Computer tomography scanning of Homo erectus crania Ngandong 7 from Java : Internal structure, paleopathology and post-mortem history

Antoine Balzeau, Dominique Grimaud-Hervé, Etty Indriati, Teuku Jacob

Berkala Ilmu Kedokteran
Vol. 35, No. 3, 2003

Computer tomography scanning of *Homo erectus* crania Ngandong 7 from Java: Internal structure, paleopathology and post-mortem history

Antoine Balzeau[1], Etty Indriati[2], Dominique Grimaud-Hervé[1], Teuku Jacob[2]
[1]Département des Sciences Préhistoriques du Muséum national d'Histoire naturelle,
Institut de Paléontologie Humaine, 1 rue René Panhard, 75013 Paris, France,
[2]Laboratory of Bioanthropology and Paleoanthropology,
Faculty of Medicine, Gadjah Mada University, Yogyakarta, Indonesia

ABSTRACT

Antoine Balzeau, Etty Indriati, Dominique Grimaud-Hervé, Teuku Jacob - ***Computer tomography scanning of Homo Erectus crania Ngandong 7 from Java: Internal structure, paleopathology and post-mortem history***

Background: Computer Tomography scanning has recently been a tool for diagnosis of normal anatomy and pathology in medical sciences. The CT method has also been applied in ancient human skeletal remains and yield good results for researching the morphology, pathology, and postfossilization bone alteration. Paleoanthropological evidences exhibit that biological remains sometimes are fossilised, thus enabling the pursuit of scientific inquiries in regard to anatomy and biology of ancient humans.
Aim of study: to know the morphology and anatomy of the crania including the internal structures that is not feasible in external bone study, such air pneumatisation, the shape of frontal sinuses, and thickness of the external table, diploe, or the internal table. This study also aims to know the mineralization distribution as a result of fossilization.
Material and Method: The material in this study was a fossil crania of Ngandong 7 that belongs to the latest representation of the *Homo erectus* from Ngandong, East Java, Indonesia. Ng 7 is from the Late Pleistocene period dated about 27,000 to 100,000 years ago. The CT scan was conducted in the Quinze-Vingts hospital, Paris, in January 2001. The method used is by applying a medical CT-based data in order to extract the maximum information concerning mineralization, internal cranial features, osseous distribution and disease. An adapted acquisition and analysis protocols are developed from the CT scan.
Results: Mineralization of Ng 7 occurred during fossilization, causing the diploe to be thickened than normally in antemortem and prefosilization periods. Because of post-mortem transformation of the individual structures, many slices of CT scans were necessary. The internal structures showed ovoid shape of frontal sinuses, and well developed pneumatisation of the mastoid region. Cracks were detected as a result of postfosilization compressions. Lesions appeared on CT scan just posterior to the bregma in the form of eroded external table. This caused diffuse boundary between external table, diploe, and internal table due to homogenous mineralization
Conclusion: It is concluded that the Ngandong 7 *Homo erectus* shares internal morphological similarities with other Ngandong and Sambungmacan fossils and presents lesions that might have caused by pathology during the life of the individual. The post-mortem history of this fossil appears to be composed of at least two distinct stages with osseous loss and fluvial transport, followed by taphonomic and diagenetic processes.

Key words: Ngandong, Homo erectus, computer tomography, paleopathology, post-mortem history

Antoine Balzeau, Dominique Grimaud-Hervéa, Département des Sciences Préhistoriques du Muséum national d'Histoire naturelle, Institut de Paléontologie Humaine, 1 rue René Panhard, 75013 Paris, France,
Etty Indriati Teuku Jacob, Laboratory of Bioanthropology and Paleoanthropology, Faculty of Medicine, University of Gadjah Mada, Yogyakarta, Indonesia

ABSTRAK

Antoine Balzeau, Etty Indriati, Dominique Grimaud-Hervé, Teuku Jacob - ***Skaning tomografi komputer tengkorak Homo erectus Ngandong 7 dari Jawa: Struktur internal, paleopatologi, dan sejarah pascamerta***

Latar belakang: Skaning tomografi komputer akhir-akhir ini digunakan sebagai alat diagnosis patologi dan anatomi normal dalam bidang kedokteran. Metoda CT juga diaplikasikan pada sisa hayat manusia purba dan membuahkan hasil yang bagus untuk penelitian morfologi, patologi, dan perubahan tulang pascafosilisasi. Bukti-bukti paleoantropologi menunjukkan bahwa mahkluk biologis kadang-kadang mengalami fosilisasi, sehingga memungkinkan dilakukan penelitian ilmiah untuk membahas anatomi dan biologi manusia purba.
Tujuan penelitian: Untuk mengetahui morfologi dan anatomi tengkorak termasuk struktur internal yang tidak bisa dilihat dari pemeriksaan luar tulang, seperti bentuk sinus frontalis, tebal tabula externa, diploe, dan tabula interna. Selain itu juga untuk meneliti distribusi mineralisasi akibat fosilisasi.
Bahan dan cara: Bahan penelitian adalah fosil tengkorak Ngandong 7 yang termasuk spesies *Homo erectus* yang paling maju anatominya, berasal dari Ngandong, Jawa Timur, Indonesia. Ng 7 berasal dari kala Pleistosen akhir, antara 27.000 sampai dengan 100.000 tahun yang lalu. Skan CT dilakukan di rumah sakit Quinze-Vingts, Paris, pada bulan Januari 2001. Cara penelitian dengan aplikasi data CT kedokteran untuk mengambil informasi maksimum mengenai mineralisasi tulang, fitur krania internal, distribusi penulangan, dan penyakit. Akuisisi adaptif dan protokol analisis dikembangkan dari skan CT.
Hasil: Mineralisasi Ng 7 terjadi selama fosilisasi menyebabkan diploe lebih tebal daripada normal ketika antemortem atau perioda prafosilisasi. Karena transformasi pascamerta struktur-struktur tulang, diperlukan banyak irisan skan. Struktur internal menunjukkan bentuk ovoid pada sinus frontalis, dan pneumatisasi pada daerah mastoid berkembang sangat baik. Retakan di tengkorak terjadi sebagai akibat tekanan dalam tanah pascafosilisasi. Terdapat lesi pada skan CT di posterior bregma dengan manifestasi erosi tabula eksterna. Hal ini menyebabkan batas yang tidak tegas antara tabula eksterna, diploe, dan tabula interna karena mineralisasi yang homogen.
Simpulan: Dapat disimpulkan bahwa tengkorak manusia purba *Homo erectus* Ng 7 mempunyai kesamaan morfologis dengan fosil-fosil tengkorak manusia purba dari Ngandong dan Sambungmacan, dan Ng 7 menderita penyakit pada atap tengkorak semasa hidupnya. Sejarah post-mortem fosil ini terdiri dari 2 fase: hilangnya struktur osseous dan diikuti oleh perubahan lebih lanjut karena proses tafonomik dan diagenetik.

(B.I.Ked. Vol. 35, No.3: 133-140, 2003)

INTRODUCTION

Ngandong 7 (Ng 7) a Homoerectus skull is a complete calvaria assigned to *Homo erectus*[1,2,3,4]. This fossil comes from the site of Ngandong, East Java, in Indonesia[5] discovered along with 12 other human cranial remains[6,7,8]. Ngandong 7 presents a very good state of general conservation and corresponds to a complete skullcap. The most recent dating method yield less than 50 000 years[9]. This fossil, with the others of the same site, has been the subject of exhaustive studies concerning their exocranial description[1,2], as well as their endocranial morphology[3], and most recently, their dry bone pathology[10,11]. All these previous studies examined dry bone. In this study, a CT scan analysis is performed, thus enable to examine the internal cranial features, fractures, distortions inside the bony structures and CT perspective of the pathology previously described[10,11]. Through a computed tomography, a more detailed insight of morphology and pathology are interpreted, thus contributing more understanding of anatomy of past human and the effect of taphonomic processes.

MATERIAL AND METHOD

Ngandong 7 is a *Homo erectus* skull housed in the Laboratory of Bioanthropology and Paleoanthropology Gadjah Mada University Faculty of Medicine, Yogyakarta, Indonesia, and dated to Late Pleistocene. The skull was scanned in January 2001 at the C.H.N.O. des Quinze-Vingts in Paris. The data acquisition parameters were 120 kV and 120 mA with the pixel size of 0.49 mm (the window of 25 cm and the matrix of 512 X 512 pixels) and the thickness cut was 1 mm. Based on our previous experiences[12,13], the medical CT-based data was used in order to extract the maximum information concerning mineralization, internal cranial features, osseous distribution and the lesion. To fulfil the purpose of the CT scan analysis, a specific protocol was developed to adapt CT data acquisition and treatment according to the specific condition of Ngandong[7].

The protocol of SMM (Seuillage Manuel Multiple) was used to define accurately the interface between two structures, and the exact extension of the region of interest at all points. This protocol allowed a precise observation on the two-dimensional cuts and an accurate reconstruction in three dimensions. The procedure consisted of measurement of the median value (the same value of that of HMH[14,15] of the Hounsfield number of the two tissues where the interface was defined[16]. The interface definition has to be adjusted or changed every time the attenuation coefficient of the tissue changed. The contour of the investigated region must be defined picture by picture on the two-dimensional CT data. This allowed the retracing precisely the interfaces of different tissues surrounding each structure. The data was visualised and analysed using 1.8.1 eFilm and Mimics 7.1 software. A rapid-prototyping technique was used to obtain the physical replication of the exocranium.

RESULTS AND DISCUSSION

Mineralization, internal conservation state, and paleopathology

The skull of Ng 7 was well mineralised. The CT scan analysis of Ng 7 skull exhibited average decreased coefficients similar to other fossils from Ngandong such as Ng 1, 2 and 12. The variations of mineral density were present, but still corresponded to the usual density distribution of the osseous tissues. Dry bone study exhibited cracks on the exocranium that might have been associated with pressure of postdeposition and postfossilization period (FIGURE. 1). The CT analysis of the internal morphology also showed breaks that propagate in the bony structures internally. The CT analysis exhibited that right parietal was very fragmented, more and more from top to bottom. The fragments that compose it in its bottom part were glued together and present some hiatuses. The squamous part of the right temporal was in the same state of preservation. A missing bony part had been replaced by a less dense matter and the fragments presenting the fewest zones of contact had been assembled with the help of a very dense matter. The left

FIGURE 1. Ngandong 7 *Homo erectus* skull, left view shows various cracks

parietal presented also fractures in its posterior part. A large break separated the temporal from the occipital. All the cracks observed exocranialy on this fossil propagate themselves very distinctly inside the bone. They often propagated a perpendicularly to the external cranial surface except at the level of the right parietal and temporal where bony fragments were isolated. These internal fractures to the skull and the absence of some fragments involved the non conservation of some regions of the endocranium surface. The observable cracks on the external surface of the fossil were obvious on the reconstruction of the endocast. One crack propagated itself from the postbregmatic lesion at the level of the sagittal suture to the coronal suture. From this one, two other fractures extended perpendicularly and continue toward the back of the skull.

The coronal, sagittal and lambdoid sutures were visible. The coronal and sagittal sutures remain very distinctly opened internally to the bony structures in the precise zone on the sagittal suture and behind the bregma, just at the level of a lesion Weidenreich[1] described as corresponding to an inflammation of the bony structures or Indriati[10,11] assigned it as lesion 1. These opened sutures spread on about 30 mm laterally for the coronal suture and on 50 mm antero-posteriorly for the sagittal suture.

Posterior to lesion 1, a second defect was observable on the left parietal surface[9,10]. It is of circular shape and wide dimensions, about 50 mm of diameter. In this point, the consequences of pathology was clearly identifiable. Lesion 210,11: a depression of oval shape, antero-posteriorly elongated and 3 mm deep was located at 47 mm of the coronal suture and 35 mm of the sagittal suture. On the scannographic pictures, it appeared that it constitutes an erosion of the external table with a remineralization of the bony surfaces that surrounded it. FIGURE 2 shows the eroded external table on the area of lesions one and two, as well as homogenous mineralization that blued the border between external table, diploe, and internal table. Another defect was visible on the left side of the nuchal plane of the occipital bone. This lesion perforated the bone but there was no evidence of previous inflammation[1,10,11].

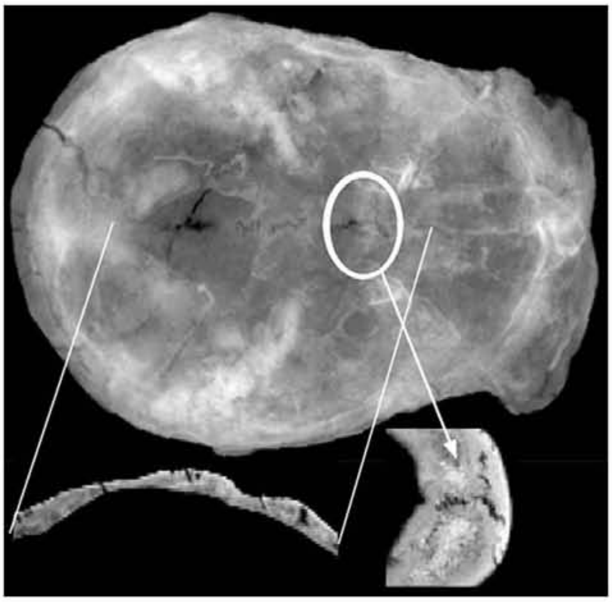

FIGURE 2. CT Reconstructions of the Ngandong 7 fossil, superior view and details of the lesions on its medial sagittal uppermost surface

The postbregmatic lesion poses problem about its origin. According to the scannographic data, the observable depression on the external surface of the skull has a sunken fragment surrounded with fractures. This form bevels from outside to inside on the surrounding cranial walls. The CT data shows that cranial structures present no alteration and are composed of the osseous tables and diploë without erosion of the external table. Thus, the disposition of this internal bone fragment might have been caused by taphonomic pressure. However, cautious must be taken that the fractures isolating the fragment are located in the prolongation of the sagittal suture and present a winding trajectory which do not correspond to what breaks of the mineralized bone would have given. CT data also shows re-mineralization of the bony surfaces surrounding the fractures (FIGURE 2)-suggesting pathological reaction. Thus, even though the present shape of the first lesion has been influenced by the taphonomic processes suffered by this skull, it results mainly from a modification during the life of the individual. Moreover, the visible porosities on the external surface of the skull in this region indicate this lesion would be of pathological origin rather than traumatic[1,10,11]. Thus, the internal fracture on lesion 1 visible on scanographic (FIGURE 2) is caused by both taphonomic pressure and pathological reaction. The mineralization state of these breaks indicates that the individual survived the disease that took place before the sutures closure in this region.

FIGURE 2 represents a transparent 3D reconstruction of the skull with the whole CT data set. FIGURE 2 also shows the detail of the sagittal cut which extends between the two white marks on the superior view of the fossil and a detail of a longitudinal cut at the level of the opened coronal and sagittal sutures. Following Indriati[10,11] lesion number designation, lesion 1 on postbregmatic and lesion 2 on the left parietal behind to lesion 1 are represented by the sagittal cut in FIGURE 2. Lesion 1, the most anterior one is a depression amplified by a fracture. Lesion 2, the second one corresponds to a thinning of the bony structures.

Internal cranial features

The description of the endocranium for this individual which was already done exhaustively by Grimaud-Hervé3, thus we do not describe the endocranial structure. However, the protocols we use allow us to get a very precise 3D reconstitutions of the endocranium, whose volume is directly measurable without a physical cubage by a classic method. Indeed, the evaluations gotten for a same individual vary according to the technique used and even according to the observer (TABLE 1). Thus, we give the value that we obtain for the endocranial capacity of Ngandong 7. It presents the interest to be a direct and reproducible assessment, only subject to the choice that we had to reconstitute the missing parts of the encephalon and without variability bound to its measure. The cerebral volume of Ngandong 7 is 1028 cm³, based n CT reconstruction.

The bony tables and the diploë were clearly discernible in the whole cranial vault. The bone was more mineralized on its external surface than internally because of differential mineralization during diagenetic process, and the diploë was relatively thick and highly mineralized. On the right side of the skull, the petrous part presented distinctive structures corresponding to the semicircular canals and the cochlea. On the left side, this region was crossed by a fracture that separated the petrous part into two fragments. Thus, we could not recognize the distinctive structures of the internal ear because of the conservation state of this region. The frontal sinusal cavities were very well preserved, and ovoid in shape. The left sinus was partially filled with sediment whereas a crack propagated itself in the supraorbital torus from the summit of this cavity. On the right side, the orbital part of the frontal bone presents an oblong shape hiatus, so the right frontal sinus was communicated by this opening with the orbital cavity. The conservation state of the frontal and the ethmoid caused the lower apex of the frontal sinuses to be broadened on both sides. The nasal, lacrimal, maxilla, frontal and ethmoid bones were incomplete enabling to observe the prolongation of the frontal sinuses downwards.

The pneumatisation was very well developed inside the two mastoid processes. Especially in the lower region of the mastoids, some infiltrations had taken place allowing the observation of the substitute of strongly mineralized bone within the air cells. The sphenoid body and the sella tursica were incomplete, especially in regard to their endocranial surface. The pneumatisation which was visible in this region was of weak extension and partially filled with sediment.

The frontal sinuses had an ovoid shape, stretched out laterally showing a weak extension relative to the well developed supraorbitals bony superstructures (FIGURE 3). The mastoid processes were weakly developed on Ng 7 but strong pneumatisation of this region was present

TABLE 1. Evaluation of the endocranial volume of Ngandong 7, comparison with the previous studies

	Author					
	Dubois[16]	Oppenoorth[17]	Weidenreich[18]	Holloway[19]	Grimaud-Hervé[3]	**Present study**
Volume	1087 cm³	1160 cm³	1035 cm³	1013 cm³	1065 cm³	**1028 cm³**

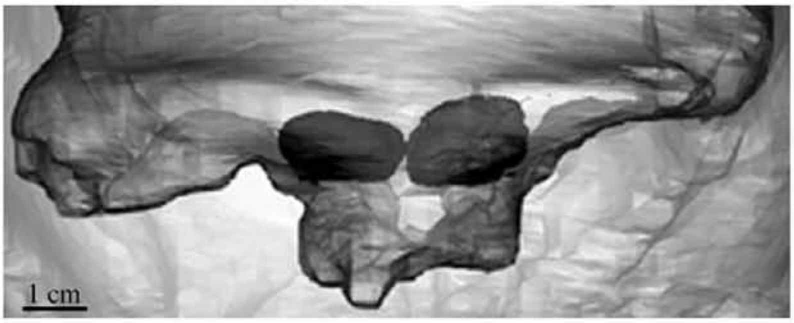

FIGURE 3. Anterior view of the Ng 7 frontal sinuses by transparency of the supraorbital torus

(FIGURE 4) on both sides. The cranial base exhibited incomplete sphenoid. Indeed, the jugum, the posterior part of the lesser wings, particularly the anterior clinoid processes, and the dorsum sellae were broken. Similarly, the bony surface of the hypophyseal fossa was absent, allowing visible openings in the anterior view corresponding to the pneumatisation of the sphenoid (FIGURE 5). The sphenoid air cells had decreased dimension because it was partially filled with sediment. Considering the air cells in the mastoid and sphenoid regions, the pneumatisation presented various extension, but was quite limited relative to the development of the bony superstructures. This condition was found in

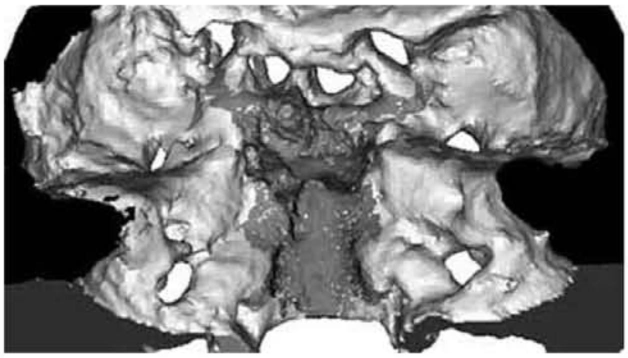

FIGURE 5. Detail of the endocranial surface of the Ngandong 7 basis in antero-superior view

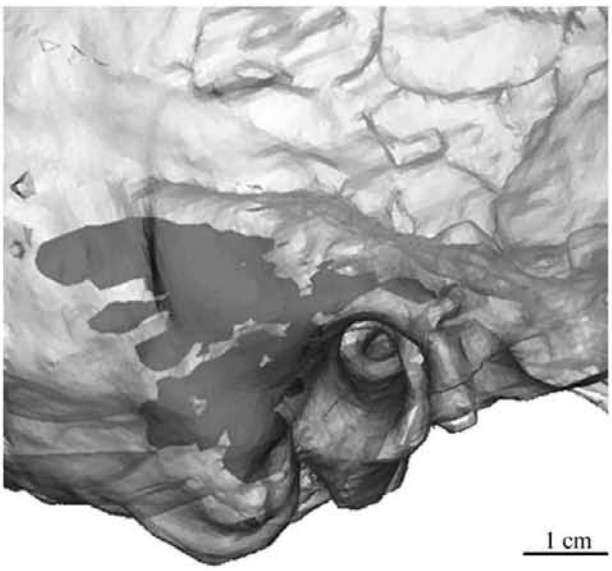

FIGURE 4. Detail of the right mastoid process of Ngandong 7.

Ngandong 1 and 12 fossils and the Sambungmacan 1 and 3 individuals[12,13]. Cranial CT had been successful in its usage for diagnosis of pathology and also normal anatomy[16,21,22]. This study exhibited the advantages of CT analysis to observe the internal preservation state and structure, and to examine whether exocranial defects and breaks propagated internally.

Post-mortem history of the Ngandong 7 fossil

Applying Shipman[23] definition of plastic deformation, the fossil skull of Ng 7 did not show distortion or plastic deformation. The taphonomic pressure on this skull must have been powerful to produce breaks and it might have taken place when the skull was already fossilized. This postfosilization breakage was suggested because the mineralized osseous structures were less likely to suffer plastic distortion than the fresh bone. The absence of facial bone and part of sphenoid on the cranial base might have taken place during transportation and fossilization processes. The taphonomic pressure that cause cracks on the skull might have taken place on the already mineralized or fossilized skull.

Ngandong 7 presented very developed bony superstructures. But this very important ossification was compensated by an internal lightening since the bone structure was mainly composed of diploë. During the life of the individual, the diploe might have been less dense than after fossilized. The original state of the bony structures was partially still visible even if the diagenetic processes had influenced the genuine position and differential mineralization of the internal and external tables and of the diploë. Therefore it was attainable to distinguish the normal distribution of the osseous structures from the effect of the post-mortem transformations.

CONCLUSION

CT analysis observes no developed air frontal sinuses and air cells in the mastoid and sphenoid relative to the well developed cranial superstructure. The internal table was more developed than external table, and the diploe was thickened during mineralization or fossilization. The post-mortem history of this fossil appeared to be composed of at least two distinct stages. First, this individual lost some osseous parts, such as the face, and the fluvial transport separated the face and the rest of the skull. Afterwards, taphonomic and diagenetic processes took place, causing numerous fractures that propagate on the cranial walls but also inside the bone. The pathology seemed to have also influenced these postdepositional and postfosilisation breaks. CT analysis complemented dry bone study. Because of post-mortem transformation of the individual structures, it is important to take in consideration all the information in order to discuss the anatomy and paleopathology.

ACKNOWLEDGMENTS

We thank to Professor E.A. Cabanis from the CHNO des Quinze-Vingts in Paris who CT scanned the fossil.

REFERENCES

1. Weidenreich F. Morphology of Solo man. Anthrop. Papers Am. Mus. Nat. Hist. 1951; 43: 205-90.
2. Santa Luca AP. The Ngandong fossil hominids. Yale University Publication in Anthropology 1980; 78: 1-175.
3. Grimaud-Hervé D. L'évolution de l'encéphale chez l'*Homo erectus* et l'Homo sapiens : exemples de l'Asie et de l'Europe. Cahiers de Paléoanthropologie, CNRS eds. Paris, 1997.
4. Détroit F. Origine et évolution des Homo sapiens en Asie du Sud-Est : descriptions et analyses morphométriques de nouveaux fossiles. Thèse de doctorat, MNHN, Paris, 2002.
5. Sartono S. Genesis of the Solo Terraces. Mod. Quat. Res. In S-E Asia 1976; 2: 1-21.
6. Jacob T. Paleoanthropological discoveries in Indonesia with special reference to the finds of the last two decades. J. Hum. Evol. 1973; 2:473-85.
7. Oakley KP, Campbell BGT, Molleson TI. Catalogue of Fossil Hominids. Part III: America, Asia, Australia, London, British Museum, 1975
8. Indriati E. Indonesian hominid discovery: 1889-2002, catalogue and problems. Article presented at the Fifth symposium of collection building and natural history studies in Asia and the Pacific Rim. December 5-6, 2002, Tokyo.
9. Swisher III CC, Rink WJ, Antón SC, Schwarcz HP, Curtis GH, Suprijo A, Widiasmoro. Latest *Homo erectus* of Java: potential contemporaneity with Homo sapiens in southeast Asia. Science 1996: 274: 1870-74.
10. Indriati E. Cranial lesion on Indonesian *Homo erectus* Ngandong 7. Paper presented at the Inter-Congress IUAES (International Unions of Anthropological and Ethnological Sciences), September 22-27, 2002, Tokyo.
11. Indriati E. Pathology of Indonesian *Homo erectus* Ngandong 7. In : N. Tayles and Oxenham M. (Eds.): Bioarchaeology of the Prehistoric South East Asia-Pacific Region. Cambridge University Press, Cambridge (in press).
12. Balzeau A, Jacob T, Indriati E. Structures crâniennes internes de l'*Homo erectus* Sambungmacan 1 (Java, Indonésie). C. R. Palevol. 2002; 1: 305-10.
13. Balzeau A, Grimaud-Hervé D, Indriati E, Jacob T, Sémah F. Etude comparative de l'endocrâne de l'*Homo erectus* Sambungmacan 3 (Java, Indonésie). Bull. Mém. Soc. Anthrop. de Paris 2002; 14 : n.s. 154-55.
14. Schwartz GT, Thackeray JF, Reid C, Van Reenan JF. Enamel thickness and the topography of the enamel-dentine junction in South Africa Plio-Pleistocene hominids with special reference to the Carabelli trait. J. Hum. Evol. 1998; 35: 523-42.
15. Spoor F, Zonneveld F, Macho G. Linear measurements of cortical bone and dental enamel by CT : applications and problems. Am. J. phys. Anthrop. 1993; 91: 469-84.
16. Balzeau A, Grimaud-Hervé D, Jacob T, Sémah F & Cabanis EA. Virtual Anthropology : the internal charac-

ters of the "Mojokerto child" *Homo erectus* using CT data. Coll. Antropol. 2002; 26 Suppl: 13.
17. Dubois E. Early man in Java and Pithecanthropus erectus. In Early Man. Mac Gurdy, G.G. (ed), Philadelphia, J.B. Lippincott Co, 1937; 315-322.
18. Oppenoorth W. The place of Homo soloensis among fossil men. In Early man. MacCurdy, George Grant, Philadelphia and New York, 1973; 349-360.
19. Weidenreich F. The skull of Sinanthropus pekinensis : a comparative study of a primitive hominid skull. Palaeont. Sinica 1943; D 10: 1-484.
20. Holloway RL. Indonesian "Solo" endocranial reconstructions: some preliminary observations and comparisons with Neandertal and *Homo erectus* groups. Am. J. phys. Anthrop. 1980; 53: 285-295.
21. Lee SH, Rao KCVG, Zimmerman RA. Cranial MRI and CT, New York, 1999.
22. Kevles BH. 1997. Naked to the Bone: Medical Imaging in the Twentieth Century. Helix Books, Addison-Wesley, Reading
23. Shipman P. The history of a fossil. Cambridge University Press, 1981, Cambridge.