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Technical Note

Standardized anthropological measurement of postcranial bones using three-dimensional models in CAD software

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ABSTRACT

This study introduces a standardized protocol for conducting linear measurements of postcranial skeletal elements using three-dimensional (3D) models constructed from post-mortem computed tomography (PMCT) scans. Using femoral DICOM datasets, reference planes were generated and plane-to-plane measurements were conducted on 3D surface rendered models. Bicondylar length, epicondylar breadth, anterior-posterior (AP) diameter, medial-lateral (ML) diameter and cortical area at the midshaft were measured by four observers to test the measurement error variance and observer agreement of the protocol (n = 6). Intra-observer error resulted in a mean relative technical error of measurement (%TEM) of 0.11 and an intraclass correlation coefficient (ICC) of 0.999 (CI = 0.998–1.000); inter-observer error resulted in a mean %TEM of 0.54 and ICC of 0.996 (CI = 0.979–1.000) for bicondylar length. Epicondylar breadth, AP diameter, ML diameter and cortical area also yielded minimal error. Precision testing demonstrated that the approach is highly repeatable and is recommended for implementation in anthropological investigation and research. This study exploits the benefits of virtual anthropology, introducing an innovative, standardized alternative to dry bone osteometric measurements.

1. Introduction

The measurement and examination of human dry bones is an established anthropological technique in the identification of unknown human remains. However, maceration prior to examination can be a time-consuming, resource intensive process and may be prohibited by national regulations or religious practices. As a non-invasive alternative, the use of radiology is emerging as a reliable tool for rapid post-mortem skeletal assessment. As stated in the INTERPOL DVI Guide [1], multi-slice computed tomography (MSCT) is a valuable tool in the post-mortem identification process and is now conducted systematically during mass disasters. The application of post-mortem computed tomography (PMCT) played an important role in Disaster Victim Identification in Australia during the 2009 Victorian Bushfires Disaster [2,3] and PMCT scanners are gaining popularity in medical examiner office settings [4,5], constituting standard protocol for post-mortem examination in Australia, Europe and worldwide.

Two-dimensional (2D) MSCT scout views, which are equivalent to plain film and digital x-ray techniques, have been previously used to conduct virtual linear measurements such as in leg length discrepancy [6–9], however depending on the orientation of the bone in the image, anatomical landmarks can be difficult to identify. Additionally, distortion of the image and superimposition of structures can also make identifying landmarks problematic. From a forensic anthropological perspective, Brough et al. [10], Robinson et al. [11] and Lottering et al. [12] have all introduced standardized protocols for conducting measurements of the juvenile clavicle, lower limb bones and the juvenile skull using MSCT, respectively, and report comparable accuracies between MSCT-derived measurements and traditional osteometric measurements. The use of reverse engineering computer software using three-dimensional surface rendered models for measuring other

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postcranial bones has not been investigated, and a standardized protocol has not been introduced. Considering anthropological examination routinely utilizes postcranial bones in DVI and medico-legal investigation, it is essential to have standard procedures in place for measurement of all bones, enabling identifiable information to be estimated that genetic analysis cannot provide.

Computed assisted design (CAD) software such as Geomagic Design X™ (3D Systems, Inc., United States), allows the user to generate three-dimensional (3D) virtual models of skeletal elements, enabling complete visualization of all surface bony features. The 3D surface rendered bones are visualized in x, y and z planes, therefore the model can be rotated to define specific anatomical landmarks, allowing accurate metric dimensions to be obtained through the application of semi-automated reference planes. CAD software also allows for analyses to be conducted from remote locations immediately, or at a later date, and offers a method of virtual record keeping of the reference geometries and bone model. In concordance with a 2009 U.S. National Research Council and U.S. National Academy of Sciences (NAS) report [13], it is critical that scientific methods be validated and standardized. The current study introduces technologically enhanced standardized protocols for performing linear measurements of postcranial bones, and assesses the precision and observer agreement using three-dimensional models of the human femur. This method aims to demonstrate the benefits of 'virtual forensic anthropology' as a

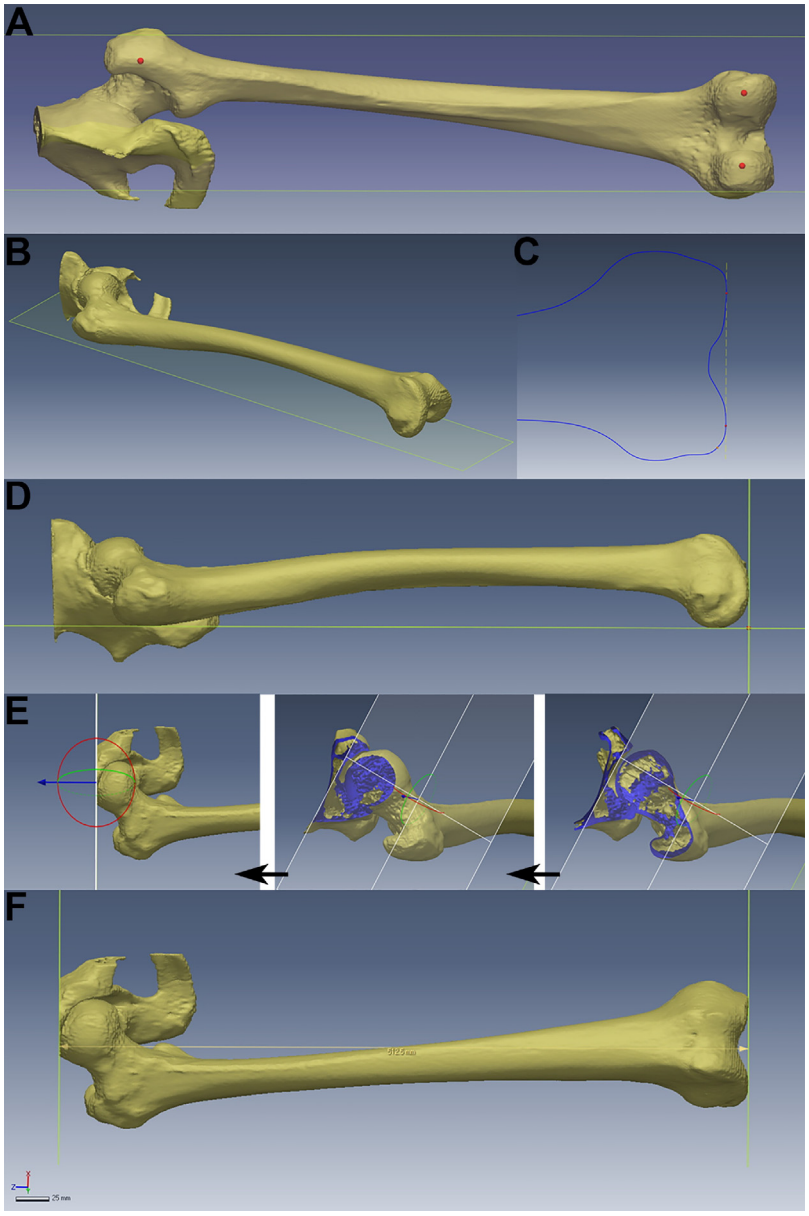

Fig. 1. Virtual measurement of long bone length in Geomagic Design X™. (A) A posterior base plane was generated. The dots indicate the user-determined reference points on the most posterior aspects of the bone. (B) The posterior plane represents the fixed base of an osteometric board. (C) A 3D sketch obtained from a silhouette curve of the external contour of the distal bone (dark outline) and the tangent vector (dashed line) obtained via selecting reference points on the most distal aspect, were used to generate a rotational plane. (D) The distal rotational plane is perpendicular to the base plane, representing the fixed raised edge of an osteometric board. (E) View clip tool was used to identify the proximal boundary of the femoral head within the acetabulum. (F) An offset plane was aligned to the user defined proximal boundary and an automated plane-to-plane measurement was conducted between the rotational plane and the offset plane.