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OSTEOID, A New Forensic Tool: Developing a Practical Online Resource for Species Identification of Skeletal Remains

Final Research Report

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Project Summary

Major Goals and Objectives

The main objective of the proposed project was to develop a searchable online database (OsteoID) to assist any individual (including forensic anthropologists, forensic pathologists, medical examiners, coroners, crime scene and death investigators, and law enforcement) in determining the species of an unknown skeletal element based on simple measurements and visual comparisons. The OsteoID webtool was aimed to be a free and easy-to-use resource, which would include metric data, quality photographs of exemplar species elements, and 3D scans. In addition, the project aimed to explore the utility of discriminant functions or other statistical measures in facilitating human versus non-human classifications and species identifications.

Research Questions

When a skeletal element is reported to law enforcement or medicolegal agencies, a forensic anthropologist is commonly consulted to determine whether the bone is human in origin. Published reports suggest that around 30% of a forensic anthropologist's caseload may consist of nonhuman elements [1-3] and as much as 90% of the skeletal elements reviewed by forensic anthropologists are determined not human [1]. When reporting that a bone is not human, the forensic anthropologist is commonly asked to what animal species it belongs. While determining human versus nonhuman is typically an easy task, assigning a correct nonhuman species to an isolated element can be more challenging for forensic anthropologists, especially if they do not have extensive zooarchaeological training or access to comparative collections [4]. Similarly, if asked to make a designation at a scene, comparative textbooks [e.g., 5-9] may not be available. Finally, if a forensic anthropologist cannot be immediately reached for a determination, law enforcement must decide whether they believe the remains are likely human (and thus, the scene should be secured and remains left undisturbed) or that they are not likely to be of forensic significance and do not warrant additional resource expenditure.

As such, this project aimed to create an online web tool (OsteoID) which could be accessed freely and anywhere via computers or smart phones/devices to assist with these designations. The goal was to create a database of basic metric measurements that could be easily taken by law enforcement or anyone else, from which the web tool could narrow down potential species and return quality photographs for visual comparisons. In addition to this primary objective, the following research questions were addressed:

- Can discriminant functions or other statistical methods classify human versus nonhuman remains from basic long bone osteometrics with a high enough accuracy to have utility as a forensic triaging tool?
- Can discriminant functions or other statistical methods accurately classify species from basic long bone osteometrics?

Research Design, Methods, Analytical and Data Analysis Techniques

Osteometric data were collected from human and nonhuman skeletal elements representing a total of 28 species commonly encountered in North America [Table 1]. Data were collected from the Smithsonian National Museum of Natural History, Washington DC; American Museum of Natural History, New York, NY; Mercyhurst University, Erie, PA; Washburn University, Topeka, KS; University of California, Davis, CA; and Des Moines University, Des Moines, IA, as well as from published manuscripts and databases [10-28]. Metric data were collected from long bones (humerus, radius, ulna, femur, tibia, fibula, fused metapodials, and the homologous structures in the five bird species) and the os coxae, sacrum, and scapula [Table 2]. See Table 2 for a list of measurements. The compiled dataset consists of

59,442 measurements from 18,867 bones. Photographs were also taken of exemplar elements for use in OsteoID (six views whenever possible).

Table 1. List of species from which data and photos were collected along with element sample sizes.

Class	Genus	Species	Common Name	Max Sample Size[1]
Aves	Anas	platyrhynchos	Mallard Duck	31
Aves	Aquila	chrysaetos	Golden Eagle	23
Aves	Branta	canadensis	Goose	34
Aves	Gallus	gallus	Chicken	32
Aves	Meleagris	gallopavo	Turkey	35
Mammalia	Alces	alces	Moose	27
Mammalia	Bos	taurus	Cow	17
Mammalia	Canis	familiaris	Domestic dog	147
Mammalia	Canis	latrans	Coyote	65
Mammalia	Canis	lupus	Wolf	45
Mammalia	Capra	hircus	Goat	83
Mammalia	Cervus	canadensis	Elk	34
Mammalia	Didelphis	virginiana	Opossum	35
Mammalia	Ovis/capra	aries/hircus	Sheep/Goat	2
Mammalia	Equus	caballus	Horse	33
Mammalia	Felis	catus	Domestic cat	40
Mammalia	Homo	sapiens	Human	2714
Mammalia	Odocoileus	hemionus	Mule deer	38
Mammalia	Odocoileus	virginianus	White-tailed Deer	39
Mammalia	Ovis	aries	Sheep	147
Mammalia	Procyon	lotor	Racoon	39
Mammalia	Sus	scrofa	Domestic Pig/Boar	20
Mammalia	Sylviagus	floridanus	Eastern Cotton-Tail Rabbit	36
Mammalia	Urocyon	cinereoargenteus	Gray Fox	42
Mammalia	Ursus	americanus	American Black Bear	38
Mammalia	Ursus	arctos	Brown Bear	48
Mammalia	Vulpes	vulpes	Red Fox	43
Testudines	Chelydra	serpentina	Snapping Turtle	30
Testudines	Terrapene	carolina	Common Box Turtle	31
			Totals	**3948**

[1]This column represents the maximum specimens per elements (e.g., Mallard Ducks had data from 31 humeri but only 28 femora). See Garvin et al. [29] for additional sample breakdowns.

Table 2. List of measurements collected by specimen. Shaded columns represent elements/measurements collected and included in OsteoID but not utilized in statistical classification analyses.

Class	Genus	Humerus	Radius	Ulna	Femur	Tibia	Fibula	Os coxae	Sacrum	Scapula	Meta carp	Meta tars
MaxL	maximum bone length	X	X	X	X	X	X	X	X	X	X	X
MaxPW	maximum proximal width (medio-lateral)	X	X	X	X	X			X		X	X
MaxPD	maximum proximal depth (antero-posterior)	X	X	X	X	X					X	X
MaxDW	maximum distal width (medio-lateral)	X	X		X	X						
MaxDD	maximum distal depth (antero-posterior)	X	X		X	X						
MidMaxD	maximum diameter of the midshaft (1/2 MaxL)	X	X	X	X	X						
MidMinD	minimum diameter of the midshaft (1/2 MaxL)	X	X	X	X	X						
FHD	maximum femoral head diameter				X							
OsCoxAD	maximum acetabullar diameter							X				

For use in the OsteoID website, descriptive statistics (mean, minimum, maximum, and +/- two standard deviations) were calculated. To be most conservative in filtering out species, the lower bounds of the filtering range was set at either the minimum or negative two standard deviation value, whichever was lowest. Similarly, the upper bounds of the search criteria for the web tool were set at either the maximum or positive two standard deviation value, whichever was largest. Photos of species elements were photoshopped so that all six views were on a single image, along with a label, scale, a penny for more intuitive scaling, and the maximum length web range. Annotations were added for discriminating species when possible. A web developer then was able to build a website where individuals can search by common name, genus, species, bone, and/or measurements. For the search by measurement feature, only maximum lengths, proximal widths, and distal widths were included in the final web tool. This was to simplify the searching procedures and these three measurements were found to be the easiest to take reliably and hold the most weight in discriminating species.

To test the utility of statistical methods in classifying human versus nonhuman remains and assigning species, step-wise linear discriminant function analyses (DFA) and decision tree models were performed. These analyses were carried out on pooled long bone samples (humerus, radius, ulna, femur, and tibia combined) as well on element-specific samples. They were conducted on all measurements, as well as subsets of measurements to represent a possible shaft, proximal, or distal fragment. The DFA utilized a leave-one-out cross-validation method, while the decision trees used a Classification and Regression Tree growth model derived from 70% of the sample and tested on the 30% hold-out sample. Additional methodological details can be found in Garvin et al. [29].

Expected Applicability of the Research

In terms of forensic anthropology, the resources developed from this project are aimed to assist practitioners in determining species from skeletal remains. Correctly reporting the faunal species along with a nonhuman designation increases stake-holder confidence in the conclusion and bolsters the forensic anthropologist's credibility [3]. For forensic anthropologists without access to comparative collections, the OsteoID web tool presents a centralized location to find species/element images and resources. The resources may also be used to train students and the 3D models can be printed to create comparative collections. Finally, the descriptive metric data and/or the statistical methods presented could be used to support forensic anthropological conclusions in reports.

Law enforcement and medicolegal personnel (e.g., death investigators) may also find the resources useful as triaging tools, e.g., when they are deciding on the importance of securing a scene or when a forensic anthropologist's opinion is not immediately available. The decision trees/discriminant functions can be used as a preliminary assessment to determine whether remains could even *potentially* be human. The OsteoID web tool can be used at a scene to review possible species and compare to photographs or 3D scans. As such, the tools presented could save agency money and resources and also minimize the possibility that human remains are dismissed as nonhuman.

Finally, the OsteoID web tool may also be beneficial to others outside of forensics. Any students studying comparative osteology may find the site useful. Archaeologists, biologists, veterinarians, wildlife specialists, park rangers, departments of natural resources, and the general public may find the tools educational when assessing faunal remains.

Participants & Other Collaborating Organizations

Those individuals involved in the development, supervision, data collection, processing, and analysis, reporting and dissemination of this project include: Heather Garvin, PhD, D-ABFA of Des Moines University (Principal Investigator), Rachel Dunn, PhD of Des Moines University (Co-Principal Investigator), and Sabrina Sholts, PhD, of the Smithsonian Institution's National Museum of Natural History (Co-Principal Investigator). Erin Menardi (Contractor) was hired as the Web Developer and was responsible for building the OsteoID web tool. Ms. M. Schuyler Litten collected measurement data as a student Intern at the Smithsonian Institution. Des Moines University students involved in data processing, photo editing, or 3D scanning include Nathan Kuttickat, Noah Skantz, Cade Harvey, and Merna Mohamed. Individuals that contributed some aspect of metric data, photographs or 3D scans include: Andrea Clendaniel and Elizabeth Dougher of Mercyhurst University, Chelsea Cataldo-Ramirez of University of California, Davis, Julie Meachen of Des Moines University, Alexandra Klales of Washburn University, and Christopher Milensky of the Smithsonian Institution. Michael Kenyhercz, PhD, conducted some additional machine learning analyses on the data for future investigations.

Outcomes

Activities/Accomplishments

The main accomplishment of this project was the creation of the online web tool, OsteoID (www.boneidentification.com) [30]. This web tool can be used to search and filter images of human and nonhuman skeletal elements either via common names, genus, species, element type, or osteometrics. In addition, the website provides links to additional resources, such as additional images, 3D scans, and metric data. As part of this project, a large database of human and nonhuman osteometrics was created. This database has been made freely available via the OsteoID website and Dryad [31]. Practitioners are welcome to use these data for case comparisons or future research. Likewise, all images and 3D models incorporated into OsteoID are freely available for download and may be used as educational resources. 3D models will be updated beyond the completion date of this project and are continually being added to the OsteoID resources as well as a Morphosource project page [32].

Decision trees and discriminant functions were developed to distinguish human from nonhuman remains with acceptable accuracy. These are presented in the additional resources in OsteoID, as well as in Garvin et al. [29].

Through data collection, this project has contributed research and comparative osteological training to five students (three graduate/medical students and two undergraduate students). Those students have been included as co-authors on published abstracts and manuscripts. This project has resulted in three published abstract/presentations at national meetings, one student presentation at an institutional research meeting, a presentation at the NIJ Research and Development Symposium, a *Just Science* podcast, and a published manuscript [29]. OsteoID has also been introduced within other short course or community presentations, such as the forensic short courses presented by Washburn University and a recent forensic anthropology presentation to the Iowa Division of Criminal Investigation

Major Crime Unit. The launch of the web tool was announced on Facebook pages and Twitter, receiving positive feedback and hundreds of shares by individuals.

Results and Findings

Statistical analyses suggest that discriminant functions and decision trees can differentiate human from nonhuman long bones with relatively high (>90%) accuracy rates. This is similar to results presented from Saulsman et al [33] on a limited Australian sample. Even when all long bones were pooled into a single sample (i.e., all humeri, femora, ulnae, radii, and tibae in one sample), a total classification accuracy of 91.4% was achieved with the DFA and 91.0% with the decision tree. Importantly, the human classification rates for each of these were even higher (95.6% for the DFA and 99.6% for the decision tree) meaning that only 0.4% of the human bones were misclassified as nonhuman in the pooled decision tree analysis. This suggests that these resources, particularly the decision trees, may be useful for preliminary assessments and triaging of remains found at scenes. In general, the bone-specific analyses presented higher classification rates. Analyses on specific bone regions of the pooled sample (mimicking a shaft, proximal, or distal fragment) were slightly lower (64.4% – 88.3, depending on variables and methods), but again increased for bone-specific analyses (all but one over 80%). Tables of specific results can be found in Garvin et al. [29].

Overall, the decision trees presented higher classification rates and exceptionally high human classification rates (98.4-99.9% depending on whether pooled or bone specific samples were used and whether all variables or only specific bone regions were included). This is in part due to the ability to assign misclassification costs in the decision tree analyses. For these models, a misclassification cost of 10 was assigned to erroneously classifying a human bone as nonhuman. I.e., the models were created assuming that it was 10x more costly to misidentify a human bone than to misidentify a nonhuman bone as human. This creates a classification bias, but also makes the method safer for use in preliminary forensic scenarios. It creates a conservative approach where anything that could *potentially* be human is assigned as preliminarily human, and then agencies can contact a forensic anthropologist for confirmation. Decision trees also do not require normally distributed data or other statistical assumptions (which were violated by the nonhuman samples in this study) [34]. Finally, decision trees are easy to apply and interpret [35-37].

Neither the discriminant functions nor the decision trees could classify elements down to the species level with acceptable accuracy rates. Although overall function/model rates were much higher than chance, accuracy rates varied highly across the 28 species and decision trees could not account for the 28 different groups. These results confirm the need to use visual comparisons when assigning species, which rely on more localized bony features and subtle shape differences in bones.

The OsteoID web tool (www.boneidentification.com) provides these resources for species identification. A user can first identify the element type (e.g., humerus) or if unknown "search all". Then, by inputting a simple measurement, such as maximum length, the pool of potential species is narrowed and only images of those species that could match the unknown element are returned. These images can be clicked on and enlarged or opened in new windows for comparison. As mentioned previously, metric data and 3D scans can also be used for comparisons.

Limitations

Sample sizes for some species (e.g., pig) were smaller than desired for this project. Travel for data collection was affected by the on-going Covid-19 pandemic. Because we are using size as a variable, it also meant that specimens included in the study had to be skeletally mature (i.e., at least partial fusion of both the proximal and distal epiphyses). Finding these samples, particularly for larger domestic animals that may be butchered prior to adult status or take up significant room in museum collections, was difficult. It is for this reason that lower and upper bounds for the web tool search algorithms were set to either min/max or two standard deviation values, whichever produced the greatest range. If specimens are encountered that extend beyond those ranges or additional data can be collected, it is easy to update the database and web tool to better encapsulate the full species size variation. There are also a few images (e.g., some elk elements) that could not be obtained, but can be updated in the future when collections may be visited or images are donated.

Although OsteoID includes 27 faunal species, it is possible that bones encountered come from a species not included. Such scenarios are discussed in the OsteoID "FAQ" page. The OsteoID database and web tool can easily be updated with metric data and photographs from additional species and an e-mail address is provided on the website for any individuals that would like to contribute to the project. The web tool also does not include skulls or some of the smaller elements (carpals, tarsals, vertebrae). In the "Additional Resources" tab of the website, images of crania, mandibles, carpals, tarsals, and vertebrae are provided for some species. Additional photographs of these other elements are being continually added, although they are not currently searchable by measurements or in the main web tool.

We also included numerous disclaimers in the OsteoID website to remind users that anyone who encounters remains that have any chance of being human should contact their local law enforcement agencies immediately. While individuals in the public may find OsteoID useful when assessing animal remains encountered, they should continue to rely on experts in the field to make final determinations in cases potentially involving human remains. The resources presented as part of this project are meant to be supplemental, similar to when individuals refer to comparative texts.

Artifacts

Publications, conference papers, and presentations (student authors underlined)

- Garvin HM, Dunn R, Sholts S, Litten MS, Mohamed MM*, Skantz N*, Kuttickat N*. OsteoID: A freely available online tool for skeletal species identification. *Biology* (In Review).

- Garvin HM, Dunn R, Sholts S, Litten MS, Mohamed M*, Kuttickat N*, Skantz N*. OsteoID: A freely available tool for skeletal species identification. Accepted for presentation at the American Academy of Forensic Sciences 74th national meeting in Seattle, WA.

- Garvin HM**,** Kenyhercz M, Dunn RH, Sholts S, Litten S. Skeletal species identification using random forest modeling. Accepted for presentation at the American Academy of Forensic Sciences 73rd annual meeting, Houston, TX (Virtual due to Covid-19).

- Skantz N, Garvin HM, Dunn R, Sholts S, Litten MS, Clendaniel A, Dougher E. (2019) Developing OSTEOID: A new forensic tool for faunal species identification. Poster presentation at DMU Winter Research Symposium, December 2019.

- Garvin HM**,** Dunn R, Sholts SB, Litten MS, Clendaniel A, Dougher E, Skantz N. Faunal species identification from basic skeletal measurements: Differentiating 21 medium-to-large sized mammals. *Accepted* Poster Presentation to be given at the American Association of Physical Anthropology 89th annual meeting, Los Angeles, CA in April 2020. Published abstract.

- Garvin HM. OSTEOID, A New Forensic Tool: Developing a Practical Online Resource for Species Identification of Skeletal Remains. *Accepted* Oral presentation to be given at the NIJ Research & Development Symposium being held at the American Academy of Forensic Sciences, Anaheim, CA in February 2020.

- Just Science Podcast: "Just Skeletal Remains": https://forensiccoe.org/2020-nij-rd-e2/. Forensic Technology Center of Excellence/National Institute of Justice. Live 3/31/2020.

Website(s) or other Internet site(s)

- www.boneidentification.com - OsteoID website.
- Morphosource OsteoID Project. Available online: https://www.morphosource.org/projects/000364427?locale=en (accessed 27/11/2021).

Data Sets Generated

- Garvin, H.M.; Dunn, R.; Sholts, S. Postcranial osteometric data from human and 27 North American faunal species, Dryad. Dataset, 2021. doi:10.5061/dryad.73n5tb2z0

Dissemination Activities

As mentioned, this project has resulted in three published abstract/presentations at national meetings, one student presentation at an internal institutional research symposium, a presentation at the NIJ Research and Development Symposium, a *Just Science* podcast, and a published manuscript [29]. OsteoID has also been introduced within other short course or community presentations, such as the forensic short courses presented by Washburn University by Alexandra Klales and a recent forensic anthropology presentation to the Iowa Division of Criminal Investigation Major Crime Unit. I have been asked to present at next year's Iowa Association of Medical Examiner's annual meeting on the topic of human versus nonhuman remains and scene searches, where I will continue to advertise OsteoID. The launch of the web tools was announced on Facebook pages (my personal page as well as on two bone identification group pages) and Twitter, receiving more than 400 re-tweets and over 800 "likes" with many positive comments from individuals around the world. We plan to further disseminate project information once the manuscript summarizing the project is published (currently In Review) and at this upcoming American Academy of Forensic Sciences meeting where we will be presenting a poster specifically on the OsteoID web tool.

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