Spectral Photon-Counting Micro-CT for Dental Implant Integrity and Infiltration Analysis

Marcello Fonda[1], Giovanni Lemma[1], Vittorio Di Trapani[1], Pierre Thibault[1], Gianluca Turco[1]
[1] *University of Trieste, Italy*

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Spectral photon-counting micro-CT (µCT) is an advanced imaging technique that combines micrometric X-ray CT with energy-resolved detection, therefore enabling material-specific analysis based on the energy-dependent attenuation of different materials. These capabilities are particularly convenient for applications making use of high-Z contrast agents, where the spectral K-edge signature of selected elements can be used to separate their signal from other highly absorbing structures and materials.

In this work, we present a gadolinium-enhanced spectral µCT approach for the non-destructive detection and quantification of infiltrations in titanium dental implants. The implants are immersed in a Gd-based contrast-agent solution while undergoing repeated mechanical loading, mimicking mastication conditions. The liquid contrast agent can therefore infiltrate through micro-gaps, possibly generated by the loading process. In this work, gadolinium is used instead of the commonly employed silver-based alternatives [1] because its K-edge lies at a higher energy, enabling spectral µCT through K-edge identification through titanium.

Tomograpgic acquisitions were performed at the OPTIMATO laboratory, a multimodal and multiresolution X-ray imaging facility [2], implementing cutting-edge technologies including a liquid MetalJet microfocus X-raysource (Excillum, Sweden), a Medipix3-based CdTe photon-counting detector (LAMBDA 350k, X-spectrum, Germany), and a six-axis robotic arm as sample stage. The robotic system enables unconventional acquisition trajectories, which are exploited to obtain artefact-free reconstructions of the implant region. To cope with the strong attenuation of the implant, two beam-hardening correction strategies, one based on polynomial fitting and the second on an iterative procedure, are investigated to reduce metal-induced artefacts and improve the stability of the spectral analysis.

The spectral data, analysed using the Minimum-Residual Basis Material Decomposition algorithm (MR-BMD) [3], show an effective identification of the Gd-filled infiltrations from the titanium of the implant. Unlike conventional attenuation-based µCT, where infiltration analysis generally relies on manual or threshold-based segmentation, the MR-BMD Gd map provides a reliable and direct material-based segmentation, allowing a clear distinction between the infiltration and possible spurious high-Z/dense inclusions in the implant.

This approach provides a laboratory-based framework for identifying contrast-agent penetration and assessing the quality of dental implants. The combination of spectral micro-CT, photon-counting detection, beam-hardening correction, and gadolinium-enhanced imaging offers a promising strategy for non-destructive validation of implant performance and integrity.

References

[1] He Y. et al., Clin Implant Dent Relat Res. 21:741–752 (2019).
[2] V. Di Trapani et al., JINST 19 C01018 (2024)
[3] V. Di Trapani et al., Opt. Express 30, 42995-43011 (2022)