Assessment of Efficacy of Implant Screwdrivers' During Multiple Tightening/ Untightening Cycles. An *in vitro* Study

ABSTRACT

Introduction: It is unclear the number of times a screwdriver may be reused without loosening its efficacy or inducing damage to implant screws while keeping appropriate torque values. Objective: Evaluate the effect of the screwdriver and internal threads on the tightening efficacy by assessing the reverse torque value (RTV). Methods: The efficacy was tested with four groups of screws: two titanium groups and two gold-platted (n=5). Each screw was tightened 10 times at 20 Ncm using the screwdriver attached to ISD900 (NSK®). In the first protocol one implant was used for the five screws. In the second protocol for each screw a new implant was used. At each untightening, the RTV was measured and recorded. Results: RTVs for Gold were statistically lower compared to the Titanium. The RTVs differed among the tested screws. In the first protocol, the first serie tightening/untightening differed statistically from the last three series. Conclusion: Titanium screws from Zimmer Biomet achieve better RTV than gold-platted. By increasing the number cycles it is expected to have a decrease in the RTV. The extensive use of screwdrivers and the internal threads of the dental implants might be factors influencing the loss of RTV.

Keywords

Torque
Denture
Dental Implants
Dental Materials
Prosthesis
Biomedical

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INTRODUCTION

Fixed implant-supported prostheses are held in place by an implant-abutment screw joint. One of the keys to successful long-term implant restorations is the stability of the implant-abutment connection. The tension or torque applied to the retaining screw inside the threaded joint generates a force that promotes the elongation of the screw, creating the preload[1]. Torque may be defined as a measurable means of developing tension in a screw joint[2]. Thus, tightening involves the application of torque. Every screw design has a specific preload/torque relationship depending on the material used in the screw and the design of the screw body and head[2]. The torque (T) and the friction coefficient (Fc) between the screw and the implant connection directly affect the preload (preload = T x Fc). The higher the preload, the more difficult it will be to separate both structures—abutment and implant[2].

If outside forces are greater than the screw's ability to keep the units tight, the screw joint will fail and get loose. Screw loosening is the most common implant prosthetic complication, accounting for approximately 33% of all

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post-implant prosthodontic complications [3-5]. Loosening causes a microgap that allows bacterial migration from the abutment to the peri-implant tissues. Moreover, the micromovement caused by loosening acts like a pump inside the implant toward the surrounding tissues[6]. Multiple abutment disconnections significantly affect marginal bone loss[7], with micromovement playing a major role[8]. Several factors may cause abutment screw loosening, including, among others, excessive loading, poor screw design, and inadequate torque application.

There are several studies on screw threads, torque application on screws, screw joints, and deformation of screw heads[9-11]. Similar investigations should be conducted for the screwdrivers responsible for transmitting the torque to the screw. Usually, manufacturers make screwdrivers out of titanium alloy and screws out of titanium or gold-plated titanium, aiming at preventing screw head deformation and stripping for a longer service life[5]. However, this is not ideal since the screwdriver is easier to replace than the deformed prosthetic screw[5].

The chemical inalterability of gold, along with its resistance to pathogenic colonization, made these devices more successful than any other competing material, over the centuries. Since the old Egyptian civilization gold have been widely used as an oral biomaterial. More recently oral appliances evolved to advanced cobalt alloys and polymer formulations[12]. Titanium implants were discovered accidently by Professor Branemark in the 60s while investigating blood microcirculation. Since then it has been extensively used for prosthodontic and restorative purposes. Titanium can be found in different grades. A variety of elements can be added to titanium, composing titanium grade 5. Grade 5 refers to the three combinations of aluminum (Al) and vanadium (V). An alloy with aluminum and vanadium, for example, will increase the material hardness[13].

If we follow the manufacturers' recommendations, a used screw head deformation will not significantly differ from a new one[8]. However, it is still unclear the number of times a screwdriver may be reused without losing its efficiency or inducing increased damage to screws while keeping appropriate torque values. Moreover, it is still unclear the influence of the internal threads of the dental implant that engages the abutment-screw on the tightening efficacy.

The aim of this study was to evaluate the effect of the screwdriver and dental implant on the tightening/untightening efficacy during multiple cycles by assessing the reverse torque value (RTV). The following hypotheses were tested: Null hypothesis 1 (H01) – The screw untightening RTV will not differ between the two types of screws (titanium and gold) and respective screwdrivers; Null hypothesis 2 (H02) - The screw untightening RTV will not differ among the 20 tested screws; Null hypothesis 3 (H03) - The screw untightening RTV will not differ throughout all the series (10 cycles of tightening the screw at 20 Ncm and untightening it); Null hypothesis 4 (H04) – The repeated use of a dental implant does not influence the RTV.

MATERIALS AND METHODS

This study used eight identical hexagonal screwdrivers (Zimmer Biomet®, USA), twelve 4.1x11.5 internal-connection implant (ref. BOST411, Zimmer Biomet®), ten titanium screws (ref. IUNIHT, Zimmer Biomet®) (Group Ti1 and Ti2), and ten gold-plated screws (ref. IUNIHG, Zimmer Biomet®) (Group Gold1 and Gold2). Two screwdrivers were used per group, one for tightening and the other for untightening. Each screw had a series of 10 tightening/untightening cycles with 10-minute intervals between cycles[14]. Tightening was performed at 20 Ncm—the torque recommended by the manufacturer. After tightening, the screw was untightened, and the RTV was measured and recorded. For each group, the tightening series of one screw was finished before moving to the next one. In the first protocol, one implant was used for each group, titanium and gold-platted *(Figure 1)*. In the second protocol for each new screw a new implant was used for the tightening/untightening *(Figure 2)*.

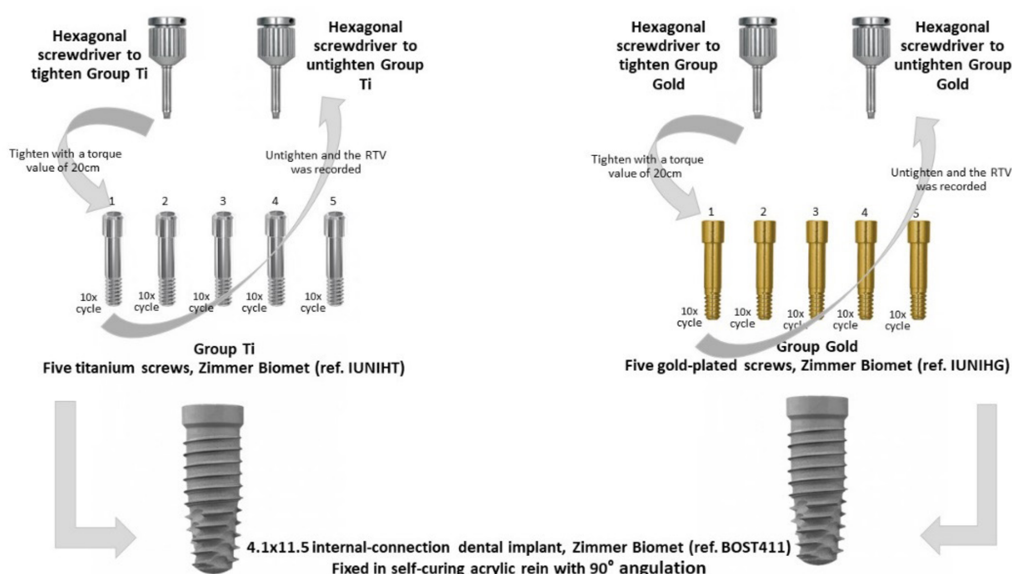

Figure 1: Protocol 1 scheme.

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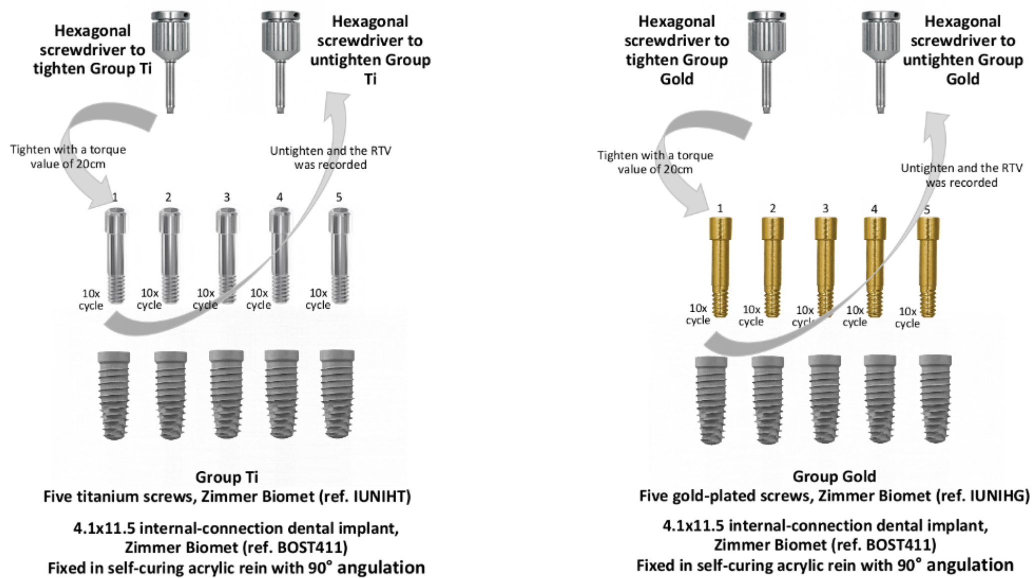

Figure 2: Protocol 2 scheme.

Each implant was fixed in self-curing acrylic resin (Vertex®, Vertex Dental Bv, The Netherlands) with a 90° angulation. The tightening was performed with the screwdriver attached to the ISD900 handpiece (NSK®, Japan), which was calibrated[14] before each new screw *(Figure 3)*. For the untightening, the screwdriver was used attached to a digital torque wrench (Tapha Tools, Taiwan) which as calibrated by ISQ prior to this experiment. Electronic torquemeters were used to reduce bias from hand-related inconsistencies and operator variability (gender and body mass index). Both operations were executed by a single operator[15,16].

Figure 3: a) Implant fixed in self-curing acrylic; b) Screwdriver used to untighten and determine the RTV.

All recorded RTVs were considered variables and were organized in IBM SPSS Statistics® version 27 for further statistical analysis. All groups underwent descriptive statistics analysis and normal distribution tests, such as the Kolmogorov-Smirnov and the Shapiro-Wilk. An independent t-test with an alpha value of 0.05 was performed to compare two samples and test H01. The one-way ANOVA with an alpha value of 0.05 was used to compare multiple samples and test H02 and H03. Then, the Bonferroni post-hoc test was conducted to compare sample by sample.

RESULTS

RTVS ANALYSIS REGARDING THE TYPE OF SCREW

By following the same torque protocol for Group Ti and Gold the mean RTV was 17.18 Ncm and 13.23 Ncm, respectively. Additionally, the minimum and maximum RTV were higher in the Group Ti *(Table 1 and Figure 4)*.

Independent t-test revealed that the RTVs of Group Gold were statistically different from Group Ti ($p < 0.05$).

When testing null hypothesis 1 (The screw untightening RTV will not differ between the two types of screws (titanium and gold) and respective screwdrivers), the behavior of the screws in the tightening/untightening cycles varied between screw types. The gold-plated screws showed statistically lower RTVs in the untightening than the Ti screws. Thus, null hypothesis 1 was rejected.

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Table 1. Descriptive statistics of the screws' reverse torque (Ncm) regarding their type (titanium and gold).

Groups:	Mean	Std. Deviation	Median	Minimum	Maximum
Ti (n=100)	17.18	2.585	17.00	7.30	24.00
Gold (n=100)	13.23	1.711	13.20	8.30	16.70

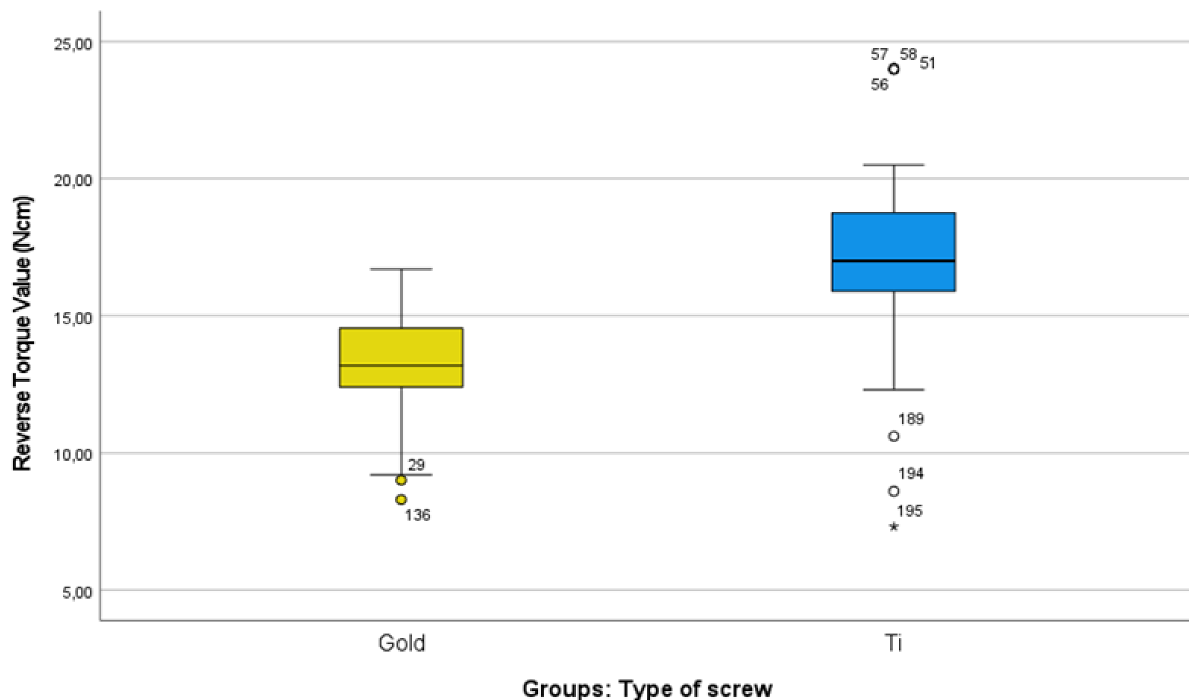

Figure 4: Box-plot chart of the Groups Ti and Gold.

RTVS ANALYSIS REGARDING THE 20 TESTED SCREWS.

By following the same torque protocol for each screw, it was possible to verify all the Ti screws showed higher RTV's means than the Gold screws *(Table 2 and Figure 5*). For both protocols the first Ti screw had the highest RTV. Only in the first protocol it was the first was statistically different from the rest of the screws. One-way Anova revealed that the RTV differed among the 20 tested groups (p. < 0.001).

Null hypothesis 2 was rejected since the 20 screws showed statistically differences regarding their RTV.

RTVS ANALYSIS REGARDING THE TEN SERIES

When it was grouped the screws depending on the series and independently of the material, it was observed higher RTV for the first series and a tendency to decrease *(Table 3 and Figure 6*). One-way Anova revealed that the RTVs differed statistically among the ten series tested (p. < 0.001). In the first protocol, Series 1 was statistically similar for Series 2, but statistically different from the rest of the Series. In the second protocol there were no statistically differences between series.

Null hypothesis 3 was partial rejected (The screw untightening RTV will not differ between series). Null hypothesis 4 was rejected. When used the same implant the five series showed statistically differences independently of have been used new screws for each serie. When performing tightening/untightening cycles with new screws and dental implants, RTV did not differ statistically between series.

DISCUSSION

When torquing a screw, energy is consumed in smoothing surface irregularities to preserve assembly connectivity. Subsequently thread engagement, the rough surface is flattened, and an additional torque is applied toward the extension of the screw and induction of preload[17]. Additionally, the tightening causes tension called preload at the threaded joints, followed by an elastic recovery[1]. The combination of these forces at the joint level results in a tightening force that keeps the interface abutment-implant together. On the other hand, an opposite force exists causing the untightening of the screw when it supplants the tightening force, or even leading to the loss of preload when too excessive[2]. The hardness of the material and the surface roughness are the two main factors that determine and increase the coefficient of friction. The

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Table 2. Descriptive statistics of the 20 screws' reverse torque (Ncm) after 10 cycles of tightening at 20 Ncm and untightening.

Groups	Mean	Std. Deviation	Median	Minimum	Maximum
Ti1 - Screw 1 (n=10)	20.30	3.368	19.50	16.00	24.00
Ti1 - Screw 2 (n=10)	17.39	1.480	17.10	15.60	20.00
Ti1 - Screw 3 (n=10)	16.10	0.346	16.20	15.30	16.50
Ti1 - Screw 4 (n=10)	16.45	1.090	16.10	15.30	18.30
Ti1 - Screw 5 (n=10)	15.76	1.141	15.55	13.40	17.30
Gold1 - Screw 1 (n=10)	14.51	0.950	14.95	12.90	15.90
Gold1 - Screw 2 (n=10)	12.79	1.429	12.75	11.00	14.50
Gold1 - Screw 3 (n=10)	12.58	1.513	12.65	9.00	15.00
Gold1 - Screw 4 (n=10)	12.22	1.090	12.45	10.40	14.00
Gold1 - Screw 5 (n=10)	12.00	1.102	12.40	9.20	13.00
Ti2 - Screw 1 (n=10)	18.41	0.774	18.40	16.80	19.80
Ti2 - Screw 2 (n=10)	16.77	1.695	16.40	14.90	19.80
Ti2 - Screw 3 (n=10)	17.48	2.286	18.40	12.30	20.00
Ti2 - Screw 4 (n=10)	16.37	2.828	17.20	10.60	19.20
Ti2 - Screw 5 (n=10)	16.80	4.774	18.55	7.30	20.50
Gold2 - Screw 1 (n=10)	14.51	1.367	14.90	11.50	15.90
Gold2 - Screw 2 (n=10)	14.88	1.283	15.05	12.00	16.70
Gold2 - Screw 3 (n=10)	13.93	0.710	14.05	12.70	15.10
Gold2 - Screw 4 (n=10)	11.25	1.770	11.35	8.30	14.00
Gold2 - Screw 5 (n=10)	13.62	1.472	13.30	10.70	15.40

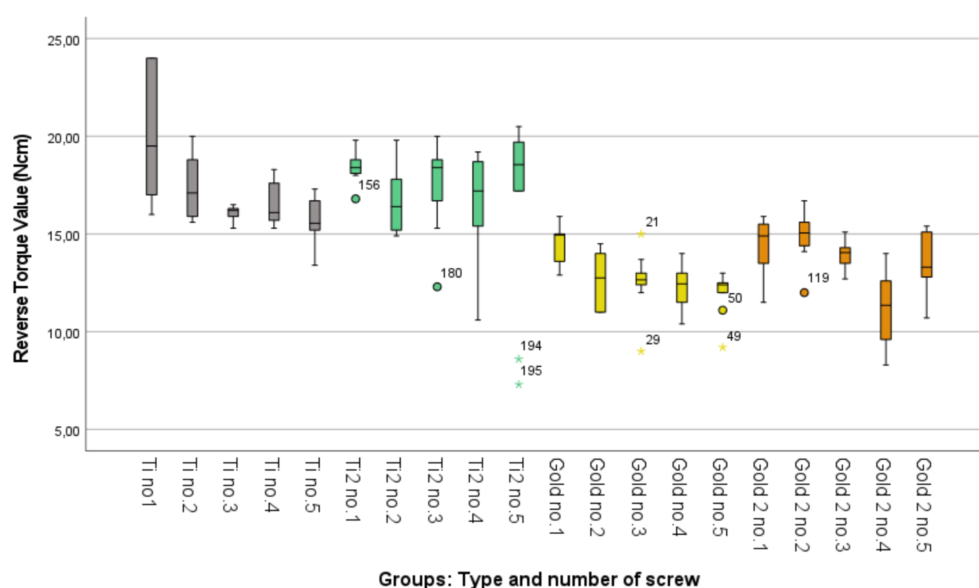

Figure 5: Box-plot chart of the 20 screws.

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Table 3. Descriptive statistics of the reverse torque value (Ncm) considering the tightening/untightening series (10 cycles at 20 Ncm).

Groups	Mean	Std. Deviation	Median	Minimum	Maximum
Protocol 1 - Series 1 (n=20)	17.41	3.824	15.95	12.90	24.00
Protocol 1 - Series 2 (n=20)	15.09	2.752	15.05	11.00	20.00
Protocol 1 - Series 3 (n=20)	14.34	2.098	15.15	9.00	16.50
Protocol 1 - Series 4 (n=20)	14.34	2.416	14.65	10.40	18.30
Protocol 1 – Series 5 (n=20)	13.88	2.216	13.20	9.20	17.30
Protocol 2 - Series 1 (n=20)	16.62	2.333	16.80	11.50	19.80
Protocol 2 - Series 2 (n=20)	15.80	1.688	15.60	12.00	19.20
Protocol 2 - Series 3 (n=20)	15.68	2.421	14.85	12.30	20.00
Protocol 2 - Series 4 (n=20)	13.86	3.560	12.95	8.30	19.60
Protocol 2 – Series 5 (n=20)	14.98	3.763	15.10	7.30	20.50

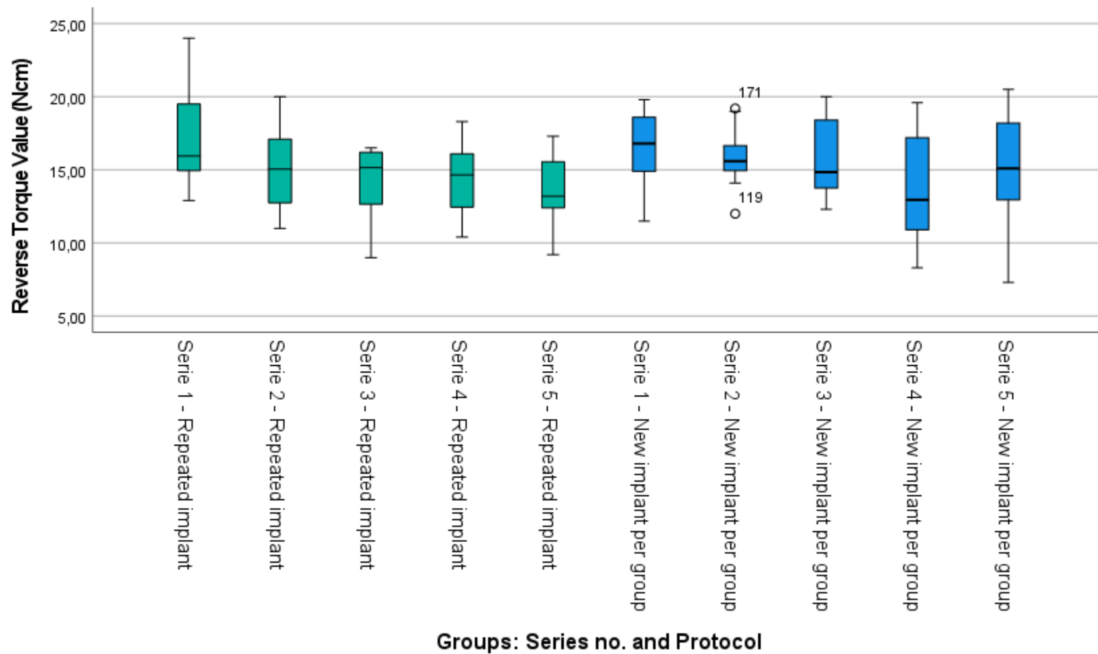

Figure 6: Box-plot chart of the 10 series. Protocol 1 used the same implant for the 5 series. Protocol 2 used a new implant per screw (10 cycles of tightening at 20 Ncm and untightening).

stability of the implant abutment joint may be influenced by the mechanical characteristics of the material used to make the abutment screw, such as its modulus of elasticity, yield strength, and hardness. Hardness plays a major influence in the coefficient of friction. The wear between the screw and the implant threads should be minimize (and thus the screw loosening). Materials of similar hardness should be used in an effort to mitigate the mutual wear of surfaces[18]. On the other hand, an alternative would be the screw hardness inferior to the than the inner threads of the implant to protect an osteointegrated implant from becoming non-functional. Besides the screw diameter and length, number and form of the threads also surface properties's differences might affect the tribological behavior of abutment screw during tightening or functional loading[18]. In addition, since the surface of the screw is not completely smooth, which is known as microroughness, contact surfaces do not completely come into contact. Settling occurs when irregular points flatten under a load, as they are the only contact surfaces when the initial tightening torque is applied. It has been reported that 2% to 10% of the preload is lost as a result of relaxation forces, which is known as the settling effect. In the present study the settling effect was clearly different between the two type of screws. As a result, the torque required to remove the screw is less

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than the torque initially used to place the screw. To reduce this phenomenon, the screw must be tightened 10 min after initial torque application[19]. In the present study two screws were compared where one group were composed by uncoated titanium screws and the other group standard gold-alloy screws with a plating of 0.76 thickness of pure gold (GoldTite 3i). The authors believe because gold alloys have a lower degree of elasticity than titanium alloys, they will suffer greater elastic deformation for the same tension (torque) applied. Titanium screws have a higher coefficient of friction than other materials used for abutment screws, such as gold alloy[20]. This goes in accordance with what was stated by Byrne that the gold-coated screws showed the greatest tendency for decay in preloads with repeated tightening[9]. However, Byrne *et al*. assessed the preload and not the RTV, their findings showed markedly higher preloads in all insertion torques for gold-coated screws compared to titanium alloy screws. The same was shown in Martin *et al*. 2001 study, greater preloads were found for GoldTite screws compared to other three types of screws (TorqTite, Gold alloy, Titanium alloy)[10]. Moreover, also the manufacturer affirm gold-tite screws (used in the present investigation) increases the implant/abutment clamping force by up to 113% when compared to the non-coated titanium alloy screws. Dental industry made the transition back to gold-alloy screws due to their lower coefficient of friction allowing a higher preload without sticking to the implant's internal threads. In addition, Jeong *et al*. 2001 affirmed gold-alloy screws were able to attain preloads in excess of 890 N at approximately 75% of its yield strength, which is more than twice what titanium screw can attain. Firstly, it is important to highlight that the yield strength is not related to RTV, but the screw fracture behavior. Secondly, as element, pure titanium shows greater values of yield strength, Young's Modulus of Elasticity and Vickers hardness than pure gold. As previously mentioned, these characteristics makes titanium a material more brittle and less elastic than gold, which may justify their different behaviors under the same tightening protocol (torque/tension and cycles). Thirdly, it has been suggested that repeated use of a coated abutment screw appears to increase the friction of the screw head and thereby decrease the preload. These results indicate that a pre-used coated implant–abutment–screw will fail reaching optimal screw preload[22]. Also Tsuge *et al* concluded the implant-abutment connection did not have an effect, but the abutment screw material did. In particular, Ti abutment screws were less likely to come loose[23].

These former studies are aligned with our results suggest Ti screw as a more effective system. Independently from the type of screw-material, when used new, screws presented the highest values. Throughout the following tightening and screw renewal series, the RTV decreased. Moreover, titanium screws when new, but tightened with a used screwdriver to a used implant, behave similarly to new gold-plated screws tightened for the first time to a new implant. When testing null hypothesis 3 it was found for the first protocol that the first tightening series was statistically different from the following ones independently of the type of screw, except for Series 2. Nevertheless, throughout the tightening/untightening cycles with new screws, the RTV required to loosen the screw decreased. Series 2, 3, 4 and 5 showed no statistically differences between them. In contrast, for the second protocol, when using for serie a new screw together with a new implant, no differences between series was found. The present findings go in agreement with Butkevica *et al*.[21] which also found a mean loosening torque from the 1st to the 10th cycles. On the other hand, contrary to what Butkevica stated, our study results showed that the alloy type of the screw may influence the mean loosening torque/RTV, this is in line with the study of Tsuge *et al*. It is expected the majority of friction occurs between the internal components of implants and the screw threads. Consequently, it is anticipated that, in comparison to other screw locations, the majority of frictional changes will be amplified around the threads. However, not only changes in the threads have been reported. A previous work has found severe changes at the screw-head section altering the screw-driver fit depending on the tightening protocol[8]. In addition, Zipprich *et al*. 2018 results showed tightening torque and screw head angle were the only study parameters that affected the resulting preload force of the abutment screw. The thread number in their study had no effect[11]. Yeo *et al*. 2014 and Lee *et al*. 2018 concluded in in-lab tests that abutment screw length had no significant effect on screw loosening[24,25]. Yet, Kanneganti in an three-dimensional finite element analysis supported the thesis that is preferred long screws with more number of threads for an effective preload[26]. The screwdriver should only be used in 10 tightening/untightening cycles with the applied tightening protocol. The authors suspect that using the same screwdriver series from series may lead to a degree of deformation and/or attrition loss at the engaging tip of the screwdriver. More clearly from the results, when comparing protocol 1 and protocol 2, was the influence of the internal threads of the dental implant on the RTV. Alnasser *et al*. recently reported no significant differences between tightening the abutment screw two times with a 10-minute interval, with no interval, or only one time[14]. The same study found that optimal RTVs were obtained when the abutment screw was tightened, counter-tightened, retightened, counter-tightened, and tightened again. From previous studies it has been shown that reverse torque values are usually smaller than the insertion torque values. Also, different tightening protocols affect the immediate and long-term stability of the abutment connection[17,27]. As already mentioned previously, another tightening protocol was suggested by Winkler *et al*. 2003, screws should be retightened 10 minutes after the initial torque application as a routine clinical procedure to help compensate for the settling effect[28]. The decreasing RTV is related to the phenomenon of the settling effect. The settling effect occurs for the reason that no surface is completely smooth. The high spots in the internal threads become flatten because initially they are the only contacting surfaces. Consequently, the torque required to remove a screw is lower than the torque initially used to place it[28].

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The present study has its limitations. Firstly, this is an *in-vitro* study; thus, clinical conditions, such as saliva, hand-operator differences, presence of debris, and material degradation, are absent. Therefore, at the clinical practice, small differences in RTV can be expected. Secondly, only one type of screwdriver was used (hexagonal from Zimmer Biomet®), preventing conclusions regarding other types of screwdrivers and screws. this study compared only two types of screws where the geometry was identical but the body material was different. There are multiple abutment's screws designs with different number of threads, type of threads, materials and with head formats (such as, square, torx, star per example). Multiple screwing and loosening may alter the internal threads of the implant and have an impact in the results. At last, it is still difficult to develop a strong discussion around the study results, still to date, the literature did not show great debate about the present topic, and few studies have been designed to test the wear consequences at the screwdrivers' screw head and engaging tip. Regarding sample size, although each group had a number of five screws, these bio-engineered materials are calibrated and always tested by the manufacturer. Therefore, no greater variations should be expected between the same type of screw. Given the variability in screw geometry, materials and head formats across manufacturers, in this research only limited comparisons were conducted. Future studies with different screw-samples and brands will provide a more comprehensive results and enhance this issue regarding reverse torque value and torque loss. There is still not a gold-standard design and size that should be universal to all implants' brands. Few manufacturers provide working screws to be used during lab confection and before providing the definitive prostheses. Although great scientific information can be found regarding dental biomaterials, thread deformation, screw design, tightening protocols, regarding screw-head characteristics there is still a gap. The authors find suitable to conduct future investigations on this specific topic and analyze its deformation depending on different parameters, the effect of screw-head's design on preload, type of head section and ease to retrieve.

CONCLUSIONS

When using Zimmer Biomet implant system, the Ti screws were more effective than Gold screws. When tightening/untightening to the same implant several times, the first tightening series showed higher RTVs than the following ones independently of the screw used. The statistically differences found between series suggest that after 10 tightening/untightening cycles, tightening mechanism might irreversibly lose its efficacy.

Clinicians should consider as factors limiting correct torque achievement and loss of RTV, the extensive use of a screwdriver and high number of tightening's performed to a particular implant (internal threads deformation).

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