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

Ellie M. Horne[1], Hunter Auck[1], Jennifer Z. Paxton[1], Stephen J. Maclean[1]
[1]Anatomy@Edinburgh, Deanery of Biomedical Sciences, College of Medicine and Veterinary Medicine, University of Edinburgh, United Kingdom

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]

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 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]*

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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