Evaluating the effectiveness of SLS and FDM 3D technology as tools to accurately replicate bone fragment morphology

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Introduction and Aim

- Traditionally, osteological specimens require physical handling to gather morphological and osteometric data which may be used to help build a biological profile[2]
- Additive manufacturing such as Structured Light Scanning (SLS) and Fusion Deposition Modelling (FDM) would help to minimise the risk of damage or loss of information whilst preserving the advantages of physical engagement[3]

Archaeological, Anthropological and Forensic Contexts[4]

- Fragmentation
- Thermal Injury
- Taphonomic and post-mortem alteration
- Peri - and anti-mortem fractures

Anatomical Context[1]

- Age
- Damage or poor preservation
- Rare variation or pathology

This project aimed to explore whether the method of SLS and FDM could be suitable to replicate fragmented bone that is haptically and metrically accurate for utilisation in environments with a high risk of damage or wear

Methods

Figure 1: Mandible Replica (left) and Bone Fragment (right)

A loan of 13 non-human skeletal remains from The University of Edinburgh: School of History, Classics and Archaeology formed the focus of this research, where 4 of these specimen typologies were used for full data analysis (**Table 1**) and a further 3 for partial data analysis (**Table 1***) due to missing replica scans.

Qualitative and quantitative comparisons were performed for each of the 7 analysed specimens to test for metric and haptic accuracy between: bone to replica; bone to bone scan; bone scan to replica; and bone scan to replica scan.

Stage 1

- All physical specimens (two examples seen in **Figure 1**) scanned using SLS (EinScan Pro HD and EinScan H)
- 5-10 measurements taken for specimen using vernier callipers for physical material and EX Scan software for digital material

Stage 2

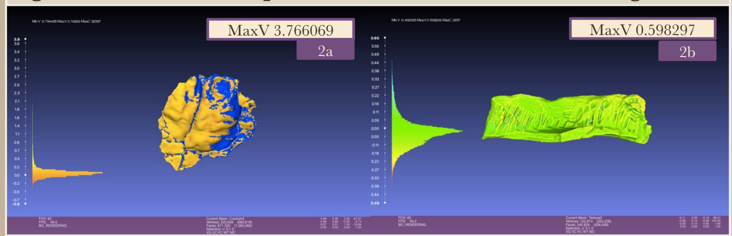
- Three-measurement average calculated for each specimen
- Unpaired two-sample Student's T-Test performed in R-Studio to obtain p-values (**Table 1**)

Stage 3

- Bone and replica scans processed in MeshLab to generate Hausdorff distances (**Figure 2a and 2b**)
- Heat maps generated in MeshLab and colorised by vertex quality (**Figure 2a and 2b**)
- Histograms generated by vertex quality (**Figure 2a and 2b**)

Results

Figure 2a and 2b: Heat Maps with Hausdorff Distances and Histograms



Hausdorff distances (MaxV) in **Figure 2a** (cranium) **and 2b** (distal humerus) measured, in mm, the distance between the bone scan and replica scan meshes.

Figure 2a visualised +ve differences through overlapping the bone scan (blue) with the replica scan (yellow), where blue is the target mesh (0.0 on histogram) and green-bright yellow-dark orange represent deviation (estimated -0.45 to 2.1 on histogram).
Figure 2b visualised +ve and –ve difference, showing the replica scan only (blue-red, where medium green is 0.0 and identical to the bone scan).

No significant differences were observed ($p>0.05$).

Table 1: Student's T-Test Comparison

Specimen	Comparison	P-Value
Cranium	Bone-Replica	0.9913
	Bone-Scan	0.9991
	Scan-Replica	0.9922
	Scan-Replica Scan	0.9996
Proximal Femur	Bone-Replica	0.9992
	Bone-Second Replica	0.999
	Bone-Scan	0.9979
	Scan-Replica	0.9971
	Scan-Second Replica	0.9989
	Scan-Replica Scan	0.9983
Middle Phalanx	Bone-Replica	0.9979
	Bone-Scan	0.9848
	Scan-Replica	0.9827
	Scan-Replica Scan	0.9963
Distal Humerus	Bone-Replica	0.999
	Bone-Scan	0.9974
	Scan-Replica	0.9983
	Scan-Replica Scan	0.9989
***Juvenile Femur**	Bone-Replica	0.9966
	Bone-Scan	0.9984
	Scan-Replica	0.995
***Mandible**	Bone-Replica	0.9984
***Ulna**	Bone-Replica	0.9984

Student' t-tests allowed for the comparison of linear metric measurements by p-value (**Table 1**).

There was a 95% confidence interval of specimen differences for each of the comparisons in **Table 1**, suggesting that 5% of p-values might fall beyond the 95% probability parameter and exclude the comparison mean.

By conventional criteria, none of the p-value results observed in **Table 1** were statistically significant ($p>0.05$).

Conclusion

- **Table 1** comparisons each showed to be near identical to a 95% confidence interval, with p-values ranging between 0.9827 and 0.9996 (where a value of <0.05 is a significant difference and a value of 1.0 is identical)
- There were indeed **areas for improvement** to note, such as how the type of scanner used made a difference to visual and haptic textural accuracy and definition e.g., sharpness of points or depth of cavities/foramen.

SLS and FDM can replicate fragmentary bone matrices successfully and are able to replicate these structures haptically to a lesser, but satisfactory extent

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