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TECHNICAL NOTE

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Application of the Suchey-Brooks Method to Three-dimensional Imaging of the Pubic Symphysis

ABSTRACT: Age determination is a major field of interest in forensic anthropology. Among the different methods based on macroscopic skeletal study, the Suchey-Brooks method, which analyzes the pubic symphysis, is one of the most reliable. We applied the Suchey-Brooks method to three-dimensional computed tomographic reconstructions of the pubic symphysis. We demonstrated excellent agreement between the results of analysis of bone samples and those of the three-dimensional images, in particular regarding ridges of the articular surface and delimitation of the extremities. The accuracy of age estimation did not significantly differ (Wilcoxon test) between the Suchey-Brooks method applied to bones and the same method applied to CT images. Using high-quality images, this approach seems as reliable as the standard Suchey-Brooks method and offers several advantages: no bone preparation, no damage to bone material, and the possibility of application to living individuals.

KEYWORDS: forensic science, forensic anthropology, bone age determination, pubic symphysis, computed tomography, three-dimensional reconstruction

Age determination, in paleoanthropology or forensic anthropology, can be done using a number of indicators (1). Most methods are based on macroscopic study of bones. The interest of the pubic symphysis lies in its late maturation. Among the many methods for determining age from the pubic symphysis (2–5), that of Suchey-Brooks is the most reliable and the one the least open to criticism from the methodological point of view (5–7). However, these methods require long and tedious preparation of the bone specimens and it is often difficult to avoid anatomic damage. Moreover, they cannot be applied to living individuals, as is necessary when age determination is requested by legal authorities for foreigners whose identity is uncertain.

In recent years, a new approach has been developed: virtual anthropology (8), based on computed tomography (CT) study (8,9). Over the last ten years, advances in CT scan, and especially the advent of helical acquisition (11–16), have resulted in significant improvement of image quality. Three-dimensional (3D) reconstructions (17) now faithfully reproduce the anatomic structure. The CT approach offers many advantages: elimination of lengthy bone preparation, no deterioration of data with time, possible application in living individuals and ease of data sharing. The fact that no preparation is required is also an advantage when the bones are fragile (carbonization, osteoporosis . . .).

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In this study, we applied the Suchey-Brooks method to three-dimensional CT reconstructions of the pubic symphysis and compared the age estimations with those obtained by direct examination of bone. We paid special attention to the interest of three-dimensional reconstruction for observation of the articular surface, the appearance of the symphyseal rim and the presence of osteophytes.

Material and Methods

Bone Collection

The bone material consisted of seven halves of dried pubic bones (from the collection of the Department of Forensic Medicine, Toulouse) and 14 symphyses with soft tissue. The latter were obtained from autopsies performed for identification purposes in the Department of Forensic Medicine, Toulouse, between November 2001 and April 2002. Both ischiopubic and iliopubic rami were resected, the adjacent joint capsule, ligaments and muscles were removed and the symphyses were then stored in a freezer.

The 21 specimens were all of known age and sex. They covered most age groups, but the 20 to 40-year-old range was the best represented; 67% were male and 33% female (Fig. 1). All were white except one black female. As this was a anatomical morphological comparison between two methods, each individual being their own control, the distribution by sex and the geographical origin of the sample did not affect concordance (18).

CT Scan Method

Helical CT scan was done using a Somatom Plus 4 (Siemens). Bone specimens were placed in an anatomic position and scanned

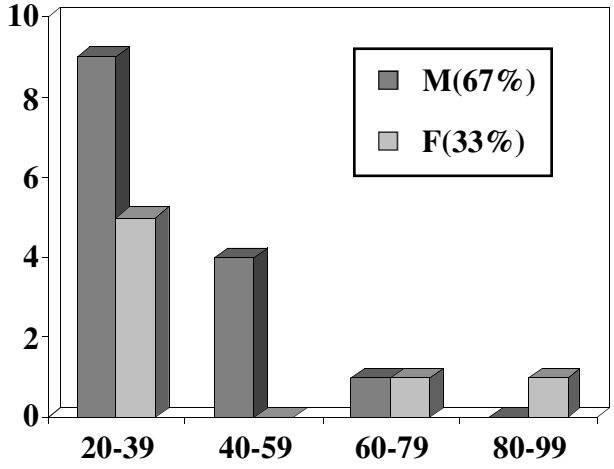

FIG. 1—*Age and sex of the 21 pubic symphysis specimens.*

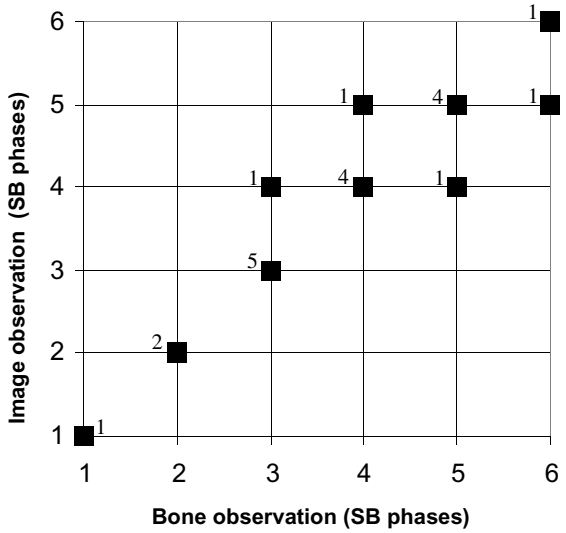

FIG. 2—*Inter-method error in age estimation.*

with their soft tissue, with the aim of applicability to a living individual. For the acquisition phase, we used a bone filter, 1-mm collimation and a pitch of 1.5. The field of view was 500 mm and the image matrix 512 × 512 pixels. Slices were then reconstructed using a 180° linear interpolation algorithm; the reconstruction interval was 0.8 mm and the increment 0.8 mm. Only the right side of each specimen was reconstructed.

Three-dimensional (3D) reconstructions were performed on an Advantage Windows 2:1 console (General Electric Medical Systems, Milwaukee, WI). Shaded surface display images were generated after selection of a threshold of 295 Hounsfield units for frozen symphyses, in order to exclude soft tissue. Four views were selected for examination: front, anteroposterior, ventral and dorsal.

Study Method

After all the specimens had been scanned, the frozen symphyses were placed in water and warmed to remove soft tissue. The Suchey-Brooks method was then applied to the CT images and to the bone specimens. Age was estimated by two observers, one experienced in the Suchey-Brooks method and the other not, who were aware of the sex but not the age of the specimens. The CT images were studied several weeks after the bones. The Suchey kit consisting of color photographs and casts (19,20) was used for analysis. Seven features were analyzed: ridges, delimitation of the two extremities, ventral rampart, symphyseal rim, face depression, ligamentous outgrowths and bone texture.

Statistical Analysis

Statistical analysis was carried out on the whole sample of 21 specimens. We did not separate males and females because of the small number. We calculated inter-method error between the phase assigned to the image and the phase assigned to bone, using the weighted kappa (WK) coefficient of agreement (21,22) calculated with SAS® version 8 software. We also evaluated the precision of the two methods of age estimation by calculating first the difference between real age and estimated age for each method, and then the standard deviations. We then applied a Wilcoxon matched-pairs signed-ranks test (23).

Results

Inter-Method Error

The age estimations made by the more experienced observer, using the two methods, were in agreement in 17 cases (81%), with a kappa value of 0.86. Those made by the second observer agreed in 15 cases (71%), with a kappa value of 0.82. Errors consisted of overestimation or underestimation of a single phase and concerned phases III/IV, IV/V and V/VI (Fig. 2).

In comparison, for the most experienced observer the two radiological observations agreed in 18 of 21 cases (86%), with a kappa value of 0.91. The errors concerned phases I/II, III/IV and IV/V. This intra-observer error was similar to that found in dried bone specimens, where phase determination agreed in 19 of 21 cases (kappa = 0.94).

Accuracy of the Two Methods of Age Estimation

The Wilcoxon test showed no significant difference of accuracy between the two methods ($z = 0.36$, $p = 0.71$).

Comparison of CT Images and Bones

The seven different features were compared by the experienced observer on bones and images and the following agreement was found:

- 100% for ridges and delimitation of extremities
- 95% for ligamentous outgrowths
- 90% for bone texture and face depression
- 86% for the rim
- 81% for the ventral rampart.

Figures 3*a* to 3*f* show bone specimens compared to the corresponding CT images for each Suchey phase.

Discussion

The weakness of our study lies in the small number of specimens. It was not possible to say if differences between kappa values were significant (24). Nevertheless, many points invite discussion.

FIG. 3*a*—*Phase I of Suchey-Brooks: 20 years male, 3/4 ventral view.*

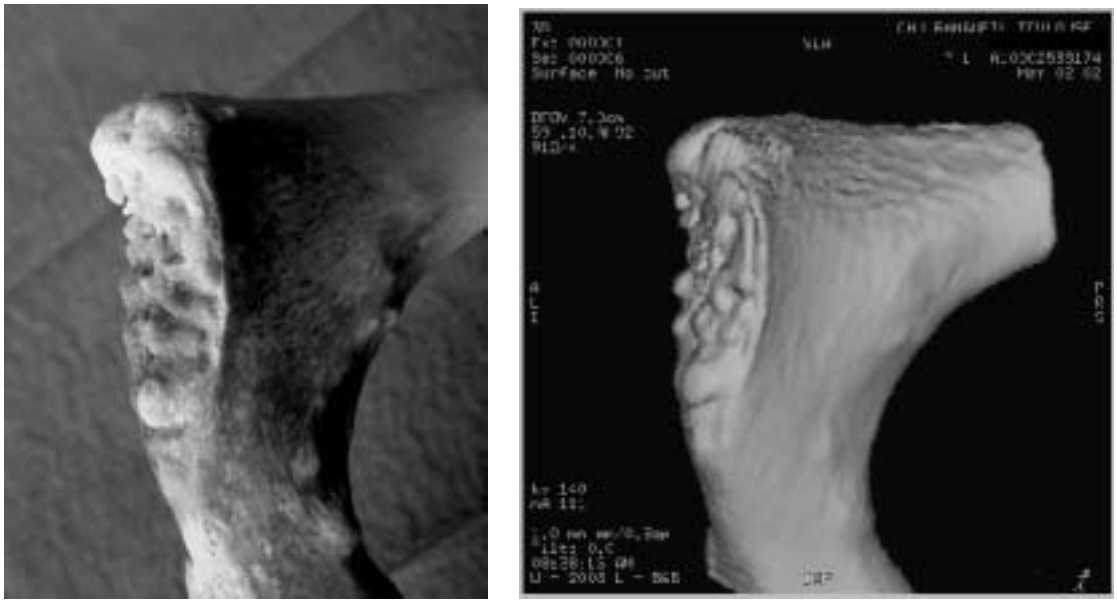

FIG. 3*b*—*Phase II of Suchey-Brooks: 21 years male, 3/4 dorsal view.*

First of all, for inter-method error, the kappa value for the more experienced observer (0.86) showed excellent agreement (25). Error was a little greater for the other observer (WK = 0.82), which appeared to indicate that the agreement between the two methods increased with observer experience. Inter-observer error was similar to inter-method error, and although the sample was small this suggests that both methods yielded a comparable level of information on the criteria used for age determination.

Comparison of bone specimens with 3D images showed that the latter provided a reliable representation of bone. Indeed, some features were particularly well visualized on images. We found that agreement between features described on bones and those described on images was perfect for ridges and delimitation of extremities and nearly perfect for ligamentous outgrowths. Porosity was underestimated on the CT images. We suspected that this could be due to the preparation process that could alter the bone, to the threshold (the higher the threshold, the more porous the bone appears), and possibly to the observer's lack of experience in reading images. The granular appearance of the face, which could be observed in bone specimens in phase V, was never seen on images, probably an effect of the threshold selected.

Depression of the face was overestimated on the CT images. This feature was dependent on the view, and thus on the images selected, and there was also some intra- and interobserver variability. Ideally, the observer would be able to analyze the reconstructed images directly on the console, because the virtual object can be rotated in space so that the image can be viewed from any perspective, exactly as when observing an actual bone. Dorsal lipping was plainly

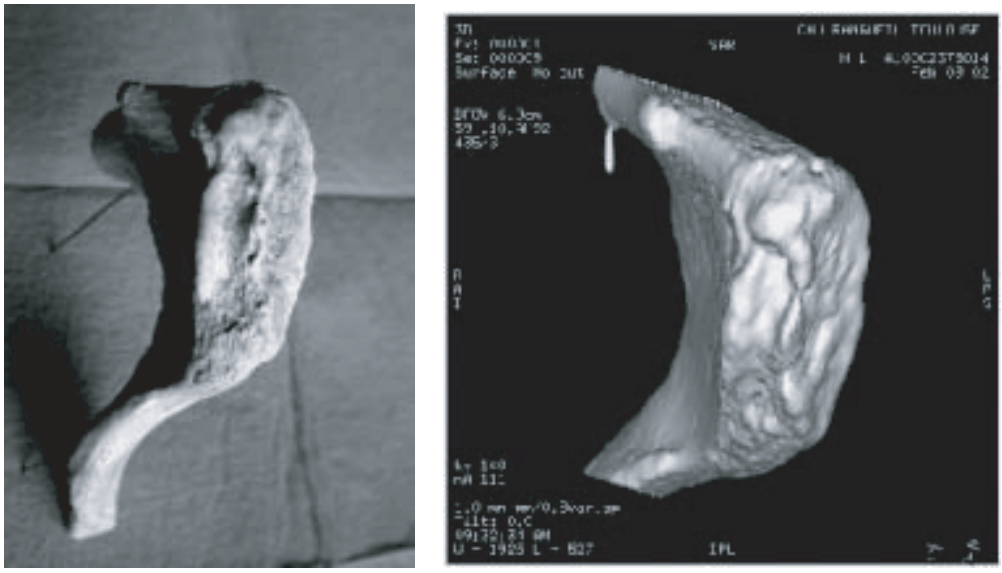

FIG. 3*c—Phase III of Suchey-Brooks: 31 years female, 3/4 ventral view.*

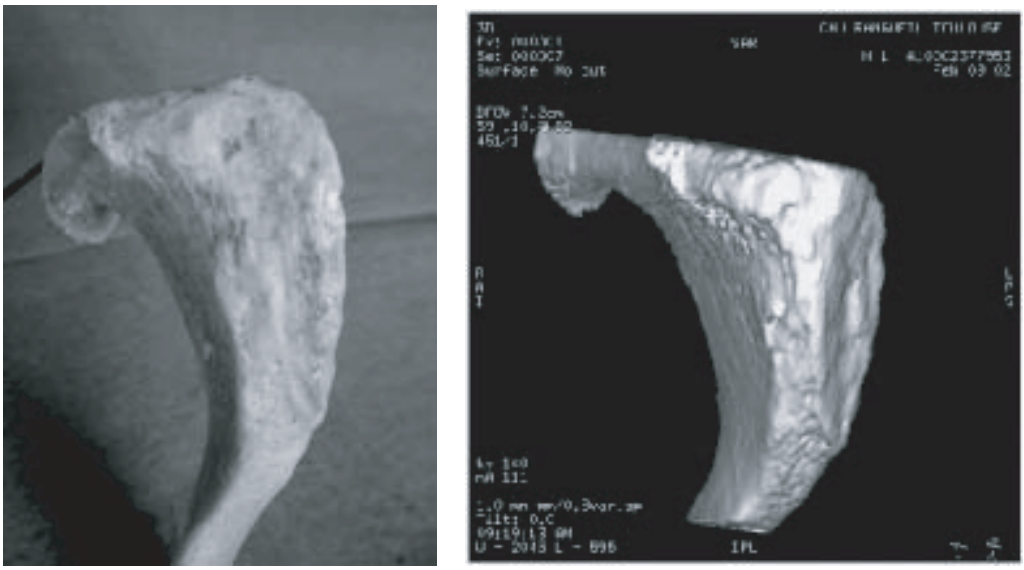

FIG. 3*d—Phase IV of Suchey-Brooks: 48 years male, 3/4 ventral view.*

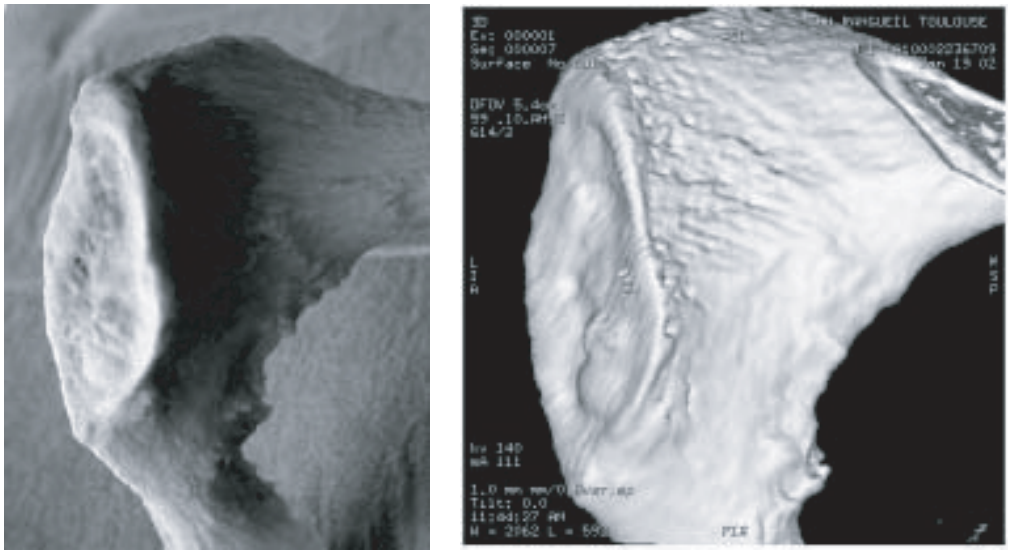

FIG. 3*e—Phase V of Suchey-Brooks: 51 years male, 3/4 dorsal view.*

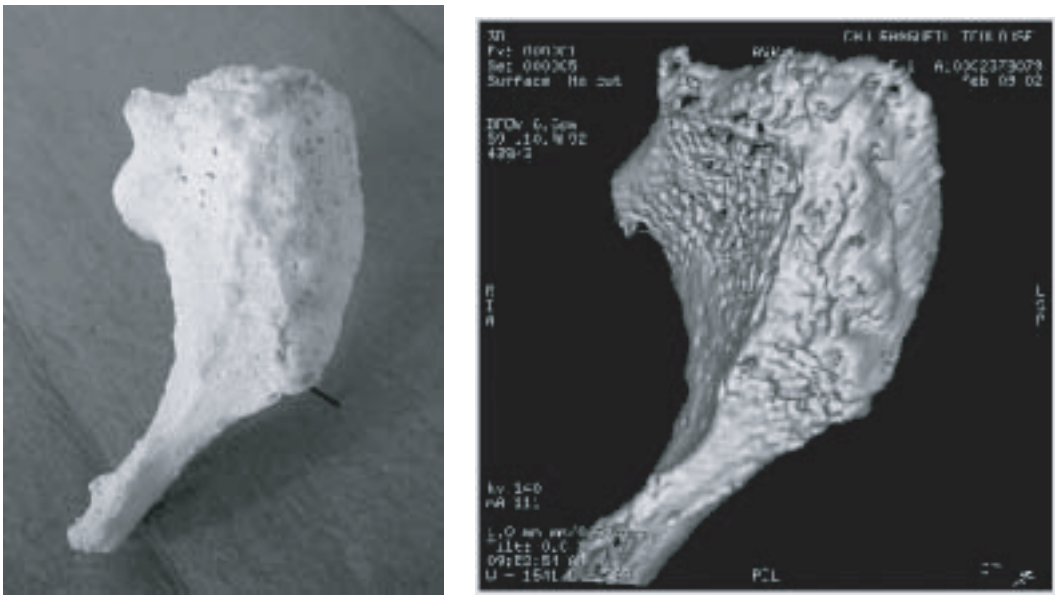

FIG. 3*f*—*Phase VI of Suchey-Brooks: 93 years female, 3/4 ventral view.*

visible on images, whereas the ventral rampart was more difficult to evaluate. Lastly, there was noteworthy variability in females: three of the four errors of the more experienced observer, but this was not surprising as it has been observed by many authors (7,26–29).

The accuracy of age estimation did not significantly differ (Wilcoxon test) between the Suchey-Brooks method applied to bones and the same method applied to CT images. Image analysis and bone analysis thus appeared to be equally reliable.

Perspectives

Image quality, and consequently interpretation reliability, depend on the type of CT scan used and on the choice of acquisition and reconstruction parameters. Use of a new type of CT scan, multislice helical CT (30,31) should lead to even better image quality. The observer experience acquired on dried symphyses seemed to be transferable to 3D image analysis. Further training in the reading of 3D images should continue to improve the observers' performances and probably validate the method based on CT imaging. We can reasonably hope that this method will be at least as reliable as standard observation, and more reproducible.

Conclusion

Three-dimensional CT imaging is applicable to study of the pubic symphysis for age estimation. The various Suchey-Brooks features can be observed on the virtual object. The two approaches, using CT images and the actual bone, appeared to yield amost totally concordant results for phase estimation and feature analysis, with nevertheless a few differences. Analysis of larger samples should allow better definition of some Suchey-Brooks features and also definition of image-specific parameters, whether morphological or metric.

This new approach is mainly applicable to forensic anthropology, for age determination of human remains but also of living individuals, although precision is less in the latter. But it can also be applied in paleoanthropology for the study of mummies, so that the archeological material is preserved intact.

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