Forensic Analysis of the Human Clavicle: Evaluating the Accuracy of Structured Light Scanning in a Forensic Context

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Introduction

- Forensic analysis requires direct access to remains – may not be possible due to location, lack of storage or damage
- Structured light scanning (SLS) could be used to generate digital representations of remains – evidence is needed to assess the accuracy of these models before they can be implemented.
- Our aim is to evaluate the applicability of SLS in a forensic context by comparing the forensic analysis of physical and digital clavicles.
- To test this, we focused on three main aspects: testing method repeatability, evaluating scanner accuracy and determining the applicability of the technique within forensics.

Materials and Methods

Scanning Protocols

- 15 clavicles were selected from the Osteology Teaching Collection within the University of Edinburgh
- Clavicles were scanned using the Einscan Pro-HD and Artec Space Spider
- A post-processing workflow was determined in order to create a repeatable process
- 1st observer generated 4 scans per bone [2 per scanner]
- Second observer generated 2 scans per bone [1 per scanner]

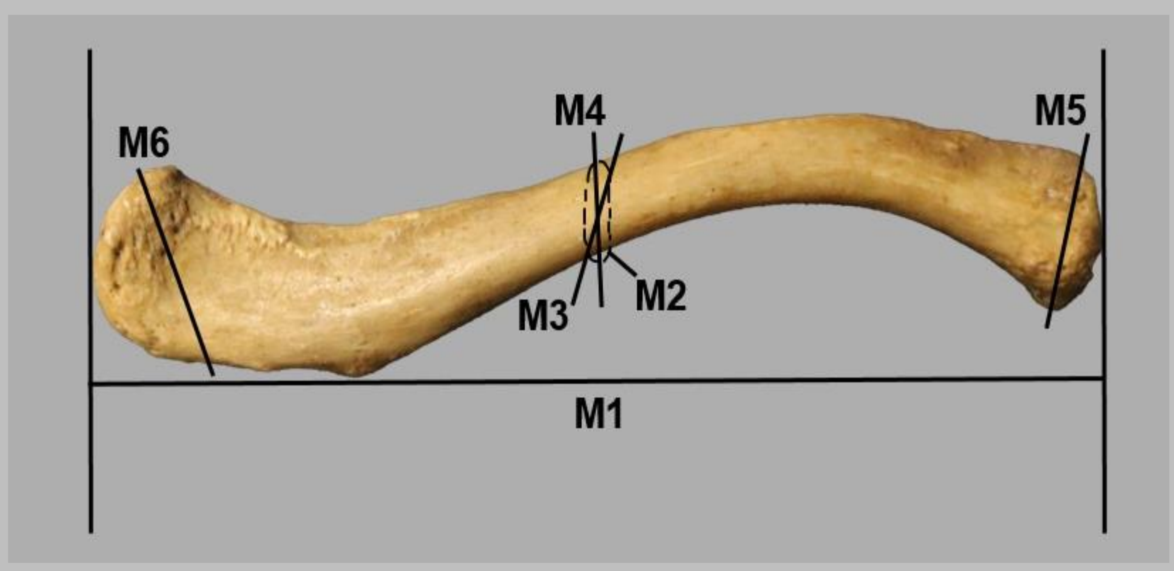

Figure 1 – Six clavicular measurements used for metric analysis. *M1: Maximum clavicular length; M2: Midshaft circumference; M3: Minimum midshaft diameter; M4: Maximum midshaft diameter; M5: Maximum width of sternal end; M6: Maximum width of the acromial surface. [Image approval: ANATED_0031]*

Measurement Tools and Protocols

- Physical metric analyses were carried out using Vernier/digital sliding callipers, a measuring tape and an osteometric board. (1)
- Physical observations were carried out directly on the bones. (2, 3)
- Digital metric and morphological data was collected within Artec Studio 18.
- Measurements and observations were repeated three times on each bone/model.

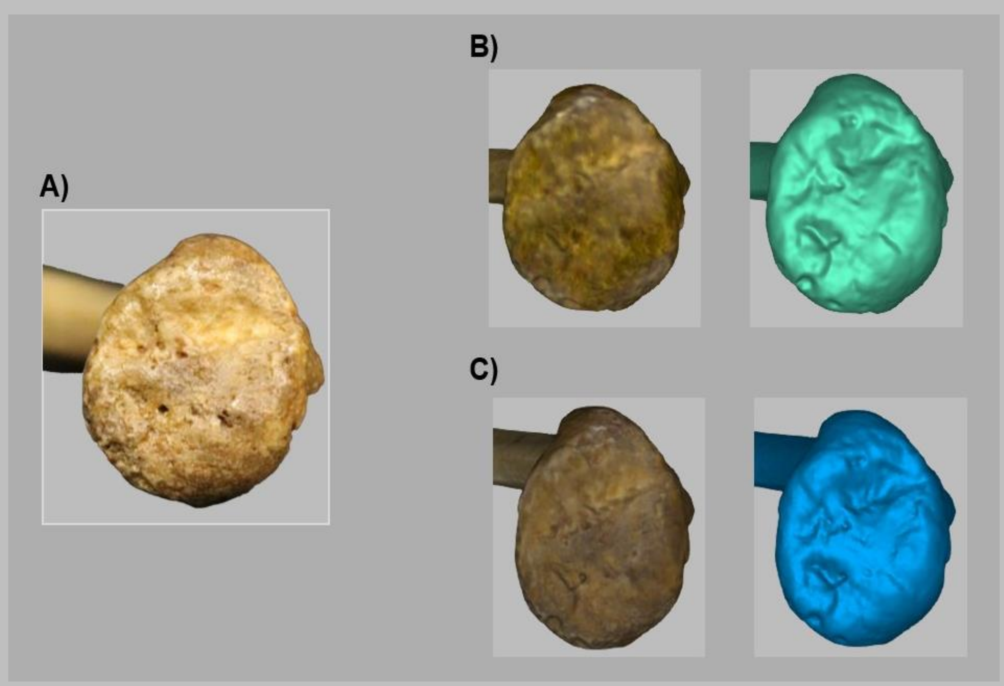

Figure 2 - Visual comparison of the sternal end of the physical and digital clavicles. *(A) Sternal surface of a physical clavicle. (B) Sternal surface of an Einscan Pro-HD model, with and without texture. (C) Sternal surface of an Artec Space Spider model, with and without texture. [Image approval: ANATED_0031]*

Method Repeatability

- Intra-rater and inter-rater ICC analysis shows that metric analysis is excellent (ICC > 0.9) in all comparisons besides M4 Inter-observer physical measurements, which showed very good agreement (ICC = 0.888).
- This demonstrates that the metric measurement protocols are repeatable.

	Physical Results		Digital Results	
Measurement	**Intra-Observer ICC**	**Inter-Observer ICC**	**Intra-Observer ICC**	**Inter-Observer ICC**
M1	0.9996	0.994	0.999	0.998
M2	0.988	0.96	0.995	0.998
M3	0.931	0.931	0.999	0.955
M4	0.951	0.888	0.996	0.961
M5	0.999	0.952	0.998	0.966
M6	0.998	0.988	0.999	0.971

Figure 3 - Intra-rater and inter-rater ICC analysis of each osteometric measurement taken. *ICC values range from 0 to 1, with a result of 1 indicating perfect agreement.*

- Kappa statistic analysis shows overarching lack of consistency across morphological analysis.
- Observation of the rhomboid fossa yielded the most consistent results digitally.

	Physical Results		Digital Results	
Observation	**Intra-Observer Kappa**	**Inter-Observer Kappa**	**Intra-Observer Kappa**	**Inter-Observer Kappa**
Rhomboid Fossa	0.727	1.000	0.458	0.371
Topography	0.403	0.366	0.229	0.040
Porosity	0.233	0.395	0.012	0.051
Osteophyte Formation	0.276	0.884	-0.139	0.082

Figure 4 - Intra-rater and inter-rater Kappa statistic analysis of the morphological observations made for both the physical and digital remains. *Kappa values to range from 0 to 1, with 0 indicating poor agreement and 1 indicating strong agreement.*

Scanner Accuracy

- ANOVA analysis shows no significant differences between datasets when comparing metric data.
- This suggests that SLS can be used to create models which are suitable for metric analysis.

Measurement	ANOVA p-value
M1	0.998
M2	0.590
M3	0.983
M4	0.843
M5	0.999
M6	0.924

Morphological Observation	KW p-value
Rhomboid Fossa	0.850
Topography	0.051
Porosity	0.005
Osteophyte Formation	0.001

Figure 5 - ANOVA and Kruskal-Wallis (KW) results testing for differences between the data groups. *A value of $P < 0.05$ is indicates the result is statistically significant. Significant differences indicate that the measurement is not repeatable.*

- Kruskal-Wallis tests show significant differences when comparing morphological data scoring.
- Morphological observation of the rhomboid fossa yielded the best KW results – this feature is the largest and therefore more easily captured by the scanners.
- Variations within the results are more pronounced where a second observer is involved.
- Observer experience may also impact the accuracy of morphological analysis when carried out on digital remains, further limiting the reliability of the method.

Conclusion

- Our evidence shows that there is potential for SLS to be implemented within a forensic setting in the future.
- Metric analysis has demonstrated overall accuracy across modalities as well as between observers - therefore we were able to obtain consistent sex estimation results (1, 4)
- Morphological analysis was less accurate and therefore we deemed it inappropriate to carry out age estimation analysis.
- Overall, further research is needed to develop forensic protocols that are digital-specific before the use of digital remains can be implemented within the field.

References

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