Micromorphological differences of the implant-abutment junction and \textit{in vitro} load testing for three different titanium abutments on Straumann tissue level implants

Authors’ affiliations:
N. Mattheos, L. Ma, G. Fokas, V. Chronopoulos, M. Janda, Faculty of Dentistry, The University of Hong Kong, Hong Kong, China
C. Larsson, Faculty of Odontology, Malmo University, Malmo, Sweden
V. Chronopoulos, Faculty of Dentistry, University of Athens, Athens, Greece
M. Janda, Specialist Clinic for Prosthodontics, Public Dental Service, Lund, Region Skane AB, Sweden

Corresponding author:
Nikos Mattheos, DDS, MASc, PhD
Oral Rehabilitation, Faculty of Dentistry, The University of Hong Kong
34 Hospital Road, Sai Ying Pun, Hong Kong, China
Tel.: +852 2859 0310
Fax: +852 28586114
e-mail: nikos@mattheos.net

Key words: imaging, material sciences, prosthodontics, radiology

Abstract

Background: The aim of this study was to investigate the micromorphological differences among three commercially available titanium abutments on Straumann implants. Furthermore, the possible impact of functional loading on the micromorphology and potential complications was investigated with the use of \textit{in vitro} testing.

Material and methods: Three groups of Titanium abutments (A: Straumann Variobase \(n = 5\), B: EBI best Duo \(n = 5\), and C: Implant Direct \(n = 5\)) were torqued on Straumann RN implants, as according to each of the manufacturer’s instructions. The implant–abutment units were scanned with Micro-CT. Three units of each group were directly sliced in the microtome and photographed under different magnifications (10–500x) through a Scanning Electron Microscope. Six units (two from each group) were restored with cement-retained crowns, subjected to 2000,000 load cycles with loads between 30 and 300 N at 2 Hz, examined through Micro-CT and finally sliced and photographed as described above. The micromorphology of each unit was studied, and the total length of tight contact (<3 \(\mu m\)) was calculated between the implant, abutment and screw contact areas.

Results: Major morphological differences were identified between the three units, as well as differences in the extent of tight contact in all areas examined. Despite the morphological differences, the 2M cycles of loading via \textit{in vitro} test did not result in any noticeable complications although some changes in the micromorphology were observed.

Conclusion: The examined implant–abutment units presented with major morphological differences. Two million cycles of \textit{in vitro} loading did not appear to affect the stability of the units despite the micromorphological changes. These results need to be interpreted however under the limitations of the small sample size and the specific set-up of the \textit{in vitro} testing.

Introduction

Implant-supported fixed dental prostheses (IsFDP) have become a widely utilized treatment modality with high predictability and long-term survival rates (Pjetursson et al. 2014), as well as high satisfaction ratings based on reported patient centred outcomes (Yao et al. 2014). However, despite the high predictability, technical complications are not uncommon. After examining 281 full arch IsFDPs reported in randomized clinical trials or prospective studies, Papasyridakos et al. concluded that only 29.3% and 8.6% of them were free of complications after 5 and 10 years, respectively (Papaspyridakos et al. 2012). Data from small span implant-supported FDPs indicate a smaller prevalence of technical complications, reportedly around 13% after 5 years (Pjetursson et al. 2012). Recent studies point out that complications appear to be “clustered,” while the occurrence of technical complications is shown to be well correlated with the prevalence of biological complications as well (Kim et al. 2014). Such findings suggest that technical complications very often have an underlying fundamental cause, rather than simply being failures of material or components.

The implant–abutment junction is the area where the functional forces from occlusion will be transferred to the rigidly anchored
implant. Consequently, any deformation or strain of the prosthesis caused by misfit or compromised fit will impact the long-term stability of the implant-abutment, possibly leading to technical complications [Mattheos & Janda 2012]. Furthermore, misfit might increase microbial leakage of the implant-abutment connection and biofilm accumulation. Bacterial and fluid microleakage has been related to oral malodour, inflammation and marginal bone loss, apart from the potential technical implications it could have for the long-term stability of the connection [Broggini et al. 2003, 2006].

Improved implant and abutment design coupled with the development of strict clinical protocols has lead to a significant improvement in the reliability of implant-abutment connections and a consequent reduction in the frequency of the related clinical complications [Schulte & Coffey 1997, Martin et al. 2001; Piermatti et al. 2006]. However, the treatment outcomes achieved with original implant components, used under strictly standardized conditions and protocols, are not always encountered in everyday clinical practice. Increasing market pressure and price competition or convenience have lead to the introduction of “compatible” or “interchangeable” third-party prosthetic components, which can be branded or generic. Empirical evidence has raised concerns in the past with regard to the risks related to the use of compatible prosthetic components [Mattheos & Janda 2012]. However, there is currently a rising body of evidence pointing towards the potential implications of this trend. A recent pilot study identified differences in the micromorphology and the accuracy of fit between original and compatible abutments, suggesting potential clinical implications through the use of finite element analysis [Mattheos et al. 2016]. After in vitro loading, Kim et al. found a significantly increased frequency of screw fractures and removal torque values for compatible abutments on Straumann implants (Kim et al. 2012). Nevertheless, this study could not link observed complications to the micromorphology and extend of misfit, as they did not study the geometry of each implant-abutment junction. Zanardi et al. (2012) observed misfit in general in all compatible specimens studied, with the median misfit “gap” being 3.4 μm for the non-rotational and 4.6 μm for the rotational parts of the junction. Berberi et al. (2014) demonstrated a significant increase in microleakage when compatible abutments were used on AstraTech implants, a finding that might explain a link between misfit of technical components and biological implications. Conclusively, although there is evidence for both significant micromorphological differences and frequency of in vitro complications between compatible and interchangeable abutments, there is still no research linking the two. Research of micromorphology coupled with in vitro testing could help to identify the factors of the microgeometry, which could correlate to increased technical complications, such as the required extent of tight fit.

Aims

The aim of this study was to provide a two-dimensional representation of the exact morphological geometry of three commercially available titanium abutments when placed on Straumann implants. This study aimed to investigate the morphological structures, as well as to measure the extent of tight contact surface between the implant and abutment (microgap of 3 μm or less between abutment, abutment screw and implant surfaces). Finally, this study aimed to investigate the possible impact of functional loading on the macroscopically observed deficiencies, the incidence of complications such as veneer fractures and abutment loosening using in vitro loading with two million cycles.

Material and methods

Implant-abutment connection

Fifteen abutments were torqued on original Straumann RN implants, as according to each of the manufacturer’s instructions. The three groups of five units each had as follows:

Group 1: Straumann 4.1 RN 10 mm implant + Straumann Variobase RN abutment, torqued at 35 Ncm.
Group 2: Straumann 4.1 RN 10 mm implant + Ebi Best Duo abutment, torqued at 35 Ncm.
Group 3: Straumann 4.1 RN 10 mm implant + Implant Direct titanium abutment, torqued at 30 Ncm.

Micro-CT analysis

After connection of the abutment, one unit from each group (n = 3) was scanned using Skyscan-1076 X-ray microtomograph (Skyscan, Kontich, Belgium) with the following setting: 88 kV source voltage, 100 μA source current, 1 mm aluminium filter, 17.33 μm image pixel size, 560 ms exposure and 0.6° rotation step. The three-dimensional reconstruction was performed using Skyscan software package (NRECON, Skyscan, Aartselaar, Belgium). The ring artefact correction was set to eight.

Implant-abutment slicing

Three implant-abutment units from each group were cleaned in liquid in a digital vibration shaker, following embedding of all units in hard acrylic form and slow setting in light polymerization unit. Each implant/abutment unit was then mounted to microscope-slide from two sides with adhesive under vacuum. Cutting of each unit with a cutting/grinding micromotome system under vacuum was followed. The final section was achieved through grinding of the sample with a micro-grinding system (800–4000 grid) under vacuum. The final slice was aimed to represent an axial slice of the implant-abutment interface located at the wider diameter of the implant in the middle of a synOcta flat surface. The slicing was guided by two laser lines at the sides of the implant to mark the ideal position (Fig. 1a,b). The guiding laser lines eliminated the need for calibration measurements, as were used in previous studies [Mattheos et al. 2016]. After cleaning and removal of debris from the sliced surface with ultrasonic and streamer, the slice was dried and prepared for scanning electron microscopy.

Scanning electron microscopy (SEM), two-dimensional imaging and measurements

The sliced implant-abutment units [three from each group, n = 9] were then viewed under different magnifications [10×–500×] through a Variable Pressure SEM (SU1510, Hitachi) and digitally photographed.

Fig. 1. [a, b] The ideal position of the vertical slice of the implant/abutment unit in the middle of a flat synOcta surface at the maximum diameter (A) was marked by two laser lines at the sides of the implant (b).
Calibrated photographic editing software (ImageJ, Bethesda, Maryland, USA) was used for measurements in photographs under magnifications corresponding to the area under assessment.

Further measurements were conducted in the three contact areas (CA) of the implant–abutment units where tight contact between components is expected, this being

1. **Implant shoulder (IS)**, that is the area of the abutment in contact with the external shoulder of the implant neck (Fig. 2). The length of tight contact [TC < 3 μm] between the abutment and the implant shoulder (CA-IS) was measured, and the ratio of TC to IS was evaluated,

2. **Internal connection (IC)**, that is the area of the abutment in contact with the internal connection of the implant (Fig. 2). The length of tight contact [TC < 3 μm] between the abutment and the internal connection [IC] was measured.

3. **Screw threads (SC)**, that is the area of the abutment screw in contact with the internal implant threads (Fig. 2). The total number of threads in tight contact [TC < 3 μm] with the implant [NT], the total length of tight contact between implant threads and implant (CA-ST), and the thread with the highest length of contact [Tmax] were evaluated. Furthermore, the three best threads of each side (left/right) were selected for each unit prior to loading ([n] = 18) and after loading ([n] = 12) and compared.

Measurement of the total linear length of tight and non-tight contact in each of the three areas was conducted by two calibrated examiners. The length of linear tight contact (TC) between the above components in the cross-sectional image was measured in mm.

The specific morphology and design of the abutment and abutment screw were observed. Furthermore, the quality of the surfaces in contact was examined, investigating the presence of surface anomalies, microroughness, microcracks or any other mismatch between the interfacing surfaces.

**In vitro testing**

Two implant–abutment units from each group ([n] = 6) were restored with cement-retained crowns and subjected further to in vitro testing. One restored unit from each group ([n] = 3) was then scanned in the Micro-CT as described previously (Fig. 3). In vitro testing was performed according to the ISO set-up for dynamic fatigue test for endosseous dental implants (ISO 14801:2007 “dentistry–implants–dynamic fatigue test for endosseous dental implants”). The crowns were made as premolars instead of the ISO standardized hemisphere. The anatomic shape of tooth crowns was chosen to ensure an in vitro set-up, mimicking as much as possible the clinical situation. The specimens were fixated in 18 × 15 mm plastic cylinders (Plexlite Produkter AB, Malmö, Sweden) using resin (Epofix, Struers, Copenhagen, Denmark; Fig. 4). After 24 h of curing, the specimens were placed in brass cylinders, mounted at a 10° angle and submerged in water via the holding devices of the preloading machine (MTI Engineering AB, Lund/Pamaco AB, Malmö, Sweden; Fig. 5). All specimens were subjected to two million load cycles with loads between 30 and 300 N at 2 Hz. The load was applied with a 2.5-mm stainless steel ball placed on the occlusal surface of the crowns.

After completion of the loading cycles, the restored implant–abutment units were examined with Micro-CT and then sliced in the microtome and photographed under the SEM with the respective measurements conducted as described above.

**Statistical analysis**

Interexaminer agreement between the two examiners was controlled with Bland–
Altman’s plot for two series of measurements of the implant shoulder (nine measurements) and the internal connection (nine measurements). Differences in the micromorphology measurements between the different implant–abutment groups were analysed with Mann–Whitney U-test. A power calculation was proved to be difficult, as no similar in vitro studies were found with adequate relevance to provide data. The power calculation aimed to provide the necessary sample size to show difference in the incidence of complications under functional load (veneer fractures, abutment loosening etc.) between original and compatible units (categorical data). Kim et al. (2012) tested four different implant–abutment groups with seven specimens in each group with in vitro loading. He found 6/7 and 4/7 units in two of the compatible abutment groups to result in mechanical failures (screw fracture/implant fracture). As in this study the failures encountered with the compatible components were more than 50% higher than the original, a potential difference exceeding 50% was assumed and a sample size of five units per group was deemed sufficient to reach statistical significance set at 0.05 with power of 0.8.

Results

Morphological observations
The three abutments presented with significant morphological differences.
1. Implant shoulder: The Variobase (Fig. 6a) and the Implant Direct (Fig. 6b) abutment presented with tight contact on the implant shoulder, while the EBI Best Duo is designed without contact in this area (Fig. 6c), similar to a “platform switching” at the tissue level.
2. Abutment screw to abutment connection: There was a major difference in the morphology of the abutment screw of the three abutments. The Variobase abutment had a tapered contact of the abutment screw (Fig. 7a–c), while EBI (Fig. 8a–c) and Implant Direct (Fig. 9a–c) had “flat-to-flat” contacts. There appeared to be some “flattening” of the screw-abutment contact in one specimen of the Implant Direct abutment, suggesting that the loading could have had an effect in this component.

Tight contact measurements of unrestored and restored units
Bland–Altman plot demonstrated good agreement between the two examiners in the two sets of measurements utilized (shoulder and internal connection, Fig. 10). Dimensional differences were identified between the three units in all three investigated contact areas (Table 1; Fig. 11). Some of the differences reached the level of statistical significance ($P < 0.05$):
- Implant shoulder: Variobase presented with significantly more areas of tight contact at the implant shoulder than the Implant Direct abutment, both left and right.
- Internal connection: Variobase presented with significantly more areas of tight contact at one side of the internal connection (right) than the Implant Direct abutment. The EBI abutment presented with significantly more tight contact regions on one side of the internal connection (left) than Variobase. In this case, however, it
must be noted that the difference was attributed to one specimen of a Variobase abutment, which presented at the left side with much less area of tight contact (0.05 mm) than the other two samples (1.59 and 1.02 mm). The EBI abutment presented with significantly more areas of tight connection on both sides of the screw threads than Variobase and Implant Direct. However, when comparing the tight contact areas of the best three screw threads prior and after loading, Variobase appeared to have the highest consistency of all three abutments, as seen by the total area of contact and the respective standard deviations (Table 2).

- Micro-CT measurements

No measurements were conducted on the vertical slices, and only qualitative characteristics were assessed.

**In vitro testing**

In vitro testing was completed without introducing any visible complications. No significant chipping of the veneering was observed in any of the tested units, and all restorations were found to be firmly seated on the implants after completion of the two million cycles of loading. No significant differences were found for the measurements of tight contact areas when comparing the before and after loading data.

**Discussion**

The current study aimed to link the specifics of the microgeometry of implant–abutment connection to technical complications after in vitro loading of 2M cycles. The loading was conducted with clinically relevant settings, that is with the presence of an anatomic porcelain fused to metal (PFM) cement-retained crown and an angle of loading of 10°. The findings of the study did not suggest higher hardware complication rates under the circumstances tested, despite the observed differences observed in the micromorphology. This might be attributed to several factors as will be discussed below.

**Tightness of contact and “microgap”**

It is difficult to identify a threshold to define the “tight contact” expected from implant system components based on scientific evidence. It is also true that our expectations of optimal fit have increased over time, matching the improvements of implant–abutment design.

Although it is generally perceived that tighter fit between the implant and abutment surfaces is desired, there is no evidence to suggest the optimal or acceptable threshold for this tight contact, in particular for the internal parts of the implant–abutment connection and the abutment screw threads.

\[ \text{Fig 7. The tapered contact of the Variobase abutment screw to the abutment prior (a, b) and after loading (c).} \]

\[ \text{Fig 8. The “flat-to-flat” contact of the EBI abutment screw to the abutment prior (a, b) and after loading (c).} \]
Some more data exist with regard to the external microgap between the abutment and the implant shoulder, as this has been studied due to the potential for bacterial and fluid leakage. In a study evaluating microleakage on AstraTech implants, Berberi et al. (2014) found that microleakage was increased by \(253 – 1113\%\) when different compatible third-party abutments were used as compared to the original combination of Osseospeed and TiDesign. Unfortunately, the authors did not measure the microgap for each combination, although they cited the microgap in the case of the original AstraTech implant–abutment to be between 1 and 2 \(\mu m\), based on previous research (Jansen et al. 1997). In the study of Jansen et al., significant microleakage was found in 10 different implant–abutment combinations, where the microgap was less than 10 \(\mu m\), a threshold that however would be considered as rather high today.

The microgap between the implant shoulder and abutment using interchangeable abutments was measured by Dellow et al. (1997). It was found to vary between 0.23 \(\mu m\) (Southern), 7.1 (Branemark), 0 (<1 (Steri-Oss) when original components were used. However, no conclusions could be drawn regarding the size of microgap that would be unacceptable. Also, these findings will have little relevance today anyway, as the design of the implant–abutment junction has improved significantly since that time.

Current scanning electron microscopy can help identify microgaps of 1 \(\mu m\). In the case of linear measurements, however, where the width of the microgap might not be consistent throughout the full length of contact, examiner’s agreement seems to decrease significantly when the measurement threshold is set to 1 or 2 \(\mu m\) despite calibration efforts. Consequently, given the indications produced by previously discussed research and aiming to optimize the validity and reproducibility of the measurements, a threshold of 3 \(\mu m\) was set to define tight contact for the purpose of this study. This is indeed a very low threshold. Due to the significant differences between the original and the compatible abutments, the results of the statistical analysis might vary significantly if a larger gap is selected to characterize “tight” contact. As stated earlier, the optimal threshold remains unclear based on the currently available evidence.

**Morphological differences**

Regardless of the tightness of contact, certain morphological differences could have a substantial impact on clinical outcomes in the long term. In particular, the area of contact between the abutment screw and the abutment is important, as this is the surface that bears the complete clumping force that keeps the abutment stable. It is reasonable to assume that this relatively small area bears the full impact of forces applied on the implant–abutment unit. There appears to be a significant difference in the design between the Variobase and the two other abutments tested in this study, as the screw of the Variobase in contact with a “bevelled” long surface, while the two others are “flat to flat” with a much smaller contact surface. Although impossible to analyse statistically, the post-loading images of the “flat-to-flat” screw contact indicated significant flattening and wear of the area in contact. In the long term, if worn out, such a connection might become the weakest link in the implant–abutment junction.

One further interesting observation has to do with the screw threads, as the tightness of contact before and after loading could be an important parameter of long-term stability. “Settling” of the abutment on the implant...
after loading is a common phenomenon as the friction between the two components is reduced with time in function. Settling will reduce the preload of the screw and commonly lead to a reduction in the tightness of contact between the abutment screw and the implant. This is commonly manifested as a reduction in the torque value after the abutment has been in function for some time and potentially leading to screw loosening. Unfortunately, due to the use of cement-retained crowns in this experiment, it was not possible to measure removal torque values. Nevertheless, the consistency of a tight contact before and after loading, and the larger standard deviations indicate a prominent settling effect for the EBI (Fig. 12) and the Implant Direct abutments, while the Variobase appears to have greater consistency in that aspect.

**In vitro loading**

The in vitro cyclic loading tests did not result in any hardware complications or major changes in the micromorphology of the implant–abutment connection interface which is in contrast to findings from some other groups [Kim et al. 2012; Murmura et al. 2013]. The test set-up in the present study largely adhered to the recommendations of the ISO standard for dynamic tests.
fatigue testing for endosseous dental implants, in particular concerning frequency and number of cycles of loading (ISO). Loads of a few hundred Newton are considered to be representative for normal chewing forces (Bates et al. 1975). Most other groups also rely on the ISO standard, but often make some exceptions. Murmura et al. and Kim et al. used similar loads as in the present study but fewer numbers of cycles, that is one million compared to two million cycles (Kim et al. 2012; Murmura et al. 2013). Those studies used higher load application frequency (6 Hz) than the 2 Hz used in the present study. Furthermore, they applied the load directly on the abutments and not via an anatomic crown, as a clinically relevant scenario would require.

One factor recommended by the ISO standard which was changed in the present study was the angulation of the specimens during cyclic load testing. A 30° angulation is recommended by the ISO to represent a worst case scenario. Such angulation is not clinically relevant for the posterior dentition although (Andrews 1972). The previously mentioned studies used standardized shaped specimens (abutments) for their testing, again largely adhering to the ISO standard. Standardization tests are used for certifying safety and quality control – but rarely predict long-term clinical performance (Kelly et al. 2012). The present study tried to replicate the clinical situation using anatomically shaped cement-retained PFM crowns and loading at an angulation of 10°, which is more representative of a clinical premolar situation (Andrews 1972, Kelly et al. 2012). It is possible that previous studies may have overemphasized risks of complications due to the use of test set-ups representing worst case scenarios rather than actual clinical conditions. Furthermore, the diversity of reported outcomes in the available few studies most likely indicates significant diversity with regard to the accuracy of fit, quality and performance of different commercially available compatible abutments, which probably reflect differences not only in the design, but also the manufacturing process and metal alloys used. Consensus regarding appropriate set-up for fatigue testing is lacking. Until laboratory testing protocols can be developed that can effectively simulate the clinical situation and correctly predict clinical performance, conclusions are limited and should be cautious and conservative. One of the limitations of this study might be the sample size, as five units per group were tested. This number is not different to other studies which have reported differences in the incidence of mechanical complications (Kim et al. 2012). As the settings of the different experiments vary substantially, calculating the appropriate sample size is not an easy task.

In conclusion, the use of moderate in vitro settings for cyclic loading of single implant crowns on abutments with different geometry and fit did not result in differences in terms of the number and type of technical complications. It has to be recognized however that the loading settings of this experiment were not as high as others reported in the literature. The settings chosen in the present study were geared towards representing the most simple of clinical scenarios, namely a single implant crown. The micromorphological observations after cyclic scenarios, with regard to frequency, duration and loading angle of cycles. It remains prudent to be aware of the differences between compatible components with different microgeometry. More extensive in vitro testing under more complex conditions (e.g. short and long span bridges), clinical trials and long-term follow-up will be required to better understand all possible implications and illustrate the link between differences in the micromorphology of the implant–abutment junction and their influence on clinical behaviour.

Acknowledgements: The study was supported by Grant No. 775113 by RGC, Hong Kong. Certain parts of the experiment were supported by Malmö University and Folkandvården Skåne AB, Sweden. Straumann implants were kindly provided by Straumann AG, Basel, Switzerland. Dr. Mattheos reports grants from RGC Hong Kong, during the conduct of the study.

Conflict of interest
The authors have stated explicitly that there are no conflict of interests in connection with this article.

References


学霸图书馆
www.xuebalib.com

本文献由“学霸图书馆-文献云下载” 收集自网络，仅供学习交流使用。

学霸图书馆（www.xuebalib.com）是一个“整合众多图书馆数据库资源，提供一站式文献检索下载服务”的24小时在线不限IP图书馆。

图书馆致力于便利、促进学习与科研，提供最强文献下载服务。

图书馆导航：
图书馆首页 文献云下载 图书馆入口 外文数据库大全 疑难文献辅助工具