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TECHNICAL NOTE

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Application of the Iscan Method to Two- and Three-Dimensional Imaging of the Sternal End of the Right Fourth Rib*

ABSTRACT: Age determination is a major field of interest in physical and forensic anthropology. Among the different methods based on macroscopic skeletal study, the Iscan method, which analyzes the sternal end of the right fourth rib, is one of the most reliable. We applied the Iscan method to two- and three-dimensional multislice computed tomography (MSCT) reconstructions of the sternal end of the right fourth rib on 39 ribs. The intra-observer variability on MSCT reconstructions was good (gamma coefficient equal to 0.86; value of the Krippendorff's alpha reliability equal to 0.79); inter-observer variability on MSCT reconstructions was also good (gamma coefficient ranging from 0.82 to 0.88; value of the Krippendorff's alpha reliability ranging from 0.78 to 0.86). We demonstrated excellent agreement between the results of analysis of bone samples and those of the two- and three-dimensional images, in particular regarding bone projections, morphology of the pit and of its rim. The accuracy of age estimation did not significantly differ between the Iscan method applied to dry bones and the same method applied to MSCT images. Determination of the Krippendorff's alpha reliability coefficient for the inter-error method confirmed the agreement between phase estimations obtained with the two methods (ranging from 0.55 to 0.71). The real civil age was comprised in 21 cases out of 36 for assessment performed on dry bones and in 23 cases out of 36 on MSCT reconstructions, which represented 58.3% and 63.9%, respectively. Use of MSCT reconstructions in forensic anthropology offers many 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, sternal end of the rib, multislice computed tomography

The determination of age at death is an important part of physical and forensic anthropology. Age can be estimated using a number of indicators (1). Most methods are based on macroscopic study of bones. While the pubic symphysis and intracortical morphometry have demonstrated their value in estimating age at death, other methods and other skeletal sites are needed to improve accuracy. Iscan et al. studied in 1983 the possibilities of estimating age at death from the rib by phase analysis (2). This method was first applied to white males and the sternal extremity of each rib was analyzed by pit depth, pit shape, and rim and wall configurations, each of which was divided into six stages. The study demonstrated that pit shape and the configurations of the rim and wall yielded better results than absolute pit depth alone. The method was improved in 1984 by Iscan. It was still applied only to white males and was based on changes observed at the costochondral junction of the fourth rib, assigned to one of nine phases (3). In 1985, the same method was applied to white females (4). These studies of age estimation from the ribs by phase analysis were performed on a sample consisting of 86 white females and 118 white males of known age, sex, and race, whose right fourth rib was collected at autopsy (5). Observations were made at the costochondral junction with special attention to pit formation (its shape and depth), changes in the walls and surrounding rim, and overall bone density and texture. Based on changes in these areas, the ribs were separated into nine phases (0 through 8) of progression spanning seven decades from the teens through the 70s. The major morphological features indicating changes in the rib were summarized and illustrated with photographs. Age is estimated from the mean age and the 95% confidence interval of the mean for each phase and each sex. According to the authors, the sternal rib end may yield a similar degree of accuracy as the pubic symphysis and perhaps better than that for cranial sutural closure. Racial variation in the sternal extremity of the rib and its effect on age determination were studied by Iscan (6). He concluded that biological differences between black and white do exist and can affect age estimation from the rib. Social factors may also be involved, but they cannot be demonstrated from the available data. While the degree of inter-racial variation does not require completely new standards, the authors have suggested specific modifications of the white standards for use on black specimens. However, we note two biases in this method: firstly, the sample is statistically small (204 cases). Recovery and identification of the fourth rib in an archeological context may sometimes be difficult. Furthermore, this method requires long and tedious preparation of bone specimens and it is often difficult to avoid anatomic damage (rib preparation requires several days for a final result which is not always suitable for analysis). Moreover, this method 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 in anthropology has been developed called "virtual anthropology," based on computed tomography (CT) studies (7–9). Over the last 20 years, developments in CT scan, and especially multislice acquisition, have resulted in significant improvement of spatial definition and isotropic image quality. Advanced computerized techniques offer two- and three-dimensional reconstructions of high quality. Multislice computed tomography (MSCT) has many advantages: a major asset of its

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application in forensic anthropology is the elimination of lengthy bone preparation, which may sometimes cause anatomical damage, especially when bone is already fragile. Documentation by radiological imaging is observer-independent, objective, and non-invasive (10). Digitally stored data may be recalled at will and provide fresh, intact reconstruction. A new approach to quality control and expert supervision becomes possible, as well as image transmission and use in forensic telemedicine. Image and data processing offer objective visualization and recapitulation of forensic results, with the high spatial resolution of MSCT.

In this study, we applied the Iscan method to two- and three-dimensional MSCT reconstructions of the right fourth rib and compared the age estimations with those obtained by examination of dry bones. We paid special attention to the value of these reconstructions for observation of articular surface, the pit (amorphous indentation), the rim and edges, and bone projections.

Material and Methods

Bone Collection

The bone material consisted of 39 right fourth ribs with soft tissue obtained from autopsies performed for identification purposes in the Department of Forensic Medicine, Toulouse University Hospital, between November 2004 and March 2005. The sternal ends of the right fourth rib, with adjacent chondrosternal cartilage, were removed and stored in a freezer. The 39 specimens were all of known age and sex, and all were French. The mean age was 41 years for males, with a standard deviation of 14.4 years, and 52 years for females, with a standard deviation of 21.4 years. The distribution of the sample is summarized in Fig. 1.

Multislice Computed Tomography

MSCT was performed on a Sensation 16 scanner (Siemens, Erlangen, Germany). Bone specimens with their soft tissue and cartilage were placed in plastic bags and scanned with 16×0.75 mm collimation. The image matrix was 512×512 pixels. Axial reconstructions 1 mm thick were then performed every millimeter. For the acquisition phase, two filters were used: a bone filter for the two-dimensional reconstructions and a soft tissue filter for the three-dimensional reconstructions.

Post-processing was performed on a Leonardo console (Siemens). Two-dimensional (multiplanar reconstructions [MPR] mode) and three-dimensional post-processing (volume rendering technique [VRT] mode) was done in all cases. MPR reconstructions were performed along the long axis of the sternal end of the rib in two planes: one antero-posterior and one cephalo-caudal. VRT reconstruction made it possible to exclude soft tissue and sometimes cartilage. Five views were selected: superior, inferior, anterior, and posterior views and view of the pit.

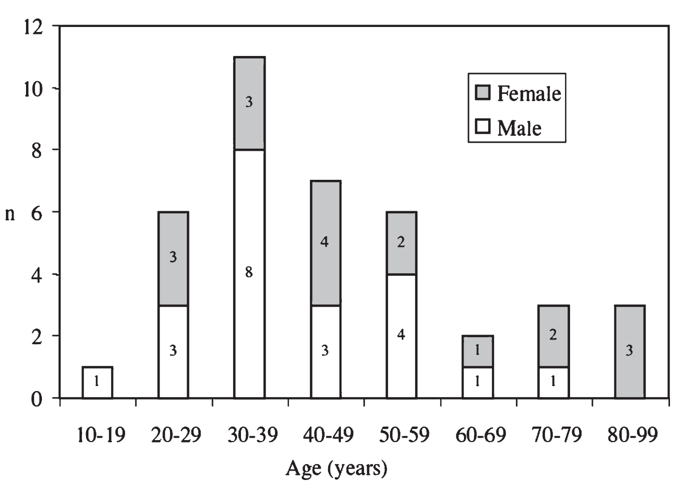


FIG. 1—*Distribution of the sample.*

Study Method

After all the specimens had been scanned, the frozen ribs were placed in water and warmed to remove soft tissue. The Iscan method was then applied to the MSCT reconstructions and to dry bones. Age was estimated by three observers, two experienced in the Iscan method (one forensic pathologist and one forensic pathologist who was also an anthropologist) and a student who was not experienced in the method, who were aware of the sex but not the age of the specimens. The MSCT images were studied several weeks after the dry bone analysis. For bone analysis and phase determination, the photographs and descriptions of the original article by Iscan were used. Six features were analyzed: amorphous indentation of the pit, articular surface, the rim and its edges, bone projections, wall thickness, and bone texture.

Statistical Analysis

Statistical analysis was performed with R 2.2.0. Software. The initial sample was composed of 39 individuals. Thirty-six ribs were examined because three were damaged during preparation. We did not separate males and females because of the small number. A first statistical analysis was performed to evaluate intra- and inter-observer variability on MSCT reconstructions and on dry bones by calculating the gamma coefficient and Krippendorff's alpha reliability coefficient (11–14). A second statistical analysis was performed in order to compare phase estimations performed on MSCT reconstructions and on dry bones by each observer (inter-method error). Because of the small number of subjects studied, the statistical test used was Krippendorff's alpha reliability coefficient.

Results

Intra-observer Variability

Intra-observer variability on dry bones was excellent with a gamma coefficient of 0.87, confirmed by a Krippendorff's alpha reliability coefficient of 0.79. Intra-observer variability on MSCT reconstructions was excellent with a gamma coefficient of 0.86, confirmed by a Krippendorff's alpha reliability coefficient of 0.79.

Inter-observer Variability

Inter-observer variability on dry bones was good with a gamma coefficient ranging from 0.73 to 0.91, confirmed by a Krippendorff's alpha reliability coefficient ranging from 0.68 to 0.83.

Inter-observer variability on MSCT reconstructions was excellent with a gamma coefficient ranging from 0.82 to 0.88, confirmed by a Krippendorff's alpha reliability coefficient ranging from 0.78 to 0.86.

Inter-method Error

Concerning inter-method evaluation for the first observer (student), Krippendorff's alpha reliability coefficient ranged from 0.55

TABLE 1—*Phase dispersion between estimations performed on dry bones and on MSCT reconstructions (observer n°3).*

Observer n° 3		Phase estimation on MSCT reconstructions									Total
		0	1	2	3	4	5	6	7	8	
Phase estimation on dry bones	0	0	0								0
	1	0	0	1							1
	2		0	0	1	2					3
	3			1	1	1		1			4
	4			1	1	3	0				5
	5				1	5	2	3	2		13
	6						2	4	0		6
	7							1	1	1	3
	8								1	0	1
Total		0	0	3	4	11	4	9	4	1	36
Legend			Perfect agreements					Disagreements by one phase (+/-)			

disagreements by one phase (+/−).

to 0.71. The agreement between phase estimations obtained with the two methods was good.

For the second observer (forensic pathologist), Krippendorff's alpha reliability coefficient was 0.69. The agreement between phase estimations obtained with the two methods was significant.

For the third observer (forensic pathologist and anthropologist) 80.56% of the estimations performed on dry bones and MSCT reconstructions agreed perfectly or differed only by one phase, with 30.56% of perfect agreement and 50% with a difference of one phase between both methods (above or below). Krippendorff's alpha reliability coefficient was 0.71 (Table 1). The agreement between phase estimations obtained with the two methods was significant.

Comparison of MSCT Reconstruction and Dry Bone Analysis

The comparison of the age range calculated according to the Iscan stage assessment was performed for dry bones and MSCT reconstructions. This age range determination was calculated with a 95% confidence interval. The real civil age was comprised in 21 cases out of 36 for assessment performed on dry bones and in 23 cases out of 36 on MSCT reconstructions, which represented 58.3% and 63.9%, respectively.

Fig. 2*a–h* show bone specimens compared with the corresponding MSCT reconstructions for each Iscan phase.

Discussion

Concerning *intra-observer variability*, results were equal for both methods. For both methods, a tendency to overestimate the phases at the second estimation was noted.

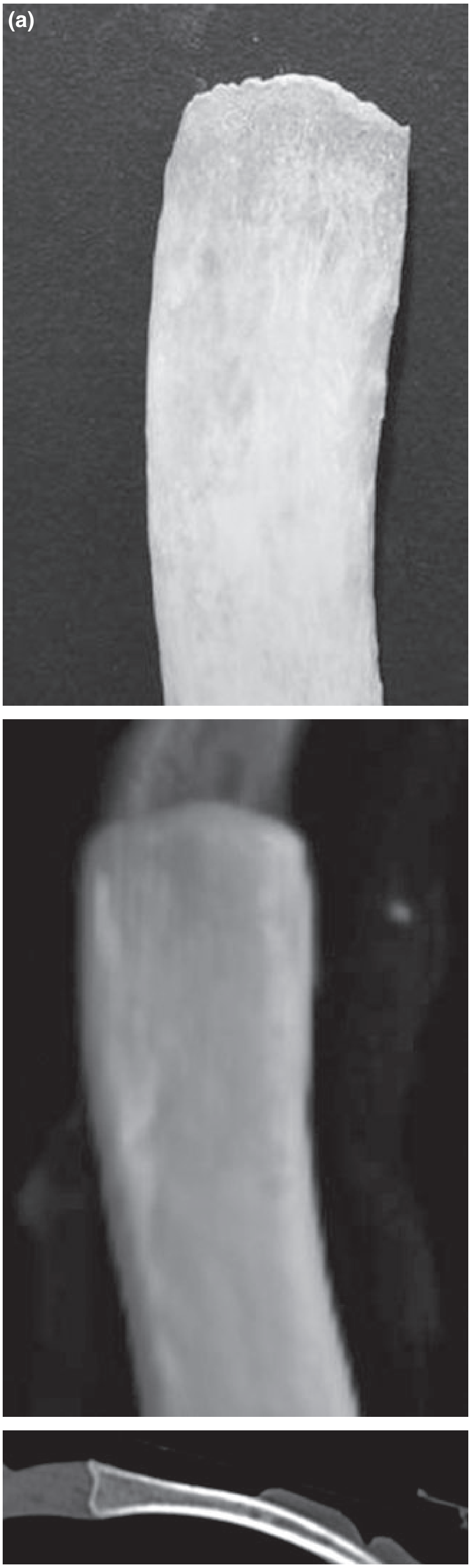


FIG. 2—*(a) Iscan phase I: male aged 16 years, dry bone, lateral 3D view (VRT mode), long axis 2D view (MPR mode). (b) Iscan phase II: male aged 23 years, dry bone, lateral 3D view (VRT mode), long axis 2D view (MPR mode). (c) Iscan phase III: female aged 26 years, dry bone, lateral 3D view (VRT mode), long axis 2D view (MPR mode). (d) Iscan phase IV: male aged 26 years, dry bone, lateral 3D view (VRT mode), long axis 2D view (MPR mode). (e) Iscan phase V: male aged 39 years, dry bone, lateral 3D view (VRT mode), long axis 2D view (MPR mode). (f) Iscan phase VI: male aged 53 years, dry bone, lateral 3D view (VRT mode), long axis 2D view (MPR mode). (g) Iscan phase VII: male aged 58 years, dry bone, lateral 3D view (VRT mode), long axis 2D view (MPR mode). (h) Iscan phase VIII: male aged 86 years, dry bone, lateral 3D view (VRT mode), long axis 2D view (MPR mode).*

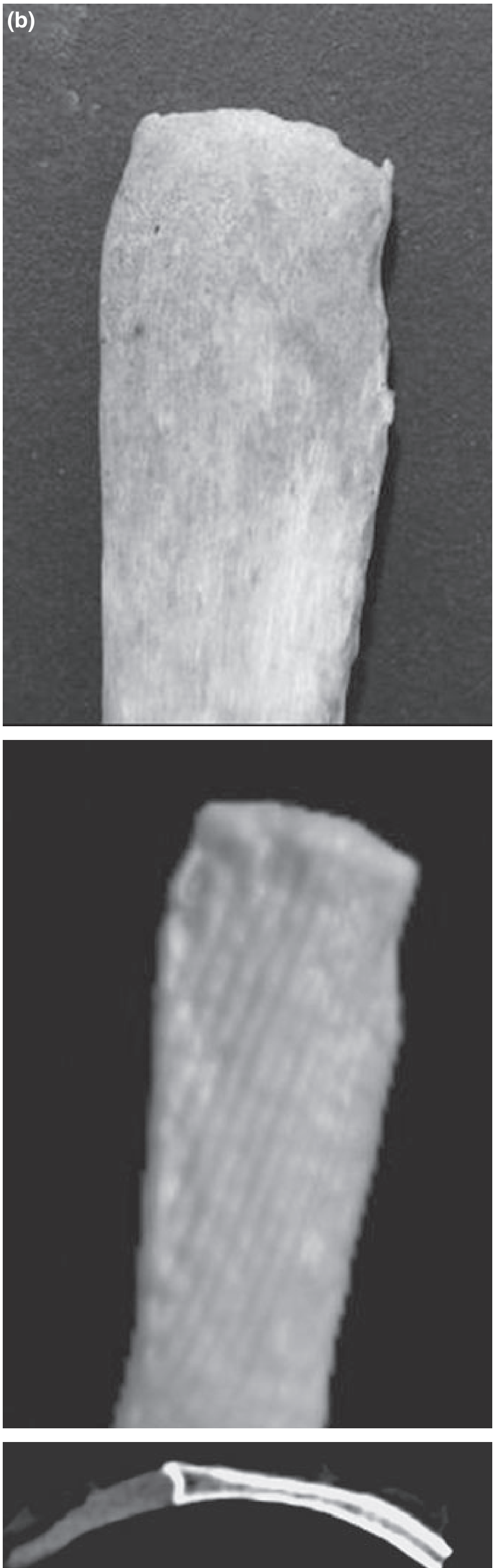
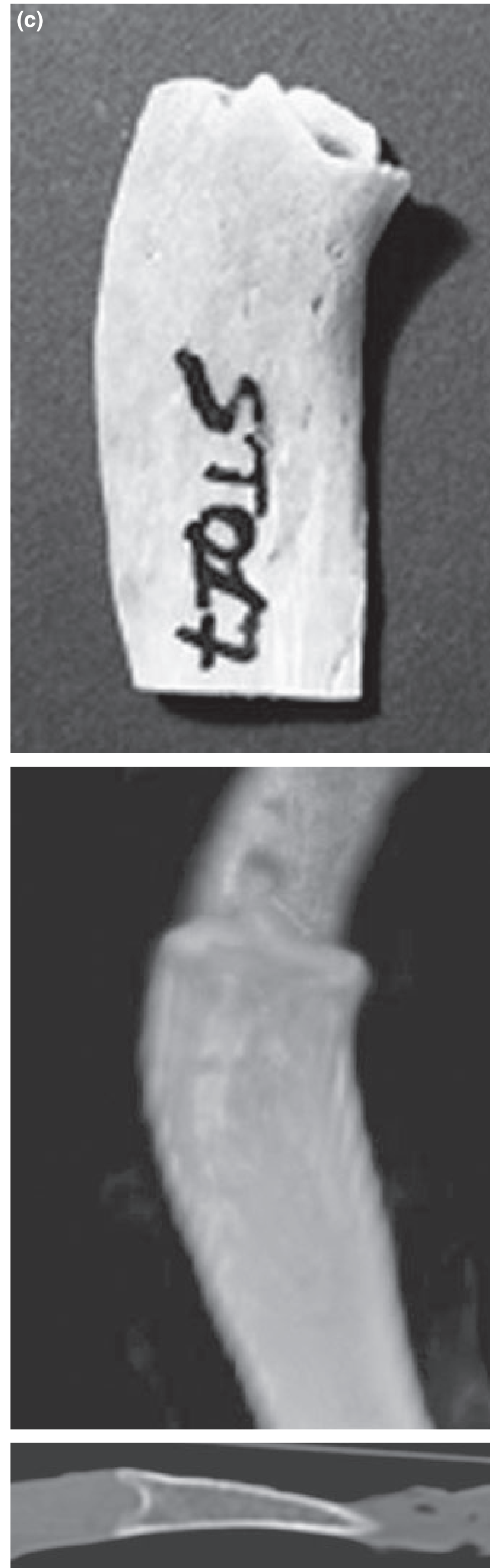


FIG. 2—*(Continued)*



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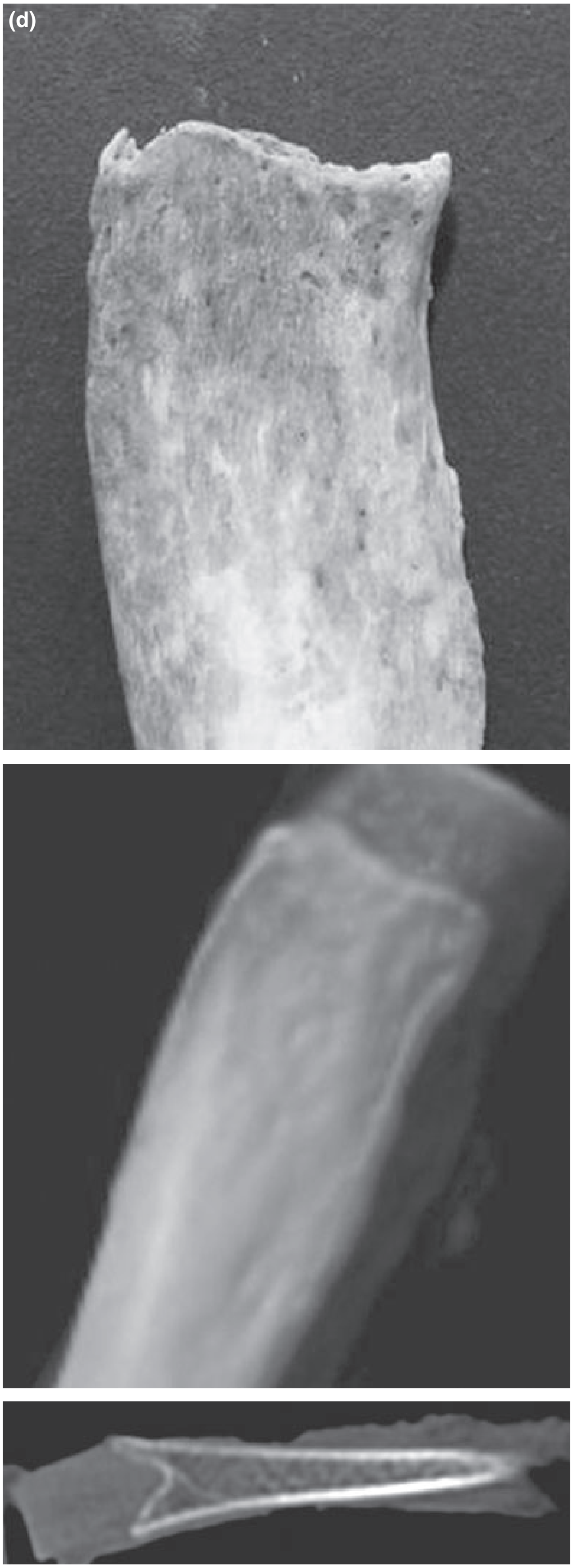

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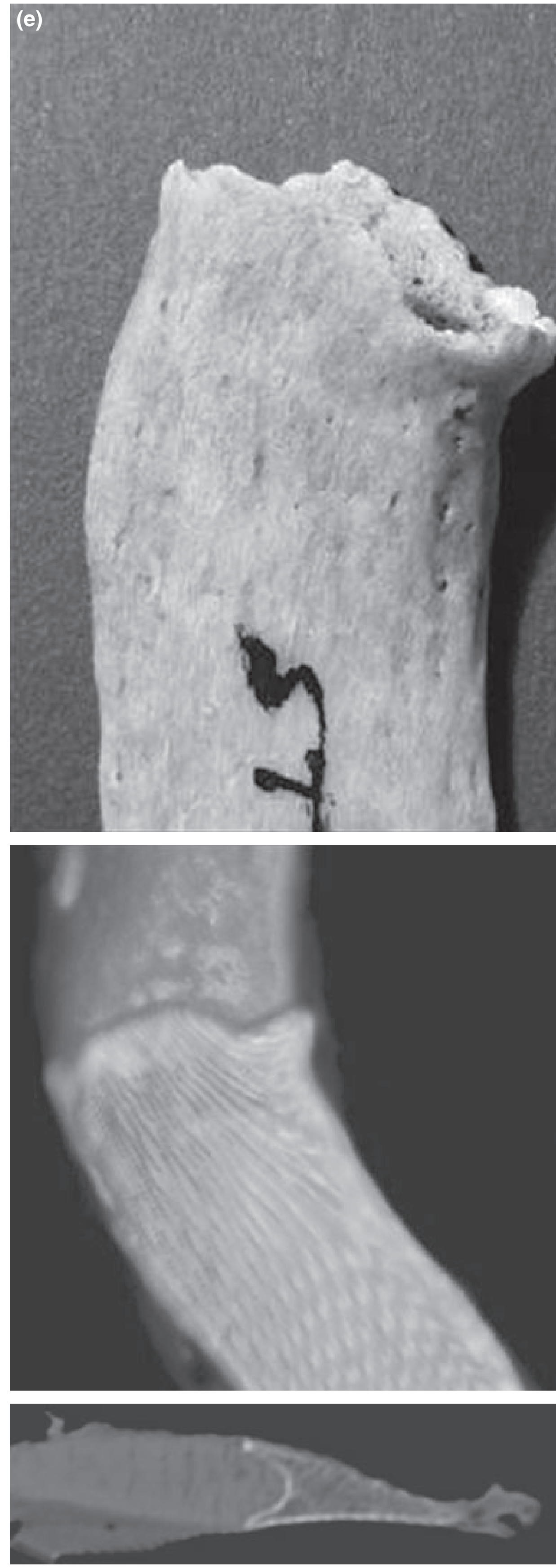

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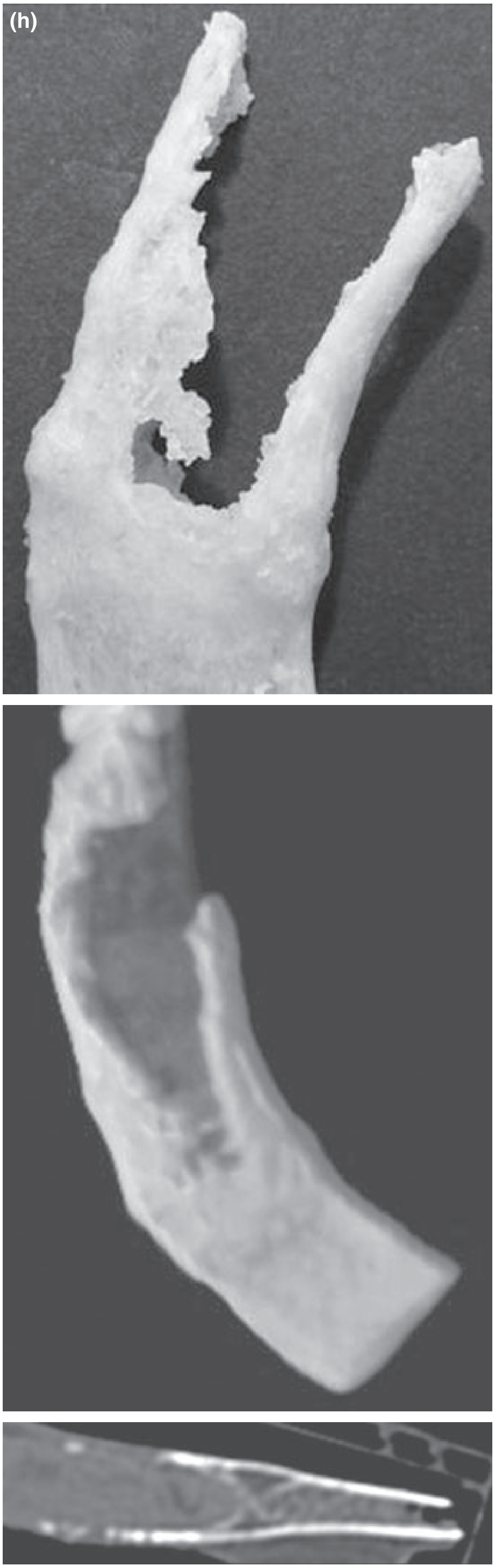

FIG. 2—*(Continued)*

Concerning *inter-observer variability*, less variability was noted with MSCT reconstructions than with dry bones: divergence was less and concordance better.

Inter-method error varied according to the observer. However, phase estimations seldom showed complete agreement between the two methods, varying from 23% to 44% according to the observer. The percentage of estimations which differed by one phase (above or below) varied from 64% to 81%.

The first observer tended to underestimate phases 5 and later on MSCT reconstructions compared with dry bones.

The second observer tended to underestimate all phases on MSCT reconstructions compared with dry bones. Phase 5 showed the greatest variability in phase determination on MSCT reconstructions.

The third observer tended to underestimate phases 4 and later, and to overestimate the younger phases on MSCT reconstructions. There are several possible explanations:

- One of the criteria used to determine phases 4 and above is thinning of the pit wall. Wall thickness is sometimes difficult to assess on three-dimensional MSCT reconstructions. The 3D images tend to smooth the tiny irregularities of the bone surface, because of the sharp extremities of the edges of the wall. In these cases, 2D images are useful to assess wall thickness.
- Porous bone is tricky. The major difficulty is to determine the threshold. If it is set too high, some parts of fragile and damaged bone are erased and it is impossible to analyze the edges correctly. If set too low, superimpositions with the chondrosternal cartilage hinder analysis of the edges on MSCT reconstructions.

The difference of accuracy for both determinations was not significant for the age assessment at the scale of a population. Indeed the civil age calculated according to the Iscan method was comprised in 58.3% of the cases for dry bones evaluations and 63.9% for age determination performed on MSCT reconstructions.

One major advantage of MSCT reconstruction is the possibility of reconstruction of fragile osteophytes and calcifications, with no risk of damage.

Conclusion

Two- and three-dimensional MSCT reconstructions are applicable to study the sternal end of the fourth rib for age assessment. Most of the Iscan features can be observed and analyzed on reconstructions. Phase estimation with the two techniques appeared to yield concordant results. Analysis of larger samples should allow better definition of some Iscan features and also definition of some image-specific parameters, development of new phase standards, whether morphological or metric intended for application to MSCT images. This preliminary work demonstrates the fact that transposition of the Iscan method on MSCT reconstruction is possible and that both evaluations are accurate, which did not differ significantly. The next step will be increasing the population of study using clinical MSCTs, with the accord of the local ethic committee.

The main applications of this new approach are in forensic anthropology for age determination of human remains as well as of living individuals, and in paleoanthropology for the study of mummies.

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