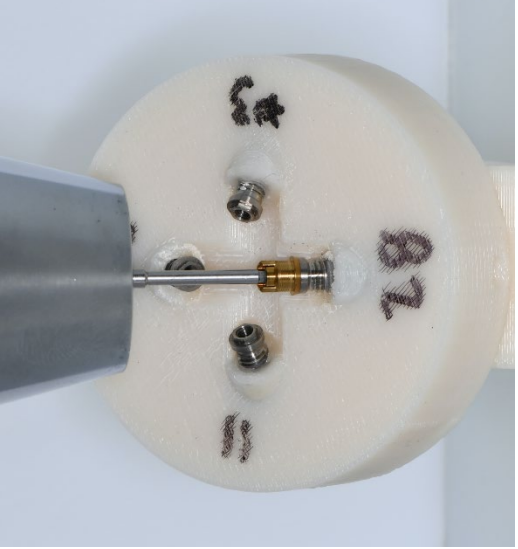


Figure 10. Digital Torque Gauge Measuring Reverse Torque.
The assembled torqued sample secured in the mount with the mount in the jig. A standard hexagon abutment screw driver is engaged with the abutment screw. Reverse torque is applied and measured with the digital torque gauge.

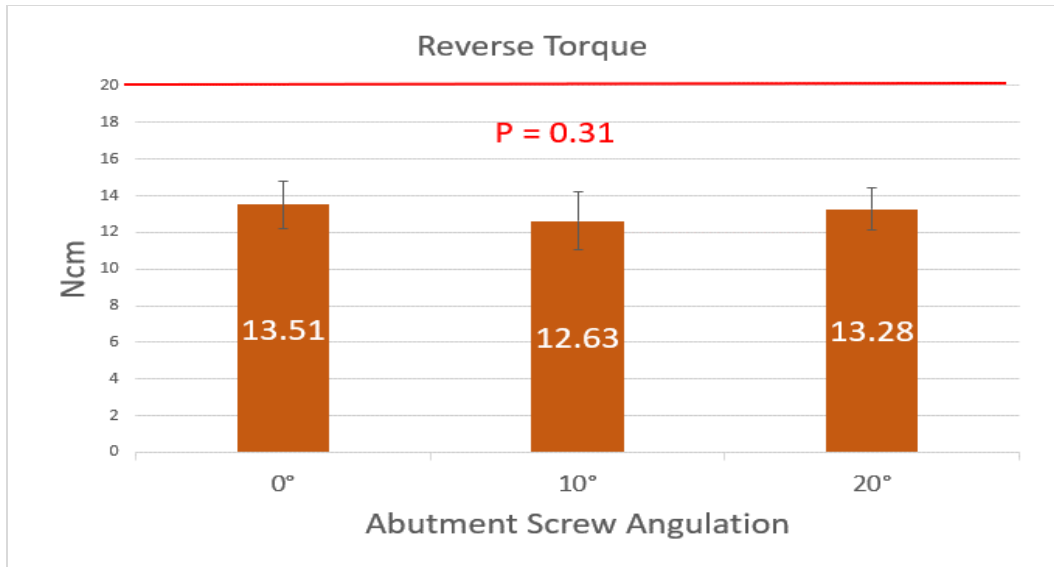


Figure 11. Mean Reverse Torque Values.

Applied torque is displayed with a horizontal red line at 20Ncm. The calculated P-value was 0.31. Each sample groups mean RTV was less than the applied torque of 20Ncm.

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