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DIGITAL REVOLUTION ERA: FORENSIC PATHOLOGIST AND ANTHROPOLOGIST PERSPECTIVE

ERA REVOLUSI DIGITAL: PERSPEKTIF BIDANG PATOLOGI FORENSIK DAN ANTROPOLOGI

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ABSTRACT

The field of forensic anthropology relies heavily on imaging technologies for detailed documentation of scenes and skeletal remains. Digital photography has greatly enhanced this process, capturing intricate details. While traditional radiographs have been standard, newer methods like computed tomography (CT) and 3D surface scans are now integrated for more comprehensive analyses. These technologies allow the recording of remains with soft tissue intact, aiding in cases where injuries are suspected. CT scans, in particular, help visualize fractures in their original position without causing damage. Forensic anthropologists are innovating techniques to predict biological attributes from 3D virtual models, using factors like surface areas and volumes for quantitative assessments of skeletal diversity. CT and MRI scans are transforming traditional autopsies into "virtopsies," providing more precise and accurate results. Modern software enables detailed manipulation of images, including 3D facial reconstruction systems that use animation software to sculpt faces onto skulls virtually, considering crucial surface details. In the broader realm of forensics, there is a call for standardized, modular methods to handle data and forensic processes to keep up with technological advancements and ensure reliable results. This talk emphasizes the importance of supporting research to avoid lagging behind in forensic progress and maintaining trust in forensic results. Digital forensics, involving the analysis of digital evidence for legal purposes, is increasingly prevalent, especially in large-scale disasters, thanks to improved software and understanding of underlying issues.

Keywords: *Imaging, CT Scan, Virtopsy, Digital Forensic, Forensic Anthropology*

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Introduction

Imaging technologies play an integral role in forensic anthropology cases. Advances in digital photography allow the anthropologist to photo-document the scene and skeletal remains in exceptional detail. Traditionally, radiographs have been used to document remains, potential trauma, and any individualizing characteristics such as healing trauma and frontal sinus morphology. Given technological advances, some forensic anthropologists have begun to incorporate more advanced imaging methods in their case analyses and research, such as computed tomography and three-dimensional (3D) surface scans.

These advanced imaging technologies provide a means to document skeletal remains and trauma, and can be used to create 3D replicas of the elements for archival and illustrative purposes. Researchers have begun to develop novel methods for estimating biological parameters from 3D virtual models, using new variables such as surface areas and volumes, and advanced statistical methods (e.g. geometric morphometric analyses) to quantitatively analyse skeletal variation for sex and ancestry estimation.

The use of these technologies in forensic anthropology remains somewhat limited, however, due to required costs, expertise, and the time involved in collecting and processing the data. Newly developed methods require further validation, and some areas of advanced imaging, such as photogrammetry, remain relatively unexplored in the field. Interdisciplinary collaborations between forensic anthropologists and other medicolegal professionals can help alleviate some of these resource constraints and facilitate advancements in forensic case analysis and research.

A well-equipped laboratory may have a microscope from which digital microscopic or macroscopic images can be captured. These images may be used to document sharp force trauma (e.g., cut marks and characteristics of those cut marks such as striations or saw marks), characteristics of compression and tension on fracture surfaces, periosteal reactions, or characteristics of taphonomic modifications (e.g., rodent and carnivore damage). Given that digital photographs are easy to take, can be reviewed immediately, and stored easily, it is not uncommon to take over 100 photographs of a single case.

All photographs, even those of poor quality or those taken erroneously, are saved in order to show the continuity in the sequence of photograph numbers and illustrate that no photographs had been deleted (either mistakenly or intentionally). Of course, all photographs must have a backup file and be stored in a secure location.

Literature Review

In forensic anthropology, CT scans can be used in variety of different ways. When performing casework, CT scanning facilitates the documentation of human remains when the soft tissue is still present and the skeletal elements remain in articulation, as opposed to post-processing, which entails disarticulation of the skeleton and removal of all soft tissue. The ability to visualize the remains non-destructively is especially important in cases where trauma is suspected, and can be especially helpful in recognizing and analysing fractures in situ.

The sequence of radiographs is important in illustrating that the trauma, such as periosteal reactions and metaphyseal fractures, was visible prior to any processing, especially given the fragility of infant and child remains.

Certain skeletal features from the scans that can be useful for identification or assist in reconstructing the circumstances surrounding their death. Because the CT scans essentially represent a 3D virtual replication of the skeleton, individualizing skeletal traits and morphologies evident on antemortem CT scans can be compared to the bone specimens to assist with positive identification.

Three-dimensional models of skeletal material can also be produced using surface scanners. There are a variety of 3D scanners currently on the market. These surface scanners use either lasers or structured light patterns to capture and reconstruct the 3D surface of an object. Unlike with CT scans, where X-rays are involved, the 3D surface scanners can only capture the external surfaces, and those surfaces must be in the line of sight of the scanner.

Automated turntables, which rotate a specified number of degrees between scans, simplify this process, and are commonly included with stationary 3D surface scanners. Most 3D surface scanners will also take photographs of the object, which are then overlaid on top of the 3D model, replicating the original coloration of the object (referred to as “texture”).

Computed tomography scanners and high-end laser scanners will likely be outside the forensic anthropologist’s budget. Some forensic anthropology labs may not even have access to digital X-ray systems. Even affordable imaging options, such as the NextEngine scanner, may require additional software to perform certain analyses. Programs such as AMIRA, GeoMagic, and Polyworks which are commonly used to view, collect, and analyze 3D data, cost thousands of dollars, with annual maintenance fees.

As there are continued advances in 3D technologies, we should expect to see the continued development of novel, more quantitative methods, including movements towards automating data collection, processing, and analysing procedures. The real key to promote the continued implementation and improvement of advanced imaging techniques is to increase collaboration between forensic anthropologists, law enforcement, and forensic pathologists and other clinicians.

FORDISC is a computer program that analyzes measurements from unknown skeletal remains and classifies them into known sex and ancestry samples from the FDB (Forensic Data Bank) using multivariate statistical techniques (Jantz and Ousley, 1993, 2005; Ousley and Jantz, 1996). FORDISC is currently used by nearly all practicing American forensic anthropologists, and is a logical extension of the need to develop new forensic statistical techniques in light of morphological changes in American groups in the last 150 years.

Data from the FDB (Forensic Data Bank) were initially used to test forensic methods developed from the Terry Collection (Smithsonian Institute, Washington, D.C.) and Hamann-Todd collection (Cleveland Museum of Natural History, Cleveland, Ohio), including the pioneering discriminant functions (Ayers et al., 1990). These skeletal collections (composed largely of unclaimed bodies from the early twentieth century), have been shown to be inadequate as a basis for analyzing modern forensic cases due to secular changes and other factors.

The BSC (William M. Bass Skeletal Collection) and the FDB offer the novelty of being representative of the populations confronted by forensic anthropologists at two levels. First, they are drawn from contemporary populations, reducing the bias derived from secular changes. Second, the FDB is largely composed of and updated from actual forensic cases, in this way representing not only the contemporary American population, but also in a sense, the exact subset of that population actually studied by forensic anthropologists in their day-to-day work.

Extensive information in the FDB includes age, sex, ancestry, stature, weight, place of birth, medical history, occupation, and other demographic information. The skeletal information in the FDB includes cranial and postcranial metrics, suture closure information, various aging criteria scores, nonmetric cranial information, perimortem trauma, congenital traits, and dental observations.

In fact, discriminant function analysis using postcranial elements (Iscan and Cotton, 1990), which were based on the Hamann-Todd collection, have been shown to be inaccurate when applied to modern groups, especially ‘‘White’’ males, due to secular increases in their lower limbs (Ousley and Jantz, 1993). As a result, new statistical methods have been developed based on more-recent data from the FDB, which also includes more middleclass individuals (Jantz and Moore-Jansen, 1988; Ousley and Jantz, 1992, 1993; Jantz and Ousley, 2000).

Today’s Golden Age of computer forensics is quickly coming to an end. Without a clear strategy for enabling research efforts that build upon one another, forensic research will fall behind the market, tools will become increasingly obsolete, and law enforcement, military and other users of computer forensics products will be unable to rely on the results of forensic analysis. This presentation summarizes current forensic research directions and argues that to move forward the community needs to adopt standardized, modular approaches for data representation and forensic processing.

An autopsy or PM examination is a surgical procedure that consists of a thorough examination of a corpse to determine the cause and manner of death and evaluation of any injury that maybe present. The progress in imagistic modalities has changed the face of conventional autopsies into a scalpel free autopsy, virtual autopsy or “virtopsy.” Virtopsy is a word combining 'virtual' and 'autopsy' and employs imaging methods that are also used in clinical medicine such as computed tomography (CT), magnetic resonance imaging (MRI), etc., for the purpose of autopsy and to find the cause of the death.

Advanced modalities such as CT and/or magnetic resonance imaging (MRI) scan the dead bodies and provide a more sensitive, specific, and accurate results than that of the conventional autopsy. The body is subjected to CT and MRI (magnetic resonance scan) and data is finally fed to the computer where displayed images could be manipulated, rotated at various angles; and density differences.

Facial reconstruction is a forensic tool that involves recognization of a skull accidentally found in forest, mass disasters, etc., for the positive identification of an individual. It is an alternative process where no evidence is available, and the face of the unknown body is severely mutilated by animals, physical attacks, etc., to such an extent that even digital photography could not establish the identity.

The manual 3D facial reconstruction is done using clay, plastic, or wax directly on to the victim’s skull, tissue depth markers that represents oft-tissue depths are inserted on to the small holes on the skull cast at specific points, and finally reconstruction is done. Tissue depth method is done by the use of needles, X rays, or ultrasound, and by shaping muscles, glands, and cartilage onto the skull layer-by-layer. It is the most accepted manual method and takes both soft-tissue thickness and adjacent facial muscles into consideration.

Software advancement has led to the development of computerized 3D-facial reconstruction systems to recreate characteristic facial morphology dependent on the skeletal features. The computerized systems employ 3D-animated software whereas few models face onto the skull by virtual sculpture systems, providing important surface details for facial reconstruction such as muscle attachment strength, position of eye, and position of malar tubercle.

Computerized systems are more rapid, easier, efficient, and cost-effective than manual reconstruction methods. It decreases practitioner’s subjectivity and skill, recreates multiple images of the same face efficiently, and provides realistic facial appearance simulating photographs.

Digital forensics could be defined as “application of computer science and investigative procedures for a legal purpose involving the analysis of digital evidence.” Due to software advancements and uncovering of root cause, the application of digital forensic investigations is increasingly becoming more common, especially in mass disasters such as terrorism, aviation, tsunamis, and earthquake.

Case Discussion

A. A Comparative Microscopic Study of Human and Non-Human Long Bone Histology

Identification of human or nonhuman skeletal remains is important in assisting the police and law enforcement officers for the investigation of forensic cases. Identification of bone can be difficult, especially in fragmented remains. It has been reported that 25 to 30% of medicolegal cases, which involved nonhuman skeletal remains have been mistaken for human. In such cases, histomorphometric method was used to identify human and nonhuman skeletal remains. However, literature has shown that histomorphometric data for human and nonhuman bone were insufficient.

Additionally, age estimation in bone may help in the identification of human individual, which can be done by using a histomorphometric method. Age estimation is based on bone remodeling process, where microstructural parameters have strong correlations with age. Literature showed that age estimation has been done on the American and European populations. However, little work has been done in the Asian population.

The aims of this project were thus, to identify human and nonhuman bone, and to estimate age in human bones by using histomorphometric analysis. In this project, 64 human bones and 65 animal bones were collected from the mortuary of the Universiti Kebangsaan Malaysia Medical Centre and the Zoos in Malaysia, respectively (Nor, 2010). A standard bone preparation was used to prepare human and nonhuman bone thin sections for histomorphometric assessment.

Assessments were made on the microstructural parameters such as cortical thickness, medullary cavity diameter, osteon count, osteon diameter, osteon area, osteon perimeter, Haversian canal diameter, Haversian canal area, Haversian canal perimeter, and Haversian lamella count per osteon by using image analysis, and viewed under a transmitted light microscope. The microstructural measurements showed significant differences between human and nonhuman samples.

The discriminant functions showed correct classification rates for 81.4% of cases, and the accuracy of identification was 96.9% for human and 66.2% for animal. Human age estimation showed a standard error of estimate of 10.41 years, comparable with those in the literature. This study project offers distinct advantages over currently available histomorphometric methods for human and nonhuman identification (Fig. 1, Fig. 2) and human age estimation. This will have significant implications in the assessment of fragmentary skeletal and forensic population samples for identification purposes.

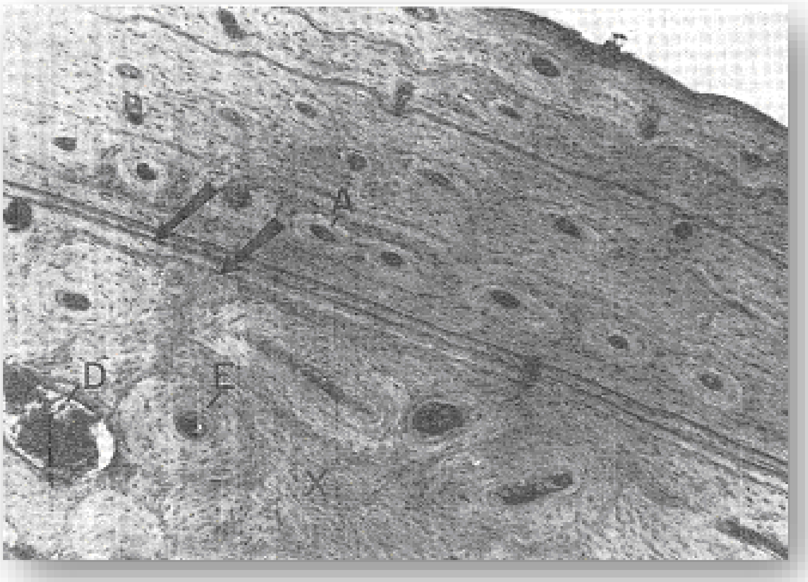

Fig. 1 Femoral section of a rhesus monkey (100x magnifications) in a decalcified and stained bone preparation. The figure shows primary osteon (marked ‘A’), Haversian system (marked ‘E’) and resorption space (marked ‘D’).

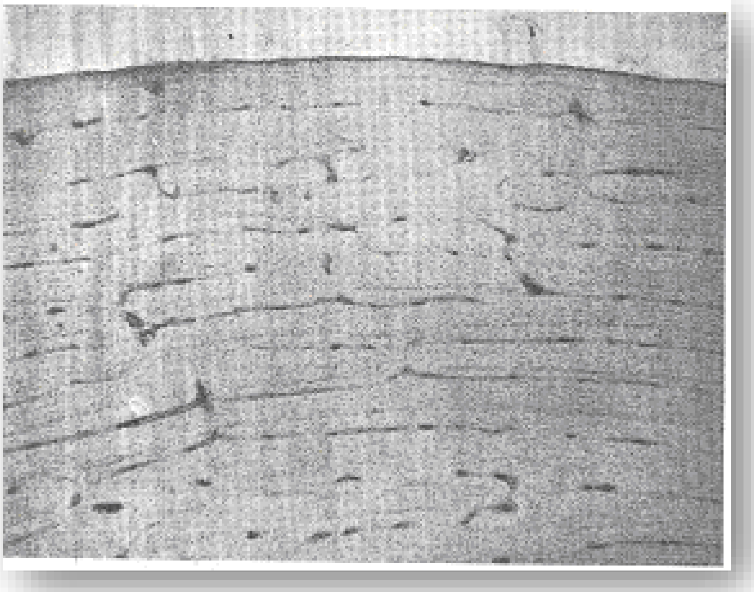

Fig. 2 Plexiform bone pattern. The figure shows plexiform bone pattern in a femur mid-diaphyseal section of a dog (60x magnifications) in a decalcified and stained bone preparation.

Compilation of data on gender from a given sample may be used to produce a proposed automated gender identification system which can identify gender form human bone sample using bone histomorphology. The proposed system is divided into two parts, whereby the bone samples are selected for analysis of differences in microstructural parameters in males and females. Next, these observations are used to design computer aided automation system.

An automatic method of human age at death estimation using image processing and pattern recognition techniques. Bone samples are taken from long bones are analysed for ten different bone microstructures to create regression equation for age estimation. Selected microstructures are extracted using image pre-processing and texture extraction algorithms.

In the modern era, digital radiographs have considerably reduced the errors in interpretation or incorrect identification as with conventional radiographs. Digital information has also made possible the communication with the pathologist in cases, where the records are from overseas.

Radiographs are one of the main sources of antemortem evidence, these are important in comparing consolidated antemortem with PM information, for example, the comparison of PM radiographs of skeletal remains to antemortem radiographs of a missing person. Digital radiographs have revolutionized the forensic investigations which are used by the radiologists in large hospital settings for quick and accurate identification of mass causality victims along with internet-based computer system.

Digital radiography is highly advantageous as it allows immediate display of images on the computer screen that can be enhanced for optimal viewing and side-to-side comparison of antemortem and PM radiographs is possible with improved image quality, thus accelerating the identification process. They also play a role in on-site identification cases in which bodies are burned out or severely mutilated. Satellite communication allows digital transmission of images to the command center without loss of image details.

The practicality and flexibility of digital radiography and digital photography greatly facilitate the forensic comparison process. In mass disaster identification situations, digital radiography becomes much more useful than conventional radiography.” Furthermore, PM scanning time is reduced by the advanced imaging modalities such as multislice computed tomography (CT) and three-dimensional (3D) CT.

B. Digital Forensic Osteology—Possibilities in Cooperation With The Virtopsy Project

This study was carried out to check whether classic osteometric parameters can be determined from the 3D reconstructions of MSCT (multislice computed tomography) scans in the context of the Virtopsy project (Verhoff et al. 2008). Four isolated and macerated skulls were examined by 6 six examiners. First the skulls were conventionally (manually) measured using 32 internationally accepted linear measurements.

Then the skulls were scanned by the use of MSCT, and the 33 measurements were virtually determined on the digital 3D reconstructions of the skulls. The results of the traditional and the digital measurements were compared for each examiner to figure out variations. Furthermore, several parameters were measured on the cranium and postcranium during an autopsy and compared to the values that had been measured on a 3D reconstruction from a postmortem MSCT scan.

The results indicate that equivalent osteometric values can be obtained from digital 3D reconstructions from MSCT scans and from conventional manual examinations. The measurements taken from a corpse during an autopsy could also be validated with the methods used for the digital 3D reconstructions. Future aims are the assessment and biostatistical evaluation in respect to sex, age and stature of all data sets stored in the Virtopsy project so far, as well as of future data sets. Furthermore, a definition of new parameters, only measurable with the aid of MSCT data would be conceivable.

The pilot study showed that digital skeletons based on the 3D reconstruction of postmortem MSCT scans acquired in the Virtopsy1 project are suitable for the examination of classic osteometric parameters. This opens up new possibilities for the collection of modern population relevant osteometric data from individuals with known and wide spread particulars of identity.

C. Anthropological and Radiographic Comparison of Vertebrae for Identification of Decomposed Human Remains

This case study demonstrates the importance of involving an anthropologist in forensic situations with decomposed remains (Mundorff et al. 2006). Anthropological consultation was used in conjunction with the comparison of antemortem and postmortem radiographs to establish positive identification of unknown, decomposed remains. The remains had no traditional identifying features such as fingerprints or dental.

Through anthropological analysis, it was determined the decedent was male, between 20 and 23 years at time of death and 5 feet 2 in tall. This information allowed for a presumptive identification and a request for antemortem radiographs. The missing person was identified comparing the spinous processes of the cervical and thoracic vertebrae between ante- and postmortem radiographs.

Conclusion

Optimal research conditions for anthropologists involve a comprehensive collection of well-documented skeletons, ensuring a balanced representation of age and sex, along with associated data on stature, weight, and medical history. The regular use of post-mortem MDCT has significantly contributed to research in forensic anthropology over the past decade due to its accessibility, permanence, and non-invasiveness.

However, the full potential of MDCT remains untapped until there is a routine practice of publishing scan parameters, technical details, and specifics of post-processing. The choice of image processing software is crucial, emphasizing the need for comparative studies on post-processing parameters, including segmentation algorithms, to standardize data and enhance generalizability.

Moreover, enhancing knowledge transfer among disciplines such as palaeoanthropology, palaeontology, archaeology, and related fields is crucial. Leveraging nearly 30 years of experience in bone imaging, research in forensic anthropology could benefit from existing methods to create more effective and advanced solutions for the future.

In the realm of virtual imaging, routine collection of biological data through X-ray, CT, or laser scanning of skeletal structures creates a lasting database serving as a substitute for traditional collections. This not only aids in archiving and safeguarding existing specimens but also provides virtual images for remote study and teaching purposes. Despite the potential of virtual imaging methods like MDCT in forensic anthropology, their assessment is often overlooked in traditional education and professional training. Bridging this knowledge gap may lead to the development of a specialization in virtual forensic anthropology to address this deficiency.

In conclusion, these research projects highlight the critical aspects of optimal research conditions, the potential of MDCT in forensic anthropology, the necessity for standardized practices, interdisciplinary knowledge transfer, and the role of virtual imaging in education and research.

Conflict of Interest

The author declares no conflict of interest in publishing this article.

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