DENTAL IMPLANT RETAINING SCREWS: THE EFFECT OF USING GOLD OR TITANIUM ON PRELOAD.

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A research report submitted to the School of Oral Health Sciences, University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Master of Science in Dentistry.

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DECLARATION

I, Rajesh Doolabh, declare that this research report is my own work. It is being submitted for the degree of Master of Science in Dentistry at the University of the Witwatersand, Johannesburg. It has not been submitted before for any degree or examination at this or any other university.

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29 October 2010.

DEDICATION

In memory of my grandmother

Mrs. Manjula Dhanjee

1931-2009

ABSTRACT

PURPOSE

The purpose of this in vitro investigation was to determine the effect of using either gold or titanium retaining screws on preload in the dental implant body-abutment complex. This preload is of vital importance for the long term success of the dental implant complex. Inadequate preload results in either loosening or fracture of the retaining screw, and is the most commonly occurring mechanical complication in implant supported/retained prostheses. Similar complications occur when excessive preload is applied to the retaining screws. These complications can result in unscheduled visits with costly and time consuming repairs for the clinician and patient.

Routine maintenance protocols for implant supported prostheses range from biannually to five year visits to the dentist. Maintenance visits involve removal of the prosthesis facilitating cleaning of both the implant and prosthesis and inspection of retaining screws .

This study sought to gain insight into changes in preload generation after repeated torque application to gold and titanium screws and to observe whether gold or titanium generated better preload. A maintenance protocol would be suggested if any observable pattern was noted.

MATERIALS AND METHODS

The test setup consisted of an implant body, a cylindrical transmucosal abutment and the retaining screws (gold or titanium). The implant body was anchored using a load cell. Transmucosal abutments were attached to the implant body using either a gold or titanium

retaining screw. A torque gauge was used to apply torque of 20Ncm, 32Ncm and 40Ncm to the retaining screws. This was undertaken to investigate the effect of gold or titanium on preload generated. The effect of applying torque beyond manufacturers recommended 32Ncm was carried out to see if greater preloads could be achieved. All components were from the Southern Implant system.

RESULTS

Gold retaining screws were found to achieve consistently higher preload values than titanium retaining screws. Preload values were not significantly different from the first to the tenth torque cycle. Titanium screws showed more consistent preload values, albeit lower than those of gold retaining screws. However due to possible galling of the internal thread of the implant body by titanium screws, gold screws remain the retaining screw of choice.

Maintenance protocols suggest replacing retaining screws every 20 years. After ten torque cycles were applied to each screw there was an insignificant change in preload generated in both titanium and gold screws. This study was therefore inconclusive with regards to maintenance protocols.

CONCLUSION

Within the limitations of this study, gold retaining screws generated better preload than titanium. Torque application beyond manufacturers’ recommendations resulted in a more stable implant complex. Further investigation into repeated torque application to retaining screws is required, to determine ideal maintenance protocols.

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TABLE OF CONTENTS

Declaration ii

Dedication iii

Abstract iv

Acknowledgements vi

Table of Contents vii

List of Figures ix

List of Tables x

CHAPTER 1. INTRODUCTION AND LITERATURE REVIEW 1

1.1 Introduction 1

1.2 Literature Review 2

1.2.1 Advantages of the retaining screw 2

1.2.2 Screw mechanics 2

1.2.3 Retaining screw loosening statistics 5

1.2.4 Gold vs titanium retaining screw 6

1.2.5 Determination of optimum preload 7

1.2.6 Maintenance protocol 9

1.3 Aim 10

1.4 Objectives 10

CHAPTER 2. MATERIALS AND METHOD 11

2.1 Study Sample 11

2.2 Test setup 11

CHAPTER 3. RESULTS 15

3.1 Statistical analysis 15

3.2 Titanium(TSS2) results 17

3.3 Gold (GSS2) Results 17

3.4 TSS2 vs GSS2 Retaining screws 17

CHAPTER 4. DISCUSSION. 19

4.1 Discussion 19

4.2 Limitations 23

CHAPTER 5. Conclusions and recommendations. 25

Appendix A. List of Results 26

Appendix B. Alloy Constituents Material Certificates 32

Appendix C. Additional Statistical Analyses 34

References 37

LIST OF FIGURES

Figure.1 The test set-up 12

Figure.2 Loadtech load cell (model LT-400, South Africa). 13

Figure.3 Mechanical torque gauge with selected driver tip. 14

Figure.4 Graph showing mean preloads achieved for TSS2 and GSS2 at torque of 20Ncm, 32Ncm and 40Ncm. 18

LIST OF TABLES

Table 1 Alloy composition of retaining screws. 11

Table 2 Number of observations (N), means and standard deviation (SD) of observed preload, and torque by metal...15

Table 3 Geometric means of preload torque by metal. 16

CHAPTER 1. INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

Osseointegrated implants have revolutionized the clinicians' approach to restoring edentulous spaces in the dentition. Single or multiple unit prostheses can predictably be used to replace missing teeth. Just as the degree of implant integration within surrounding osseous tissue is paramount to physiologic success, the mechanical fit within the implant-abutment-prosthesis complex is essential for prosthodontic success (Gratton, Aquilino and Stanford 2001). Whether the prosthesis is screw or cement retained, it relies on the integrity of the screw joint to ensure predictable long term outcomes. This screw joint consists of the implant fixture and transmucosal abutment clamped together using a retaining screw. The tension created in the retaining screw, especially the fluked threads is defined as preload (Glossary of Prosthodontic Terms-8 2005). The most commonly used retaining screws are gold and titanium, each having different and unique properties. However, screw loosening continues to be a commonly occurring mechanical complication encountered by clinicians with implant supported prostheses.

Although previous studies have investigated preload generated by gold and titanium screws, alloy constituents and manufacture of retaining screws vary from company to company and even within different batches from the same company (Rambhia et al 2002, Tan and Nicholls 2002, Cantwell and Hobkirk 2004).

1.2 Literature Review

1.2.1 Advantages of the retaining screw

The retaining screw forms a screw joint between the implant body and the transmucosal abutment. It confers the advantages of retrievability, allowing individual implant assessment, soft tissue assessment around the implant, debridement of calculus, and prosthetic modification (McGlumphy, Mendel and Holloway 1998). Treatment options are rendered greater flexibility and are achieved more cost effectively. The clinician is able to effect porcelain repair, a change in shading and if necessary additional access for more effective oral hygiene.

The retaining screw is designed to loosen or fracture before damage to the implant fixture or overlying prosthesis occurs (Rangert, Jemt and Jorneus 1989). This fail safe characteristic is due to their reduced size and metallurgical composition (Weinberg 1993). The treatment of screw loosening requires an understanding of the characteristics and biomechanical parameters of the screw and the screw joint (Yousef, Luke, Ricci et al 2005).

1.2.2 Screw mechanics

The maintenance of an optimum preload in the screw joint is of critical importance to ensure the long term functioning of the implant complex and to maximize the fatigue life of the retaining screw (Martin, Woody, Miller et al 2001). Inadequate preload results in increased wear on the retaining screw, and accelerates fatigue of the screw. Metal fatigue is the most common cause of structural failure and occurs after repeated loading at stress levels below the ultimate tensile strength of the material (Tzenakis, Nagy, Fournelle et al 2002). Application of torque to the retaining screw causes elongation and subsequent elastic recovery of the screw results in the generation of a compressive clamping force. Wang, Kang, Lang et al (2009), using finite element analysis, established that for every 1.0 micrometer of elongation in gold screws there was a 47.9N increase in preload.

Preload is affected by a number of factors, these include torque applied to the screw, type of screw alloy, screw head design, abutment alloy, abutment surface and the presence of lubricants (Tan and Nicholls 2002). As torque applied is the primary determinant of preload, it follows that the greater the torque applied to the retaining screw the greater the preload generated (Burguete, Johns, King et al 1994).

There is however, an indirect correlation between preload and the applied torque because of frictional forces that act on the interfaces involved. Some energy is expended to overcome friction (Tan and Nicholls 2002). Friction coefficients depend on the geometry and material properties of the interfaces involved. Size and surface area of the contacting threads, pitch, screw radius and diameter of the head play a major role in the relationship between applied torque and preload (Tan and Nicholls 2001). Surface area contact is also dependant on length of the screw, which determines the number of thread surfaces engaging. Finite element analysis studies have shown that the first three threads engage the most (Gratton et al 2001).

To mitigate the problem of screw loosening, screw designs have been modified for improved performance, although the optimum design has not yet been fully established. Current designs generally consist of a flat head seat (for less frictional resistance and higher preload), long stem length (for optimal elongation and preload) and 6 threads to reduce friction because the first three threads carry most of the load (Tan, Tan and Nicholls 2004), with the maximal stress being concentrated between the shank and first thread (Alkan, Sertzog and Ekici 2004).

Screw loosening occurs when the axial and bending moments acting on the screw, collectively called joint separating forces, generated by the cyclic forces of mastication are greater than the clamping force (Jaarda, Razzoog and Gratton 1995). Joint separating forces are amplified by excursive contacts, off-axis centric contacts, interproximal contacts, cantilevers and the lack of a passively engaging prosthesis (McGlumphy et al 1998). Parafunctional habits and functional deformation of bone have also been implicated (Rambhia et al 2002). It has also been suggested that bone remodelling to functional stresses may contribute to the loss of preload (Kallus and Bessing 1994). From an engineering perspective, screw loosening and/or fracture may be attributed to machining tolerances, component materials, metal fatigue, micro-movement during function and the settling of screws. This settling effect or embedment relaxation occurs when the surface asperites produced during milling and tapping of retaining screws are burnished with the initial application of torque (Jabbari, Fournelle, Zibert et al 2008). It has been reported that 2% to 10% of preload is lost within 10 minutes (Winkler, Ring, Ring et al 2003, Tzenakis et al 2002) of the initial torque application.

Two stages of screw loosening have been described. The first involves slippage of the joint surfaces, when joint separating forces are large enough to cause disengagement of mating male and female threads. This has been termed the critical bending moment (Tan et al 2004) which is the bending moment at which slippage occurs. The second phase occurs when preload has reduced to the point that external forces and vibration cause mating threads to turn, leading to the screw backing out (Cantwell and Hobkirk 2004).

Abutment screws have either slotted, square, star or hexagonal driver engagement. The slotted, flat head retaining screw was investigated in this study because this design is more commonly used to secure the transmucosal abutment to the implant body. It has been shown that it is more difficult to apply manual force when tightening slotted retaining screws because clinicians are “anxious” of slippage of the driver from the slot. A guiding effect can be achieved with geometric designs resulting in more effective force transfer and greater stability of hexed screws (Kallus and Bessing 1994).

1.2.3 Retaining screw loosening statistics

When retaining screws are subjected to functional loading, screw loosening has been cited as the most common mechanical complication, for single or multiple unit implant supported prostheses (Duncan, Nazarova, Voiatzi et al 2003). Screw loosening appears to be an early indicator of design inadequacies (Gratton et al 2001) and may cause many complications. These include soft tissue complications, because micromovement at the implant interface results in bacterial colonization and mechanical irritation of the surrounding soft tissue, causing gingival tenderness, inflammation and hyperplasia. Subsequent fistulae formation can occur (Kallus and Bessing 1994). Fracture of the overlying prostheses and implant body fracture have also been reported (Gratton et al 2001). These complications result in unscheduled visits to the clinician which can be costly and time consuming for the patient and practitioner concerned. A concerted effort has therefore been made by clinicians and manufacturers to help reduce the recurrence of these problems (Martin et al 2001).

The incidence of screw loosening in reports is quite variable but remarkably high. One study showed that screw loosening most commonly occurs in single tooth implant replacement with 65% becoming loose over a 3 year period (McGlumphy et al 1998). In a prospective multicentre investigation, Jemt, Laney, Harris et al (1991) treated 92 patients with 107 implants, and within the first year the most frequently encountered complication was screw loosening for 42% of maxillary and 27% of mandibular prostheses. Naert, Quirynen, Steenberghe et al (1992), in a follow up study of 589 consecutively placed implants supporting full fixed prostheses, also suggested that retaining screw loosening was the most commonly encountered complication. In a similar study that included patients restored with implant-retained prostheses for at least five years, 40% of gold slotted retaining screws were loose at the recall appointment (Kallus and Bessing 1994).

Goodacre, Bernal, Rungcharassaeng et al (2003) reviewed dental implant literature spanning from 1981 to 2001 and found the average loosening of early retaining screws in single crowns was 25%. They found that the mean of data from 6 recent studies was 6% alluding to improvement in retaining screw design.

1.2.4 Gold vs titanium retaining screw

The most commonly utilised retaining screws are either gold or titanium. Gold alloy screws became preferable to titanium alloy screws primarily because of the larger frictional resistance between mating male and female threads of titanium screws (Jabbari et al 2008). Gold screws are designed to be the most “flexible” portion of the implant assembly and permit adequate micromovement to distribute force to the implant body due to their higher modulus of elasticity than titanium (Weinberg 1993). This design attribute also makes it the “weak link” in the implant-abutment complex, i.e. in cases of occlusal overload the gold screw would loosen or fracture first, thus protecting the implant and underlying bone from excessive stresses and being the most easily retrieved component (Rangert et al 1989). Goodacre et al (2003) reported that, in various studies the incidence of gold screw loosening ranged from 1 to 9%. A gold screw can attain a preload of more than twice that of a titanium alloy screw (Tan et al 2004).

Titanium retaining screws are stronger than gold but have a lower modulus of elasticity; metal fatigue will produce gold screw fracture before the titanium retaining screw is affected (Weinberg 1993). The major disadvantage of titanium retaining screws is their tendency to cause galling, which is defined as the condition whereby excessive friction between two mating surfaces results in localized welding with a further roughening of the mating surfaces (Jabbari et al Part 2 2008). Galling occurs in the following manner: titanium of the retaining screw slides in contact with the titanium of the implant body, the coefficient of friction increases whereby titanium molecules transfer from the mating surfaces (Martin et al 2001). This has been described as the adhesive wear mechanism (Jabbari et al Part 1 2008). In the case of titanium retaining screws, there can be slight damage to both the implant body and the retaining screw threads. Conversely, gold retaining screws have a smaller coefficient of friction, allowing them to be tightened more effectively than titanium without risking galling between threads. Metallurgical properties of titanium screws allow for the generation of a more consistent albeit lower preload than gold retaining screws. However gold retaining screws should only be used for the actual seating of the prostheses and not for any laboratory procedures because of the soft structure of the material, and such use may result in damage of the threads (Michalakis, Hirayama and Garefis 2003).

1.2.5 Determination of optimum preload

The ultimate aim in tightening a screwed joint is to obtain optimum preload that will maximise the fatigue life of the retaining screw while offering a reasonable degree of protection against loosening (Martin et al 2001). An optimal preload is important to maximize the frictional forces between mating threads and to ensure the stability of the implant complex. There is a difference between optimum torque which can be defined as that torque which actually achieves an optimum preload and design torque as specified by the manufacturer to achieve optimum preload based on the nominal properties of the retaining screw (Burgette, Johns, King et al 1994).

Optimum preload in the retaining screw is achieved at 75% of ultimate torque to failure values (fracture point). Manufacturer recommended values may not approach this value, as they have established a safety margin to optimise preload and decrease screw fracture. In a previous study Tan et al (2004), showed that recommended torque values were 57.5% of the yield strength for gold alloy screws and 56% for titanium screws. Another study showed that this value was below 55% for gold retaining screws (Alkan et al 2004). It has been established that a preload of 75% of yield strength was not established using recommended tightening torque values (Lang et al 2003). However, torque cannot be applied arbitrarily without due consideration being given to the elastic limit of the screw and the biomechanics of the system, especially at the bone implant interface (Jabbari et al 2008). If too much torque is applied to the implant complex, debonding at the implant-bone interface can sometimes occur with forces as small as 30Ncm (Brunski 1999). The retaining screw can also fail if torque is applied beyond its yield strength (Khraisat, Hashimoto, Nomura et al 2004) and threads can be stripped (McGlumphy et al 1998).

The manner in which torque is delivered to the system has also been found to be important in delivering a constant torque, as variations have been found between hand screw drivers, torque wrenches and electronic torque drivers, the latter being the most consistent when regularly calibrated (Tan and Nicholls 2002).

There are currently no suggestions for the torque that can safely be applied to the retaining screw beyond the manufacturers' recommendations.

1.2.6 Maintenance protocol

Retaining screws are like the hardware parts on any equipment requiring periodic check-ups, maintenance, and replacement. There is however, no definitive protocol with many varying suggestions made.

It is difficult to predict the fatigue life of retaining screws because of the uncertainty in establishing the stress state in the component and the lack of accurate data on the fatigue behaviour of these materials. Also intraorally each retaining screw is presented with variable loads. To maintain clinical success of the implant complex, it has been suggested that patients' be recalled for regular clinical and radiographic check-ups.

The fatigue life of an implant screw has been estimated at 20 years (Tzenakis et al 2002). One needs to be careful not to exceed a critical number of torque cycles for the retaining screw. Gold retaining screws can be removed and tightened up to 20 times with no effect on its ultimate tensile strength (Rafee, Nagy, Fournelle et al 2002). They also suggested an initial 6 month service to compensate for embedment relaxation, and thereafter an annual maintenance protocol. However, Tzenakis et al (2002) suggested retorquing after 3-12 months. Kallus and Bessing (1994) suggested that full arch fixed prostheses be retightened after 5 years in service. Jabbari et al (2008) observed severe thread deterioration in a study of 100 retaining screws after a period of 4 to 10 years in service, and suggested replacing retaining screws every 10 years. Weinberg (1993) suggested replacement of gold screws during the lifetime of the restoration without any further detail being given. There appears to be little consensus in the literature regarding maintenance protocols for titanium screws.

The purpose of this study was to examine the changes in the screw joint preload occurring as a result of repeated torque application to gold and titanium retaining screws.

1.3 Aim

The aim of this study was to evaluate and compare the preload generated in gold and titanium retaining screws and the effect of repeated torque on this preload.

1.4 Objectives

a) To determine the effect of gold or titanium on preload.

b) To assess the effect of repeated torque on preload.

c) To suggest a protocol for maintaining an optimum preload.

CHAPTER 2. MATERIALS AND METHOD

2.1 Study Sample

In an effort to minimize variables in screw design and geometry, an unused stack of components from one manufacturer (Southern Implants, Irene, South Africa) was used. Testing was done on components of the same batch/lot (lot number 071A07/1), to reduce the variations that occur between different lots even when manufactured by the same company. The test sample consisted of two groups of retaining screws, the first being ten Titanium Slotted Screw 2 (TSS2) and the second ten Gold Slotted Screw 2 (GSS2). The alloy constituents of each retaining screw is tabulated in Table 1.

Table 1 Alloy composition of retaining screws.

Retaining screw	Alloy composition*
TSS2	90% Ti, 6% Al, 4% Vn.
GSS2	61% Au, 16.5% Ag, 13.5% Pt, 9% Cu.

*Alloy composition gathered from certificates of conformity supplied by manufacturer. Refer to Appendix B.

2.2 Test setup

The test setup consisted of an implant body, a cylindrical transmucosal abutment and the retaining screw. Two self tapping external hexagon implants (Southern Implants) with a 5mm diameter and a 13mm length were used (BA13 lot number 06051801/2). This diameter is often used in the clinical situation (Steinbrunner, Wolfart, Ludwig et al 2008). Brunski (1999) showed that any increase in length beyond 13mm does not confer improved stability of the implant body. The initial purpose of the external hexagon was to allow surgeons to drive the implant body into position after the osteotomy site had been prepared, it was ironically not designed as an antirotational device for single implant restorations for which it now serves the primary function (Drago 2003). The height of the external hexagon was 2mm, which is most effective at dispersing lateral and bending forces through to hexagon corners, thereby securing the preload in the retaining screw (Khraisat et al 2004). The external hexagon has also been shown to significantly increase resistance to screw loosening (Binon 1996).

Two titanium cylindrical transmucosal abutments (TCBASnh, lot number 06051801/2, Southern Implants) designed for use with single implant restorations were attached to the implant body with the retaining screws. (Figure 1).

Two groups of retaining screws, consisting of ten TSS2 and ten GSS2 were tested. Each group of screws was loaded using a new implant body and cylindrical transmucosal abutment. This same implant abutment complex mimics clinical conditions, although an element of bias is introduced due to the possibility of gold or titanium molecules coating the internal surface of the implant.

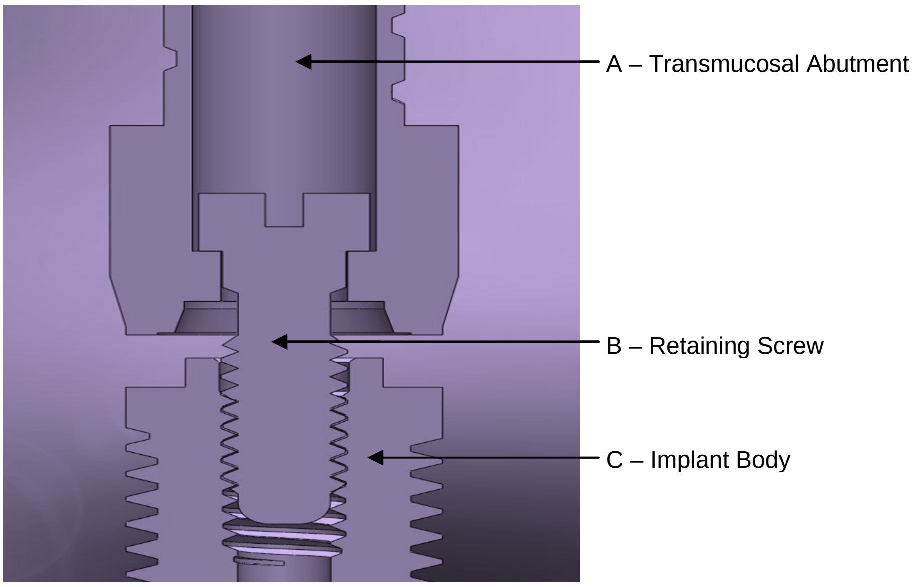

Figure.1 The test set-up

A load cell (Loadtech, model number LT-400, South Africa), comprising a central adjustable clamp for fixation of the implant body and a horizontal plate housing the cylindrical transmucosal abutment and retaining screw was used to measure preload in the screw (Figure 2). A space was maintained between implant and abutment to try eliminating any interferences. Preload was measured digitally in kilograms.

Figure.2 Loadtech load cell (model LT-400, South Africa).

Torque was delivered to the system using an implant driver (I-WI-BL, Southern Implants), which was slotted into a torque gauge (Tohnichi, Japan, model BTG 150 CN, serial number 501935T) (Figure 3). The torque gauge and load cell were calibrated using known loads to give accurate and reproducible recordings prior to testing. All tests were performed in an air conditioned environment set at 25^{0}C. Tests were performed by a single operator (myself) to ensure consistency in recording data. Retaining screws were carefully handled throughout testing using plastic tweezers to ensure that no operator induced damage to the thread occurred. Screw torque was delivered in a steady manner by stabilizing and holding the head of the driver vertically with one hand, while the other hand applied the torque force to the torque gauge. This method was practised before testing to ensure that torque was applied in a steady and repeatable manner. An initial torque of 20Ncm was applied to the retaining screw. After a period of 2 minutes (measured by a digital stopwatch) to allow for embedment relaxation, torque was re-applied to the retaining screw to 20Ncm and a reading was captured. After 30 seconds torque was increased to 32Ncm and data was captured. After a further 30 seconds 40Ncm of torque was applied and data captured. 20Ncm corresponds to the recommended tightening torque for TSS2 and 32Ncm to the torque recommendation for GSS2. Retaining screws were then torqued below, at and beyond manufacturers' recommendations to assess the impact of further torque delivery to the integrity of the retaining screw. The purpose of the time intervals between applications of torque was to permit for some of the settling effect, so that at the next torque application better contact between mating surfaces would allow for a greater preload value. These three levels of torque correspond to 62.5%, 100% and 125% of manufacturers recommended torque levels respectively. This process was repeated 10 times per screw at each of the above mentioned torque values.

Figure.3 Mechanical torque gauge with selected driver tip.

CHAPTER 3. RESULTS

3.1 Statistical analysis

The experimental procedures resulted in preload values for two groups of screws, gold and titanium at each of the specified torque values: 20Ncm, 32Ncm and 40 Ncm. See Appendix A for tabulated table of results for both TSS2 and GSS2. For preload values during the first cycle, the mean and the standard deviation for each metal-torque combination was calculated. The marginal values, i.e. indicating the average of the means (a mean of 45.580Ncm for GSS2 and a mean of 30.457Ncm for TSS2) and for both gold and titanium retaining screws are presented in Table 2.

The mean preloads achieved for both GSS2 and TSS2 at applied torque of 20Ncm, 32Ncm and 40Ncm are depicted in Figure 4.

Table 2 Number of observations (N), means and standard deviation (SD) of observed preload, and torque by metal.

TORQUE	GSS2	TSS2	TOTAL	
20Ncm	10	10	20	**(N)**
	31.240	20.270	25.755	**(MEAN)**
	4.620	1.070	6.506	**(SD)**
32Ncm	10	10	20	**(N)**
	47.250	31.520	39.385	**(MEAN)**
	7.710	2.078	9.763	**(SD)**
40Ncm	10	10	20	**(N)**
	58.250	39.580	48.915	**(MEAN)**
	9.458	1.487	11.625	**(SD)**
TOTAL	30	30	60	**(N)**
	45.580	30.457	38.018	**(MEAN)**
	13.419	8.201	13.406	**(SD)**

The preload data was subjected to an analysis of variance (ANOVA) for repeated measures in the first cycle (i.e. for each screw preload was measured following torque repeated at 20Ncm, 32Ncm and 40Ncm) analyzing preload on the natural logarithmic scale. As the original data was heteroskedastic (Breusch-Pagan/Cook-Weisburg test for homogeneity of variance: $p<0.0001$), i.e. the assumption of equal variances in the groups is violated and the data also does not follow a normal distribution (Shapiro-Wilk W-test: $p=0.0169$), the data was logarithmically transformed. After transformation the data complied with the assumptions of homogeneity of variance and being normally distributed ($p=0.2210$ and 0.2279 respectively). An ANOVA showed that metals do differ significantly ($p < 0.0001$). Geometric means were calculated as the antilog of the mean of the log values and hence the geometric mean of gold is significantly higher than that of titanium, 43.7Ncm as opposed to 29.3Ncm, as illustrated in Table 3.

Table 3 Geometric means of preload torque by metal.

TORQUE	GSS2	TSS2
20	30.959	20.244
32	46.726	31.457
40	57.637	39.554
TOTAL	43.686	29.313

To determine if there was an inherent difference in the qualities of the different screw types, a final analysis comparing the two screw types with respect to the change in preload from 20Ncm in the first cycle to 40Ncm in the tenth cycle was done using an analysis of covariance (ANCOVA) with baseline (20Ncm in the first cycle) as covariate. The two metals did not differ significantly with respect to the mean change in preload, adjusted for baseline, (p=0.5159 : 18.7 for GSS2 and 16.9 for TSS2). All further statistical analyses can be found in Appendix C.

3.2 Titanium(TSS2) results

The mean preload measured for every torque cycle was 20.270Ncm, 31.520Ncm and 39.580Ncm at 20Ncm, 32Ncm and 40Ncm respectively. As the data was heteroskedastic it was transformed and the geometric means were then calculated. The geometric mean for TSS2 was 29.313Ncm.

3.3 Gold (GSS2) Results

The GSS2 screws yielded mean preload values of 31.240Ncm, 47.250Ncm and 58.250Ncm at 20Ncm, 32Ncm and 40Ncm respectively. After transformation of the data, owing to heteroskedasticity, the GSS2 retaining screws showed a geometric mean of 43.686Ncm.

3.4 TSS2 vs GSS2 Retaining screws

The mean preload values for all the torque cycles for TSS2 retaining screws was 30.457Ncm and 45.580Ncm for GSS2 screws. An ANOVA for repeated measures in the first cycle (i.e. for each screw preload measured following torque measured at 20cm, 32Ncm and 40Ncm) revealed that there was no significant difference between the metals ($p < 0.0001$). Geometric means of gold is significantly higher than that of titanium, 43.7Ncm as opposed to 29.3Ncm. (Figure 4).

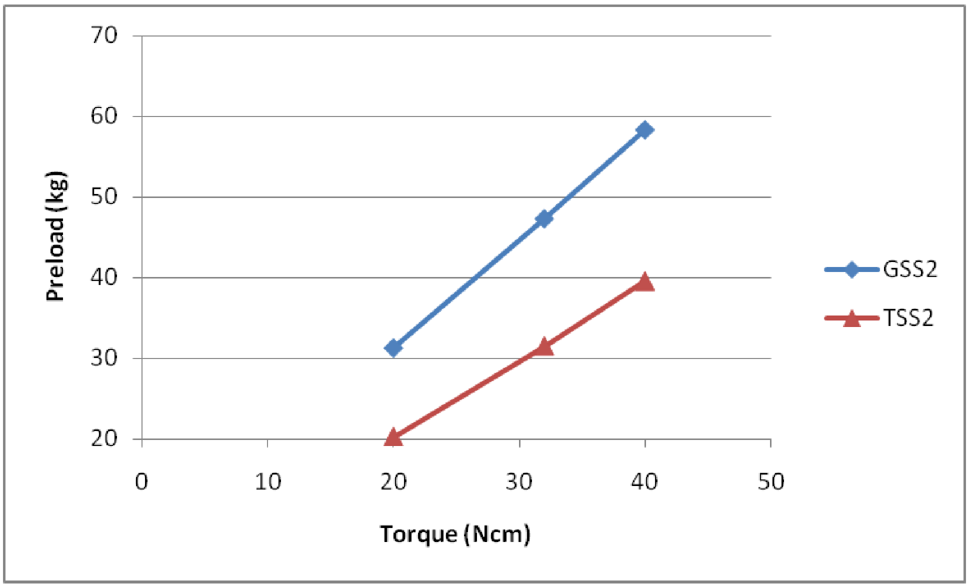

Figure.4 Graph showing mean preloads achieved for TSS2 and GSS2 at torque of 20Ncm, 32Ncm and 40Ncm.

A further analysis was done to compare TSS2 and GSS2 with respect to the change in preload from 20Ncm in the first cycle to 40Ncm in the tenth cycle, using an ANCOVA. The ANCOVA revealed that the metals were not significantly different ($p > 0.5159$), showing mean preloads of 18.6874Ncm and 16.9226Ncm for GSS2 and TSS2 retaining screws respectively.

CHAPTER 4. DISCUSSION.

4.1 Discussion

Screw loosening has been recognised as a significant problem in dental implant therapy. Retaining screws have been extensively studied and designs continue to improve (Goodacre et al 2003). There was a change from a mean of 25% of gold retaining screws loosening in earlier studies, to a mean of 6% from six more recent studies. Optimum retaining screw function is governed by many parameters including design, material used and insertion torque (Byrne, Jacobs, Connell et al 2006). Retaining screws are inherently limited by size, material properties and maximum permissible torque. The gold screw was originally designed as the “weakest link” in the implant supported complex, allowing for loosening or fracture of the gold screw before damage to the retaining screw, prosthesis or implant body would occur.

There are many strategies to minimise screw loosening, and these are mainly focussed on the position of the implant placement and design of the prostheses associated with the implant. It has been suggested that placement of the implants must be ideally parallel to occlusal forces (McGlumphy et al 1998). The associated prosthesis must be designed to direct occlusal forces through the long axis of the implant. Further retaining screw loosening can be limited by minimising cantilever length, eliminating posterior working and balancing contacts, centralising contacts and sharing anterior guidance with the natural dentition. Also antirotational features must be engaged and passively fitting frameworks for multiple units are essential (Rangert et al 1989).

There are other contributory factors to screw loosening. The cyclic forces of mastication cause repeated deformation of the retaining screw. Embedment relaxation or the settling effect, also results in the loss of preload as the initial energy is expended to burnish surface asperites of mating surfaces caused during the milling and tapping procedures of retaining screw manufacture (Jabbari et al Part 3 2008). Tzenakis and co-workers (2002) found that within two minutes up to 10% of the initial preload was lost. Screw loosening is initiated when the mating threads slip, termed the critical bending moment (Tan and Nicholls 2002) and subsequently the loss of preload reaches a threshold point and vibration causes the retaining screw to back out.

The results of this study indicate that material composition of the retaining screw significantly influences preload developed within the implant abutment complex. During the experiment the gold alloy screws generated consistently higher preload values. This is consistent with previous studies. However, preloads generated in this study were found to be slightly below the 2:1 ratio, between gold and titanium retaining screws, shown by Tan et al (2004). This difference may be owing to retaining screws being used from other manufacturers.

Gold retaining screws have a higher modulus of elasticity than titanium. Gold is also “softer” than titanium resulting in higher preload values being generated by gold screws. With gold screws greater mating of female and male threads also occurs. However this “softness” results in long term deformation of the threads and subsequent loss of preload occurs when subjected to the cyclic forces of mastication. Preloads generated by titanium alloy screws were essentially unchanged during the series of tightening episodes, whilst the gold alloy screws showed a significant drop in preload after the first torque cycle and remained reasonably consistent thereafter. This consistency was ratified by the ANCOVA which showed that there was no significant difference in preload generated between GSS2 and TSS2 when adjusted to a baseline mean of 25.755Ncm. Gold retaining screws are preferred to titanium due to the possibility of galling in the latter. When titanium slides in contact with titanium, the coefficient of friction is initially fairly low. With repetitions of tightening and loosening, the values gradually increase, causing damage to the internal thread of the implant body. This is thought to be on account of galling and the seizing tendency of titanium whereby molecular transfer occurs between mating surfaces. Differences in the strength of screws from different manufacturers and between different lots of screws made by the same manufacturer can also give rise to inconsistent and often conflicting clinical observations (Rambhia et al 2002).

The preload values in retaining screws vary considerably among studies and may also be owing to differences in experimental procedure. Experimental studies have calculated preload from opening torque values (Weiss, Kozak and Gross 2000), compression in the implant complex (Cantwell and Hobkirk 2004), or from rotational angles (Martin et al 2001). The load cell employed in this test maintained a gap between the implant body and transmucosal abutment resulting in a more direct measure of tension in the retaining screw compared with other methods. This may account for the slightly lower preloads recorded here. The lower preloads could also have been owing to small misalignment between the implant body and transmucosal abutment.

Guda and co-workers (2008) cited Bickford(1998) stating that the optimum preload recommended for the retaining screw is that which produces a stress level that is between 60% and 75% of the yield strength of the material from which the screw is manufactured. Preload induced stress equal to the ultimate tensile strength of the material results in tightening induced fracture of the retaining screw. Stress at or slightly above yield causes the retaining screw to function in the plastic deformation zone with resulting sub-optimal function and loss of preload. However, a preload within the elastic range of the material is the most appropriate in terms of resisting joint separating forces generated during occlusal loading. Furthermore, optimum preload maximises the fatigue life of the retaining screw as the load is transferred from the abutment to the implant surface with minimal effect to the screw (Yousef et al 2005). When the elastic limit is not exceeded during application of torque, the higher modulus of elasticity of the gold retaining screws enables the generation of higher preloads than that of titanium retaining screws. In this study when applied torque was beyond manufacturers recommendations, corresponding to 125% of the stipulated torque, consistently higher preload values were achieved as expected. One is still unsure as to whether this is within the elastic limits of the screws. Clinically, the biomechanics of the system must be carefully evaluated before exceeding the manufacturers guidelines as debonding between the implant and bone interface can occur with forces as little as 30Ncm (Brunski 1999). Thus it is not advised to torque at 125% of manufacturers recommendation, corresponding to 40Ncm.

The retaining screw forms the cornerstone of the implant abutment complex. A relationship exists between preload, screw design, and material property. Friction influences preload generation quite considerably, especially when new components are used, as was done in this experiment. The results of this investigation suggest that wear as a result of repeated closing or opening torque cycles, may decrease the coefficient of friction of screw head, threads, and other mating components and consequently, resistance to opening gradually decreases with resultant lower preload values. Coefficient of friction is controlled by the manufacturing process and is affected by the metallurgical properties of the components, design and quality of the surface finish. As the study was done under dry conditions, the results are difficult to extrapolate to the clinical situation wherein oral fluids (saliva, peri-implant fluid, and/or blood) between the implant mating components act as a lubricant. Lubricants decrease the coefficient of friction and allow for greater tightening. It then follows that the preload values in this study would be lower than those expected in clinical conditions (Weiss et al 2000). It also will be affected by how many times a prosthesis is screwed in and taken out clinically.

As there was no significant change in preload values after repeated application of torque, this study was inconclusive with regard to defining a maintenance protocol. Further investigations could mimic cyclic loading and the number of torque cycles can be increased to indicate when a definitive drop in preload values occurs.

It is of vital importance that the clinician understands the forces active during the assembly of the implant complex, as a sufficient preload is essential for long term success. The significance of this study is that higher preload values can be achieved through the use of gold retaining screws and the application of higher torque. The sequelae of insufficient or loss of preload that have clinically significant consequences, such as screw loosening, adverse soft tissue reactions and loss of implant function may be avoided.

4.2 Limitations

There were several potential limitations to this study:

-The specimens were tested by the same researcher, but as with any study, errors in data collection and specimen preparation are possible. Screws from the same lot minimized the problem of intra-manufacturer variation.

-Although general conclusions can be drawn from the results of this study, it should be noted that the recorded preload values correspond to the specific screw type and lot. These results are not transferrable to another design, even from the same manufacturer. These results were obtained using the Southern Implant complex/load cell, and may differ from that of other manufacturers.

-The number of torque cycles in this study was limited and may have been insufficient to cause screw joint deterioration.

-Only tensile forces were applied to the retaining screws, there was no cyclic loading.

-Reduction in preload values was observed in this study under dry and static conditions. This could be attributed to using the same implant body for each of the groups of screws, especially the GSS2 which could have resulted in coating of the implant internal threads with particulate material lost from the relatively soft threads of the gold retaining screws. With the host of challenges in the oral environment, this study understates the loss preload that would occur clinically.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS.

Under the conditions of this in vitro investigation:

- The results indicated that GSS2 screws generated higher preload values than TSS2 at the measured torque values.
- The application of 40Ncm of torque to the retaining screw resulted in consistently higher preload values. In my opinion, depending on the clinical situation, one could consider torquing the retaining screws to much higher preload values to ensure a more stable screw joint, however manufacturers' recommend a maximum torque of 32Ncm to be applied to the retaining screws evaluated in this study.
- As there was no significant reduction in preload generated after the tenth torque cycle, a definitive maintenance protocol cannot be formulated using this study.

For maintenance protocol guidelines the number of torque cycles should be increased. Further investigation is needed to measure these values under cyclic loading as occurs intra-orally. This however, is both technically challenging and time consuming. The effects of lubricants, eg saliva on preload generated also needs to be investigated.

APPENDIX A. LIST OF RESULTS

	TORQUE CYCLE	20Ncm	32Ncm	40Ncm
TSS2 SCREW 1	1	18.0	28.4	36.7
	2	21.1	32.4	39.5
	3	20.4	31.6	39.6
	4	20.5	33.1	38.8
	5	21.6	30.4	39.6
	6	20.2	31.0	38.8
	7	19.9	28.4	35.8
	8	19.4	26.2	33.3
	9	20.1	29.4	41.9
	10	20.4	31.7	38.8
TSS2 SCREW2	1	20.7	30.0	40.2
	2	17.9	30.9	41.6
	3	21.1	33.1	42.1
	4	20.1	32.9	43.7
	5	21.3	33.4	41.9
	6	21.0	33.0	41.3
	7	20.6	33.6	44.9
	8	21.1	31.5	41.1
	9	20.9	29.6	38.2
	10	20.8	32.9	43.7
TSS2 SCREW 3	1	21.6	32.8	40.1
	2	20.1	31.9	39.9
	3	20.3	29.7	38.1
	4	20.1	31.1	40.0
	5	22.7	33.7	42.4
	6	19.1	31.3	40.9
	7	20.0	31.6	36.3
	8	21.0	32.0	39.2
	9	21.0	31.1	39.7
	10	21.5	31.2	39.3
TSS2 SCREW 4	1	20.5	31.5	38.6
	2	20.0	29.6	38.8
	3	21.8	30.6	38.9

	TORQUE CYCLE	20Ncm	32Ncm	40Ncm
	4	22.3	32.6	40.8
	5	21.0	29.7	39.7
	6	19.3	28.8	35.3
	7	20.2	29.3	37.7
	8	20.0	29.8	36.3
	9	18.7	28.5	35.8
	10	18.6	30.9	38.2
TSS2 SCREW 5	1	21.2	32.7	37.5
	2	20.1	29.7	39.8
	3	21.1	31.0	41.2
	4	17.6	30.1	39.9
	5	18.5	30.1	41.4
	6	20.6	29.8	38.2
	7	17.1	31.1	38.7
	8	17.4	27.1	37.1
	9	19.5	31.9	40.3
	10	20.1	31.9	39.6
TSS2 SCREW 6	1	18.9	33.4	41.2
	2	21.0	32.6	40.2
	3	20.7	32.4	42.8
	4	18.7	30.8	38.0
	5	20.0	32.7	37.8
	6	19.8	31.0	39.0
	7	18.8	30.2	36.2
	8	17.4	29.0	37.1
	9	18.2	28.1	37.4
	10	20.0	32.0	40.7
TSS2 SCREW 7	1	20.1	32.0	40.4
	2	18.9	31.4	40.2
	3	19.4	31.2	39.8
	4	19.3	30.5	40.3
	5	17.1	28.9	37.6
	6	17.8	28.7	37.1
	7	19.4	30.0	39.8
	8	18.7	29.2	38.8
	9	18.1	29.6	36.5

	TORQUE CYCLE	20Ncm	32Ncm	40Ncm
	10	19.3	30.0	38.3
TSS2 SCREW 8	1	20.7	34.2	40.9
	2	19.6	32.6	38.9
	3	19.1	30.6	36.6
	4	18.9	31.3	39.1
	5	19.3	31.4	38.6
	6	18.6	29.4	39.4
	7	18.9	30.5	35.9
	8	19.5	28.0	34.4
	9	19.8	30.2	40.8
	10	20.1	30.9	39.7
TSS2 SCREW 9	1	20.7	28.0	39.9
	2	16.3	31.3	37.8
	3	19.2	29.6	39.3
	4	19.6	30.5	38.6
	5	20.3	30.9	38.0
	6	15.2	30.4	37.0
	7	16.6	29.9	38.3
	8	19.1	29.3	40.8
	9	17.0	29.6	36.9
	10	20.3	31.4	39.1
TSS2 SCREW 10	1	20.3	32.2	40.3
	2	19.7	30.9	40.9
	3	18.8	30.4	39.6
	4	18.8	31.4	39.9
	5	19.5	33.0	39.3
	6	17.5	31.9	39.9
	7	19.1	31.8	37.8
	8	19.0	32.2	40.1
	9	19.6	32.2	38.6
	10	18.5	30.7	38.4
GSS2 SCREW 1	1	28.5	41.7	52.0
	2	24.0	37.4	46.9
	3	21.8	34.7	40.6
	4	21.8	37.4	46.2
	5	27.5	41.1	52.3

	TORQUE CYCLE	20Ncm	32Ncm	40Ncm
	6	25.0	40.2	50.6
	7	22.4	37.7	47.9
	8	24.2	38.0	47.5
	9	27.7	40.3	50.8
	10	24.2	36.6	47.0
GSS2 SCREW 2	1	27.3	41.0	50.1
	2	24.8	42.4	50.4
	3	25.6	38.6	49.4
	4	25.5	37.4	48.0
	5	24.0	37.1	46.3
	6	24.7	37.4	47.1
	7	27.0	38.6	46.7
	8	24.8	38.7	47.3
	9	25.9	38.2	47.5
	10	23.6	32.8	43.0
GSS2 SCREW 3	1	30.8	47.0	58.8
	2	25.0	39.9	51.9
	3	24.3	36.4	46.9
	4	21.9	34.9	46.1
	5	22.9	34.0	43.3
	6	23.9	37.7	45.3
	7	22.5	35.8	45.2
	8	24.0	36.2	45.5
	9	21.7	35.1	43.2
	10	22.6	34.1	44.2
GSS2 SCREW 4	1	30.1	46.7	57.0
	2	26.6	40.5	50.7
	3	25.3	39.1	50.8
	4	23.8	38.6	48.3
	5	26.5	41.8	52.0
	6	26.2	39.9	48.9
	7	28.5	44.1	57.3
	8	25.7	43.8	51.9
	9	26.2	39.0	49.1
	10	26.1	43.0	50.2
GSS2 SCREW 5	1	28.7	39.2	49.9

	TORQUE CYCLE	20Ncm	32Ncm	40Ncm
	2	21.8	33.5	41.3
	3	21.3	33.1	46.1
	4	22.2	34.2	45.5
	5	21.7	33.4	42.9
	6	19.6	28.1	36.5
	7	22.6	34.8	45.3
	8	22.2	33.2	43.3
	9	22.9	35.1	43.0
	10	22.1	32.9	44.0
GSS2 SCREW 6	1	40.4	62.6	80.6
	2	36.4	56.1	71.3
	3	30.6	51.0	62.6
	4	26.2	45.9	58.1
	5	26.5	39.9	54.0
	6	26.4	41.8	51.0
	7	26.8	41.5	51.1
	8	29.2	44.4	52.6
	9	28.9	47.4	58.5
	10	22.6	40.5	50.9
GSS2 SCREW 7	1	32.8	50.1	59.1
	2	25.4	38.4	48.6
	3	24.5	37.4	44.3
	4	20.8	36.2	44.5
	5	21.4	32.6	45.7
	6	24.1	38.3	45.5
	7	24.3	35.3	48.1
	8	22.4	35.5	45.5
	9	23.6	33.5	44.8
	10	24.1	35.8	43.6
GSS2 SCREW 8	1	38.3	57.9	67.4
	2	33.3	49.7	60.5
	3	32.7	51.3	62.5
	4	26.3	44.6	57.3
	5	29.8	41.6	57.8
	6	27.0	39.2	55.6
	7	28.5	42.4	55.4

	TORQUE CYCLE	20Ncm	32Ncm	40Ncm
	8	30.5	46.2	62.1
	9	29.6	46.2	58.8
	10	28.5	43.1	57.0
GSS2 SCREW 9	1	27.2	41.0	55.3
	2	26.5	38.4	47.0
	3	27.1	38.6	42.3
	4	24.6	37.5	40.1
	5	23.8	36.5	45.3
	6	24.5	38.5	46.2
	7	22.3	39.6	46.5
	8	25.5	40.2	50.1
	9	25.3	39.7	49.2
	10	24.8	39.5	51.2
GSS2 SCREW 10	1	28.3	45.3	52.3
	2	26.2	42.2	51.3
	3	25.1	37.5	48.2
	4	22.3	38.1	48.0
	5	26.2	39.3	47.5
	6	25.9	36.2	49.2
	7	28.2	37.2	48.6
	8	24.3	39.0	46.3
	9	24.5	38.5	42.2
	10	22.2	34.2	44.3

APPENDIX B. ALLOY CONSTITUENTS MATERIAL CERTIFICATES

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L.KLEIN SA
ACIERS FINS ET MÉTAUX
FINE STEEL AND METALS

Chemin du Long-Champ 110 / Case postale 973
CH-2501 Biel/Bienne / Switzerland
Tél. ++41 (0) 32 341 73 73 / Fax ++41 (0) 32 341 97 20
info@kleinmetals.ch / www.kleinmetals.ch

Bienne, the 12.08.2008

SAETRA (Pty) Ltd

Saetra (Pty) Ltd
Importers & Distribuors
PO BOX 25396 Monumentpark
ZA-0105 Pretoria
South Africa

CERTIFICATE OF CONFORMANCE
Transciption of the inspection certificate in accordance with EN 10204 - 3.1

date of order	: 07.08.2008	order nr	: 11022
net weight	: 36.50 kg	dimension	: 4.00 mm
article nr	: 705130*04000	serie nr	: 210 608
delivery note nr	: 28080201	delivery date	: 12.08.2008

quality: **Titanium Grade 5**
TiAl6V4 (ELI), German no 3.7165
Astm F 136, ISO 5832-3
drawn, ground, polished, in bars of 3m
pointed, chamfered, ends
eddy current crack tested
diam. 4.00 mm, tolerance ISO h6

analyse	results				standard value			
	C	=	0.011	%	C	= max	0.08	%
	N	=	0.004	%	N	= max	0.05	%
	O	=	0.11	%	O	= max	0.13	%
	Fe	=	0.17	%	Fe	= max	0.25	%
	Al	=	6.12	%	Al	=	5.5-6.5	%
	V	=	4.05	%	V	=	3.5-4.5	%
	H	=	0.0028	%	H	= max	0.015	%
	Ti	=		balance	Ti	=		balan:

Beta Transus Ingot top	963	C°
Beta Transus Ingot bottom	968	C°
Tensile strength Rm:	1096-1172	N/mm2
Yield strength Rp 0,2:	938-1017	N/mm2
Elongation A20mm:		%
Elongation A4d:	20	%
Reduction of aera:	45-47	%
Grain size:	ETTC 2 A1	

As per ISO norm 5832-3 199
As per ASTM F 136-98

Heat number: 000W04E
Control-No: 020000166777
We confirm herewith that for this shipment a certificate of conformance from the supplier/steelmill with the indicated values is in our possession.

L. Klein Ltd.
R Sdmann

Certificate of Conformity

for : Elasticor (0053) CM16-86-2

COPY

Wire Ø 2.80 mm +0/-0.025 (400030)
Lot No. 0000093387

1. Composition

Au + Pt group metals	74.5 %
Au	61.0 %
Pt	13.5 %
Ag	16.5 %
Cu	9.0 %

2. Physical Properties

Melting range	950 - 1050 °C
Density	15.7 gcm^3
Young's Modulus	96 GPa
Colour	pale yellow

3. Mechanical Properties

	as drawn
Hardness HV5	> 250
Tensile strength (Rm)	> 800 MPa
0.2% Proof stress (Rp 0.2%)	> 700 MPa
Elongation A5	> 6.0 %

4. Monitoring

Manufacture, packing and delivery are constantly monitored by the quality management system standards according to ISO 9001 and ISO 13485.

CENDRES & MÉTAUX SA

P. Bürki

Patricia Bürki
Administration
Medical

Patricia Biedermann
Administration
Medical

APPENDIX C. ADDITIONAL STATISTICAL ANALYSES

Analysis of variance (ANOVA) log_Ncm metal/uniq id|metal torque metal*torque if cycle =1, repeated (torque). Number of observations =60, R-squared =0.9924, Root MSE =0.039554 and Adjusted R-squared =0.9875.

SOURCE	PARTIAL SS	df	MS	F	Prob>F
MODEL	7.31874393	23	0.318206258	203.39	0.0000
METAL	2.38799979	1	2.38799979	70.07	0.0000
UNIQ_ID|METAL	0.613413988	18	0.034078555		
TORQUE	4.31141042	2	2.15570521	1377.85	0.0000
METAL*TORQUE	0.005919739	2	0.00295987	1.89	0.1655
RESIDUAL	0.056323638	36	0.001564545		
TOTAL	7.37506757	59	0.125001145		

Breusch-Pagan / Cook-Weisburg test for heteroskedasticity

Ho: Constant variance

Variables: fitted values of log_Ncm

Chi2(1) = 1.50

Prob>chi2 = 0.2210 > 0.05

Shapiro-Wilk test for normal data.

VARIABLE	Obs	W	V	Z	Prob>z
Log_Ncm	60	0.97400	1.414	0.746	0.2279>0.05

Means and sstandard deviations (SD) of observed change in preload from 20Ncm for cycle 1 to 40Ncm for cycle 10, by metal.

METAL	N	MEAN	SD
GSS2	10	16.3	4.191
TSS2	10	19.3	1.876

Analysis of Co-Variance (ANCOVA) max_ch metal Ncm1, continuous (Ncm1). Number of observations=20, R-squared =0.3559, Root MSE=2.98427 and Adj R-squared=0.2801.

B	PARTIAL SS	Df	MS	F	Prob>F
MODEL	83.6497119	2	41.824856	4.70	0.0238
METAL	3.92000599	1	3.92000599	0.44	0.5159
Ncm1	38.349228	1	38.349228	4.31	0.0535
RESIDUAL	151.399789	17	8.90586992		
TOTAL	235.049501	19	12.3710263		

Means and standard deviations of observed change in preload from 20Ncm for cycle 1 to 40Ncm for cycle 10 adjusted to a baseline preload of 25.755, by metal.

METAL	ADJUSTED MEAN
GSS2	18.6874
TSS2	16.9226

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity

Ho: Constant variance.

Variables: fitted values of max_ch

chi2 (1) = 3.55

Prob > chi2 = 0.0594 > 0.05

Shapiro-Wilk W test for normal data.

VARIABLE	Obs	W	V	Z	Prob>z
max_ch	20	0.94817	1.227	0.412	0.3402>0.05

REFERENCES

Alkan I, Sertgoz A, Ekici B. Influence of occlusal forces on stress distribution in preloaded dental implant screws. J Prosthet Dent 2004;91:319-325.

Binon P. The effect of implant/abutment misfit on screw joint stability. Int J Prosthodont 1996;9:149-160.

Brunski JB. In vivo bone response to biomechanical loading at the bone/dental-implant interface. Adv Dent Res 1999;13:99-119.

Burguete RL, Johns RB, King T, Patterson EA. Tightening characteristics for screwed joints in osseointegrated dental implants. J Prosthet Dent 1994;71:592-599.

Byrne D, Jacobs S, O'Connell B, Houston F, Claffey N. Preloads generated with repeated tightening in three types of screws used in dental implant assemblies. J Prosthodont 2006;15:164-171.

Cantwell A, Hobkirk JA. Preload loss in gold prosthesis-retaining screws as a function of time. Int J Oral Maxillofac Implants 2004;19:124-132.

Drago CJ. A clinical study of the efficacy of gold-tite square abutment screws in cement retained implant restorations. Int J Oral Maxillofac Implants 2003;18:273-278.

Duncan JP, Nazarova E, Voiatzi T, Taylor TD. Prosthodontic complications in a prospective clinical trial of single stage implants at 36 months. Int J Oral Maxillofac Implants 2003;18:561-565.

Goodacre CJ, Bernal G, Rungcharassaeng K, Kan JYK. Clinical complications with implants and implant prostheses. J Prosthet Dent 2003;90:121-132.

Glossary of prosthodontic terms (GPT-8). J Prosthet Dent 2005;94:10-92.

Gratton DG, Aquilino SA, Stanford CM. Micromotion and dynamic properties of the dental implant-abutment interface. J Prosthet Dent 2001;85:47-52.

Guda T, Ross TA, Lang LA, Millwater HR. Probabilistic analysis of preload in the abutment screw of a dental implant complex. J Prosthet Dent 2008;100:183-193.

Jaarda MJ, Razzoog ME, Gratton DG. Geometric comparison of five interchangeable implant prosthetic retaining screws. J Prosthet Dent 1995;74:373-379.

Jabbari YL, Fournelle R, Ziebert G, Toth J, Iacopino AM. Mechanical behavior and failure analysis of prosthetic retaining screws after long-term use in vivo. Part 1: Characterization of adhesive wear and structure of retaining screws. J Prosthodont 2008;17:168-180.

Jabbari YL, Fournelle R, Ziebert G, Toth J, Iacopino AM. Mechanical behavior and failure analysis of prosthetic retaining screws after long-term use in vivo. Part 2:Metallurgical and microhardness analysis. J Prosthodont 2008;17:181-191.

Jabbari YS, Fournelle R, Ziebert G, Toth J, Iacopino AM. Mechanical behavior and failure analysis of prosthetic retaining screws after long-term use in vivo. Part 3:Preload and tensile fracture load testing. J Prosthodont 2008;17:192-200.

Jemt T, Laney WR, Harris D, Henry PJ, Krogh PHJ, Polizzi G, et al. Osseointegrated implants for single tooth replacement: A 1-year report from a multicenter prospective study. Int J Oral Maxillofac Implants 1991;6:29-36.

Kallus T, Bessing C. Loose gold screws frequently occur in full-arch fixed prostheses supported by osseointegrated implants after 5 years. Int J Oral Maxillofac Implants 1994;9:169-178.

Khraisat A, Hashimoto A, Nomura S, Miyakawa O. Effect of lateral loading on abutment screw loosening of an external hexagon implant system. J Prosthet Dent 2004;91:326-334.

Lang LA, Kang B, Wang RF, Lang BR. Finite element analysis to determine implant preload. J Prosthet Dent 2003;90:539-546.

Martin WC, Woody RD, Miller BH, Miller AW. Implant abutment screw rotations for four different screw materials and surfaces. J Prosthet Dent 2001;86:24-32.

McGlumpy EA, Mendel DA, Holloway JA. Implant screw mechanics. Dent Clinics North America 1998;42:71-89.

Michalakis KX, Hirayama H, Garefis PD. Cement retained versus screw retained implant restorations: A critical review. Int J Oral Maxillofac Implants 2003;18:719-728.

Naert I, Quirynen M, van Steenberghe D, Darius P. A six-year prosthodontic study of 509 consecutively inserted implants for the treatment of partial edentulism. J Prosthet Dent 1992;67:236-245.

Rafee MA, Nagy WW, Fournelle RA, Dhuru VB, Tzenakis GK, Pechous CE. The effect of repeated torque on the ultimate tensile strength of slotted gold prosthetic screws. J Prosthet Dent 2002;88:176-182.

Rambhia SK, Nagy WW, Fournelle RA, Dhuru VB. Defects in hexed gold prosthetic screws: A metallographic and tensile analysis. J Prosthet Dent 2002;87:30-39.

Rangert B, Jemt T, Jorneus L. Forces and moments on Branemark Implants. Int J Oral Maxillofac Implants 1989;4:241-247.

Steinebrunner L, Wolfart S, Ludwig K, Kern M. Implant-abutment interface design affects fatigue and fracture strength of implants. Clin Oral Impl Res 2008;19:1276-1284.

Tan BF, Tan KB, Nicholls JI. Critical bending moments of implant-abutment screw joint interfaces: Effect of torque levels and implant diameter. Int J Oral Maxillofac Implants 2004;19:648-658.

Tan KB, Nicholls JI. Implant-abutment screw joint preload of 7 hex-top abutment systems. Int J Oral Maxillofac Implants 2001;16:367-377.

Tan KB, Nicholls JI. The effect of 3 torque delivery systems on gold screw preload at the gold cylinder abutment screw joint. Int J Oral Maxillofac Implants 2002;17:175-183.

Tzenakis GK, Nagy WW, Fournelle RA, Dhuru VB. The effect of repeated torque and salivary contamination on the preload of slotted gold implant prosthetic screws. J Prosthet Dent 2002;88:183-191.

Wang RF, Kang B, Lang LA, Razzoog ME. The dynamic natures of implant loading. J Prosthet Dent 2009;101:359-371.

Weinberg LA. The biomechanics of force distribution in implant-supported prostheses. Int J Oral Maxillofac Implants 1993;8:19-31.

Weiss EI, Kozak D, Gross MD. Effect of repeated closure on opening torque values in seven abutment-implant systems. J Prosthet Dent 2000;84:194-199.

Winkler S, Ring K, Ring JD, Boberick KG. Implant screw mechanics and the settling effect: an overview. J Oral Implantology 2003;29:242-245.

Yousef H, Luke A, Ricci J, Weiner S. Analysis of changes in implant screws subject to occlusal loading: A preliminary analysis. Implant Dent 2005;14:378-385.