Comparative in-situ loading analysis of narrow diameter implants by high resolution X-Ray tomography

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Topic: Basic research

Background and Aim

The sealing performance of implant-abutment connections and its importance regarding peri-implant infectious complications at bone level has been a matter of debate for years now. The mechanical comparison between external hexagon platforms and conical connections revealed much less movement and nearly no opening in the latter, which certainly played a role in the new design orientations favored by implant manufacturers. Indeed, most of the recently developed implant designs include bone-level conical connections.

The current downsizing trend in implant dentistry as well as the fast emergence of customized abutments with unequal machining precisions challenge the sealing performance of conical connections and claim for appropriate methods to characterize it.

The range of narrow-diameter implants offered to surgeons starts generally with a diameter of 3.0mm or even below. Considerable efforts may apply to these systems, which require high strength materials and robust design. Two types of designs are employed, either screw-retained conical connection or screw-less Morse taper abutment. Mechanical comparisons of the two designs are rarely found in the literature, as well as in-situ analysis of strains under loading.

Conventional X-ray imaging can be used to qualify the mechanical behavior of dental implant assemblies. The work of Zipprich *et al.* (2007) gave interesting insights on this method by comparing different types of implant-abutment junctions during in-situ loading. However in the context of micro-movements or micro-gaps analysis in conical connections, conventional X-Rays imaging systems are not sufficiently precise. On the other hand, synchrotron radiation appears as the holy grail for such characterizations, as demonstrated by Blum *et al.* (2015), but is very costly and requires an enormous infrastructure. **Therefore, intermediate systems such as high-resolution lab scale tomographs represent an interesting alternative to enable fast, reliable and affordable control of implant-abutment connections.**

The aims of this study are:
- To set-up a method for qualitative (and possibly quantitative) assessment of the implant-abutment interface opening under standardized loading conditions by using **high-resolution lab scale** X-ray imaging.
- To perform a comparative analysis of commercial narrow-diameter implants using this method.
- To compare the sealing performances of screw-retained internal conical connection versus Morse taper connection.

Methods and Materials

Test devices and Loading conditions

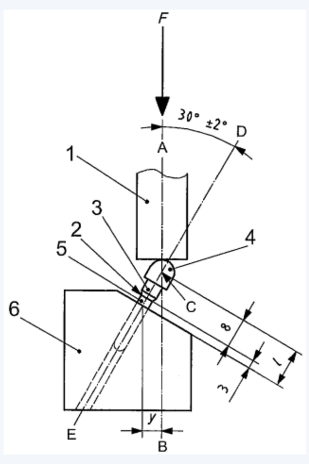


Fig. 1 Loading geometry as specified by ISO14801:2008


Fig. 2 Axial loading system with inclined loading surface and calibration load cell (bottom right)

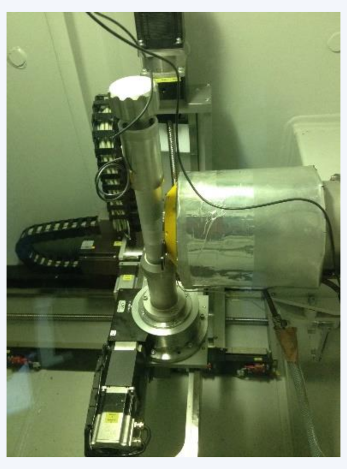
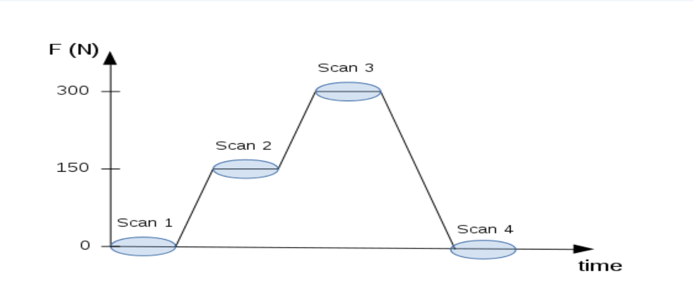


Fig. 3 In-situ loading rig placed as close as possible from the radiation source (on the right).

Three commercially available **narrow diameter implants (Ø≤3mm)** with various designs were selected and assembled with abutments following each manufacturer Instructions for use. A testing rig was developed to apply in-situ mechanical loading following **ISO14801 geometrical prescriptions** to the implants within an X-Ray tomography chamber. The 3D characterization of the implant was carried out by means of X-Ray tomography using a vtomex device (GE Phoenix|X-Ray GmbH) equipped with a 160 kV nano-focus tube, a tungsten transmitting target, and a 1920 x 1536 pixel Varian detector.



SCAN	LOAD (N)	Resolution (µm)	BENDING MOMENT (N.m)
1	0	3	0
2	150	4.5	0.825
3	300	4.5	1.650
4	0	3	0

Fig. 4 Loading sequence with associated resolutions and bending moments

In addition, cyclic compression loading between 12 and 120N was performed on the implants at 15Hz in air, also according to ISO14801 prescriptions. Images were taken from the implants who survived 5 millions of cycles.

Image analysis

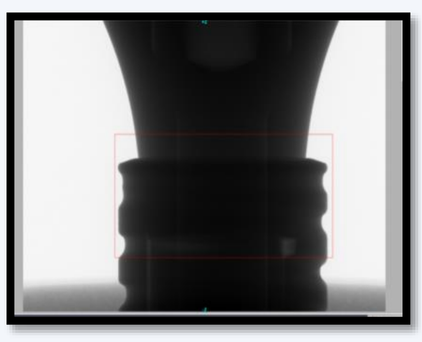


Fig. 5 Rotating system is used to take 360° X-Rays, followed by volume reconstruction.

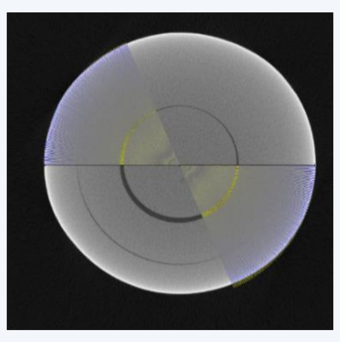


Fig. 6 Radial reslices are performed to find out the slice with the worst opening.

After volume reconstruction, data were analyzed with the free image processing software Fiji (Schindelin et al. 2012). Radial slices have been created to observe the totality of the implant over 360° following the implant / abutment interface. Then, the location of the larger gap was visually determined.

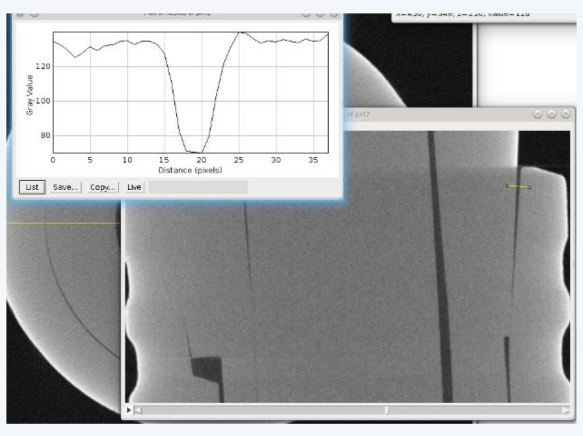


Fig. 7 **Measurements can be performed** for instance by plotting gray levels along a pixels line (1 pixel equals 3 to 4,5µm here).

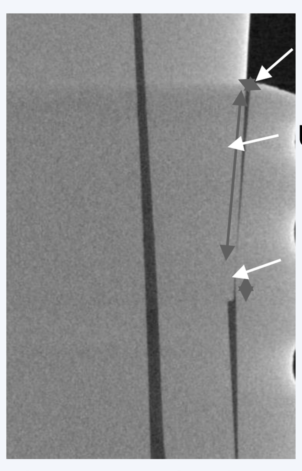


Fig. 8 Example of some available measurements

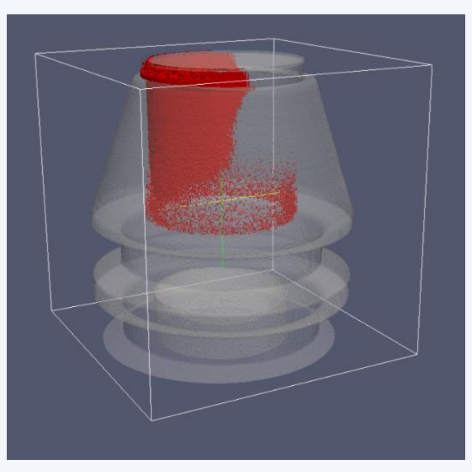


Fig. 9 Example of 3D rendering image under loading at 300N for implant B. Red spots are voxels of about 4,5µm edge.

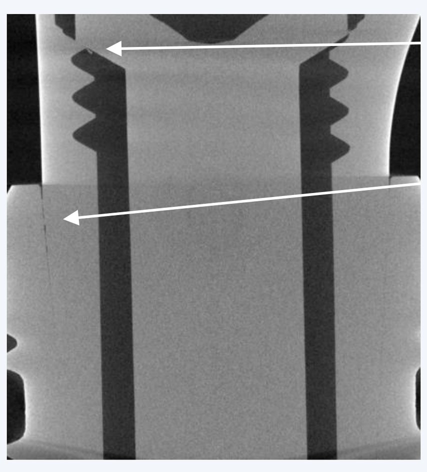
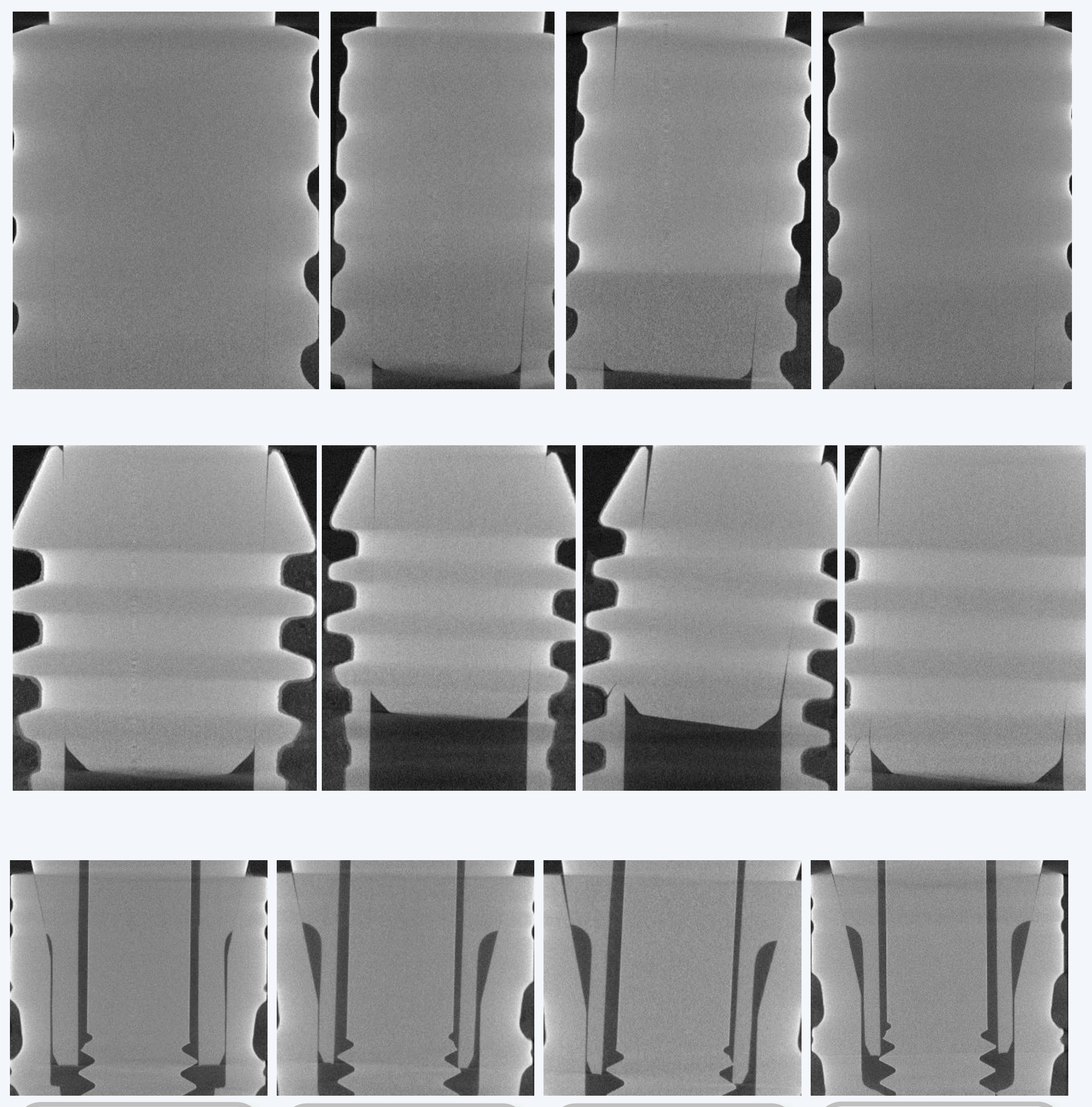


Fig. 10 Small manufacturing defects are also clearly visible in X-Ray tomography.

The 3D characterization gives access to geometrical parameters such as implant abutment **interface length**, **opening cone angle** and minimum **opening width and length**, which can be difficult to interpret when it comes to the comparison of fundamentally differing designs. Following results are then voluntary limited to a **qualitative comparison of the implants after different loading steps.**

Results

Static loading results



Very drastic loading conditions were applied to these implants regarding their clinical indications and the severe geometrical requirements stated by ISO14801. Nevertheless the method **highlights clearly the differences between implants**:

Initial state: Slight cone angle differences between implant and abutment where visible in implants A and B, resulting in the existence of a tiny free space inside the implant (A) or on top of the implant (B). In implant C, probably due to the manufacturing variations, it was possible to identify a section with a minimal opening.

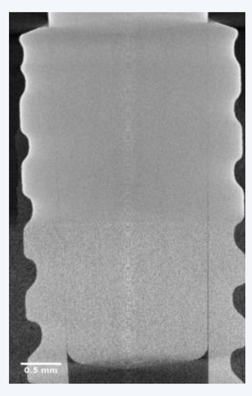
Loading at 150N: significant changes were not observed for implant A while implant B and C showed an increase of their top gap dimension.

Loading at 300N: deformations became significant for all three implants. Top and bottom gap were visible in implants A and B, and a crack could be observed in implant B. In implant C a through gap appeared.

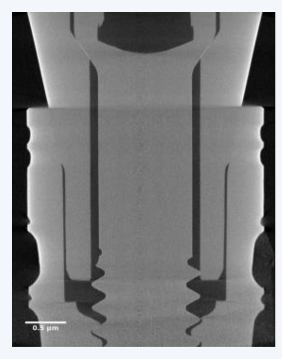
Post loading: significant top gaps for implant B and C due to strong plastic deformation. No gap could be observed on implant A.

Implant A: Morse-taper screw-less implant (Axiom 2.8, Anthogyr, France)
Implant B: Morse-taper screw-less implant (Integra 3.0 CP, Bicon LLC, USA)
Implant C: Screw-retained conical connection (Nobel Active 3.0, Nobel Biocare, Switzerland)

After cyclic loading


Implant A
5.10^6 cycles

Failure
<15 000 cycles
Implant B


Implant C
5.10^6 cycles

Implants were tested according to ISO14801 geometrical prescriptions with a sinusoidal alternate loading (frequency 15Hz) between 12 and 120N (0.66 N.m). Implants A and C survived 5 millions cycles and didn't show any through gap after this testing. Implant B failed after 15 000 cycles and was therefore excluded from the tomography analysis.

Conclusions

Method
- The use of lab scale high resolution X-Ray tomography enables qualitative and quantitative assessment of dental implant connections during in-situ loading.
- The method is applicable to evaluate the sealing performance of implant/abutment junctions of any implant type.
- The proposed testing method is reproducible, discriminating and could be standardized to measure connections misfit or openings as small as 2 to 3 microns.

Comparative analysis of narrow diameter implants
- Both tomography and cyclic loading revealed a **significant dispersion in mechanical strength** among the systems tested.
- Narrow diameter implants (Ø≤3,0mm) can sustain relatively high loads (0.825 N.m) without gap opening and in certain cases (Implant A) without increasing the initial implant/abutment connection misfit.
- Intense loading (bending moment of 1,65N.m) may result in full opening of the connection (implant C) or breakage (implant B).

Sealing efficacy of the different designs
- When designed specifically to ensure zenithal connection closing, **Morse taper connections do maintain the best sealing quality** under high load than conventional screw-retained conical connections.
- In screw-retained conical connections, intermediate and intense loadings may release the implant/abutment sealing which is mostly ensured by axial screw tension efforts.

Limitations and perspectives
- The relevance of the loading geometry can be questioned, because the assumption of 3 mm bone loss might be **too severe for current implant systems** and does not allow mechanical testing of short (<6mm) implants.
- The correlation of these findings with bacterial contamination of implants connection needs to be further studied in relevant in-vitro or in-vivo set-ups incorporating bacteria.
- Further clinical studies will be necessary to correlate in-situ loading strains with mechanically-induced crestal bone loss (micro-movements issue) and likelihood of bacterial infections("micro-gap" issue).

Acknowledgements

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ISO 14801:2007 Dentistry -- Implants -- Dynamic fatigue test for endosseous dental implants

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