

# Fixture-abutment connection surface and micro-gap measurements by 3D micro-tomographic technique analysis

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**Summary.** X-ray micro-tomography (micro-CT) is a miniaturized form of conventional computed axial tomography (CAT) able to investigate small radio-opaque objects at a-few-microns high resolution, in a non-destructive, non-invasive, and tri-dimensional way. Compared to traditional optical and electron microscopy techniques, which provide two-dimensional images, this innovative investigation technology enables a sample tri-dimensional analysis without cutting, coating or exposing the object to any particular chemical treatment. X-ray micro-tomography matches ideal 3D microscopy features: the possibility of investigating an object in natural conditions and without any preparation or alteration; non-invasive, non-destructive, and sufficiently magnified 3D reconstruction; reliable measurement of numeric data of the internal structure (morphology, structure and ultra-structure). Hence, this technique has multi-fold applications in a wide range of fields, not only in medical and odontostomatologic areas, but also in biomedical engineering, materials science, biology, electronics, geology, archaeology, oil industry, and semi-conductors industry. This study shows possible applications of micro-CT in dental implantology to analyze 3D micro-features of dental implant to abutment interface. Indeed, implant-abutment misfit is known to increase mechanical stress on connection structures and surrounding bone tissue. This condition may cause not only screw preload loss or screw fracture, but also biological issues in peri-implant tissues.

*Key words:* micro-gap, fixture-abutment connection, X-ray microtomography.

**Riassunto** (*Misurazione della superficie di contatto e del microgap della connessione impianto-abutment attraverso la tecnica di analisi tridimensionale microtomografica*). La microtomografia a raggi X (micro-CT) altro non è che una forma miniaturizzata di tomografia assiale computerizzata (TAC) convenzionale in grado di indagare in maniera non distruttiva, non invasiva e tridimensionale piccoli oggetti radiopachi con una elevata risoluzione dell'ordine di qualche micron. Rispetto alle tradizionali microscopie ottica ed elettronica, che forniscono immagini di tipo bidimensionale, questa innovativa tecnologia di indagine consente di effettuare un'analisi tridimensionale di un campione senza che questo debba essere sottoposto a tagli, coperture o trattamenti chimici particolari. La microtomografia a raggi X soddisfa dunque i requisiti della microscopia 3D ideale: possibilità di indagare un oggetto in condizioni naturali e senza alcun tipo di preparazione o alterazione; capacità di visualizzazione 3D non invasiva, non distruttiva e con un ingrandimento sufficiente; attendibilità della misurazione delle caratteristiche numeriche della struttura interna (morfologia, struttura e ultrastruttura). Da qui l'infinito ventaglio di applicazioni della metodologia in oggetto, non soltanto in campo medico e odontostomatologico, ma nell'ingegneria biomedica, nella scienza dei materiali, nella biologia, nell'elettronica, nella geologia, nell'archeologia, nell'industria petrolifera e dei semiconduttori. In questo lavoro viene presentata la possibilità applicativa della microtomografia nel campo dell'implantologia dentale per l'analisi delle micro caratteristiche tridimensionali dell'interfaccia tra impianti dentali e relativi *abutment* protesici. È noto infatti che la presenza di un non corretto accoppiamento (*misfit*) tra impianto e *abutment* è alla base di un aumento dello stress meccanico sulle strutture di connessione e sul tessuto osseo circostante. Questa condizione può essere la causa di una perdita di precarico o di frattura delle viti di serraggio ma anche di conseguenze di ordine biologico sui tessuti periimplantari.

*Parole chiave:* micro-gap, connessione impianto-abutment, microtomografia a raggi X.

## INTRODUCTION

Dental implantology has reached levels of reliability and predictability unexpected only a few years ago, al-

lowing clinicians to successfully implement even very complex rehabilitations. Over the last thirty years, enhanced surgical techniques, increased know-how and

sky-rocketing technological progress have contributed to raise over 90% the percentage of successful rehabilitation by implants, giving clinicians a meaningful reference point for treatment, even if there is still a number of issues to face, and predictability of rehabilitation by implants relies on a dynamic balance between biological and mechanical factors. The final goal of implant-prosthetic treatment is an aesthetic and most of all functional restoration, and preventing any implant component from possible collapse [1-3]. Implant failure may depend on two distinct types of factors, biological and mechanical. Biological causes are essentially peri-implantitis, affecting the soft and hard tissues surrounding dental implants, while mechanical causes involve implant-prosthetic components at large. Mechanical complications are: implant fracture, abutment fracture, screw loosening and loss, over-structure (ceramic and /or metal) fracture [1, 2]. Implant-abutment misfit is known to increase mechanical stress on connection structures and surrounding bone tissue. This condition may induce screw preload loss or fracture, and cause biological issues due to bacterial penetration within a possible fixture-abutment gap [1-8].

Today, materials evolution allows clinicians to choose in an ever wider range of implant-abutment systems. Despite their large number, the systems essentially are based on three types of implant-abutment connection: screwed, cemented and conometric. The most popular connection is the screw type, featuring external hexagon according to the Swedish tradition. In literature, a high number of studies on mechanical issues focuses on screw-type connection, since this is widely used and more often than other types shows the following disadvantages: screw loosening, possible fracture of the screw or even of the implant neck [9-18]. In light of these considerations, new types of connection have been developed. For instance, the fixture anti-rotation feature has been progressively modified over time, taking distance of classical geometries – hexagon, octagon – and evolving to the very conometry or a combination of traditional and conical shapes [12, 15-19].

The aim of this paper is to show possible applications of X-ray micro-tomography in measuring and *in vitro* two-dimensional and three-dimensional visualizing, in static condition, implant-abutment interface in three different types of conic fixture-abutment connection of commercial implant systems. This new investigation technique is envisaged as a reliable support to implant system engineering and implementing.

## MATERIALS AND METHODS

For abutment-fixture interface assessing and the resulting contact surfaces measuring, three *in vitro* conical connection implant systems have been considered:

1. Ankylos connection, implant mod. C/X 4.5 mm diameter (Dentsply Friadent). The precision-manufactured, geometrically- and dynamically-coupled TissueCare Connection is cone-shaped and minimizes implant-abutment gap formation, hence bacterial colonization. The over structure-implant

connection is moved internally in the implant, according to platform-switching, is movement-free, and extremely mechanically stable. This connection is not recognized as a gap by peri-implant bone and tissue structures, paving the way for long-term healthy and irritation-free soft and hard tissues;

2. Straumann connection, implant mod. Bone Level 4.1mm diameter (Straumann). Straumann Bone Level implants feature the CrossFit connection, which combines the know-how and advantages of the Morse Taper connection with connection needs located at bone level. The self-guiding internal prosthetic connection shows an optimized design for long-term mechanical stability under all loading conditions, and ensures an exact fit between implant and secondary component. The 15° internal cone enables more flexible prosthetic treatments. Four internal grooves allows for precise positioning of prosthetic components;
3. Bicon connection, implant mod. Narrow 4.0 mm diameter (Bicon). Precision conometric connection of 1.5° assures a valid bacterial sealing at implant-abutment interface, eliminating micro-gap (less than 0.5 micron). Thanks to the locking taper, 360° positioning of the universal abutment is possible. The sloping shoulder allows a higher flexibility when placing the implant, and ensures an exceptional bone preservation. It also provides more space for crestal bone over implant head and support for interdental papillae, enhancing gingival aesthetics line.

Each sample underwent five X-ray microtomography consecutive acquisitions by Skyscan 1072 (SkyScan, Kartuizersweg 3B, 2550 Kontich, Belgium) to measure implant-abutment contact areas of the three implant systems considered, and to detect the possible presence of microgaps over and along the whole interface. This innovative investigation technique has made it possible to assess the perfection of connection sealing in a non-destructive, non-invasive, and three-dimensional way [20, 21].

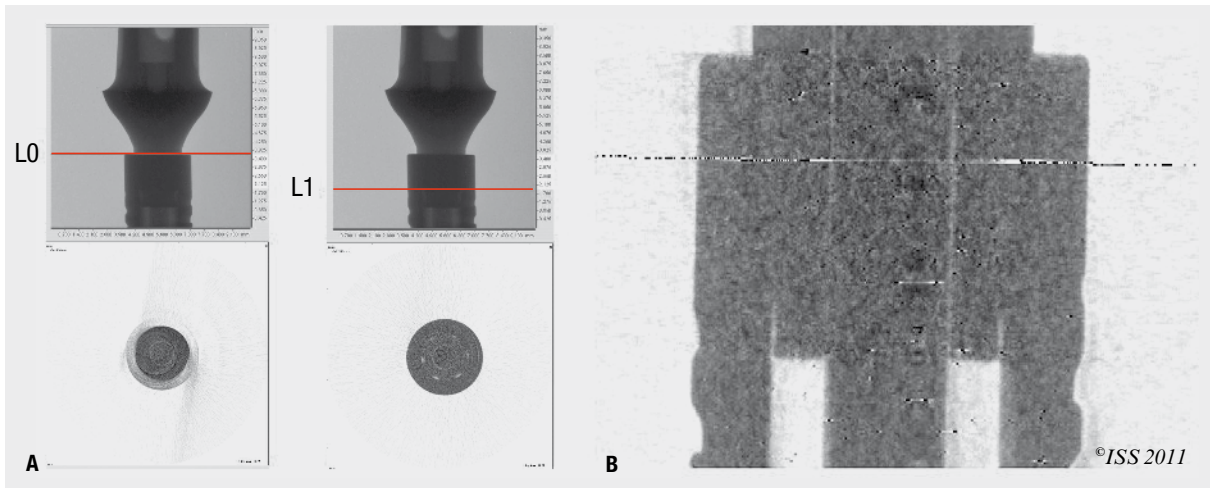
All implants have been resin-embedded in vertical position within a cylinder-shaped mould to avoid motion artifacts. The same acquisition parameters adopted for all sample are as follows:

- rotation step = 0.45°,
- total rotation angle = 180°,
- power source 100 KV / 98 microA,
- filter thickness 1 mm (Al)

Magnification and cross-section pixel size acquisition parameters have been chosen according to the following values:

- Sample 1: magnification at 30X and cross section pixel size of 9.77 µm
- Sample 2: magnification at 26X and cross section pixel size of 11.27 µm
- Sample 3: magnification at 26X and cross section pixel size of 11.27 µm

All images obtained have been processed by a dedicated reconstruction software (CTan), able to reproduce the exact 3D model of each examined implant, making it



**Fig. 1** | Microtomographic horizontal (A) and vertical (B) section of sample 1 with its X-ray images (left corner) and indication of the L0, L1 levels.

possible to observe the model in any internal and external components, through its acquired sections, with no need of destructing, cutting or altering the sample [20, 21].

Sample reconstruction in approximately 600-900 slices has been followed by definition and detection of fixture-abutment contact zones and of coronal and apical limits, to focus on connection sealing. Acquisition resolutions made it possible to observe gaps larger than 10 µm.

Through the sequential analysis of all reconstructed axial sections, it has been decided that L0 identifies the level of initial contact between implant and abutment, while L1 identifies the section in which can be observed a micro-gap (a thin circular radiolucency) between the two near surfaces, at the end of connection's seal (Figure 1, 2 and 3). By means of CTan software it has been also possible to measure the lateral surface of truncated cone between L0 and L1 that indicates the contact surface between the two components.

After measuring contact height and major and minor radius of the truncated cones so obtained, the resulting areas have been calculated.

**RESULTS**

Table 1 shows mean values of fixture-abutment contact areas of each implant system. In Table 2 the same mean values have been calculated by geometric formula

**Table 1** | Results of microtomographic analysis of fixture-abutment connections of three processed dental implant systems by CTan software calculation

| Sample | Contact surface (mm <sup>2</sup> ) |
|--------|------------------------------------|
| 1      | 13.55                              |
| 2      | 5.08                               |
| 3      | 17.32                              |

as a result of contact height, and minor/major radius of truncated cone.

A preliminary data evaluation shows that sample 2 has less fixture-abutment contact surface compared to the other two types of connections.

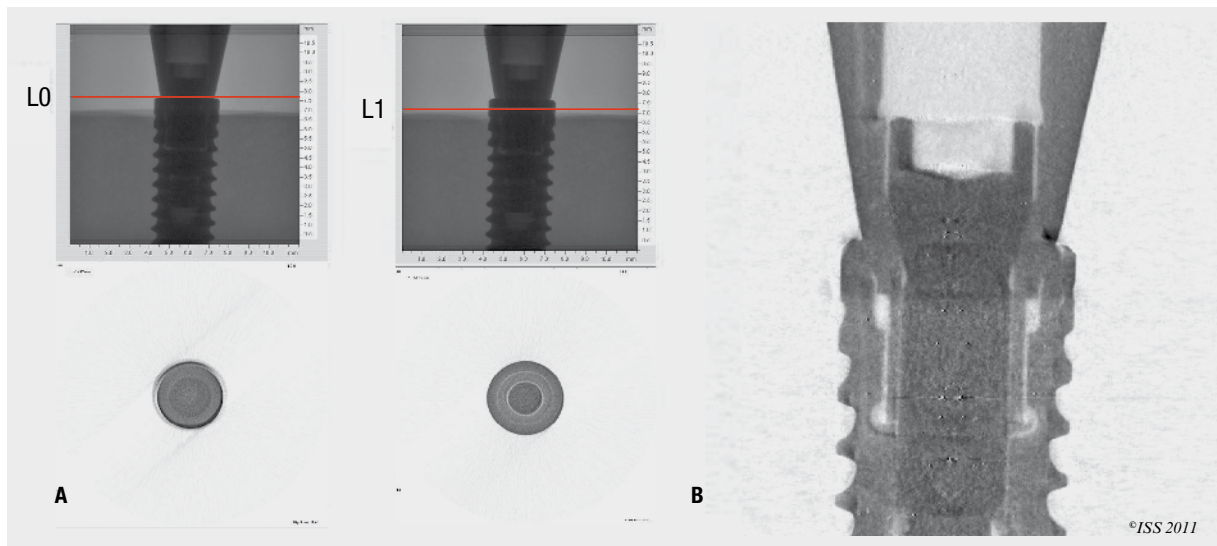
**DISCUSSION**

Implant-abutment misfit is known to raise mechanical and biological issues. A mechanical stress rise on connection structures and surrounding bone tissue may lead to a preload loss or screw fracture, and also have biological outcomes [1, 2, 9, 22]. Moreover, fixture-abutment interface microgap induced by connection structure misfit allows bacteria to penetrate and colonize in the inner part of the implant, causing inflammatory processes [2, 9, 10, 22-25].

In literature, the importance of the role of the implant-abutment interface position and geometry on quality and loss of surrounding bone tissue is largely demonstrated [9, 22]. There is evidence that bone tissue or peri-implant gingiva adjacent to microgaps are prone to inflammatory processes. Microgaps allow bacterial penetration within the implant-abutment system, causing outwards circulation of bacterial endotoxins from inside into the

**Table 2** | Results of microtomographic analysis of fixture-abutment connections of three processed dental implant systems by geometrical calculation

| Sample | Fixture-abutment contact surface |                   |                   | Contact surface (mm <sup>2</sup> ) |
|--------|----------------------------------|-------------------|-------------------|------------------------------------|
|        | Height of contact (mm)           | Major radius (mm) | Minor radius (mm) |                                    |
| 1      | 1.7                              | 1.2               | 1.0               | 12.2                               |
| 2      | 0.5                              | 1.4               | 1.2               | 4.4                                |
| 3      | 2.7                              | 1.0               | 0.9               | 16.1                               |

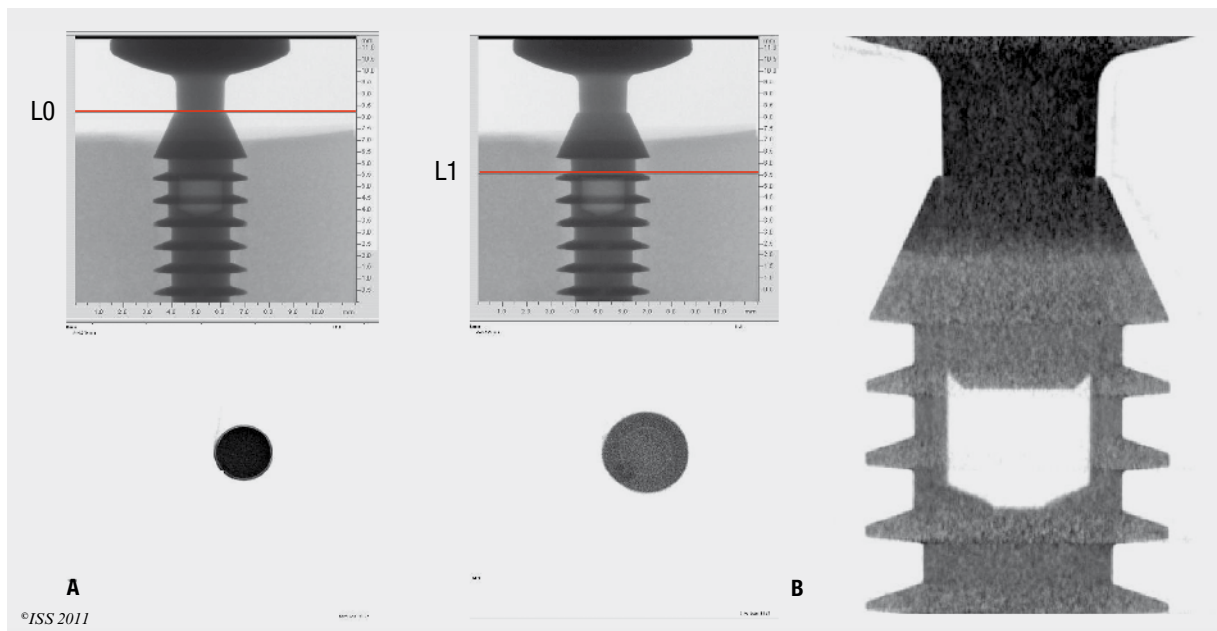


**Fig. 2** | Microtomographic horizontal (A) and vertical (B) section of sample 2 with its X-ray images (left corner) and indication of the L0, L1 levels.

surrounding tissues. A physiopathological process is so triggered, leading at worst to bone resorption and implant loss [26-30]. To avoid these problems, dental implant producers focused their attention on fixture-abutment connection designs able to enhance the seal and to prevent peri-implant tissue inflammation. The best seal has been found in screwless cone interfaces, like Morse taper and locking taper, since these provide such a perfect fixture-abutment fit [9, 11, 12, 31] to prevent bacterial penetration and mechanical com-

lications. Moreover, conical connections have a more central interface to implant platform, compared to external hexagon connections where peri-implant tissues are much closer [4, 6, 8].

Although at present conical connections are best performing from a biological and mechanical point of view, thanks to their implant-abutment better fitting, however the ideal implant connection, able to zero down the risk of bacterial penetration, hasn't been implemented yet [9, 11, 32-36].



**Fig. 3** | Microtomographic horizontal (A) and vertical (B) section of sample 3 with its X-ray images (left corner) and indication of the L0, L1 levels.

To obtain a quality seal against bacteria, a large number of studies have focused on microorganism penetration through implant-abutment interface microgaps. The majority of these papers have studied the seal *in vitro*, in static condition, not considering *in vivo* temperature variations and chewing stresses [9, 11, 14, 32-34, 37].

It is possible to directly observe the implant-abutment microgap through a wide range of tools, though presenting some limits. For instance, traditional intra- and extra-oral radiographic analytical methods and computed tomography are routinely used for patients, to evaluate implant stability or failure [26, 38-40]. However, there are only a few studies on the possibilities of *in vitro* direct observation, usually concerned with butt-joint connections: micro-radiography, SEM, optical microscopy, laser scanning microscopy or theoretical approaches through finite element modelling [26, 40-43]. Although many authors reported a perfect fit as regards conical connections, on the contrary a recent study shows the presence of a microgap thanks to direct *in vitro* observation of conical coupling through hard X-ray synchrotron radiation [26]. Also recent leaking tests have demonstrated that this geometry cannot grant a perfect seal [26, 40-42].

This paper proposes *in vitro* direct observation through microtomography of three conic implant systems, to detect possible microgaps, visible or not within the resolution levels adopted for acquisition, and to calculate fixture-abutment contact surfaces.

All implant systems showed no peripheral microgap visible at resolutions of acquisition (microgap, whenever present, is less than 10  $\mu\text{m}$ ) (Figures 1, 2 and 3).

In light of the analysis of fixture-abutment contact surface values of the three implant systems considered, sample 2, showing the least values, seems to be less reliable as regards mechanical properties and bacterial sealing of the connection.

Moreover, the absence of statistically-significant difference between CTan-calculated surface data and values measured by traditional geometry formulas demonstrates the utility and reliability of X-ray microtomography in this application field.

## CONCLUSIONS

The connection geometry of the fixture-abutment complex influences the mechanical properties of an implant system. Two flat surfaces in contact show less possibilities

to distribute occlusal loading, especially eccentric ones, in a homogeneous and multi-directional way, compared to another connection such as the conometric one, characterized by a contact surface featuring also a vertical component inside the implant body. Therefore, from a biomechanical point of view, a conic connection is more geometrically suitable than a flat one, as well documented in literature [4, 10-12, 16-18, 24, 31, 35, 41, 44-49]. Moreover, it is possible to observe that, instead of problems connected to chewing load on surrounding bone tissue, at bone crest level, there are other serious problems such as mechanical stress on the prosthetic component of the implant support that results more stressed in flat type connections. This kind of connection, in fact, is often subjected to mechanical stress bringing on unscrewing or fracture of tighten screw, abutment or fixture fracture in the worst cases [8, 12, 20, 21, 44, 50].

Nowadays, commercial development allows clinicians to choose between several implant systems. Literature shows that a tube-in-tube conical shape of fixture-abutment contact has a better seal against bacteria and a better mechanical stability [4, 9-12, 16-18, 24, 31-36, 41, 44-49]. In spite of the large number of advantages of this type of geometry, recent studies have shown that fixture-abutment ideal connection does not exist, and that misfit eventually causes biological and mechanical complications [9, 11, 32-36].

The need for engineering and developing more performing implant designs, as well as evaluating geometrical features of currently-used systems, has boosted the development of ever more sophisticated and precise investigation techniques.

To this end, X-ray microtomography is one of the best tools in this kind of applications, compared to other traditional investigation methods, because it allows to acquire three-dimensional images and to perform evaluations in a non-invasive and non-destructive way.

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## Conflict of interest statement

There are no potential conflicts of interest or any financial or personal relationships with other people or organizations that could inappropriately bias conduct and findings of this study.

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