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Validation of clinical CT-based volumetric analysis using Ti implants for *in vivo* monitoring of Mg-based orthopaedic devices

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INTRODUCTION

In situ quantification of residual implant volume is desirable in long-term Mg implant studies where repeated *ex vivo* measurements require euthanising animals. Although clinical X-ray computed tomography (CT) is commonly used for *in vivo* imaging, its accuracy for measuring implant volumes against CAD models or *ex vivo* micro-CT is still lacking. The study represents a preliminary methodological validation of CT-based volumetric analysis using Ti implants and evaluates CT measurement error relative to micro-CT and CAD reference before application in longitudinal studies of degrading Mg-based devices.

METHOD

Unstable zygomatic arch osteotomies were created in farm pigs and stabilised with a craniofacial Ti-6Al-4V plate-screw system (right arch). Clinical CT scans were acquired using a Philips Big Bore scanner (Philips Healthcare, Best, Netherlands) operated at 120 kVp and 350 mA. Images were reconstructed with a 768 × 768 matrix. The 12-month CT scan, with a pixel size of 471 µm, was used for validation of CT-based implant volume measurements. Following explantation at 12 months, the devices were imaged using X-ray micro-computed tomography (micro-CT) (NeoScan N80, Kontich, Belgium) operated at 92 kV and 174 µA with a 0.25 mm copper filter, and a pixel size of 30 µm.

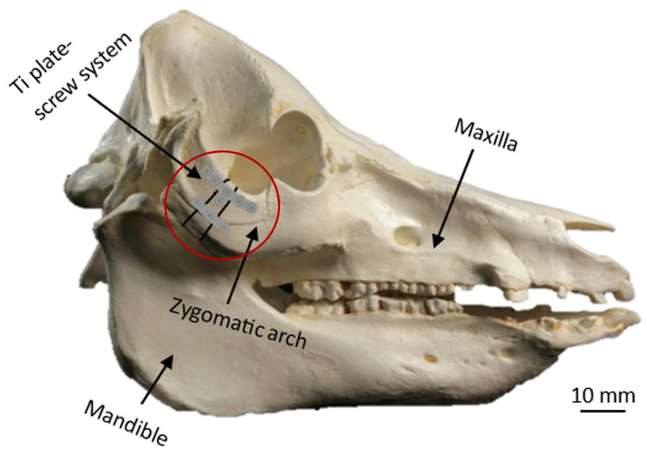

Fig.1: Schematic of zygomatic wedge osteotomy stabilised using a Ti-based implant fixation system

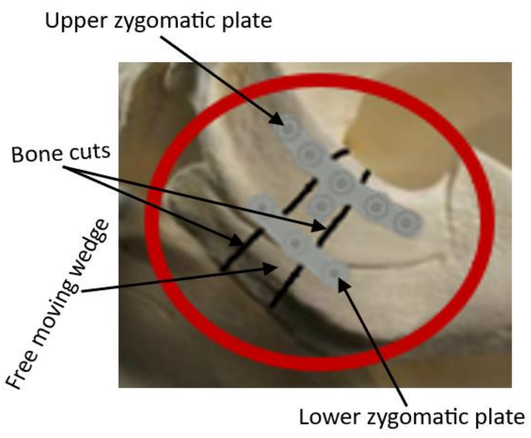

Fig.2: Detailed view of surgical site with two zygomatic plates

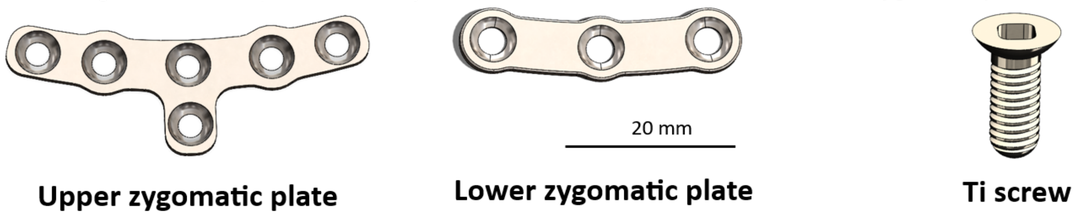

Fig.3: Titanium alloy plate-screw fixation system used in the zygomatic arch study

Implant segmentation was performed in 3D Slicer (v5.8.1) using modality-specific intensity thresholds, optimised and applied consistently within each modality. Volumetric image analysis of the combined Ti plate-screw system at 12-month implantation was performed using CT and micro-CT datasets.

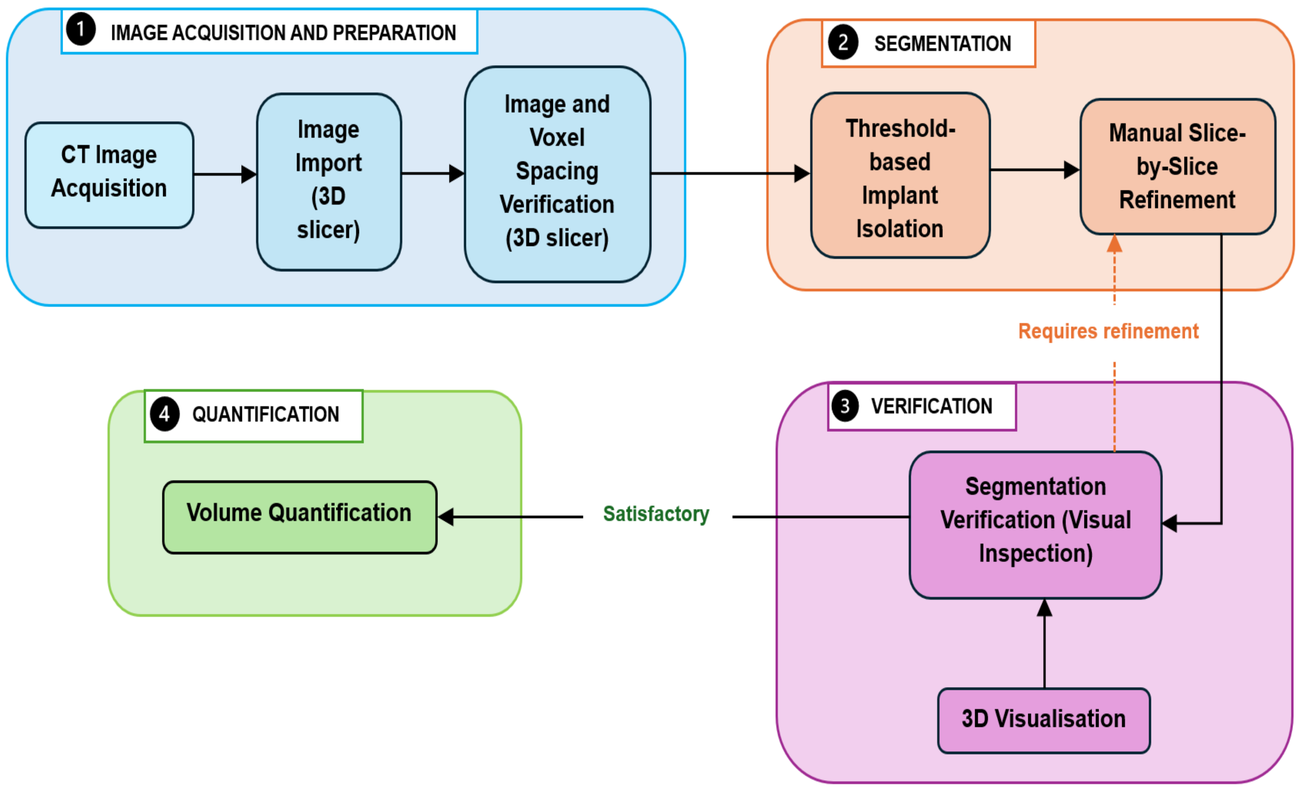

Fig.4: Implant volume quantification workflow using 3D slicer

RESULTS & DISCUSSION

Ex vivo micro-CT data were highly accurate, with a mean error of 0.944 %, whereas clinical CT showed a higher deviation with a mean error of 9.107 %. The mean clinical CT error may still be acceptable for longitudinal monitoring depending on the magnitude of implant degradation over time. The coefficient of variation was 0.212 % for micro-CT and 1.054 % for clinical CT, indicating good reproducibility for both modalities. The deviation in clinical CT measurements is attributed to partial-volume effects and limited spatial resolution.

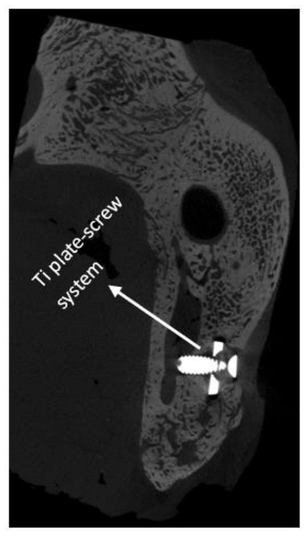

Fig.5: Representative micro-CT image of the explanted zygomatic specimen with Ti implant

***Ex vivo* micro-CT**

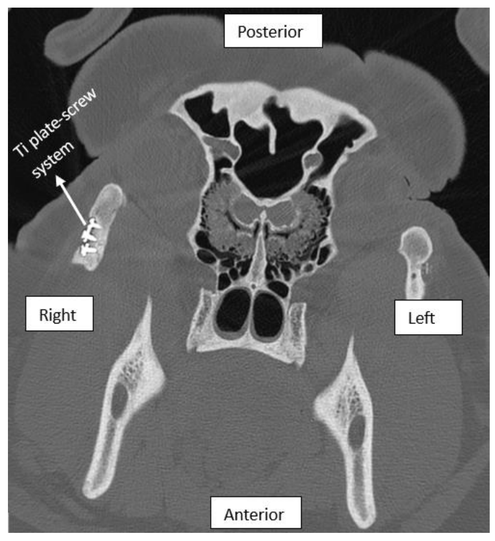

Fig.6: Representative clinical CT image of the Ti plate-screw system after 12 months implantation

***In vivo* clinical-CT**

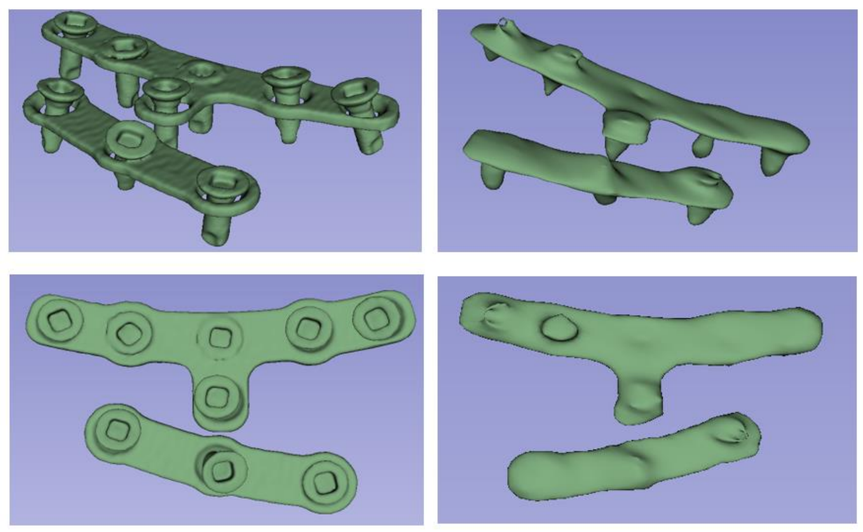

Fig.7: 3D visualisation of Ti implant volumes obtained from micro-CT and clinical CT datasets using 3D Slicer

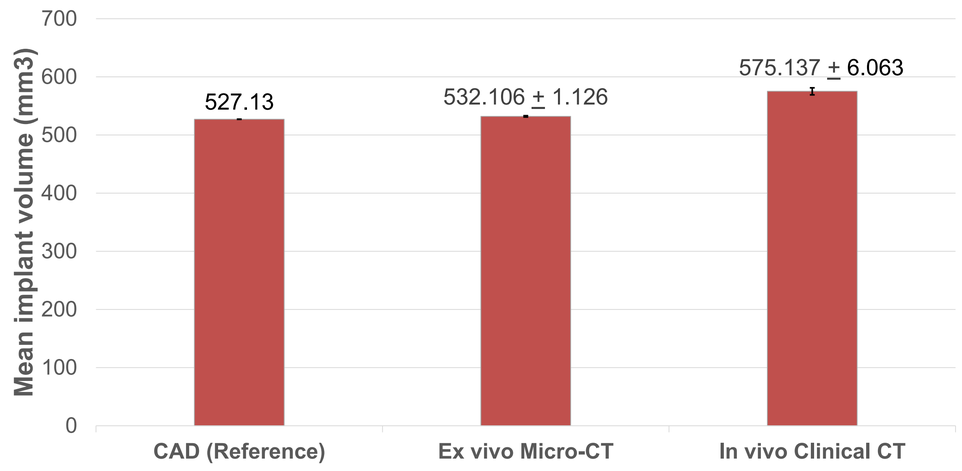

Fig.8: Comparison of Ti implant volume measurements. Error bars represent ± SD

Table 1 - Comparison of Ti implant volume from *in vivo* clinical CT and *ex vivo* micro-CT with CAD reference

Modality	Mean volume (mm^3)	Standard Deviation (SD)	Absolute error (mm^3)	% Error	Coefficient of variation (%)	Standard error - SE (SD/√n) mm3	Margin of error (mm3)	95% CI (mm3)
***Ex vivo* micro-CT**	532.106	1.126	4.976	0.944	0.212	0.46	1.182	532.106 ± 1.182
***In vivo* clinical-CT**	575.137	6.063	48.007	9.107	1.054	2.475	6.36	575.137 ± 6.36

CONCLUSIONS

CT-based volumetric analysis of Ti implants demonstrated good reproducibility but lower accuracy than micro-CT, with a mean volumetric error of 9.107 %. The observed reproducibility and quantified error support the use of CT-based analysis for longitudinal *in vivo* monitoring. Further studies are underway to assess Mg-based implant degradation at different timepoints using the validated methodology.

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