euspen's 17th International Conference & Exhibition, Hannover, DE, May 2017
www.euspen.eu

Assembly analysis of titanium dental implants using X-ray computed tomography

Filippo Zanini[1], Simone Carmignato[1], Enrico Savio[2]

[1]*Department of Management and Engineering, University of Padova, Vicenza, Italy.*
[2]*Department of Industrial Engineering, University of Padova, Padova, Italy.*

filippo.zanini@unipd.it

Abstract
Dental implants are commonly used as replacement of tooth roots to support dental prosthetics. A successful implant therapy can be complicated by biological and/or mechanical factors. Tight dimensional tolerances are required to ensure a correct fit between implant, abutment and screw. In this context, verifying the quality of the assembly becomes crucial. Micro X-ray computed tomography (CT) is a unique tool for inspection of assemblies, since it allows analysing the individual components in the assembled state. However, the identification of contact surfaces is complicated when the components that are in contact are made of the same material, as holds for several dental implant types. In this work, new CT-based methods to assess the quality of mono-material assemblies are presented. Experiments are performed on different types of titanium dental implants. A metrological CT system was used to measure dimensional deviations and deformations of the assembled components caused by assembly operations. Moreover, contact surfaces between implant, abutment and screw were identified and measured.

X-ray computed tomography, assembly analysis, dental implants

1. Introduction

State-of-the-art dental implants are made of materials promoting the osseointegration, e.g. titanium and ceramic. Over the last years, surgical and technological progress has contributed to raise over 90% the percentage of successful rehabilitation by dental implants [1]. However, a successful implant therapy can be complicated by biological and/or mechanical factors. In particular, a non-perfect implant sealing may produce mechanical stress on connection structures and surrounding bone tissue, increasing risks of screw preload loss or fracture and microbiological leakage in peri-implant tissues [2]. Tight dimensional tolerances are then required to ensure a perfect implant-abutment fit, minimizing the possible complications. In this context, verifying the quality of the assembly becomes crucial. Micro X-ray computed tomography (CT) is a unique tool for non-destructive inspection of assemblies, since it allows analysing the individual components in the assembled state [3]. However, identifying the exact interface between assembled components made of the same material (as holds for several types of dental implants) might be complicated. In a previous work [1], CT was used to identify contact surfaces and micro-gaps through sequential analysis of reconstructed axial sections (micro-gap was here described as thin circular radiolucency). Gap measurements performed by CT were also investigated in [4] using a dedicated reference standard. In this work, new CT-based methods for quality assessment of mono-material assemblies are presented. Experiments were performed on titanium dental implants with screw-type connection. Dimensional deviations and deformations caused by the assembly operation were evaluated and contact surfaces between implant, abutment and connection screw were identified and measured.

2. Implant systems and instrumentation

Two types of implant systems produced by Sweden&Martina S.p.A. were investigated in this work (see Figure 1): one with cylindrical connection (CYC) and the other with conical connection (COC). Both implant types consist of three components: (i) implant, made of Ti-Grade4, to be implanted in the gum, (ii) abutment, made of Ti-grade5, supporting the dental prosthesis and (iii) connection screw, made of Ti-grade5. CT data were acquired using a metrological CT system with micro-focus X-ray source, thermal controlled cabinet and 16bit 2000x2000 X-ray detector. The maximum permissible error (MPE) for length measurements of the CT system is MPE = 9 + L/50 µm (L is the length in mm). CT data were then elaborated by means of the commercial software VGStudio MAX (Volume Graphics GmbH, Germany).

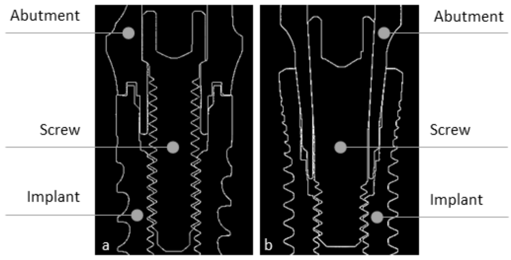

Figure 1. Implants with cylindrical (a) and with conical (b) connections.

3. Evaluation of dimensional deviations and deformations

Dimensional evaluation of each individual component of an implant system is fundamental for ensuring the quality of the assembly. However, a mere evaluation of the as-produced components is not sufficient for an accurate assessment of the assembly functionality. For this reason, in this work, CT was employed to evaluate in a non-destructive way deviations and deformations of components arising after *in vitro* assembly operations. For example, the screw elongation, which gives information about the induced preload, would not be measurable, without cutting or disassembling the part, with other coordinate measuring systems (e.g. tactile and optical CMMs), due to its internal position, impossible to access. Cutting or disassembling one part would furthermore alter the actual condition of its individual components after the assembly. The correct screw preload value, fundamental to prevent screw failures, is connected to the tightening torque [5]. For this reason, different torque values were applied for assembling the two types of implants under investigation: 20, 25 and 30 N·cm. As illustrated in Figure 2-a, the CYC screw was found to elongate more than the COC screw for equal torques. Moreover, the CYC screw is more sensitive to the specific exerted torque. Even after 5 repeated tightening-loosening operated at 25 N·cm, no particular components deformations were observed, except for those produced on the screw by the tightening operation itself (see Figure 2-b). Such tests also revealed that the screw elongation was mostly due to elastic deformation. In fact, when loosening the screw, its length always came back to the original dimension.

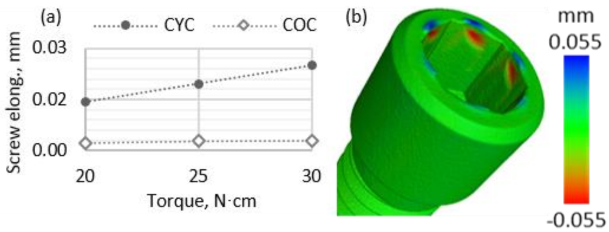

Figure 2. (a) Screw elongation obtained for 3 torques and 2 types of implants. (b) Deviations/deformations map of a CYC screw.

4. Contact surfaces analysis

As mentioned in Section 1, implant-abutment misfit leads to mechanical as well as biological complications. The presence of micro-gaps where two components are supposed to interfere may allow dangerous bacterial infiltrations. For this reason, assessing the quality of the assembly requires to analyse the contact surfaces between the assembled components. This task is not viable with conventional inspection techniques. For example, optical analyses are limited to few specific cut sections. In the following, new CT-based methods aimed at identifying and quantifying contact surfaces and micro-gaps are presented. When two components of the same material interfere, they are imaged by CT as they were one unique component. Thus, contact surfaces can't be accurately identified in a direct way. To overcome this limitation, CT scans of single components in the pre-assembled state were performed prior to CT scan the assembled implant system. After determining the surfaces of the CT reconstructions using locally adaptive methods, a proper alignment was conducted between corresponding pre- and post-assembly components by considering only the non-deformed regions. The original components were so used to get information about their final relative positioning after the assembly. In this way, the contact surfaces could be identified, as seen in Figure 3-a. When overlaps between touching components occur, it means that not only contact but also a local deformation is produced by the assembly operation. The quantification of contact surfaces was operated considering that, when determining the surface of an assembled implant (with components made of the same material), no surface can be found in correspondence of contact points (Figure 3-b). Consequently, the contact surfaces were quantified by subtracting the total surface (in mm^2) of the three pre-assembled components with the surface of the final assembled implant. This analysis can be also focused on specific portions of the assembly to calculate the contact surface within specific regions of interest.

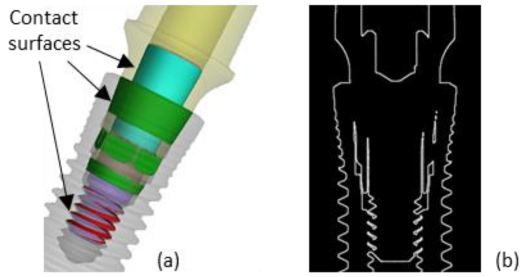

Figure 3. (a) Three-dimensional visualization of contact surfaces between assembled components. (b) Extracted surface (white line) of an assembled implant.

To assess the presence of micro-gaps, a proper alignment was performed between pre- and post-assembled components, as described above. Deviations maps were then generated between touching components with VGStudio MAX, by measuring the distance between surfaces with opposite normal vectors. The false-colour deviation map depicted in Figure 4 shows contact surfaces (green regions) and micro-gaps (blue regions) between screw and abutment of a COC implant taken as an example.

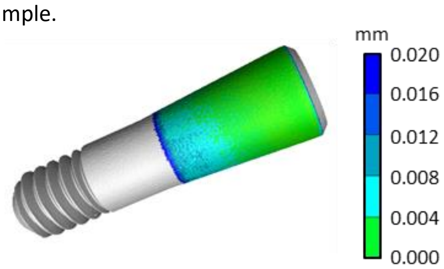

Figure 4. Deviation maps showing contact surfaces (green) and micro-gaps (blue) between screw and abutment of a COC implant system.

5. Conclusions

In this work, new CT-based methods for assembly analysis of dental implants were proposed. Experiments were conducted on two different types of dental implants made of titanium and characterized by different connections (i.e. cylindrical and conical). Dimensional evaluations were performed after applying different tightening torques. The screw elongation was measured by CT scanning the implants before and after the assembly. Moreover, new methods to identify and quantify contact surfaces and micro-gaps between assembled components made of the same material were proposed. These methods can be extended to other types of mono-material assemblies as well. Further work is planned to assess the accuracy of the proposed methods.

Acknowledgements

This work has received funding from University of Padova (projects Nr. CPDA151522/15 and BIRD167853/16) and from Sweden&Martina S.p.A.

References

[1] Meleo D et al 2012 Fixture-abutment connection surface and micro-gap measurements by 3D micro-tomographic technique analysis *Ann. Ist. Super. Sanità* **48 (1)** 53-58

[2] Callen D P et al 1998 Loss of crestal bone around dental implants: a retrospective study. *Implant. Dent.* **7** 258-266.

[3] De Chiffre L et al 2014 Industrial applications of computed tomography *CIRP Annals Man. Tech*. **63** 655-667

[4] Hermanek P et al 2017 Experimental investigation on multi-material gap measurements by computed tomography using a dedicated reference standard, EUSPEN 2017.

[5] Cibirka R M et al 2001 Examination of the implant - abutment interface after fatigue testing *J. Prosthet. Dent.* **85 (3)** 268–275.