UNDERGRADUATE SUMMER VACATION SCHOLARSHIP AWARDS – FINAL SUMMARY REPORT FORM 2023/24
NB: This whole report will be posted on the Society's website therefore authors should NOT include sensitive material or data that they do not want disclosed at this time.

Name of student:

Ellie M Horne

Twitter Handle*:
*(*optional)*

Name of supervisor(s):

Dr Stephen Maclean

Project Title: (no more than 220 characters)

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

Project aims: (no more than 700 words)

Background -

Forensic anthropology is a field focused on the analysis and identification of unknown skeletal remains. Common forensic analysis generally involves the observation of qualitative traits or the osteometric analysis of known skeletal landmarks and distances.

Physical access to skeletal remains is currently required in order to carry out forensic analysis. This can restrict analyses to local experts and can also pose a problem where evidence needs to be revisited once the remains of the deceased have been returned to their next of kin. Skeletal remains are often fragile through factors such as fragmentation or thermal damage, which can also impact the success of an investigation due to the limits that it introduces to the handling process (Collins and Brown, 2020).

The use of three-dimensional (3D) imaging technology allows for the creation of high-resolution digital replicas of human tissues, including the skeleton, which may offer a solution to the aforementioned limitations (Jani et al. 2021). The promise of 3D visualisation technology has previously been demonstrated within a forensic context, particularly for use in courtroom visualisation (Carew et al. 2021). However, in order to be considered admissible as expert evidence, techniques must meet thresholds of evidentiary standards, and therefore data is needed in order to demonstrate the accuracy and reproducibility of a technique (Crown Prosectution Service 2023).

Aims –

Our project aims to evaluate the applicability of structured light scanning (SLS) in the field of forensic anthropology by comparing the results of forensic sex and age estimation techniques when applied to physical remains and SLS-generated representations of those remains. Human clavicles were chosen to test two different structured light scanners in order to determine the strengths and limitations of this 3D imaging technology.

To better structure our project, we split our aim into three distinct objectives that could be examined individually:

1) Determining the reliability of the measurement tools and observation protocols

2) Assessing the accuracy of the structured light scanners
3) Evaluating the applicability of SLS within a forensic context

Method -

For use in our study, fifteen human clavicles were selected from the osteology teaching collection within the University of Edinburgh [Anatomy@Edinburgh]. Ethical approval for this study was granted under the AMERGE process [24-AM-011].

To test our aim, a combination of metric and morphological analysis was carried out on the physical sample clavicles as well as their digital counterparts generated using the Einscan Pro-HD and Artec Space Spider.

Three models were generated for each clavicle: two repeated models produced by the primary observer, and the third produced by a second observer. This process was carried out using each of the two scanners.

Metric analysis of both the physical and digital bones involved taking six different measurements from each clavicle.

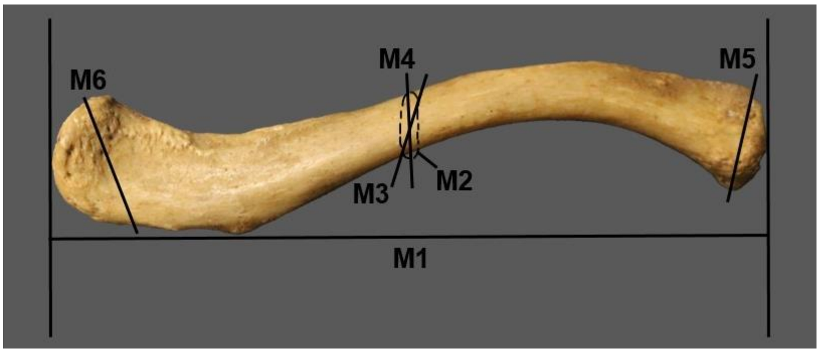

Figure 1 – Six clavicular measurements used for metric analysis. *M1: Maximum clavicular length; M2: Midshaft circumference; M3: Minimum midshaft diameter; M4: Maximum midshaft diameter; M5: Maximum width of sternal end; M6: Maximum width of the acromial surface. This image has been approved for use within this report [Approval code: ANATED_0030].*

Physical osteometrics were carried out using an osteometric board (M1), a measuring tape (M2) and digital Vernier calipers (M3-M6). Digital osteometrics were carried out using the measuring tools available within the Artec Studio 18 Professional software [v. 18.1.4.9] - in particular the sectioning tool (M2) and the linear measurement tool (M1 + M3-M6).

Morphological analysis was carried out by visually grading the presence of the rhomboid fossa, as well as by observing and grading the degree of surface topography, porosity and the degree of osteophyte formation at the sternal surface of the clavicle.

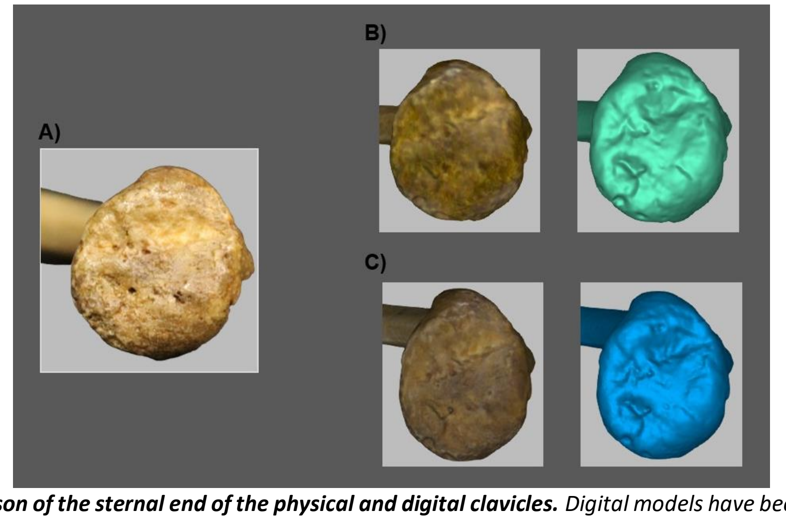

Figure 2 - Visual comparison of the sternal end of the physical and digital clavicles. *Digital models have been depicted both with and without texture applied to highlight the extent to which the scanners are able to capture much finer morphological features and details. (A) Sternal surface of a physical 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. This image has been approved for use within this report [Approval code: ANATED_0030].*

The same measurement and observation protocols were also carried out by a second observer.

Project Outcomes and Experience Gained by the Student (no more than 700 words)

Outcomes -

1) Metric analysis has greater reliability and consistency across modalities than morphological analysis.

Intraclass correlation coefficient (ICC) intra-rater and inter-rater testing for each of the six osteometric measurements shows high levels of agreement between both observers as well as within the data from the primary observer. This suggests that metric forensic analysis is comparable between both physical and digital remains and can be carried out by multiple observers.

	Physical				Digital			
	Intra-Observer		Inter-Observer		Intra-Observer		Inter-Observer	
Measurement	ICC	p-value	ICC	p-value	ICC	p-value	ICC	p-value
M1	0.9996	3.25E-21	0.994	7.10E-13	0.999	6.45E-18	0.988	5.20E-11
M2	0.988	5.06E-11	0.96	1.79E-07	0.995	9.08E-14	0.988	6.83E-11
M3	0.931	3.25E-21	0.931	5.87E-06	0.999	1.26E-11	0.955	3.56E-07
M4	0.951	6.66E-07	0.888	1.03E-04	0.996	4.92E-14	0.961	1.53E-07
M5	0.9988	3.25E-21	0.952	5.89E-07	0.998	8.48E-16	0.966	4.37E-14
M6	0.998	9.99E-16	0.988	5.99E-11	0.999	6.45E-18	0.971	2.13E-08

***Table 1 - 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. A value of $p<0.05$ indicates the results are of statistical significance and therefore indicates that the intra and inter-observer agreement is not due to chance.*

The ICC values for measurement M2 – midshaft circumference - appeared to be slightly higher for the digital data than for the physical data. This was the case for both the intra-rater and inter-rater ICCs (0.995>0.988 and 0.988>0.960 respectively). These differing values suggest that this particular measurement is more accurate when carried out digitally due to the digital measurement tool conforming to the shape of the clavicle, whilst the physical measuring tape cannot.

Kappa statistic analysis was carried out to assess the intra-rater and inter-rater consistency of the morphological observations made for both the physical and digital clavicles.

	Physical				Digital			
	Intra-Observer		Inter-Observer		Intra-Observer		Inter-Observer	
Observation	Kappa	p-value	Kappa	p-value	Kappa	p-value	Kappa	p-value
Rhomboid Fossa	0.727	1.23E-06	1	9.43E-11	0.458	0.00045	0.371	0.0045
Topography	0.403	0.00139	0.366	0.0356	0.229	0.0652	0.04	0.805
Porosity	0.233	0.0541	0.395	0.0191	0.012	0.927	0.0506	0.704
Osteophyte Formation	0.276	0.116	0.884	1.52E-05	-0.139	0.186	0.0816	0.543

***Table 2 - Intra-rater and inter-rater Kappa statistic analysis of the morphological observations made for both the physical and digital remains.** Kappa values tend to range from 0 to 1, with 0 indicating poor agreement and 1 indicating strong agreement.*

These results show an overall lack of consistency within the observations made for each feature, however physical observations proved to be more reliable than digital observations. Previous research has proven morphological analysis of the clavicle to be problematic due to a limited correlation between estimated and known age in certain populations (Madentzoglou et. al., 2023). This therefore suggests that the inconsistencies observed during this study may be due to the method itself rather than due to the accuracy of the scanners.

2) SLS can be used to create metrically similar digital remains. Finer morphological features are often imperceptible on the final models.

ANOVA and Kruskal-Wallis analysis was carried out to test for the presence of any significant differences between the different modalities used, for both the metric and morphological data respectively.

A)

Measurement	F value	p-value
M1	0.085	0.998
M2	0.776	0.59
M3	0.175	0.983
M4	0.451	0.843
M5	0.059	0.999
M6	0.322	0.924

B)

Observation	Chi-squared value	p-value
Rhomboid Fossa	3.3625	0.8496
Topography	14.028	0.05069
Porosity	20.102	0.005353
Osteophyte Formation	23.757	0.001257

Figure 3 - ANOVA and Kruskal-Wallis results testing for differences between the data groups. *A) ANOVA table showing no statistically significant differences between the results from each dataset. An F value closer to 1 indicates no significance between groups, as is the same when p>0.05. B) Kruskal-Wallis analysis of the morphological data. A value of p<0.05 indicates statistically significant differences between groups. Higher chi-squared values are indicative of substantial variability between groups.*

The ANOVA results show that there are no statistically significant differences between any of the physical or digital datasets. It is worth noting that measurement M2 once again stands out, further suggesting that the two different measurement strategies yielded slightly different results.

In contrast, the results of the Kruskal-Wallis test show that there are significant differences between the groups, except for the analysis of the rhomboid fossa. This result is expected as this is a much more obvious feature than the surface topography and porosity and therefore both scanners were able to easily recreate the feature on the model. Further testing determined that it was the inter-observer comparisons that showed the biggest difference between results, which suggests that observer experience is an important factor to consider when carrying out morphological analysis on both physical and digital remains.

3) SLS has the potential to be implemented for use in metric forensic analysis. It is not presently recommended for use where morphological forensic analysis is concerned.

Sex estimation analysis was carried out using three differential equations in order to determine the consistency of the output across the datasets, as well as the extent to which the sensitivity of the equation can affect the outcome.

	Estimated Sex Across Sample (%)					
	F5		F6		S+J	
Measurement Modality	Male	Female	Male	Female	Male	Female
Physical	66.67	33.33	73.33	26.67	20.00	80.00
Observer Physical	86.67	13.33	86.67	13.33	26.67	73.33
Einscan Pro-HD	70.00	30.00	70.00	30.00	13.33	86.67
Observer Einscan Pro-HD	46.67	53.33	53.33	46.67	13.33	86.67
Artec Space Spider	66.67	33.33	73.33	26.67	13.33	86.67
Observer Artec Space Spider	66.67	33.33	66.67	33.33	20.00	80.00

Table 3 - Estimated sex of the sampled remains expressed as the percentage male vs percentage female for each of the measurement modalities tested. *F5 and F6 refer to the clavicular equations outlined by Kharuhadetch et al, 2022. S+J refers to the sex estimation equation outlined by Spradley and Jantz, 2011.*

F5 and F6 yielded similar results, with most deviations occurring within the second observer data. This suggests that small deviations in measurement can impact the estimation result due to the sensitivity of the equation. The S+J equation yielded a very different set of results, however they were still consistent across the dataset. Each equation was derived from existing analysis of physical remains, therefore it is likely that sex estimation accuracy and consistency could be improved by developing differential equations that are specific for use with digital remains.

Due to the lack of consistency among the digital morphological results that we obtained, we deemed it inappropriate to carry out age estimation analysis on our study sample.

Experience Gained -
Throughout my 8-week research project I have gained both knowledge and confidence in using SLS technology – having used both the Einscan Pro-HD and the Artec Space Spider, and their respective softwares.
The statistical analysis carried out during my project enabled me to gain further experience with data interpretation and the use of R Studio.
I also had the opportunity to work with others in a research-group setting. This was a very rewarding experience as it gave me the chance to learn from and collaborate with other students.

Please state which Society Winter or Summer Meeting the student is intending to present his/her poster at:

Winter Meeting 2025

Proposed Poster Submission Details (within 12 months of the completion of the project) for an AS Winter/ Summer Meeting – (no more than 300 words)

Background & Aims -
- Forensic anthropology is concerned with the analysis of skeletal remains.
- 3D imaging can be used to overcome limitations that arise during forensic investigations.
- Evidence is needed to prove accuracy and reliability of the technique.
- Aim is to assess the strengths and limitations of SLS as a form of 3D imaging using clavicle bones and determine whether the technology can be used for forensics.

Methods -
- Einscan Pro-HD and Artec Space Spider used to create digital replicas of a sample size of 15 left human clavicles.
- Physical and digital remains underwent metric analysis [six clavicular measurements] and morphological analysis [observation of four different features at the sternal end].
- Protocols were repeated by a second observer to assess the repeatability and consistency of the method.

Measurement/Observation Reliability -
- ICC and Kappa data tables.
- Results show that metric analysis is consistent when comparing observers as well as comparing physical vs digital.
- Kappa results show lack of consistency within the morphological data.

Scanner Accuracy -
- ANOVA and Kruskal-Wallis data tables.
- No difference between data groups when considering metric data.
- Morphological data showed significant differences between groups; most differences were between observers therefore experience is an important influence on accuracy.

Conclusion (Forensic Application) -
- SLS can be used to generate digital representations of remains with relative accuracy.
- Metric analysis is highly reliable and therefore digital remains have the potential to be used for sex estimation.
- Lack of morphological accuracy suggests that SLS-generated remains are not suitable for use in age estimation analysis.
- Further research is needed to develop digital-specific forensic sex and age estimation equations.

Brief Resume of your Project's outcomes: **(no more than 200-250 words)**.
The title of your project and a brief 200-250 word description of the proposed/completed project. The description should include sufficient detail to be of general interest to a broad readership including scientists and non-specialists. Please also try to include 1-2 graphical images (minimum 75dpi). NB: Authors should NOT include sensitive material or data that they do not want disclosed at this time.

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

Forensic anthropology is a field that entails the analysis of skeletal remains, therefore access to remains is imperative when conducting a forensic investigation. This is not always possible, however, due to restrictions such as location or a lack of long-term evidence storage. Structure light scanning (SLS) offers a potential solution to this - creating digital representations of the remains that can then be easily shared with others if needed, and stored long-term in case further analysis is required in the future.

The aim of this study was to evaluate the accuracy of SLS and its applicability in a forensic context using human clavicles.

Digital clavicle models were generated using the Einscan Pro-HD and Artec Space Spider, before undergoing metric and morphological analysis to estimate the sex and age of the remains.

The digital models produced displayed very similar metric results in comparison to each other as well as to the physical clavicles. However, this was not the case for the morphological results as the SLS scanners were unable to accurately capture finer textural details. Therefore, the technique is more appropriate for sex estimation only.

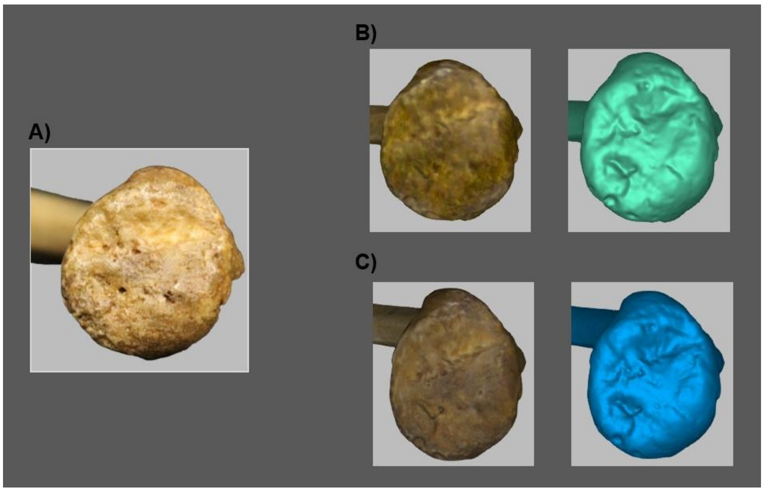

Figure 1 - Visual comparison of the sternal end of the physical and digital clavicles. *Digital models have been depicted both with and without texture applied to highlight the extent to which the scanners are able to capture much finer morphological features and details. (A) Sternal surface of a physical 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. This image has been approved for use within this report [Approval code: ANATED_0030].*

This study shows evidence to suggest that SLS technology can be used to generate digital bone replications with relative accuracy, however they are more applicable for use when focusing on metric analysis only.

A)

Measurement	F value	p-value
M1	0.085	0.998
M2	0.776	0.59
M3	0.175	0.983
M4	0.451	0.843
M5	0.059	0.999
M6	0.322	0.924

B)

Observation	Chi-squared value	p-value
Rhomboid Fossa	3.3625	0.8496
Topography	14.028	0.05069
Porosity	20.102	0.005353
Osteophyte Formation	23.757	0.001257

Table 1 - Estimated sex of the sampled remains expressed as the percentage male vs percentage female for each of the measurement modalities tested. *F5 and F6 refer to the clavicular equations outlined by Kharuhadetch et al, 2022. S+J refers to the sex estimation equation outlined by Spradley and Jantz, 2011.*

Further research is needed to develop specific protocols for the forensic analysis of digital remains.

Other comments: (no more than 300 words)

Acknowledgements -

First and foremost, I would like to express my gratitude towards the Anatomical Society for the generous funding that made this project possible. The opportunity that their funding granted me is one that I am incredibly grateful for and shall be for many years to come.

I would like to thank my supervisor Dr Stephen Maclean for his unwavering support and encouragement throughout the duration of my project. His advice and support not only aided in the completion of this project, but it also helped me to gain a greater sense of research confidence.
I would also like to thank Hunter Auck for taking on the role of my second observer during this study.
Additionally, I would like to thank the other members of the ATLAS Facility - Dr Jennifer Paxton, Victoria McCulloch and the MSc students working within the facility over the summer. I thoroughly enjoyed being able to work in a more collaborative environment and I appreciated the presentation practice. It has truly been a pleasure working with you all over the summer.

References -

Carew, R.M., French, J. and Morgan, R.M. (2021). 3D forensic science: A new field integrating 3D imaging and 3D printing in crime reconstruction. Forensic Science International: Synergy, 3, p.100205. doi:https://doi.org/10.1016/j.fsisyn.2021.100205.Collins, A.J. and Brown, K. (2020). Reconstruction and physical fit analysis of fragmented skeletal remains using 3D imaging and printing. Forensic Science International: Reports, [online] 2, p.100114. doi:https://doi.org/10.1016/j.fsir.2020.100114.Crown Prosecution Service (2023). Expert Evidence | The Crown Prosecution Service. [online] Cps.gov.uk. Available at: https://www.cps.gov.uk/legal-guidance/expert-evidence.

Falys, C.G. and Prangle, D. (2014). Estimating age of mature adults from the degeneration of the sternal end of the clavicle. American Journal of Physical Anthropology, 156(2), pp.203–214. doi:https://doi.org/10.1002/ajpa.22639.

Jani, G., Johnson, A., Marques, J. and Franco, A. (2021). Three-dimensional(3D) printing in forensic science–An emerging technology in India. Annals of 3D Printed Medicine, 1, p.100006. doi:https://doi.org/10.1016/j.stlm.2021.100006.

Kaewma, A., Sampannang, A., Tuamsuk, P., Kanpittaya, J. and Iamsaard, S. (2016). Incidence of Clavicular Rhomboid Fossa in Northeastern Thais: An Anthropological Study. Anatomy Research International, 2016, pp.1–4. doi:https://doi.org/10.1155/2016/9298043.

Kharuhadetch, P., Wattanawaragorn1, S., Chaiwit Tiamtongon, Wathanyutakon, Navic, P. and Mahakkanukrauh, P. (2022). Sex Determination Using Scapular and Clavicular Parameters in Modern Thai Population Determinación del Sexo Utilizando Parámetros Escapulares y Claviculares en la Población Tailandesa Moderna. Int. J. Morphol, [online] 40(3), pp.768–773. Available at: https://www.scielo.cl/pdf/ijmorphol/v40n3/0717-9502-ijmorphol-40-03-768.pdf [Accessed 17 Jun. 2024].MS Madentzoglou, D Nathena, Pongpon Traithepchanapai, A Karantanas, G Kontakis and EF Kranioti (2023). Age estimation based on the metamorphosis of the clavicle end: A test of Falys and Prangle method in two contemporary samples. Legal Medicine, pp.102331–102331. doi:https://doi.org/10.1016/j.legalmed.2023.102331.

Spradley, M.K. and Jantz, R.L. (2011). Sex Estimation in Forensic Anthropology: Skull Versus Postcranial Elements. Journal of Forensic Sciences, 56(2), pp.289–296. doi:https://doi.org/10.1111/j.1556-4029.2010.01635.x.

Data Protection/GDPR: I consent to the data included in this submission being collected, processed and stored by the Anatomical Society. Answer YES or NO in the Box below

YES

Graphical Images: If you include graphical images you must obtain consent from people appearing in any photos and confirm that you have consent. A consent statement from you must accompany each report if relevant. A short narrative should accompany the image. Answer N/A not applicable, YES or NO in the box below
YES
Copyright: If you submit images you must either own the copyright to the image or have gained the explicit permission of the copyright holder for the image to be submitted as part of the report for upload to the Society's website, Newsletter, social media and so forth. A copyright statement must accompany each report if relevant. Answer N/A not applicable, YES or NO in the box below
N/A

Signature of student: *Date: 05/09/2024*

Signature of supervisor: *Date: 05/09/2024*

END OF FORM

File: USVRS-Award Letter 2024_ v1-170524_Template_ Dr Stephen Maclean_200524