The Effects of Screw Torque Maintenance and Re-applying Screw Torque on the Retention of Implant Abutment Screws in Single Implant Restorations

by

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Abstract

Purpose: To investigate if screw tightening protocol modification through torque maintenance or abutment screw retightening on an internal Tri-lobe connection implant influences abutment screw reverse torque values (RTV). To also investigate if torquing and retorquing the same implant screw has an influence on the RTV of the screw.

Methods: Nine implants with an internal Tri-lobe connection (Nobel Replace Select, Nobel Biocare) were placed in cold-cure acrylic (ProBase Cold, Ivoclar) to simulate bone and a final abutment (Esthetic Abutment NobelReplace RP, Nobel BioCare) was inserted. Nine screw tightening protocols were tested: 1) torque to 35Ncm, 2) hold torque for 10 seconds, 3) hold torque for 20 seconds, 4) retorque at 2 minutes, 5) retorque at 10 minutes, 6) hold torque for 10 seconds and retorque at 2 minutes, 7) hold torque for 10 seconds and retorque at 10 minutes, 8) hold torque for 20 seconds and retorque at 2 minutes, 9) hold torque for 20 seconds and retorque at 10 minutes. Peak RTVs were measured after 30 minutes using a torque meter (MTT03-05, Mark-10). Each implant screw was changed after each insertion with 10 total screws used per implant. After determining the protocol with the highest average RTV, the specific protocol was used to evaluate if cycles of insertion on a single screw would have an impact on the reverse torque values. Five implants were used with the same five abutments. A single screw was torqued with the specified protocol and de-torqued after 30 minutes with the RTV measured. This was conducted another nine times over for a total of 10 cycles.

Results: Protocol 2 (holding torque for 10s) had the highest average reverse torque value of 22.63Ncm and the Protocol 1 (control) had the lowest at 20.21Ncm with no statistically significant difference. A statistically significant trend was seen in the RTV over the number of insertion cycles with each insertion cycle showing an increase by 0.252Ncm.

Conclusion: Implant screw tightening protocols do not influence the reverse torque values. Multiple insertions of an implant screw may increase the reverse torque value.

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Dedication

This thesis is dedicated to my wonderful partner Jenny, my parents Shirley and Dennis, and my co-resident Dr. Singla. Your unwavering support throughout this residency have made me a better person and clinician today and I cannot thank you enough.

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Chapter 1

Introduction and Background

The treatment of edentulous sites in dentistry has been revolutionized by the introduction of osseointegrated implants. The use of dental implants of both single and multiple units has transformed the way clinicians approach the restoration of edentulous sites (Priest, 2017). Multiple studies have evaluated the rates of implant complications and one of the most commonly occurring complications is abutment screw loosening (Goodacre, 2003). There are many factors that may increase the risk of screw loosening including off-axis load, increased occlusal loads, large cantilever prosthesis, as well as poor manufacturing and fit (Katsavochristou, 2019; Kourtis, 2017). Throughout the years of dental implant use, advances in research and technology have helped to decrease the rate of screw loosening (Goodacre, 2018). This includes using improved materials for the screw, lubrication of the screw surface, improved connections between the prosthetics and the implant fixture, among other things.

Regardless of whether the final prosthesis is screw retained or cement retained, it relies on the screw for retention of a portion of the prosthesis. The screw joint comprises of the screw which clamps together the abutment to the implant fixture (Winkler, 2003). The screw loosens only when external forces, known as separating forces, are greater than the force keeping the screw joint together, known as clamping forces (Khalili, 2019; Varvara, 2019; Winkler, 2003; Tan, 2004). Therefore, separating forces should remain below the threshold of the clamping force and there should be enough tension placed on the joint to prevent separation from any masticatory forces that may occur. The tension applied is usually proportional to the tightening torque (Siamos, 2002). When too small of a force is applied, there is a risk of screw loosening and separation of the joint, however when too large of a force is applied, there is a risk of screw fracture or stripping of screw threads (Siamos, 2002). When torque is applied to the screw joint, it develops preload which is defined as “the tension in a screw when tightened” (Glossary of Prosthodontics Terms Ninth Edition). However, since there is no perfect manufacturing process that can create two perfectly smooth surfaces, embedment relaxation (also known as the settling effect) occurs where the rough areas of the screw are flattened leading to a reduction in preload (Varvara, 2019; Al-Otaibi, 2018; Kim, 2011). The flattening of the surfaces require energy which is transferred from the force that was applied, this decreases the total amount of force remaining to clamp the screw joint. Multiple methods have been proposed to deal with the decrease in preload due to the settling effect. Previous studies have recommended retightening the screw after 10 minutes to account for the settling effect as well as holding the screw torque for certain periods of time during torque application (Bacchi, 2015; Siamos, 2002; Al-Otaibi, 2018; Pardal-Pelaez, 2017; Sella, 2013).

Although previous studies have reported on these methods of trying to reduce the effect of embedment relaxation, they were all conducted on external hexagon implant connections (Sella, 2013; Siamos, 2002; Bacchi, 2015). Currently many clinicians and manufacturers are using implants with internal connections with or without some form of conical connection to improve abutment-implant stability and decrease micromovement. The benefits of having a conical connection have been reported in the literature and its effects on screw loosening have also been documented and will be discussed in detail later (Kim, 2020; Kourtis, 2017). As a clinician, there are only certain factors that are able to be controlled at the time of delivering the abutment or prosthesis. Many of the factors that may improve screw retention (ie. screw material or coating) are in the hands of the manufacturer. As such, the purpose of this thesis is to develop a screw tightening protocol optimizing torque maintenance and abutment retightening that may help minimize the embedment relaxation effect during time of abutment/prosthesis delivery in modern internal connection implants.

Literature Review

1.1 Implant Dentistry

Titanium dental implants were introduced in the late 1960s to support intraoral and extraoral prostheses with high survival and success rates (Branemark et al., 1977; Branemark et al., 1983). Initially, these implants were placed to restore full arches with 4-6 implants inserted into the mandible and placed with a two-stage protocol (Branemark et al., 1977). A few years later, after a 15-year follow-up study completed by Adell published in 1981 and results from the University of Gothenburg, published by Albrektsson in 1988, there was a greater acceptance of the osseointegration concept and its use to restore completely edentulous jaws as well as restoration of partial edentulism and single missing teeth (Adell et al., 1981; Albrektsson, 1988).

Currently, dental implants are used to restore edentulous arches, partially edentulous arches, as well as single missing teeth with high survival and success rates. In a retrospective analysis conducted by Ducommun et al. in 2019, patients receiving dental implants at the University of Bern between 2014 -2016 were analyzed and compared to patients with implants placed between 2002 - 2004 as well as between 2008 - 2010. It was found that the mean age of individuals receiving implant therapy was significantly higher in the 2014-2016 population compared to either populations from the previous time frames. This was theorized to be due to constant improvement in geriatric care as well as an aging population of baby boomers. The study also showed that the most common indication for implant therapy was a missing single tooth (50.5%) (Ducommun et al, 2019). The global market of dental implants is expected to reach 4.497 billion USD by 2022 with an annual growth rate of 6.1% during the forecast period of 2017 to 2022. Much of this growth is attributable to an aging edentulous population, rising awareness, and increasing demand for preventive and cosmetic dental procedures (Meticulous Research, 2017). As compared to its original development and uses, modern implant dentistry has evolved far beyond its initial use presented by Dr. Branemark in 1965 when dental implants were used to treat edentulous jaws with fixed bridges (Adell et al., 1981)

1.2 Implant Complications

As the use of dental implants increased, more information regarding the complications that may arise also surfaced. Dental implants have both biologic complications as well as mechanical complications. Screw loosening has been cited as one of the most common types of mechanical complication (Goodacre et al., 2003; Katsavochristou and Koumoulis, 2019; Kourtis et al., 2017). In a literature review conducted by Goodacre et al. in 2003, abutments screw loosening was detected in 6% of the prostheses and was found to be as high as 45% with implant single crowns (Goodacre et al., 2003). When divided into early and late screw designs, the authors found an average of 25% screw loosening in the early designs while the data from more recent studies showed a mean incidence of 8% showing improvement in the screw/joint design of more modern implants (Goodacre et al., 2003). As a follow-up study in 2018, Goodacre et al. conducted another literature review on prosthetic complications with implant prostheses to compare with the data they compiled in 2003. They organized the study results into groups related to the type of prosthesis. With regards to single crowns, abutment screw loosening was found to be the most common complication at an incidence rate of 3% as reported in 22 studies while screw loosening in screw-retained implant supported bridges was found to be 4% as reported in 7 studies (Goodacre et al., 2018). In a 2019 review published by Katsavochristou and Koumoulis on abutment screw complication rates, the incidence of screw loosening was found to range from 7% to 11.3% while abutment screw fracture was found to be 0.6% (Katsavochristou and Koumoulis, 2019). The incidence of screw loosening was also greater in the posterior region (8.9%) compared to the anterior region (1.6%). Studies reviewed in this article were mostly completed on external hex implants, with only a few single case reports that reported screw loosening on internal connection implant systems. The study which reported an incidence of 11.3% screw loosening was conducted on implants which had hand-tightened screws. Hand tightened screws have limited control of the torque applied and is not applicable to current modern-day protocols of implant restoration. The incidence of screw loosening was greater in the posterior region (8.9%) compared to the anterior region (1.6%).

In a systematic review conducted by Theoharidou et al. in 2009, it was found that the estimated percentage of screw loosening in single implants at 3-year follow-up only occurred at a rate of approximately 3% in both internal and external implant connections (Theoharidou et al., 2009). In other studies, however, the incidence of screw loosening ranged from 5.1% to 11.7% after an observation time of 5.3 years and remains a common mechanical complication that may occur in clinical practice (Kourtis et al., 2017). The review found that the incidence of screw loosening ranged from 2.1% to 12.7% over a multitude of studies (Kourtis et al., 2017).

Although it appears that through improvements in implant and screw design, the incidence of screw loosening has decreased over the evolution of implant dentistry and there is still room for improvement with design and protocols to further prevent and/or reduce the risk of abutment screw loosening.

1.3 Screw Mechanics

The connection between an abutment and the implant fixture when retained by an implant screw has similar mechanics to a screw joint. One of the most important factors involved is the application of optimum preload in the screw joint to maintain the connection between the implant and the abutment. “Preload” is defined as “the tension created in a screw; an engineering term used in dentistry to describe the degree of tightness or clamping force of a screw” in the Glossary of Prosthodontic Terms (GPT 9, 2017). When inadequate preload is applied, there is increased wear on the retaining screw, acceleration of the fatigue of the screw, as well as increased probability of screw loosening. Proper tightening of the screw with adequate amounts of torque should be done to obtain optimum preload (Krishnan et al., 2014).

When torque is applied to a screw, there is elongation which occurs, placing the shank and the threads in tension (Siamos et al., 2002). The elastic recovery of the screw creates the clamping force which pulls the abutment and the implant together (Haack et al., 1995). If joint separating forces applied to the system are greater than the clamping forces, then screw loosening will occur – hence there are two factors that are involved in keeping the screws tight: maximizing the clamping force and minimizing join separating forces (Siamos et al., 2002; McGlumphy et al, 1998). If the amount of torque applied is too small, the joint may be more prone to separation. However, if the amount of torque applied is too large, mechanical failure of the screw or stripping of the screw threads may occur (Siamos et al., 2002). It has been recommended that ideally the preload should be 75% of the yield strength of the material which is also when the screw would fail (McGlumphy et al., 1998).

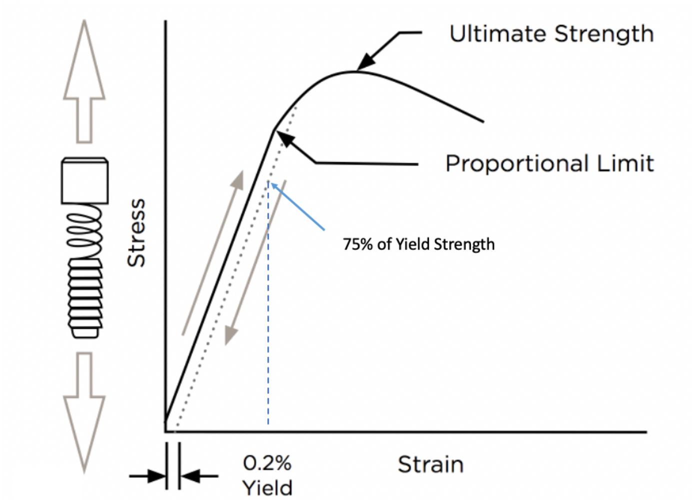

Figure 1. Stress strain curve demonstrating where ideal preload should be applied at 75% of yield strength when torquing an implant screw (adapted from Hurson, 2016).

Clinically, the implant prothesis will be subject to many different forces as the prosthesis is in function. Joint separating forces in the clinically setting include off-axis occlusal contacts, lateral excursive contacts, interproximal contacts between natural teeth and implant restorations, protrusive contacts, parafunctional forces, and non-passive frameworks that attach to the implant (Winkler et al., 2003). Once these forces exceed the preload which is applied to the system, then the joint becomes unstable and micromovement occurs leading to rapid screw loosening. Thus, the final design of the restoration plays a key factor when attempting to prevent implant screw loosening.

1.4 The Settling Effect

The settling effect, also known as embedment relaxation, is defined by the Glossary of Prosthodontic Terms when “microscopic rough spots on the threads [of an implant screw] begin to flatten causing a reduction in the preload” (GPT 9, 2017). This occurs because of no surface ever being completely smooth, no matter how carefully machined the component is (Winkler et al., 2003). As components are clamped together under load, the rough spots begin to flatten since they are the only surfaces which contact initially as the load is being applied. Thus, a portion of the preload that is being applied will always be converted to forces that is used to flatten the surfaces, rather than energy entirely being transferred as clamping forces on the joint itself. It has been estimated that up to 10% of the initial preload may be lost due to surface imperfections in the first few seconds after torque application (Sakaguchi and Borgersen, 1995; Winkler et al., 2003; Tzenakis et al., 2002; Sella et al., 2013).

Multiple investigators have attempted to minimize the settling effect through different screw tightening protocols. The concept of retorqueing a screw a second time is based on the idea that the first torque of the screw will eliminate a portion of the microroughness of the mating components, allowing the second torque to apply more directly to the preload of the system. In a classic in-vitro study conducted by Siamos et al, (2002), abutment screws in sample models were tightened to 25, 30, 35, and 40Ncm. One group of samples was retorqued after 10 minutes with the same initial torque while the other was left alone as a control. Cyclic loading was also applied, and the torque values required to loosen the screws were measured. The results from their study showed that removal torque was always less than the initial torque, with samples which were retorqued after 10 minutes having a greater removal torque value than the control group. Hence, the authors recommended to retorque the implant screw after 10 minutes, to allow for the settling effect to take place (Siamos et al., 2002).

Multiple other studies have been published since that have agreed with this result. Khalili and coworkers (2019) compared three different protocols: the control which was tightened only once, the second group which was retightened after 10 minutes, and the third group which was retightened after 2 weeks of simulated functional loading; each with a sample size of 10. They found that the mean torque loss was significantly greater in the control group compared to both the groups that were retightened. However, there was no significant difference between the group which was tightened after 10 minutes compared to the group, which was retightened after 2 weeks, suggesting that they are both equally effective (Khalili et al., 2019). Al-Otaibi and coworkers (2018) used an All-on-4 model with a passive metal bar direct to four implant fixtures and torqued the abutment screws using different protocols: one torque, once retorqued, and twice retorqued. They found that retorquing the screw once had the highest removal torque compared to both no retorque and retorquing twice. The authors postulated that torquing the screw multiple times may over-flatten the mating surfaces and cause slippage between the threads and cautioned against retorquing the screws more than once (Al-Otaibi et al., 2018). Varvara et al., in 2019 found that a retightening time of 2 minutes showed significantly reduced preload loss compared to the control yet was not significant when retightened after 5 or 10 minutes. There was also no difference between the external hexagon group compared to the internal hexagon group. It was postulated that because most of the preload is lost within the first few minutes, early retorquing showed improvements against the reduction of preload torque (Varvara et al., 2019). In a recent study by Alnasser et al (2021) evaluating different screw tightening protocols on modern day conical connection implants, they found there was no difference in reverse torque values between tightening once and tightening twice, with or without a 10-minute time interval (Alnasser et al., 2021).

Some issues have been raised with regards to the number of times a prosthetic screw may be tightened. In a study conducted by Guzaitis et al (2011) they observed the effects of repeated screw torque and measured the reverse torque values after 9, 19, 29, or 39 times. Their results found that the highest reverse torque values were seen in 9 or fewer insertion cycles. After 19, 29, or 39 cycles, a reference screw experienced greater reverse torque values than the screw which had been torqued multiple times. The authors also evaluated the implant thread surface morphology that occurred and found most changes occurred during the first 10 insertions which lead to a more homogenous surface with less debris. The authors postulated that a decrease in surface roughness of the screw over time lead to decreased frictional resistance of the screw which ultimately resulted in decreased reverse torque values (Guzaitis et al., 2011). Byrne and coworkers (2006) also reported a decrease in preloads generated, however they only tested the screw joint three times compared to Guzaitis et al., which tested it 39 times (Byrne et al., 2006).

Another proposed protocol to help combat the settling effect is the maintenance of torque on the system. The idea here is similar to retorquing after a set amount of time: as the torque is held on the system, irregularities between the surfaces should dissipate and torque should be then transferred as preload. Sella and coworkers (2013) investigated the influence of different maintenance times of torque application on external hexagon implants. They divided the samples into 4 groups (n=10): no maintenance, 10 seconds, 20 seconds, and 30 seconds of maintenance and reverse torque values were recorded at 10 minutes post-insertion. The results of their in-vitro study showed that maintenance of torque for over 20 seconds was significantly better than no maintenance and 10 second maintenance. The results also showed that 10 seconds of maintenance was still significantly better than the control (Sella et al., 2013). Al-Otaibi and coworkers (2018) tested the effect of maintenance time on abutments in a full-arch implant supported fixed prosthesis and compared the immediate protocol, 10 second protocol, and 30 second protocol. The results of the study showed that there was no significant difference in reverse torque values between any of the given protocols (Al-Otaibi et al., 2018). Bacchi et al., investigated different tightening protocols including a torque and hold for 20 seconds and found no significant difference in reverse torque values (Bacchi et al., 2015).

An interesting concept shown by Kim and coworkers (2011) indicates that due to settling, there may be a vertical misfit of the implant prosthesis leading to a disruption in passive fit and distortion of the superstructure. In their study testing different implant-abutment connections with different torque values and repeated torques after 10 minutes, they found that all groups developed settling with repeated tightening. After the second tightening of 30Ncm, repeated tightening showed near constant settling results and thus the authors suggested that the abutment screws should be retightened at least twice to 30Ncm at 10-minute intervals. An important point to mention is that the recommendation was for both laboratory and clinical procedures, as changes in the fit between the lab and the mouth can cause misfit in the components (Kim et al., 2011). To add onto this, al-Turki et al (2002) found that vertical misfits of 100 and 175 microns between an implant-supported complete denture and the terminal abutment resulted in significant prosthetic screw instability, emphasizing the importance of vertical fit when transferring from the laboratory to the clinical situation (al-Turki et al., 2002).

2.1: Joint Stability

There are many factors that can influence the stability of an implant-abutment joint. These factors include the connection type, the material of the screw, as well as the frictional coefficient between components (Krishnan et al., 2014; Binon, 2000; Shetty et al., 2014).

2.2: Connection Type

In implant dentistry, there are multiple different connections between the implant and the abutment. When implants were first introduced, the connection type was exclusively a 0.7mm external hexagon connection as the connection itself was used as a way for instruments to insert the implants. This connection was fine for a full arch prosthesis, however when clinicians started using implants to restore smaller spans or even single crowns, the connecting screw is exposed to more rigorous load application and subject to lateral loads. The internal hexagon was then developed as a new interface, moving the connection to the inside of the implant body itself. This offered a distribution of lateral load deeper within the implant which helped shield the abutment screw from external forces. Longer internal walls also created a stiff and unified body that helps resist joint opening. Following this, a conical connection was developed where there is a morse taper connection between the abutment and the implant, usually along with an internal hexagon for proper abutment timing. This was originally introduced by Straumann with the International Team for Implantology (ITI) in 1985 with the idea that the tapered connection would create a mechanically sound self-locking interface (Scacchi et al, 2009). The more stable the joint, the less force which would be placed on the small abutment screw, which should decrease the chances of screw loosening (Binon, 2000). As mentioned previously, Goodacre et al., had mentioned that screw loosening incidence has seen to be decreased in modern implant articles compared to those from before. Changes in the abutment interface may be one of those reasons (Goodacre et al., 2008).

In a systematic review conducted by Gracis et al. in 2012 on internal vs. external connections for implant abutments, it was found that the 3-year cumulative screw loosening incidence was 1.5% for the internal connection and 7.5% for the external connection design (Gracis et al., 2012). Tsuge and Hagiwara measured reverse torque values after oblique loading on internal and external hexagon designs with gold and titanium screw materials. They found that the connection itself did not have an effect, however the screw material did, with the titanium screw being less likely to come loose than the gold screw (Tsuge and Hagiwara, 2009). Rocha Bernardes et al., tested different connection types using custom fabricated titanium implants and measured the strain at the cervical level of the implant. They found higher levels of strain in internal connections, and a torque of 20Ncm vs. 32Ncm made no difference in terms of the strain on the conical connection, recommending that the higher torque be used since it allows increased stability without increased strain on the implant (Rocha Bernardes et al., 2014). Sammour and coworkers (2019) conducted a study comparing conical connection and internal hexagon connections after loading and found that conical connection implants showed better screw stability than the internal hexagon counterparts. The values of reverse torque for post-loaded conical connection were greater than the original torque provided to the system. This resulted from the cold welding which is inherent to the system through the friction between the conical connection providing high stability of the joint (Sammour et al., 2019). Although not every article shows a benefit to having a conical connection for implant-abutment stability, the majority of the literature shows there is a benefit to having an internal connection, specifically an internal conical connection over the tradition external hexagon.

2.3 Screw Material and Friction

Another topic of debate in the literature has been the material of the screw, and its influence on the amount of preload delivered to the system. There are two main materials used for the implant screw: gold and titanium. Gold alloy screws have a lower frictional resistance compared to the titanium alloy screw (Al Jabbari et al., 2008). Along with that, they have a higher modulus of elasticity which allows them to stretch to a higher percentage compared to titanium screws. However, a titanium screw is stronger than a gold screw and thus metal fatigue will produce gold screw fracture before titanium (Weinberg, 1993). A phenomenon that occurs between the screw and the implant is galling which is defined as "a condition whereby excessive friction between two mating surfaces results in localized welding with a further roughening of the rubbing surfaces of one or both of the two mating parts" (Kuhn and Medlin, 2000). Due to the nature of the titanium screw, there is increased adhesive wear in this form which limits the preload characteristics of the titanium screw (Binon, 2000). A gold screw having a decreased coefficient of friction should be able to be tightened to an increased torque without the risk of galling between threads.

One key factor to take into consideration as mentioned previously is the effect of the coefficient of friction on preload. The coefficient of friction is defined as the ratio of frictional force to the force acting perpendicular to the two surfaces in contact. The coefficient of friction is inversely correlated with the amount of preload (Bulaqi et al. 2015). In order to minimize friction, dry lubricants have been developed to coat the surface of the implant screw. Some of these coatings include Gold-Tite (3i Implant Innovations), TorqTite (Nobel Biocare), and Diamond-Like Carbon (Nobel Biocare). Multiple in-vitro studies have been conducted to compare the amount of preload generated in these different lubricated systems (Assunção et al, 2012; Byrne et al., 2006; Kim et al., 2005; Tsuge and Hagiwara, 2009). Byrne et al. (2006) conducted a study comparing three different screws: titanium alloy, gold alloy, and gold-coated gold alloy. They found that the gold-coated screw showed significantly higher preloads for all insertion torques compared with the uncoated screws. However, upon removal and retightening, the gold-coated screw lost more preload on the second and third tightening compared to the uncoated screws which may indicate some wear of the gold coating during insertion and a decrease in effectiveness. The titanium alloy screw preloads were essentially unchanged throughout the three tightening protocols and the gold screw lost preload after the first but was consistent after the second and third (Byrne et al., 2006). Another study conducted by Kim et al (2005) compared a Diamond Like Carbon (DLC) coating on a titanium screw with the uncoated titanium screw and they found that the DLC coated screw showed more resistance to screw loosening. The DLC coating has similar properties to a real diamond which includes its low frictional resistance and excellent wear resistance which may be part of the reasoning for this difference (Tang et al., 1995; Kim et al., 2005). Tsuge and Hagiwara (2009) compared reverse torque values of titanium alloy versus gold alloy screws after cyclic loading and found that the titanium alloy abutment screws were less likely to come loose than the gold alloy (Tsuge and Hagiwara, 2009). Assunção and coworkers (2012) also found that the titanium alloy screw had the highest amount of torque retention when compared to DLC coating and gold screws with gold coatings (Assunção et al, 2012). However, this contrasts with Martin et al (2001) which compared 4 groups of screws: Gold-Tite, Torqtite, gold alloy, and titanium alloy and found that the greatest preload values were in the Gold-Tite group. The authors also found a similar finding as Byrne et al (2006) in which the Gold-Tite and Torqtite screws had the highest torque on the first tightening but decreased afterwards possibly due to the surface treatment wearing off during repeated tightening and loosening cycles (Martin et al., 2001).

Another important factor to consider when discussing friction is the difference between the kinetic friction coefficient and the static friction coefficient. The kinetic friction coefficient affects the dynamic tightening torque when torque is being applied to the system, this is the friction that would ideally be decreased for increased preload. The static friction coefficient is the friction that prevents the screw from loosening once torque applied. The efficiency of the joint system can be enhanced if the kinetic friction coefficient is smaller than the static friction coefficient (Katsavochristou and Koumoulis, 2019).

Some authors have advocated using Teflon coatings and other lubricants to help with the reduction of friction to increase joint stability. However, studies have shown that this increase in lubrication although decreases the friction, may also result in a lower opening torque which may have an adverse effect on the stability of the abutment screw (Elias et al., 2006; Wu et al, 2017). Chen and coworkers (2020), when comparing screws with polyetheretherketone (PEEK) and polytetrafluoroethylene (PTFE) coatings found that they were able to reduce friction coefficient and increase clamping force and decrease the wear of the implant internal threading (Chen et al., 2020)

3.0 Torque Application

Another important consideration when clinically applying torque to the screw is the accuracy and ability of the torque device to transfer the proper amount of torque to the system. Mechanical torque devices can be classified as friction (toggle) or spring (beam) devices. The frictional device has a force applied to the screw until the handle automatically releases which discontinues the torque application. The spring device has markings on the surface to indicate where to bend the application handle to so that the amount of torque is applied. Albayrak et al., found that the accuracy of these devices varies by device type and manufacturer and none of the evaluated devices were able to meet the target torque values successfully (Albayrak et al., 2017). Thus, it is important for the torque wrenches being used to be calibrated so that the proper amount of preload can be achieved. Pesun et al., have also found that the amount of torque applied is operator dependent and proper training with each device should take place to ensure standardized results (Pesun et al., 2001).

Statement of Problem

There is currently no standardized tightening protocol for single implant abutment screws on modern day internal connection implants to ensure proper preload application and decrease risks of screw loosening.

Purpose of the Study

The aim of this study is to determine if tightening technique modification through torque maintenance or abutment screw retightening on a trilobe connection implant influences abutment screw torque.

Objectives of the Study

- Evaluate if torque maintenance influences reverse torque values on single implant abutments
- Evaluate if retightening the implant screw influences reverse torque values on single implant abutments
- Evaluate if multiple closing and opening cycles on the screw influences reverse torque values on single implant abutments
- Determine an ideal protocol for torque application of single implant abutments

Null Hypotheses

H_{01}: Using a tightening technique that includes torque maintenance has no effect on the abutment screw reverse torque.

H_{02}: Using a tightening technique that includes abutment screw retightening has no effect on the abutment screw reverse torque.

H_{03}: Multiple cycles of closing and opening on an abutment screw has no effect on the abutment screw reverse torque.

Chapter 2

Materials and Methods

Sample Preparation

To fabricate an acrylic holder for the implants, a three-compartment tray design was found on Thingiverse.com and 3D printed using a Formlabs Form 3B printer in the available Dental Model Resin v2 (Formlabs) following manufacturer's recommendations for washing and curing. Figure 2. Nine dental implants (Replace Select, Nobel Biocare) were obtained from the manufacturer. The length of the implants varied; however, the platform of all implants is identical (Nobel RP 4.3mm). Cover screws were placed on all implants to prevent any form of contamination of the implant platform during the sample preparation. Dental implants were embedded into acrylic resin in groups of three; one group of three for each compartment of the fabricated tray. The head of the implants (with the cover screw intact) was luted to a tongue depressor using heated baseplate wax at even distances from each other. Clear cold-cure acrylic resin (Probase Cold, Ivoclar Vivadent Inc) was mixed and slowly poured into a single compartment of the tray on a vibrator (Heavy Duty Vibrator, Whip Mix). The tongue depressor with the respective implants were then flipped and slowly lowered into the acrylic resin of the tray with the edges of the tongue depressor holding the implants in the correct vertical height relative to the acrylic resin. The acrylic was allowed to fully set and then tongue depressor removed from the head of the implants. The procedure was then repeated two more times with the two other compartments of the tray resulting in three rows of three implants embedded into acrylic supported by the tray (Figure 3). Each implant was then numbered directly on the acrylic resin to facilitate organization for testing procedures. A stock anterior implant abutment (Esthetic Abutment NobelReplace RP 1 mm, Nobel BioCare) was placed on each implant for testing with the implant screw (Figure 4).

3D Printer

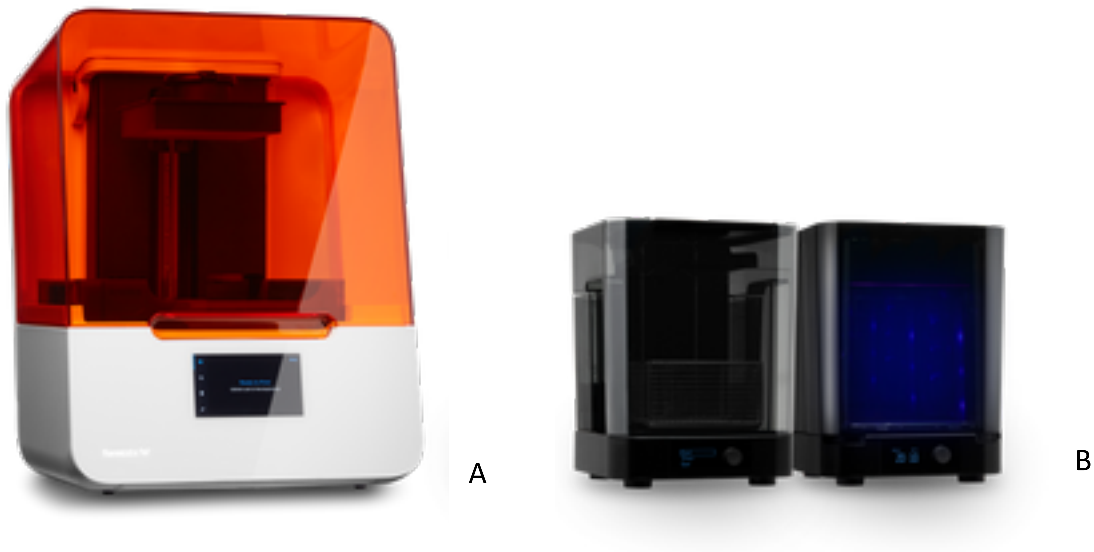

Figure 2: **A**. FormLabs 3B 3D Printer; **B**.FormLabs Automated Wash and Cure Units

Dental Implant and Components

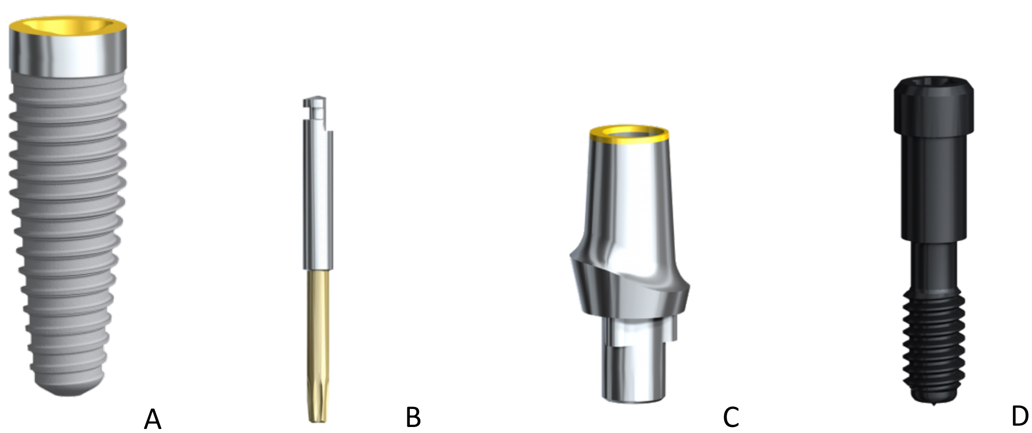

Figure 3: **A**. Nobel BioCare Replace Select RP Dental Implant; **B**. Nobel BioCare UniGrip Screwdriver; **C.** Nobel BioCare Esthetic Abutment for Replace Select RP, **D**. Nobel BioCare Replace Select RP Abutment Screw

Implant Assembly

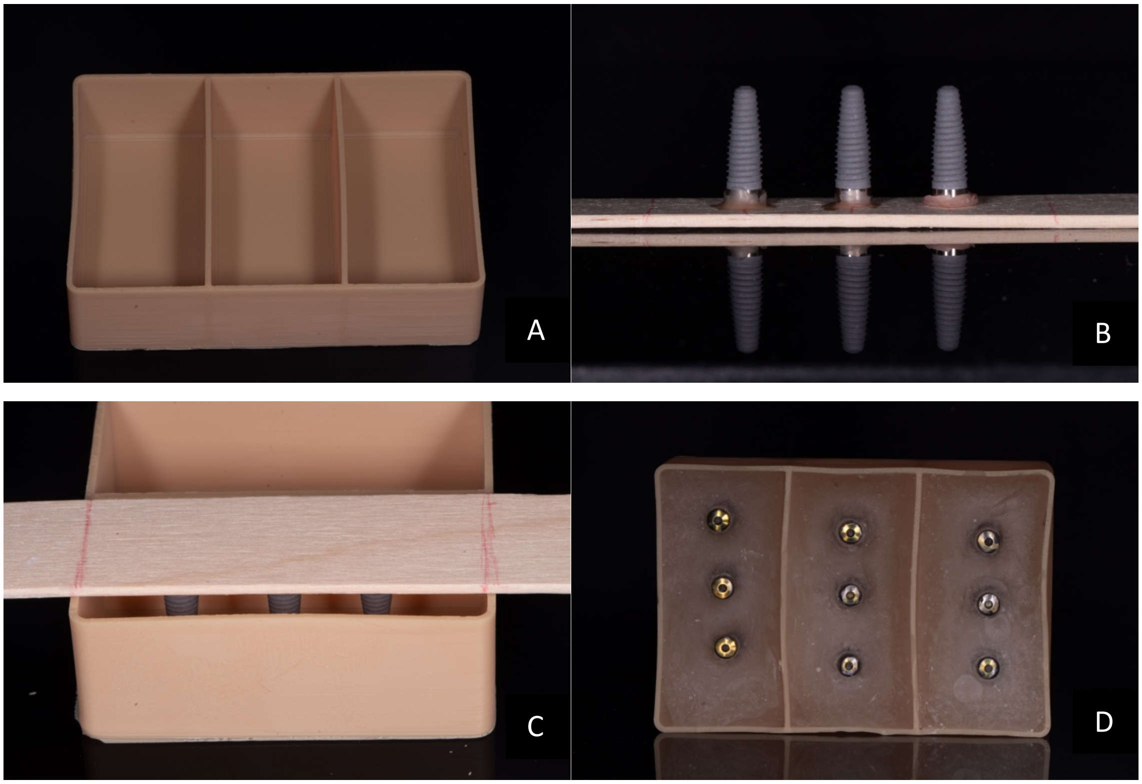

Figure 4: A. 3D Printed Tray; **B**. Implants Luted to Tongue Depressor; **C**. Visual Showing How Implants are to be Embedded into Acrylic; **D.** All Nine Implants in Acrylic

Cold Cure Acrylic

Figure 5. Clear Cold Cure Acrylic (ProBase Cold, Ivoclar)

Testing

Screw Protocol Testing

A total of 90 dental implant abutment screws (Replace Select RP Abutment Screw, Nobel BioCare) compatible with the dental implants were obtained. A total of nine protocols were tested: one control group and eight test groups. A digital torque meter (MTT03-50, Mark-10) is used to apply torque to the implant screw as well as to record the removal torque of the implant screw. A screwdriver tip for the Nobel Implant (UniGrip 25mm, Nobel BioCare) was inserted on to the digital torque meter which has a Jacob's chuck attachment. Using the provided tool from Mark-10, the screwdriver tip was tightened to ensure no movement within the torque meter. The manufacturer's recommended screw torque was 35Ncm.

Digital Torque Meter

Figure 6. Digital Torque Meter with Jacob's Chuck Attachment (MTT03-05, Mark-10)

Figure 7. Nobel UniGrip driver (Nobel BioCare) attached to the Torque Meter (MTT03-05, Mark-10) through the Jacob's Chuck.

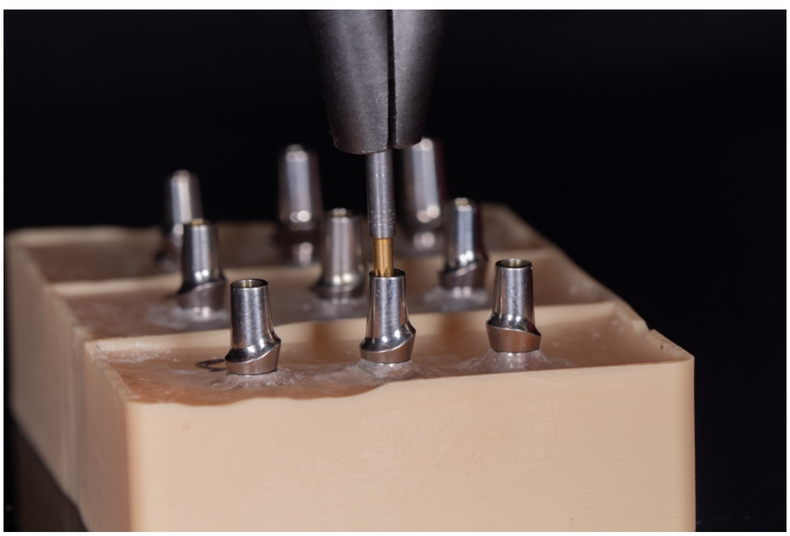

Figure 8. Visualization of how torque was applied to the system.

Group 1 (control):

An implant screw was placed in the abutment/implant assembly labeled “1”. Using the digital torque meter, the screw was torqued until the meter read 35Ncm and then released. After thirty minutes of time had passed, the screw was then reverse torque using the same digital torque meter. The specific meter reads the value of the screw and keeps track of the greatest value which was then recorded as the reverse torque value for that sample.

Group 2:

An implant screw was placed in the abutment/implant assembly labeled “2”. Using the digital torque meter, the screw was torqued until the meter read 35Ncm, held for 10 seconds and then released. After thirty minutes of time had passed, the screw was then reverse torque using the same digital torque meter and recorded.

Group 3:

An implant screw was placed in the abutment/implant assembly labeled “3”. Using the digital torque meter, the screw was torqued until the meter read 35Ncm, held for 20 seconds and then released. After thirty minutes of time had passed, the screw was then reverse torque using the same digital torque meter and recorded.

Group 4:

An implant screw was placed in the abutment/implant assembly labeled “4”. Using the digital torque meter, the screw was torqued until the meter read 35Ncm. After 2 minutes, the screw was once again torqued until the meter read 35Ncm. After thirty minutes of time had passed, the screw was then reverse torque using the same digital torque meter and recorded.

Group 5:

An implant screw was placed in the abutment/implant assembly labeled “5”. Using the digital torque meter, the screw was torqued until the meter read 35Ncm. After 10 minutes, the screw was once again torqued until the meter read 35Ncm. After thirty minutes of time had passed, the screw was then reverse torque using the same digital torque meter and recorded.

Group 6:

An implant screw was placed in the abutment/implant assembly labeled "6". Using the digital torque meter, the screw was torqued until the meter read 35Ncm, held for 10 seconds and then after 2 minutes, the screw was once again torqued until the meter read 35Ncm. After thirty minutes of time had passed, the screw was then reverse torque using the same digital torque meter and recorded.

Group 7:

An implant screw was placed in the abutment/implant assembly labeled "7". Using the digital torque meter, the screw was torqued until the meter read 35Ncm, held for 10 seconds and then after 10 minutes, the screw was once again torqued until the meter read 35Ncm. After thirty minutes of time had passed, the screw was then reverse torque using the same digital torque meter and recorded.

Group 8:

An implant screw was placed in the abutment/implant assembly labeled "8". Using the digital torque meter, the screw was torqued until the meter read 35Ncm, held for 20 seconds and then after 2 minutes, the screw was once again torqued until the meter read 35Ncm. After thirty minutes of time had passed, the screw was then reverse torque using the same digital torque meter and recorded.

Group 9:

An implant screw was placed in the abutment/implant assembly labeled "9". Using the digital torque meter, the screw was torqued until the meter read 35Ncm, held for 20 seconds and then after 10 minutes, the screw was once again torqued until the meter read 35Ncm. After thirty minutes of time had passed, the screw was then reverse torque using the same digital torque meter and recorded.

Each protocol was repeated nine times for a total sample size of 10. Table 1. shows the protocols involved.

Table 1. Protocols for Torquing Implant Screws

	Torque Maintenance	**Retightened**
1 (Control)	N/A	N/A
2 (Hold 10s)	10 seconds	N/A
3 (Hold 20s)	20 seconds	N/A
4 (Retorque 2 mins)	N/A	2 minutes
5 (Retorque 10 mins)	N/A	10 minutes
6 (Combination 2+4)	10 seconds	2 minutes
7 (Combination 2+5)	10 seconds	10 minutes
8 (Combination 3+4)	20 seconds	2 minutes
9 (Combination 3+5)	20 seconds	10 minutes

Torque and Removal Cycle Testing

To test if multiple closing and opening cycles affected the implant reverse screw torque, implants numbered 1 to 5 were used. A single screw was placed into each of the abutment/implant assemblies. From preliminary results of the protocol testing, *group 4* (torque maintenance for 20 seconds) had the highest average reverse torque value and as such this protocol was applied for this part of testing. After 30 minutes from torque application, the implant screw was removed, and the reverse torque value recorded. The same screw was then retightened with the same protocol. This was repeated nine times, leading to a total of ten cycles of torque application and removal for each implant screw.

Statistical Analysis

Statistical analysis was completed on R Software (R-Foundation). The data was analyzed using a 1-way ANOVA to evaluate differences in protocols followed by Pairwise difference tests. A linear regression model was used to investigate dependence of reverse screw torques on multiple cycles of insertion.

Chapter 3

Results

The mean values for the reverse torque values of each protocol are presented in Table 2. Of the test groups, protocol number 3 (holding torque for 20 seconds) had the highest average reverse torque value of 23.64 Ncm and protocol number 4 (retorque at 2 minutes) had the lowest average reverse torque value with 21.06 Ncm. None of the reverse torque values for any of the protocols were as high as the initial torque which was applied. Summary tables of the raw data for each sample can be found in Table 4.

Table 2. Mean Reverse Torque Values and Standard Deviation for Screw Torque Protocols (n=10)

	Mean Reverse Torque Values (Ncm)	**Standard Deviation**
1 (Control)	22.03	4.06
2 (Hold 10s)	23.34	1.89
3 (Hold 20s)	23.64	2.74
4 (Retorque 2 mins)	21.06	1.65
5 (Retorque 10 mins)	22.2	1.53
6 (Combination 2+4)	21.87	2.31
7 (Combination 2+5)	21.92	2.02
8 (Combination 3+4)	22.56	2.55
9 (Combination 3+5)	22.55	2.41

The first sample data point of the experiment appeared to be different from the remaining data set. Statistical analysis using a t-test of the first sample point with the second sample point was not statistically different. However, both the first and second sample points were different from the remaining 3 – 10 sample points and thus were excluded from further analysis. This data is presented in Table 3 and graphically in Figure 9 with updated values where Protocol 2 (holding torque for 10s) had the highest average reverse torque value of 22.63Ncm and the Protocol 1 (control) had the lowest.

Based on the one-way ANOVA test on the remaining data, there was a statistically significant difference between protocols ($p=0.00661$). A standard error comparison of the pairwise difference between protocols 1 and 2, which were the least and greatest values respectively, was

1.28 with a confidence interval of the difference being (-0.10, 4.93) and not enough to prove statistical significance. More data is required to definitively prove that one protocol is better than another.

Table 3. Mean Reverse Torque Values and Standard Deviation for Screw Torque Protocols (n=8)

	Mean Reverse Torque Values (Ncm)	**Standard Deviation**
1 (Control)	20.21	1.39
2 (Hold 10s)	22.63	1.25
3 (Hold 20s)	22.46	1.28
4 (Retorque 2 mins)	20.58	1.23
5 (Retorque 10 mins)	21.84	1.51
6 (Combination 2+4)	20.95	1.37
7 (Combination 2+5)	21.04	0.66
8 (Combination 3+4)	21.63	1.76
9 (Combination 3+5)	21.55	1.28

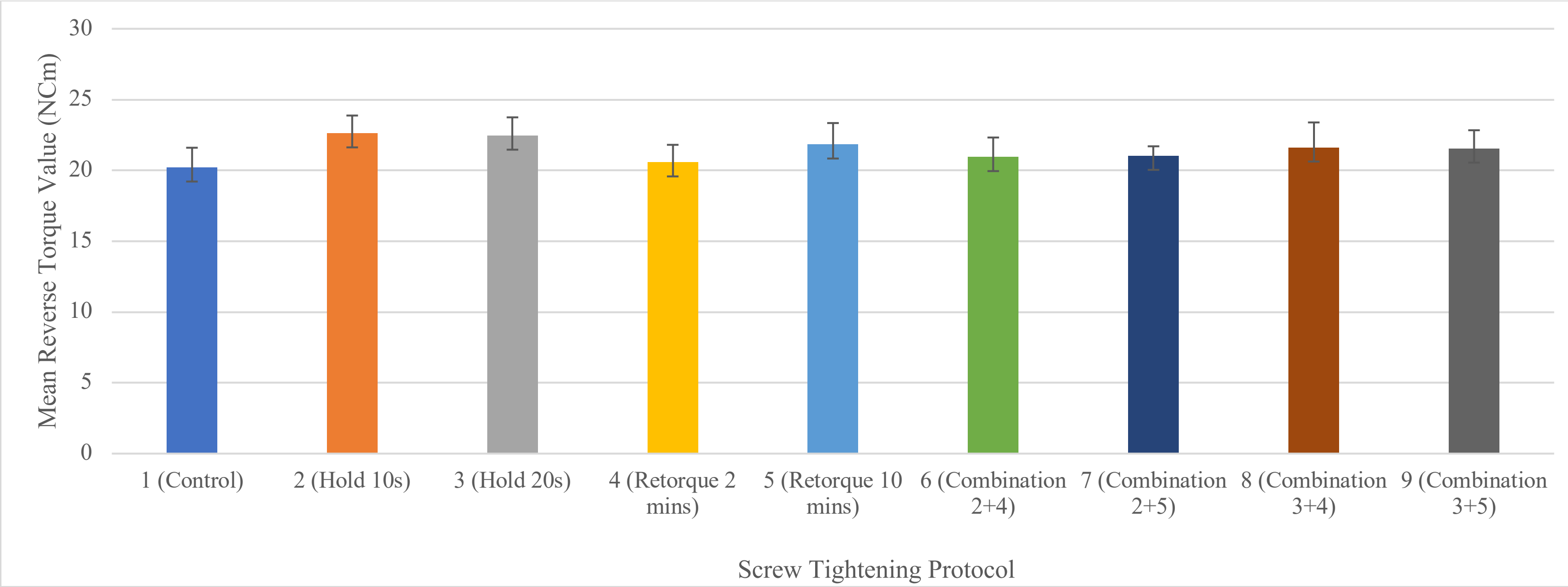

Figure 9. Graphical Representation of Mean and Standard Deviation for Reverse Torque Values of Each Tested Protocol

Table 4. Raw Data of Reverse Torque Values for All Samples Tested for Screw Tightening Protocols Listed in Ncm

Test Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	30.5	26.8	27.9	24.5	23.8	24.9	26.6	27.3	27.1
2	28.1	25.6	28.8	21.5	23.5	26.2	24.3	25.3	26
3	22.4	23.7	23	20.6	22.2	23.1	21.6	22.6	20.7
4	20.4	23.6	21.7	19.3	23.9	20.4	20.5	21.4	21.6
5	19.8	22.2	20.7	19.6	21.4	18.3	19.9	21	20.8
6	19.5	20.9	21.7	19.6	22.1	21.1	20.7	17.7	20
7	17.7	22.3	21.9	21.5	19	21.1	21.8	21.7	22.3
8	21.4	24.5	24.9	23	21.7	21.7	21.5	23.3	24
9	20.6	21.2	22.5	20.1	21	21.5	20.8	22.7	20.7
10	19.9	22.6	23.3	20.9	23.4	20.4	21.5	22.6	22.3

The mean values and standard deviations for the single screw retorque test is presented in Table 5 and graphically in Figure 10. Greatest mean reverse torque values were seen in the last tested sample at 25.82 Ncm and the lowest mean reverse torque values were seen in the first tested sample at 23.24 Ncm. None of the reverse torque values for any of the protocols were as high as the initial torque which was applied. Summary tables of the raw data for each sample can be found in Table 6.

Table 5. Mean Reverse Torque Values and Standard Deviations of Repeated Torque Tests on the Same Screw

Number of Torque Applications	Mean Reverse Torque Values (Ncm)	Standard Deviation
1	23.24	0.83
2	23.96	0.90
3	24.36	1.06
4	24.30	0.87
5	25.12	0.99
6	25.24	0.87
7	25.40	0.59
8	25.02	0.45
9	25.56	0.55
10	25.82	0.52

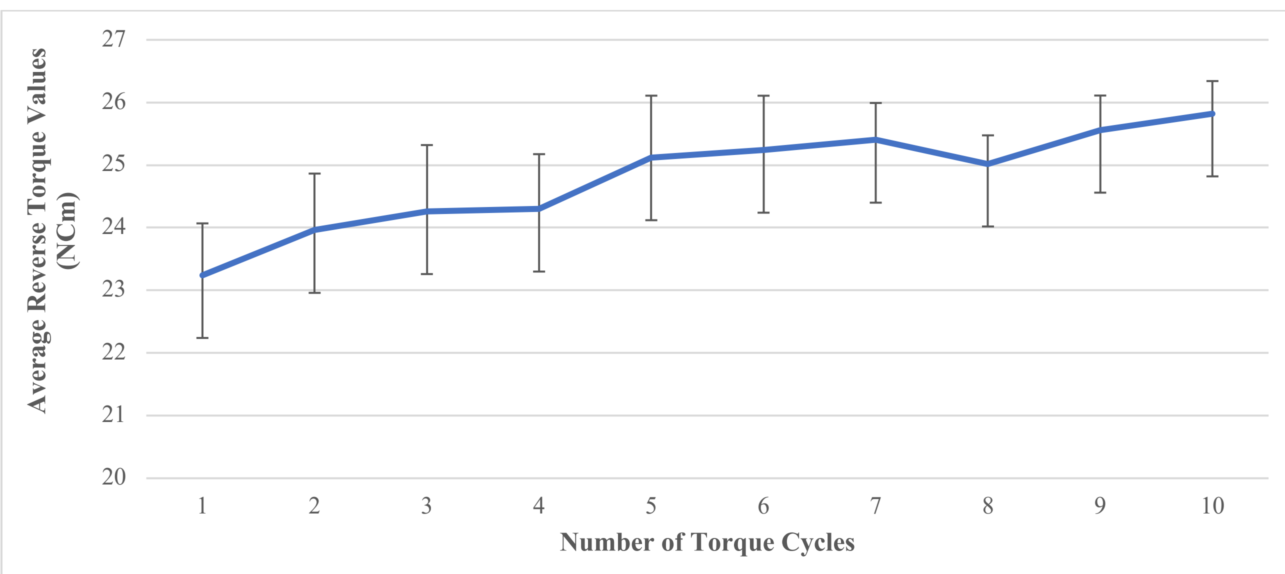

Figure 10. Graphical Representation of Mean and Standard Deviation for Reverse Torque Values of Repeated Torque Cycles

Table 6. Raw Data of Reverse Torque Values for All Samples Tested for Repeated Screw Tightening Cycles Listed in Ncm

Cycle Number	1	2	3	4	5
1	22.1	23.5	24.3	23.5	22.8
2	22.7	24.5	24.6	24.7	23.3
3	22.5	24.7	24.8	25.2	24.1
4	22.8	24.7	25	24.7	24.3
5	23.4	25.4	25.3	25.9	25.6
6	23.9	25	25.4	25.7	26.2
7	24.7	26.1	25	25.3	25.9
8	25	25.8	24.7	24.7	24.9
9	25.1	26.4	25.1	25.4	25.8
10	25.7	26	25	26.4	26

Statistical analysis using a mixed effects linear regression model was fit to the data set with the number of cycles as the fixed effect and a random intercept for each sample. There was a statistically significant (p-value = 0) correlation found where each extra cycle increased reverse torque by 0.252Ncm.

Chapter 4

Discussion

Screw Protocols

The first part of this study evaluated multiple different dental implant screw insertion protocols to determine if there was an ideal protocol for screw insertion. The results of the study show that there may be a statistically significant difference between the protocols, but a paired test could not prove that one protocol was significantly better than another one with the current amount of data. Thus, the null hypothesis is accepted. There was no relationship between the interval of time between screw tightening, nor was there a relationship between the time of maintenance of torque on the reverse torque values of the screws. A combination of the two experimental groups also resulted in no significant difference. The initial two data points were removed from statistical analysis due to being outlying data points. As the experiment was initially being conducted, there were variations in the actual performance of protocols that needed to be worked out which may cause errors in the data. As a result of conducting the experiment the first two times, the protocol and testing process was streamlined, and thus more consistent results were obtained for test numbers 3 to 10.

These results agree with the results of recent screw torque study as shown by Alnasser et al (2021) which showed no significant different in tightening the abutment screw 2 times with a 10-minute interval, no interval, or tightening it 1 time only. The previous authors did find an increase in reverse torque when a 3-time tightening cycle was used and this is something which could be investigated further in the future (Alnasser et al., 2021).

When it comes to retightening of the screw after a set amount of time to allow for embedment relaxation, our results differ from those of Siamos et al. which reported that retightening after 10 minutes increases the reverse torque values. Differences in results may be due to the material of the screws that were used, as well as the implant system and connection. Furthermore, a small sample size of n=2 may have accounted for differences in results (Siamos et al., 2002). The results also differ from that of Khalili and coworkers (2019) which found that retorquing after 10 minutes reduced the amount of torque loss compared to the control. Differences in study design and the fact that the implants were cyclically loaded in their study may play a factor when it comes to the amount of torque that is retained in the system (Khalili et al., 2019).

When it comes to maintenance of the torque to combat the settling effect, our results differed from that of Sella et al (2013) which found increased reverse torque values at 10 second maintenance and above. These differences may be due to differences in implant connection, screw materials, and abutments. Their study used an external hexagon connection which is known to be a less stable connection compared to an implant system with an internal connection which was used in our study (Sella et al., 2013). On the contrary, our results were similar to Al-Otaibi and coworkers (2018) who compared different maintenance protocols in a full arch implant supported fixed prosthesis model as well as Bacchi et al (2015) who also found no difference in a torque and hold for 20 seconds in an external hexagon model single implant model (Al-Otaibi et al., 2018; Bacchi et al., 2015) Anecdotally, during the testing of the samples, the main investigator who conducted the experiment found that in order to have maintenance of the screw torque at 35Ncm, a constant increase in force was needed. This would theoretically signal that some form of insertion torque was being lost as the maintenance was being held. Although this was not reflected throughout the results of the study, it does lead to further questions of why this may be occurring.

With regards to the connection of the implant system, to the best of the author's knowledge, there is no literature regarding the specific TriLobe connection design of the NobelReplace implant. This could account for differences between the results found in this study compared to other previous studies which either focused on internal hexagon, external hexagon, or conical connection implants. The current implant system tested was supplied with a final abutment screw which was fabricated from a titanium alloy screw (90% Ti, 6% Al, 4%V) which had a diamond-like carbon (DLC) coating. The low frictional resistance and excellent wear properties make it a useful material as a lubricant and protectant (Kim et al., 2005) As mentioned previously, the material of the screw is not exactly a choice made by the practitioner and the clinician is more so stuck with what the manufacturer uses to produce their screw.

A consistent finding throughout the literature, which was also shown in our results, was the decrease in reverse torque value from the insertion torque, regardless of the protocol which was used. This shows the nature of the system and the forces which are lost to embedment relaxation and the settling effect. From the first portion of this study, it appears that any screw tightening protocol can be used to achieve the same results with regards to the amount of preload left in the system. The author does believe that holding torque still improves the clamping force, although not shown in the statistical analysis.

Repeated Torque Tests

The second part of the study evaluated if retorquing the same screw multiple times over would have an effect on the reverse torque values. A significant result was found where a positive linear trend showing an increase in the reverse torque values over the 10 times the screw was torqued. Thus, the null hypothesis was rejected.

This part of the study was conducted using the protocol which showed the highest average reverse torque values from the first part of the study which was protocol #4 – 20 second torque maintenance. A logical explanation for what could be happening is the settling effect and embedment relaxation. There is flattening of any defects or irregularities between the surfaces of the screw and the internal portion of the implant. As the screw is held for 20 seconds each time, the defects between the two surfaces are compressed and smoothed, leading to future torque being purely transferred as preload to the system rather than being spent on flattening the two surfaces. When compared to the results of the study by Guzaitis et al (2019), they had found that the highest reverse torque values were seen in 9 or fewer insertion cycles. Their evaluation of the threads under SEM also showed most of the implant thread surface morphology changes occurred within the first 10 insertions leading to a more homogenous surface. This part of their results correlates similarly to ours and can help explain the increase in reverse torque values with a maximum value before 10 insertions. The authors continued to test the screw for further cycles up to 39 times and found a reduction in reverse torque values after the first 10 insertions and explained this through the decrease in friction between the surfaces as they became smoother (Guzaitis et al., 2011). Based on the observations from our test and theirs, there may be a possible peak number of insertions where the screw torque is maximized. This could be based on a specific amount of friction which is achieved after the smoothening of the surfaces from embedment relaxation but before the surfaces become too smooth where the dynamic friction begins to decrease. Further investigation regarding this topic should be investigated to see if there is a continuous trend or a drop-off point for the preload remaining in the system.

A lack of decrease in the loss of preload after multiple cycles of insertions could also be explained by the material of the screws. Titanium alloy screws as shown by Byrne and coworkers (2006) were able to be screwed multiple times without losing preload whereas gold screws lost preload after the first insertion torque (Byrne et al., 2006). Multiple other studies have shown the advantages of titanium alloys and its ability to achieve higher torque values than gold screws (Assunção et al., 2012; Byrne et al., 2006; Tsuge and Hagiwara, 2009). This is due to the material strength of the titanium alloy enabling it to not cause permanent deformation after it has been torqued. The study results would appear to differ if a gold screw had been cyclically torqued in the same protocol.

The second portion of the study infers that when using a titanium alloy screw, it can be removed and retorqued at least up to 10 times. As such, clinically, there is no need to replace the screw that is being used if the restoration must be removed for maintenance or a new restoration was to be fabricated.

Study Limitations

There are multiple study limitations that were encountered during this experiment. With regards to the first portion of the study regarding protocols, it would be ideal to have a new implant fixture torqued each time with a new implant screw. However, due to financial limitations, it was unrealistic to order 90 dental implants, and thus the decision was made to re-use each implant for the protocols that were tested. When the torque is being applied by the torque meter, there was no instrument to standardize the rate, or the angle which the torque was being applied. Torque to the implant screws was being applied by a single investigator by hand and small deviations were seen with regards to the amount of torque which could range from 34Ncm to 36Ncm, especially when torque was being held for maintenance time. This could possibly be solved in future studies with the use of an instrument such as the manual or motorized test stands by Mark-10 which enable locked positions and angles between the torque meter and implant screw head as well as a controllable rate of insertion torque (See Figure 11). The lack of consistent control could lead to increases in the standard deviation of the resulting data.

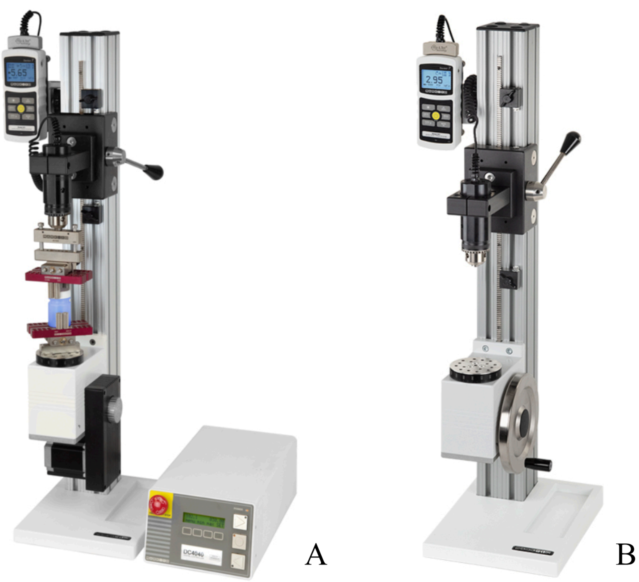

Figure 11. A. Mark-10 Series TSTM-DC Motorized Torque Test Stand **B.** Mark-10 Model TST Manual Torque Test Stand

With regards to the second portion of the study, one limitation was the re-use of 5 of the initial implants that were used in protocol testing portion. It is possible that the internal threading of these 5 implants had already been flattened a slight amount from the previous testing procedures which were applied in the first segment. Secondly, the 5 screws that were tested and retested had each been torqued once prior, once again, in the first portion of the study. Both these factors may play a role in the results of the study.

Future Recommendations

In the future, it would be beneficial to be able to test the screws and determine the reverse torque values after cyclic loading. This would help simulate a more applicable clinical environment where the implant restorations will be under function and then test the amount of preload that is remaining in the system. Another recommendation would be to have SEM images of the threads of the implants as well as the internal threading of the implants. This would allow for proof of if there was any embedment relaxation and actual physical changes occurring on the surfaces to justify and explain what is occurring with the trends in reverse torque values.

Both these tests could also be applied to other implant restorations. This includes testing multi-unit screws on multi-unit abutments, screws on angulated screw channels at different angles, or screws on non-engaging vs. engaging abutments. Alternating the platform of the implant is another variable that can be investigated. The repeated screw test can especially be applicable for multi-units since the prosthesis is often removed and replaced for maintenance or repair.

Chapter 5

Conclusions

The results of this study highlight that specific screw tightening protocols may not have an impact on the amount of preload that is maintained within the implant screw assembly. Within the limitations of this study, the following conclusions can be drawn.

- The maintenance of screw torque did not yield statistically significant differences in reverse torque values
- The retorquing of screws at various times did not yield statistically significant differences in reverse torque values
- A combination of maintenance and retorquing screw did not yield statistically significant differences in reverse torque values
- Retorquing a single screw may lead to the benefit of an increase in the reverse torque values

All torquing protocols were comparable with regards to how much the reverse torque values were from the implant system. When using a single titanium alloy screw, the reverse torque values may increase with multiple uses.

Hypotheses Revisited

H_{01}: Using a tightening technique that includes torque maintenance has no effect on the abutment screw torque.

- No statistically significant differences were found with torque maintenance and the controls investigated
- **Null hypothesis accepted**

H_{02}: Using a tightening technique that includes abutment screw retightening has no effect on the abutment screw torque.

- No statistically significant differences were found with screw retightening and the controls investigated
- **Null hypothesis accepted**

H_{03}: Multiple cycles of closing and opening on an abutment screw has no effect on the abutment screw torque.

- There was a statistically significant increase after multiple cycles of closing and opening on the abutment screw torque
- **Null hypothesis rejected**

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Appendix 1. Journal Article Manuscript for Journal of Prosthodontics

Title: The Effects of Screw Torque Maintenance and Re-applying Screw Torque on the Retention of Implant Abutment Screws in Single Implant Restorations

Running Title: Implant Abutment Screw Torque

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Abstract

The Effects of Screw Torque Maintenance and Re-applying Screw Torque on the Retention of Implant Abutment Screws in Single Implant Restorations Abstract

Purpose: To investigate if screw tightening protocol modification through torque maintenance or abutment screw retightening on an internal Tri-lobe connection implant influences abutment screw reverse torque values (RTV). To also investigate if torquing and retorquing the same implant screw has an influence on the RTV of the screw.

Methods: Nine implants with an internal Tri-lobe connection (Nobel Replace Select, Nobel Biocare) were placed in cold-cure acrylic (ProBase Cold, Ivoclar) to simulate bone and a final abutment (Esthetic Abutment NobelReplace RP, Nobel BioCare) was inserted. Nine screw tightening protocols were tested: 1) torque to 35Ncm, 2) hold torque for 10 seconds, 3) hold torque for 20 seconds, 4) retorque at 2 minutes, 5) retorque at 10 minutes, 6) hold torque for 10 seconds and retorque at 2 minutes, 7) hold torque for 10 seconds and retorque at 10 minutes, 8) hold torque for 20 seconds and retorque at 2 minutes, 9) hold torque for 20 seconds and retorque at 10 minutes. Peak RTVs were measured after 30 minutes using a torque meter (MTT03-05, Mark-10). Each implant screw was changed after each insertion with 10 total screws used per implant. After determining the protocol with the highest average RTV, the specific protocol was used to evaluate if cycles of insertion on a single screw would have an impact on the reverse torque values. Five implants were used with the same five abutments. A single screw was torqued with the specified protocol and de-torqued after 30 minutes with the RTV measured. This was conducted another nine times over for a total of 10 cycles.

Results: Protocol 2 (holding torque for 10s) had the highest average reverse torque value of 22.63Ncm and the Protocol 1 (control) had the lowest at 20.21Ncm with no statistically significant difference. A statistically significant trend was seen in the RTV over the number of insertion cycles with each insertion cycle showing an increase by 0.252Ncm.

Conclusion: Implant screw tightening protocols do not influence the reverse torque values. Multiple insertions of an implant screw may increase the reverse torque value.

KEYWORDS: Dental Implant, Reverse Torque

Introduction:

The use of dental implants of both single and multiple units has transformed the way clinicians approach the restoration of edentulous sites.[1] Multiple studies have evaluated the rates of implant complications and one of the most commonly occurring complications is abutment screw loosening[2]. There are many factors that may increase the risk of screw loosening including off-axis load, increased occlusal loads, large cantilever prosthesis, as well as poor manufacturing and fit.[3,4] Throughout the years of dental implant use, advances in research and technology have helped to decrease the rate of screw loosening. This includes using improved materials for the screw, lubrication of the screw surface, improved connections between the prosthetics and the implant fixture, among other things.[5]

The screw joint comprises of the screw which clamps together the abutment to the implant fixture.[6] The screw loosens only when external forces, known as separating forces, are greater than the force keeping the screw joint together, known as clamping forces.[5-9] Therefore, separating forces should remain below the threshold of the clamping force and there should be enough tension placed on the joint to prevent separation from any masticatory forces that may occur. The tension applied is usually proportional to the tightening torque.[10] When too small of a force is applied, there is a risk of screw loosening and separation of the joint, however when too large of a force is applied, there is a risk of screw fracture or stripping of screw threads.[10] Since there is no perfect manufacturing process that can create two perfectly smooth surfaces, embedment relaxation (also known as the settling effect) occurs where the rough areas of the screw are flattened leading to a reduction in preload.[8, 11, 12] The flattening of the surfaces require energy which is transferred from the force that was applied, this decreases the total amount of force remaining to clamp the screw joint. Multiple methods have been proposed to deal with the decrease in preload due to the settling effect. Previous studies have recommended retightening the screw after 10 minutes to account for the settling effect as well as holding the screw torque for certain periods of time during torque application.[10, 11, 13-15] Some issues have been raised with regards to the number of times a prosthetic screw may be tightened. A previous study has shown that the highest reverse torque values were seen in 9 or fewer insertion cycles and recommended a new screw after 10 cycles.[16]

Although studies have reported on these methods of trying to reduce the effect of embedment relaxation, most were conducted on external hexagon implant connections. [10, 13, 15] Currently many clinicians and manufacturers are using implants with internal connections with or without some form of conical connection to improve abutment-implant stability and decrease micromovement. The purpose of this study was to investigate if screw tightening protocol modification through torque maintenance or abutment screw retightening on an internal Tri-lobe connection implant influences abutment screw reverse torque values as well as if multiple closing and opening cycles on the screw influences reverse torque values on single implant abutments.

Materials and Methods:

To fabricate an acrylic holder for the implants, a three-compartment tray design was 3D printed using a Formlabs Form 3B printer in the available Dental Model Resin v2 (Formlabs) following manufacturer's recommendations for washing and curing. Nine dental implants (Replace Select, Nobel Biocare) were used for the test samples. The length of the implants varied; however, the platform of all implants is identical (Nobel RP 4.3mm). Clear cold-cure acrylic resin (Probase Cold, Ivoclar Vivadent Inc) was mixed and slowly poured into a single compartment of the tray on a vibrator (Heavy Duty Vibrator, Whip Mix). Dental implants were embedded into acrylic resin in groups of three; one group of three for each compartment of the fabricated tray. A stock anterior implant abutment (Esthetic Abutment NobelReplace RP 1 mm, Nobel BioCare) was placed on each implant for testing with the implant screw.

A total of 90 dental implant abutment screws (Replace Select RP Abutment Screw, Nobel BioCare) compatible with the dental implants were obtained. A total of nine protocols were tested: one control group and eight test groups. A digital torque meter (MTT03-50, Mark-10) was used to apply torque to the implant screw as well as to record the removal torque of the implant screw. A screwdriver tip for the Nobel Implant (UniGrip 25mm, Nobel BioCare) was inserted on to the digital torque meter which has a Jacob's chuck attachment. Using the provided tool from Mark-10, the screwdriver tip was tightened to ensure no movement within the torque meter. The manufacturer's recommended screw torque was 35Ncm. If torque was to be maintained, the digital torque wrench was held at 35Ncm for the required time. If torque was to be reapplied, the screw was torqued again to 35Ncm after the specified amount of time. Details of each protocol can be seen in Table 1. After 30 minutes from the completion of the insertion torque protocol, the implant screws were reverse torqued using the same digital torque driver which would record the peak reverse torque value.

To test if multiple closing and opening cycles affected the implant reverse screw torque, implants numbered 1 to 5 were used. A single screw was placed into each of the abutment/implant assemblies and a torque maintenance of 20 seconds was used as the applied protocol. After 30 minutes from torque application, the implant screw was removed, and the reverse torque value recorded. The same screw was then retightened with the same protocol. This was repeated nine times, leading to a total of ten cycles of torque application and removal for each implant screw.

Results:

The raw values for the reverse torque values of each protocol are presented in Table 2. The first sample data point of the experiment appeared to be different from the remaining data set. Statistical analysis using a t-test of the first sample point with the second sample point was not statistically different. However, both the first and second sample points were different from the remaining 3 – 10 sample points and thus were excluded from further analysis. This data is presented in Table 3 and graphically in Figure 2 with updated values where Protocol 2 (holding torque for 10s) had the highest average reverse torque value of 22.63Ncm and the Protocol 1 (control) had the lowest with 20.21Ncm.

Based on the one-way ANOVA test on the remaining data, there was a statistically significant difference between protocols ($p=0.00661$). A standard error comparison of the pairwise difference between protocols 1 and 2, which were the least and greatest values respectively, was 1.28 with a confidence interval of the difference being (-0.10, 4.93) and not enough to prove statistical significance. More data is required to definitively prove that one protocol is better than another.

The mean values and standard deviations for the single screw retorque test is presented in Table 4 and graphically in Figure 3. Greatest mean reverse torque values were seen in the last tested sample at 25.82Ncm and the lowest mean reverse torque values were seen in the first tested sample at 23.24Ncm. None of the reverse torque values for any of the protocols were as high as the initial torque which was applied. Statistical analysis using a mixed effects linear regression model was fit to the data set with the number of cycles as the fixed effect and a random intercept for each sample. There was a statistically significant (p-value = 0) correlation found where each extra cycle increased reverse torque by 0.252Ncm.

<u>Discussion:</u>

The first part of this study evaluated multiple different dental implant screw insertion protocols to determine if there was an ideal protocol for screw insertion. The results of the study showed that there may be a statistically significant difference between the protocols, but a paired test could not prove that one protocol was significantly better than another one with the current amount of data. Thus, the null hypothesis is accepted. There was no relationship between the interval of time between screw tightening, nor was there a relationship between the time of maintenance of torque on the reverse torque values of the screws. A combination of the two experimental groups also resulted in no significant difference. The initial two data points were removed from statistical analysis due to being outlying data points.

Our results differ from previous studies which showed retightening increased reverse torque values.[7, 10] Differences in study design and the fact that the implants were cyclically loaded in their study may play a factor when it comes to the amount of torque that is retained in the system.

When it comes to maintenance of the torque to combat the settling effect, our results differed from that of Sella et al. which found increased reverse torque values at 10 second maintenance and above[15]. These differences may be due to differences in implant connection, screw materials, and abutments. Their study used an external hexagon connection which is known to be a less stable connection compared to an implant system with an internal connection which was used in our study.[15] On the contrary, our results were similar to Al-Otaibi and coworkers who compared different maintenance protocols in a full arch implant supported fixed prosthesis model as well as Bacchi et al. who also found no difference in a torque and hold for 20 seconds in an external hexagon model single implant model.[11, 13]

With regards to the connection of the implant system, to the best of the authors' knowledge, there is no literature regarding the specific TriLobe connection design of the NobelReplace implant. This could account for differences between the results found in this study compared to other previous studies which either focused on internal hexagon, external hexagon, or conical connection implants. The current implant system tested was supplied with a final abutment screw which was fabricated from a titanium alloy screw (90% Ti, 6% Al, 4%V) which had a diamond-like carbon (DLC) coating. The low frictional resistance and excellent wear properties make it a useful material as a lubricant and protectant.[17] A consistent finding throughout the literature, which was also shown in our results, was the decrease in reverse torque value from the insertion torque, regardless of the protocol which was used. This shows the nature of the system and the forces which are lost to embedment relaxation and the settling effect.

There was a positive linear trend showing an increase in the reverse torque values over the 10 times the screw was torqued. An explanation for what could be happening is the settling effect and embedment relaxation. There is flattening of any defects or irregularities between the surfaces of the screw and the internal portion of the implant. As the screw is held for 20 seconds each time, the defects between the two surfaces are compressed and smoothed, leading to future torque being purely transferred as preload to the system rather than being spent on flattening the two surfaces. When compared to the results of the study by Guzaitis et al., they had found that the highest reverse torque values were seen in 9 or fewer insertion cycles. Their evaluation of the threads under SEM also showed most of the implant thread surface morphology changes occurred within the first 10 insertions leading to a more homogenous surface. This part of their results correlates similarly to ours and can help explain the increase in reverse torque values with a maximum value before 10 insertions. The authors continued to test the screw for further cycles up to 39 times and found a reduction in reverse torque values after the first 10 insertions and explained this through the decrease in friction between the surfaces as they became smoother.[16] Based on the observations from our test and theirs, there may be a possible peak number of insertions where the screw torque is maximized. This could be based on a specific amount of friction which is achieved after the smoothening of the surfaces from embedment relaxation but before the surfaces become too smooth where the dynamic friction begins to decrease. Further investigation regarding this topic should be investigated to see if there is a continuous trend or a drop-off point for the preload remaining in the system.

A lack of decrease in the loss of preload after multiple cycles of insertions could also be explained by the material of the screws. Titanium alloy screws as shown by Byrne and coworkers were able to be screwed multiple times without losing preload whereas gold screws lost preload after the first insertion torque.[18] Multiple other studies have shown the advantages of titanium alloys and its ability to achieve higher torque values than gold screws.[18-20] This is due to the material strength of the titanium alloy enabling it to not cause permanent deformation after it has been torqued. The study results would appear to differ if a gold screw had been cyclically torqued in the same protocol.

One limitation of the study was that torque to the implant screws was being applied by a single investigator by hand and small deviations were seen with regards to the amount of torque which could range from 34Ncm to 36Ncm, especially when torque was being held for maintenance time. This could possibly be solved in future studies with the use of an instrument such as the manual or motorized test stands which enable locked positions and angles between the torque meter and implant screw head as well as a controllable rate of insertion torque. Another limitation was the re-use of dental implants instead of having a new dental implant for each screw. In the future, it would be beneficial to be able to test the screws and determine the reverse torque values after cyclic loading. This would help simulate a more applicable clinical environment where the implant restorations will be under function and then test the amount of preload that is remaining in the system.

Conclusion:

The results of this study highlight that specific screw tightening protocols may not have an impact on the amount of preload that is maintained within the implant screw assembly. All torquing protocols were comparable with regards to how much the reverse torque values were from the implant system. When using a single titanium alloy screw, the reverse torque values may increase with multiple uses.

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Figures and Tables:

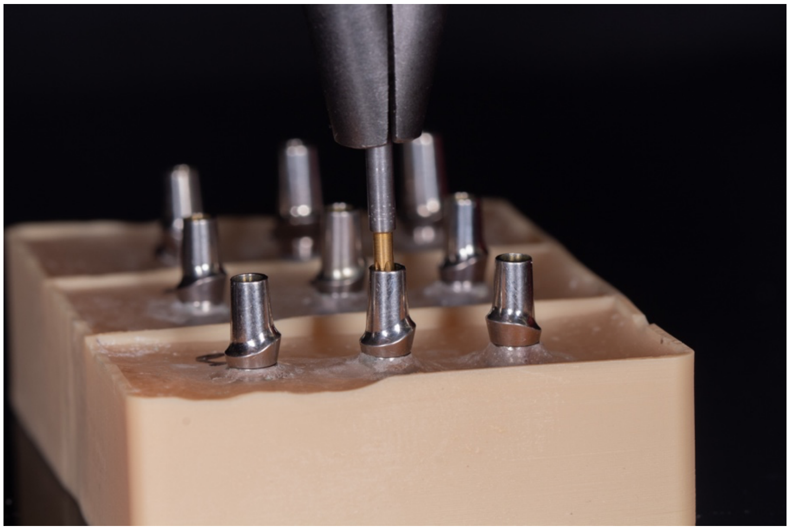

Figure 1. Visualization of how torque was applied to the system.

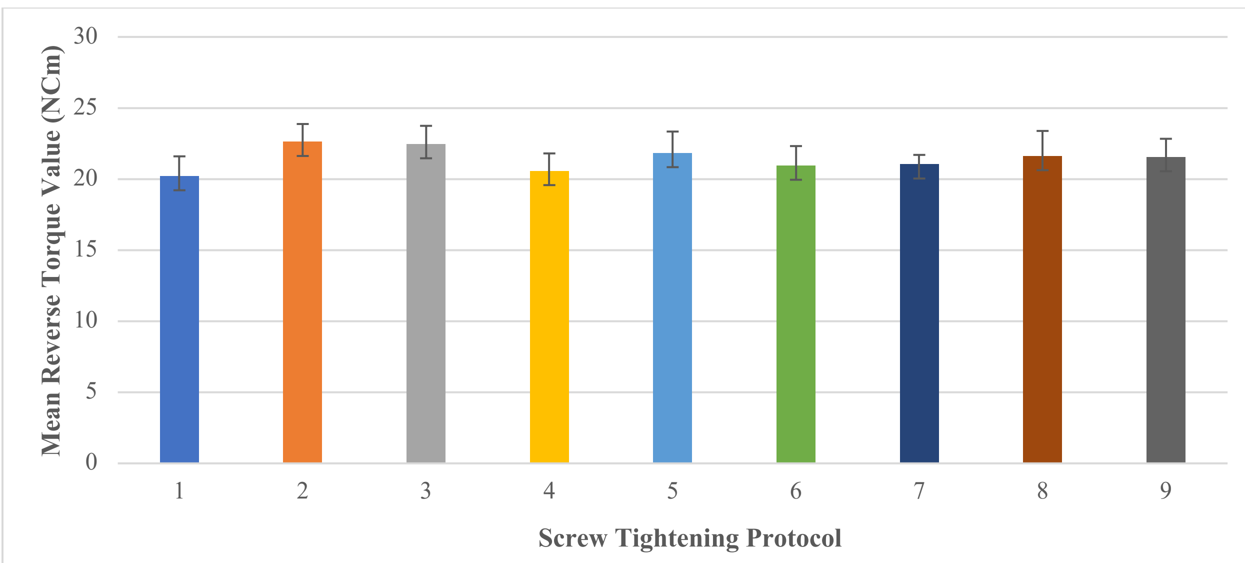

Figure 2. Graphical Representation of Mean and Standard Deviation for Reverse Torque Values of Each Tested Protocol

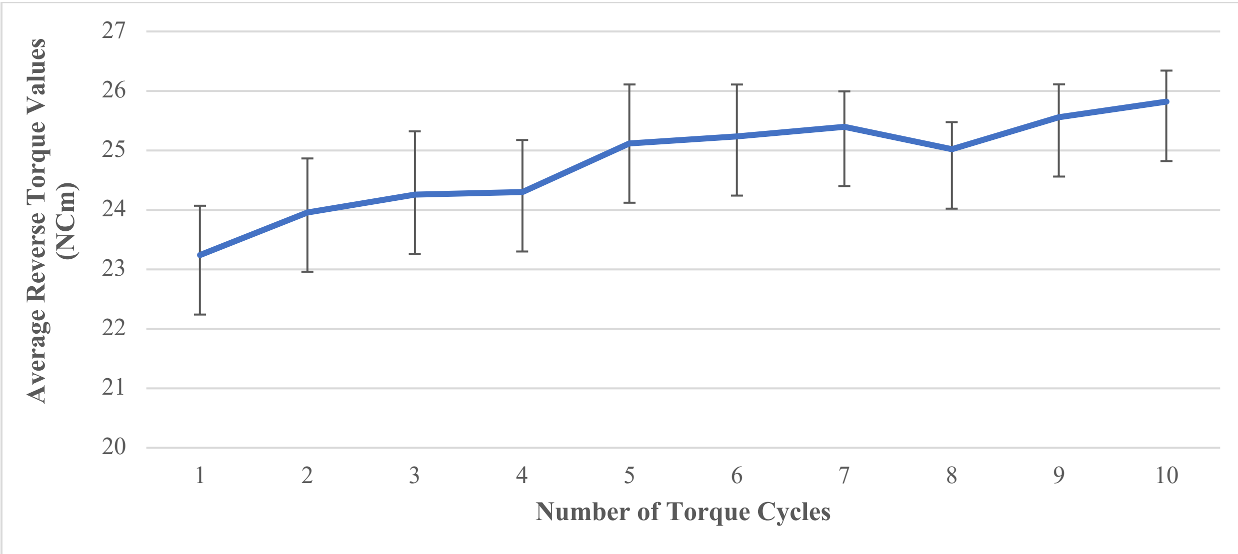

Figure 3. Graphical Representation of Mean and Standard Deviation for Reverse Torque Values of Repeated Torque Cycles

Table 1. Protocols for Torquing Implant Screws

	Torque Maintenance	**Retightened**
1 (Control)	N/A	N/A
2 (Hold 10s)	10 seconds	N/A
3 (Hold 20s)	20 seconds	N/A
4 (Retorque 2 mins)	N/A	2 minutes
5 (Retorque 10 mins)	N/A	10 minutes
6 (Combination 2+4)	10 seconds	2 minutes
7 (Combination 2+5)	10 seconds	10 minutes
8 (Combination 3+4)	20 seconds	2 minutes
9 (Combination 3+5)	20 seconds	10 minutes

Table 2. Raw Data of Reverse Torque Values for All Samples Tested for Screw Tightening Protocols Listed in Ncm

Test Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	30.5	26.8	27.9	24.5	23.8	24.9	26.6	27.3	27.1
2	28.1	25.6	28.8	21.5	23.5	26.2	24.3	25.3	26
3	22.4	23.7	23	20.6	22.2	23.1	21.6	22.6	20.7
4	20.4	23.6	21.7	19.3	23.9	20.4	20.5	21.4	21.6
5	19.8	22.2	20.7	19.6	21.4	18.3	19.9	21	20.8
6	19.5	20.9	21.7	19.6	22.1	21.1	20.7	17.7	20
7	17.7	22.3	21.9	21.5	19	21.1	21.8	21.7	22.3
8	21.4	24.5	24.9	23	21.7	21.7	21.5	23.3	24
9	20.6	21.2	22.5	20.1	21	21.5	20.8	22.7	20.7
10	19.9	22.6	23.3	20.9	23.4	20.4	21.5	22.6	22.3

Table 3. Mean Reverse Torque Values and Standard Deviation for Screw Torque Protocols

	Mean Reverse Torque Values (Ncm)	**Standard Deviation**
1 (Control)	20.21	1.39
2 (Hold 10s)	22.63	1.25
3 (Hold 20s)	22.46	1.28
4 (Retorque 2 mins)	20.58	1.23
5 (Retorque 10 mins)	21.84	1.51
6 (Combination 2+4)	20.95	1.37
7 (Combination 2+5)	21.04	0.66
8 (Combination 3+4)	21.63	1.76
9 (Combination 3+5)	21.55	1.28

Table 4. Mean Reverse Torque Values and Standard Deviations of Repeated Torque Tests on the Same Screw

Number of Torque Applications	Mean Reverse Torque Values (Ncm)	Standard Deviation
1	23.24	0.83
2	23.96	0.90
3	24.36	1.06
4	24.30	0.87
5	25.12	0.99
6	25.24	0.87
7	25.40	0.59
8	25.02	0.45
9	25.56	0.55
10	25.82	0.52