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TECHNICAL NOTE

Myra L. Sitchon,[1] *M.A. and Robert D. Hoppa,*[2] *Ph.D.*

Assessing Age-Related Morphology of the Pubic Symphysis from Digital Images Versus Direct Observation*

ABSTRACT: The increasingly global role of a forensic anthropologist necessitates a proper means for archiving evidence for re-examination. Large quantities of evidence can be stored and be made readily accessible through digital imaging. This study focuses on age assessment from digital photographs for personal identity reconstructions. A comparison of 52 Suchey-Brooks scores assigned to digital images and actual bone revealed that age assessment from digital images can be completed with accuracy. Coefficients of concordance imply that there significant agreement between osteological assessment of aging criteria from digital images and direct observation—greater than random change alone ($p < 0.05$). However, assessments from images should be approached with caution since there are inherent limitations of the naked eye in identifying morphological changes in certain skeletal features, especially where older adults are concerned. Although there is no replacement for a hands-on physical assessment, a digital archive may facilitate the global needs of the forensic anthropologist.

KEYWORDS: forensic science, forensic anthropology, age assessment, image processing, physical anthropology

More and more, forensic anthropology is playing a major role in global issues related to human rights violations, war crimes, and terrorism, in addition to the individual medico-legal cases (1–10). In these contexts, forensic anthropologists are required to assist in the personal reconstruction of human skeletal remains, the methods of which are well reviewed by a number of recent papers (11–14). With the increasing global role of forensic anthropology, particularly with respect to large-scale investigations (mass graves, war crimes, natural disasters etc), there is an increasing need to properly archive evidence after the human remains have been examined and reburied. Digital imaging provides a method for which large quantities of evidence can be archived, not just for illustration, but potentially for other experts to re-examine, confirm or question interpretations from the evidence after the physical remains have been reburied. Further, it may allow online consultation and collaboration between specialists across the globe without always requiring face-to-face meetings. There is also demonstrated use for digital image analysis software to aid in the personal identification of human skeletal remains (15–17).

[1] Department of Anthropology, University of Manitoba, Winnipeg, Manitoba, Canada R3T 5V5.

[2] Associate Professor and Canada Research Chair in Skeletal Biology, Department of Anthropology, University of Manitoba, Winnipeg, Manitoba, Canada R3T 5V5.

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The morphological assessment of personal identification such as age at death, normally requires the investigator to be in direct contact with a skeletal sample. The development and increasing global access of technology such as the Internet, email, and digital imaging have introduced the concept of assessing aspects of personal reconstruction from remote imagery (16,18). Hutchinson and Russell (18) recently evaluated this idea through a comparison of auricular surface aging scores obtained by direct observation with scores derived from digital, printed, slide, and scanned reproductions.

Hutchinson and Russell (18) assumed that age estimates obtained through direct observation of the sample were the most accurate estimations of chronological age. To test the reliability of age estimates acquired from digital and slide representations, they compared the estimates of age at death from the images with those rendered from the actual bones. None of the age estimates determined from the digital and visual representations were results compared to known ages of the specimens.

The present study extends Hutchinson and Russell's (18) approach by examining the issue of assessing osteological age stages from digital images of the pubic symphysis. This paper does not examine the issue of age estimation, since such determinations are directly derived from the stage-indicator data itself. Rather, this paper explores the potential impact of using digital images to aid forensic and other anthropological investigations of human skeletal remains.

Methods

A series of 52 pubic symphyses (38 male and 14 female) from the Grant collection at the University of Toronto (16,19) were scored against the written descriptions and cast replicas of the different phases outlined by the Suchey-Brooks method (20–22). The

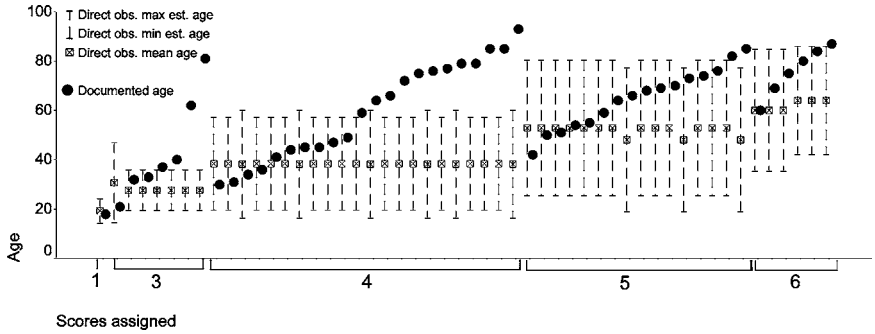

FIG. 1—*Distributions of scores (n = 52) assigned by the first author through direct observation of actual bone. Age ranges represented two standard deviations for the stage mean, and are sex specific.*

distribution of these scores against documented age is outlined in Fig. 1. After all scoring was completed, digital images of the pubic symphyseal surface were captured using an Olympus C3030 Zoom digital camera. All images were saved in an uncompressed TIFF format at 2048 × 1536 pixels. Pictures were taken at F11.0 under controlled lighting conditions with the assistance of tungsten lighting, gel light diffusers, and black velvet skirting. The lighting source for this study consisted of a Calumet Travellite 250 and was used in conjunction with a light diffuser to eliminate unwanted shadows. Controlled background conditions consisted of black velvet skirting placed around the pubic symphysis to absorb reflective light and eliminate unwanted shadows (16).

Three months following the initial examination and scoring of the sample, the Suchey-Brooks phase was assessed by each author individually from the digital images. All of the images were viewed on a 17-in. monitor in a colour format and compared with the Suchey-Brooks casts and phase descriptions. A second trial was completed by the first author after an additional three months period had lapsed. The Suchey-Brooks scores from both trials were then evaluated against those scores obtained from direct observation of the pubic bones.

Results

In trial one, 28 scores (52%) matched the scores obtained through direct observation of the sample (Fig. 2). Fourteen (27%) individuals were assigned to stages younger than those derived from direct observation while there were ten (19%) adults assigned to stages older than those obtained through direct observation. One (2%) adult was assigned a score four phases older than the score assigned during direct contact with the actual pubic bone.

In trial two, there were 31 (60%) scores assigned to the digital images that matched those scores assigned to the actual pubic bones (Fig. 2). Twelve adults (23%) were assigned to stages younger than the original scores assigned through direct observation of the target sample. Nine (17%) individuals were allocated to stages older than those assigned during direct contact with the sample.

The scores were examined further with the application of the Kendall's W coefficient of concordance test to measure the agreement between the scores obtained from both trials and those derived from direct observation of the sample. The high Kendall's W values indicated in Fig. 3 for both trials denote that there is a statistically significant concordance between scoring from digital images of the pubic symphysis and from actual bone ($p < 0.05$). For the first author, approximately 75% concordance is observed between pubic symphyseal scores assigned by gross observation and those assigned from the digital images. However, the concordance falls to 66% for the second author, which is no longer statistically significant ($K = .661$, $df = 51$, $p = 0.062$). It is suggested that this is a result of inter-observer error since the comparison is between traditional observations scored by the first author, and scores on digital images by the second author. A direct comparison of a smaller subset of the sample ($n = 31$) supports this hypothesis, as there is not always agreement between the two authors in their scoring of the sample from direct observation. For the 31 specimens observed independently by the two authors, approximately 38.7%

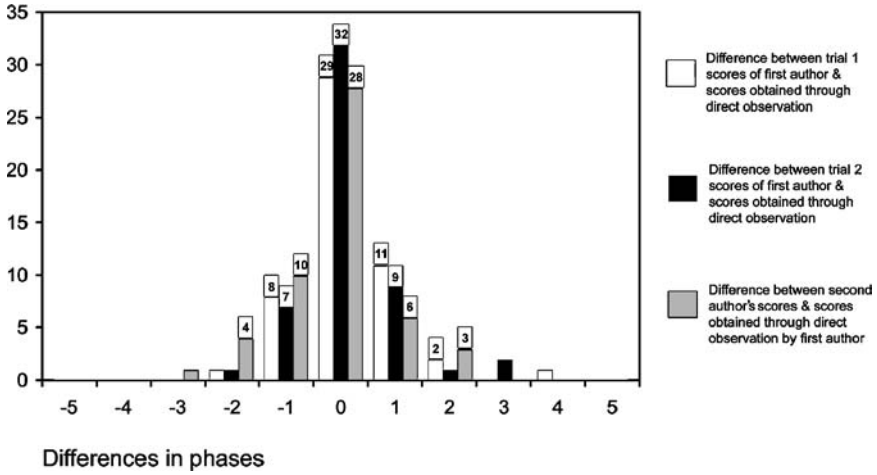

FIG. 2—*Differences between scores assigned to digital images of the pubic symphysis and to actual pubic bones in all trials.*

First author's trial 1 scores & direct observation scores

N	2
Kendall's Coefficient of Concordance	0.765
Chi-Square	78.053
df	51
Asymp. Sig.	0.009

First author's trial 2 scores & direct observation scores

N	2
Kendall's Coefficient of Concordance	0.750
Chi-Square	76.510
df	51
Asymp. Sig.	0.012

Second author's scores & direct observation scores

N	2
Kendall's Coefficient of Concordance	0.660
Chi-Square	67.331
df	51
Asymp. Sig.	0.061

FIG. 3—*Kendall's W coefficient of concordance for agreement in stage assessment between direct observation and those derived from digital images.*

were one stage different (Fig. 4) resulting in no significant concordance between observers ($K = .642$, $df = 30$, $p = .137$). The issue of inter-observer error for assessing age from the Suchey-Brooks technique has been documented (23). A variety of conditions may contribute to this including user experience, lighting conditions and fatigue (24). While intra-observer discrepancies in excess of 50% disagreement (25) have been documented, intra-observer error in the assignment of stages from the digital images in this study (Fig. 5) demonstrated significant concordance between trials, suggesting that intra-observer error is not substantive ($K = .689$, $df = 51$, $p = .038$).

The recent study by Hutchinson and Russell (17) explored the reliability of estimating age at death from remote images of the

First author's trial 1 scores & trial 2 scores

N	2
Kendall's Coefficient of Concordance	0.689
Chi-Square	70.294
df	51
Asymp. Sig.	0.038

FIG. 5—*Kendall's W coefficient of concordance for agreement in stage assessment between both trials completed by first author.*

auricular surface. Their study assigned age at death estimates to images of the auricular surface in a digital and slide format. They concluded that images from the auricular surface do not provide significant information specific to age at death compared to actual bone.

Similar procedures with slight modifications were adopted in this study and resulted in interesting observations related to age assessment from digital images of the pubic symphysis. The magnification or "zoom" function offered by various computer software applications facilitated the process of determining age at death from the images. For example, features that were unrecognizable to the naked eye could be magnified for further inspection. A main concern of magnification with imaging programs is that the photograph may appear pixelated or distorted. Hutchinson and Russell (18) address this concern by suggesting that the slide projector images offer better resolution for magnification purposes than digital images. However, they overlook that the resolution of digital images can be controlled by the digital camera or scanner. Scanning or capturing digital photographs at a high resolution (i.e., 1600×1800 pixels) will eliminate or reduce the amount of distortion exhibited in the image during magnification. Distortions may also be eliminated by saving images as a Tagged Image File Format (TIFF). This format does not affect the quality of the images since there are no compression schemes to affect pixel information, unlike images saved in a Joint Photographic Experts Group (JPEG) format that uses compression schemes to reduce the information contained within an image to save disk space. A JPEG format recompresses the pixel information every time it is saved on to disk, resulting in a loss of image quality. Continual opening and saving of JPEG images destroys pixels and affects the quality of an image.

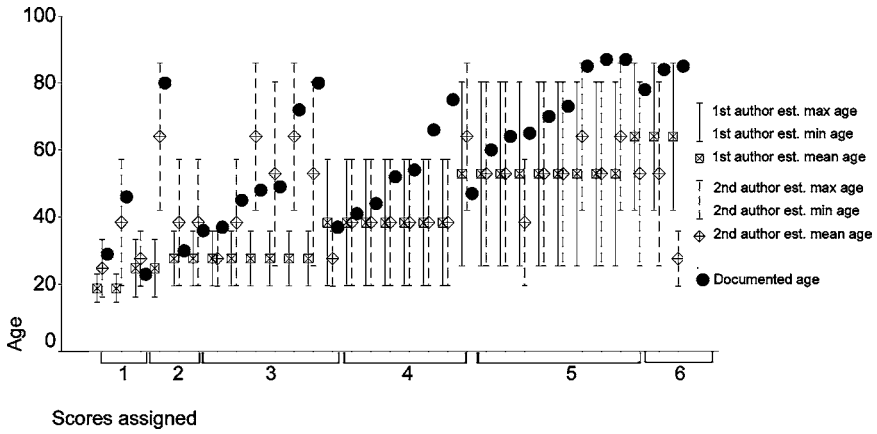

FIG. 4—*Distributions of scores ($n = 31$) assigned by the first author and second author through direct observation of actual bone. Age ranges represented two standard deviations for the stage mean, and are sex specific.*

Discussion

The results of this research imply that it is possible to assess age from digital images that are accurate and correlate strongly with those obtained through direct or traditional observation. A Kendall's W coefficient of concordance value of 0.765 for trial one and traditional scores and a value of 0.750 for trial two and traditional scores imply that there significant agreement between osteological assessment of aging criteria from digital images and direct observation—greater than random change alone ($p < 0.05$).

However, given that only 28 (54%) scores in the first trial and 31 (60%) scores in the second trial matched the scores obtained from direct observation suggests that there is a certain degree of error in scores obtained from digital images of the pubic symphysis. Furthermore, the results imply that age assessment from the digital photographs is not foolproof and should be approached with caution.

It was expected that more scores from the digital images of the pubic symphyses would be equal to those obtained from direct observation of the study sample. This outcome can be attributed to several causes, the first being an increase in observer experience scoring stages for the pubic symphyses. This is suggested by the slight increase in success in trial two. Most of the erroneous age assessments, however, result from interpretive errors. It is often difficult for osteologists to decipher from actual bone if the age-related changes exhibited in the pubic symphysis are developmental or degenerative. In fact there are suggestions that the ventral rampart is an epiphysis, and therefore the pubic symphysis is only usable until development is complete in the 4th decade of life has also been proposed (26,27). These problems are compounded from two-dimensional images where identifying developmental or degenerative changes of bone from digital images can be an even more difficult task to complete. For instance, many of the pubic symphyses that were assigned a score of 6 during direct observation were assigned lower scores in their digital image format.

However, a majority of the interpretive errors were related to the development and degeneration of the ventral rampart and the dorsal margin. Most of the individuals scored from the digital images were assigned to a stage of either 3, 4, 5, or 6. These stages describe changes that are associated with build up or breakdown of bone in these regions. A close examination of the digital images of pubic bones assigned erroneous scores revealed that it was difficult to determine if the lipping of the dorsal area was slight, moderate, or non-existent from the photograph. Furthermore, it was more difficult to ascertain if the there were fusing ossific nodules developing on the ventral rampart or if this region was in the process of irregular erosion. These interpretive errors imply that the naked eye possesses inherent difficulties in identifying three-dimensional features from two-dimensional images.

Summary

This study focused on the use of remote imagery to aid in the assessment of personal identification of human skeletal remains. An evaluation of 52 Suchey-Brooks scores assigned to remote images and actual bone suggest that age assessments from images can be completed with accuracy. However, errors exist resulting from an inability to determine whether bone morphology represented in an image is characteristic of a stage of development or degeneration. These interpretive errors suggest that there may be difficulties in identifying three-dimensional features from two-dimensional images with the naked eye, especially where older adults are concerned. Nevertheless, these errors are minimal such that the use of digital images in forensic anthropology should not be discounted. Coefficients of concordance imply that there is significant agreement between osteological assessment of aging criteria from digital images and direct observation—greater than random chance alone ($p < 0.05$). If morphological assessments of personal reconstruction can be reliably made from 2D digital archives of the physical evidence, the ability for forensic anthropologists to re-examine evidence is greatly enhanced. This paper has shown, for one aspect of personal reconstruction, that such assessments may be possible. While there is no replacement for a hands-on physical assessment, the ability to refer to a 2D digital archive after the fact may greatly facilitate the medico-legal process.

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Additional information and reprint requests:
Myra L. Sitchon, M.A.
Department of Anthropology
University of Manitoba
435 Fletcher Argue
Winnipeg, Manitoba R3T 5V5
Fax: (204) 474-7600
E-mail: umsitcho@cc.umanitoba.ca