Quantitative Three-Dimensional Interfacial Analysis between Bone and Implant: the Helical Scanning Path and Digital Image Processing

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Introduction

Bone-to-implant contact (BIC) is difficult to measure accurately using micro-computed tomography (micro-CT) due to artifacts that can make it hard to distinguish between the implant and surrounding bone. Histological analysis, or two-dimensional (2D) BIC, is considered the gold standard for evaluating osseointegration around an implant. However, this method requires destructive specimen preparation and can only represent a single plane. In this study, a digital image processing technique and helical scanning path were used to identify the optimal bone-implant interface and calculate three-dimensional (3D) BIC.

Materials & Methods

Two New Zealand white rabbits were used in this study, with a sandblasted, large-grit, acid-etched (SLA) implant and a turned implant inserted into each tibia (Fig. 1). All implants had an identical macroscopic design. After four weeks, the animals were sacrificed and the bone-implant blocks were removed en bloc. The blocks were scanned using a micro-CT with a helical path for the x-ray source and detector. Histological sections were prepared for light microscopy, and the digital image that matched each histologic section was found. The partial volume effect was optimized and the 3D interface was reconstructed for each specimen. 3D BIC was calculated using the reconstructed micro-CT interface, while 2D BIC was measured using the histologic section (Fig. 2). The Pearson's test was used to evaluate correlations between the 2D and 3D BIC, and the paired-t test was used to compare means between the SLA and turned surfaces. The significance level was set at 0.05.

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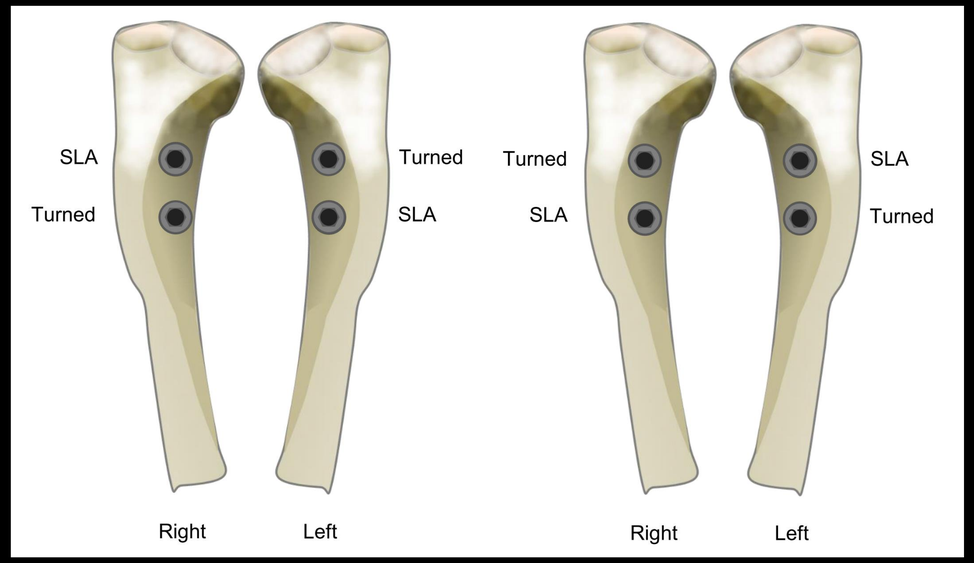

Fig. 1 Implant placement on rabbit tibiae

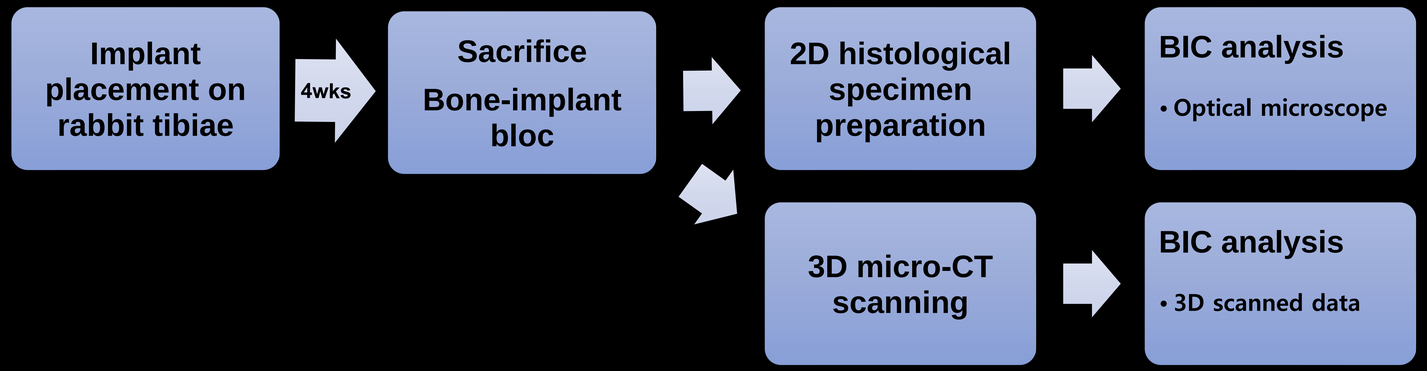

Fig. 2 Experiment process

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Results

The helical path produced less artifacts on the micro-CT images than the traditional path (Fig. 3).

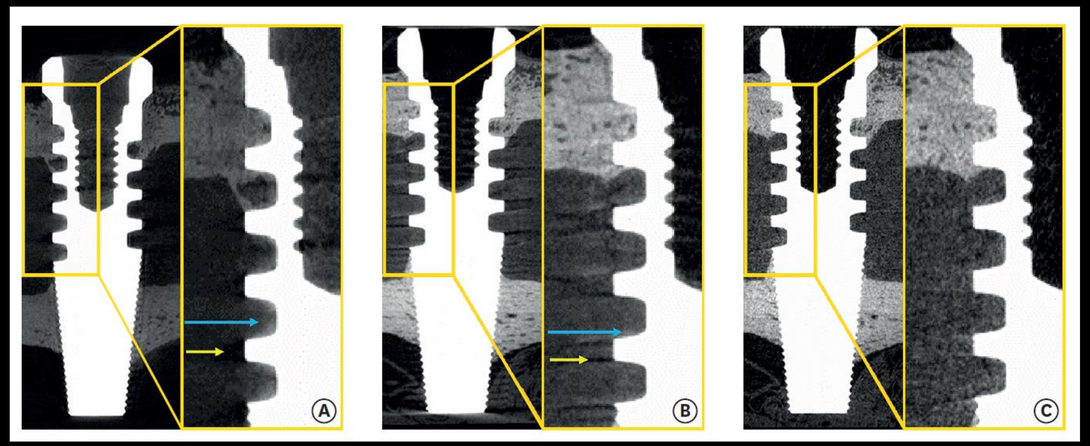

Fig. 3 Comparison of scanned image between scanning path. (A) & (B) are images using traditional scanning path. (C) is image using helical path. (C) shows less artifacts than (A) & (B). Blue arrow: halo, yellow arrow: shadow

Once the partial volume effects were optimized, the 3D interfaces were reconstructed, making it possible to calculate quantitative BIC using these images (Fig. 4).

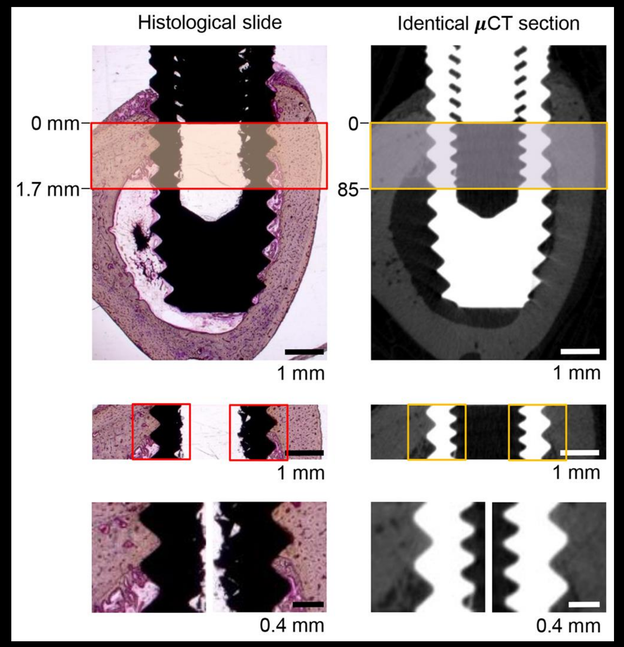

Fig. 4 Comparison of 2D histological specimen and 3D μCT section.

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No significant correlation was found between the 3D BIC, as determined by the reconstructed μCT images, and the 2D BIC obtained by measuring the histologic section using light microscopy (r=-0.38, P=0.39) (Table 1). Although a marginal significance was found in the 3D BIC between the SLA and turned surfaces (P=0.087), there was no significant difference in the 2D BIC (P=0.11).

	2D Histologic BIC (mean ± SD)	3D μCT BIC (mean ± SD)	Correlation between 2D & 3D
Total	42.4 ± 14.4	52.1 ± 5.9	-0.38 (P = 0.39)
SLA	50.5 ± 16.0	48.6 ± 5.1	
Turned	34.3 ± 7.3	55.7 ± 4.8	

Table 1. Bone-to-implant contact (BIC) ratios of the implants using 2D histologic sections, 3D μCT, and the correlations between the two approaches

Conclusion

The results of this study suggest that the use of a helical scanning path can help to reduce metal artifacts and improve the clarity of 3D bone-implant interfaces, enabling quantitative analysis. Furthermore, 3D micro-CT analysis may have an advantage over 2D histologic analysis, as it eliminates random variables that can arise due to the cutting direction. However, these conclusions are subject to the limitations of this study.

References

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Acknowledgment

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