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CASE REPORT

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A Forensic Case Study of a Naturally Mummified Brain from the Bushveld of South Africa

ABSTRACT: The present study reports our observations of a naturally mummified human brain found in the bushveld of South Africa. This case extends the geographic and climatic ranges in which mummified brains have been found, and it represents an additional case where no human activity has led to the mummification. The mummified brain was *c*. one fifth the size of a normal human brain, while the gyral and sulcal patterns of a typical human brain were clear. CT scanning of the brain revealed that subcortical structures, normally evident in this type of imaging, were not discernable, indicating a slow mummification process. Histological examination of the tissue revealed near complete degradation of the microanatomical structure, with only putative Nissl bodies remaining as identifiable neural microstructures. The specimen appears to have survived several veld fires, as well as a high annual rainfall, and a high relative humidity. It is thought that specific conditions amenable to brain mummification, but not other soft tissues, occurred in the skull of this specimen in the weeks postmortem.

KEYWORDS: forensic science, mummification, archaeology, neuroanatomy, human, cerebral cortex

In the modern context the word "mummy" refers to any naturally or artificially preserved body, or soft tissue, where desiccation has prevented its decomposition (1). Uhle (1917) has classified mummies into several categories, including "type 1" or "simple" mummifications, in which there has been no human attempt to preserve the body tissues, and the preservation occurred secondarily to climatic conditions. This form of preservation has been documented for most New World mummies (2). The decomposition of soft tissue is influenced by both internal and external factors, and is accelerated by warm and damp conditions (3). Naturally mummified human remains are often found in arid desert areas, but there is usually no evidence of preserved brain tissue because of the rapid decomposition that the brain undergoes in the postmortem period (4); however, in some cases the brain has been naturally preserved, and sometimes the preserved brain tissue persists even after the cranial bone has decomposed (5).

Gerszten and Martinez (3) examined naturally mummified human brain tissue from 15 mummies found in the deserts of northern Chile. These specimens exhibited well-preserved dura mater, cerebral hemispheres, cerebella, and spinal cords. The cerebral hemispheres were described as having a dark brown gritty appearance. Radanov et al. (4) reported a case of naturally occurring mummified human brain tissue in the presence of complete decomposition of other soft tissues. They found two skulls containing complete preserved human brains within a mass grave in Bulgaria and postulated that the tissue was preserved due to very specific conditions within the cranium during the postmortem period. Medieval skulls exhumed in Denmark have also been observed to contain preserved brain tissue that had retained its external morphological appearance (5).

Histological examination of preserved/mummified brains has been undertaken by rehydrating the tissue and applying various stains (1). Gerszten and Martinez (3) used a variety of stains to examine the rehydrated mummified tissue, but only had significant results with a stain that revealed myelination, demonstrating the distinction between white and gray matter in the cerebral cortex. A hematoxylin and eosin stain revealed collagen fibrils, but no individual neurons or other cellular elements of the CNS could be observed. The study of Radanov et al. (4) provides similar results to that of Gerszten and Martinez (3).

The present study reports our gross and microscopic morphological observations of a single case of a mummified human brain found in the savannah grasslands of Gauteng Province, South Africa. The present example extends the geographic range (to sub-Saharan Africa) and climatic conditions (average annual rainfall of 720 mm, with summer temperatures averaging 25°C) in which naturally mummified human brains may be found.

Case History

A skull found by police in the bushveld (savannah grassland with thorn scrub) near Randfontein, Gauteng Province, South Africa, was brought to the School of Anatomical Sciences, University of the Witwatersrand, South Africa, for forensic examination (Fig. 1). Large portions of the maxillae were missing, and the inferior margin of the left orbit, the left zygomatic arch, and the right mastoid process were damaged. The skull appeared to have sustained extensive fire damage to the cranial base and the lower facial region. A complete mandible was found with the skull, but no teeth were present. The posterior alveolar portion of the mandible exhibited some bone resorption. Within the endocranial cavity a desiccated and shrunken (mummified) human brain was observed through the damaged foramen magnum (Fig. 1, lower panels).

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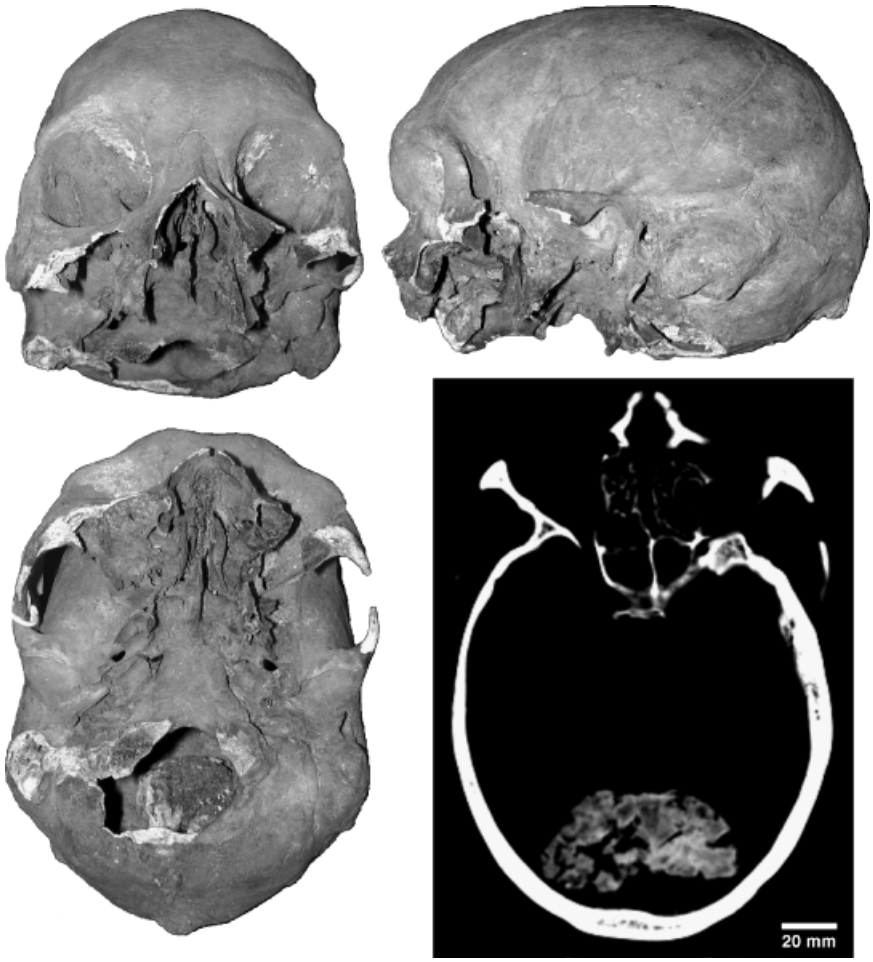

FIG. 1—*Photographs of the forensic specimen showing frontal (upper left), lateral (upper right), and inferior (lower left) views of the external surface of the skull. Note the extensive damage to the maxillary region. The lower right panel shows a horizontal CT slice through the skull at the lower level of the zygomatic arch. Note the clearly visible structure of the mummified brain in the posterior portion of the endocranial space. In the lower left panel the mummified brain is partially visible through the damaged foramen magnum.*

Skull Analysis

Metrical and morphological methods were used to assess the age, population affinity, sex, and stature from the cranium. Because of the fragmented nature of the specimen, only certain methods that pertain to the available material, and also only those methods that were derived from South African populations, were used, as all metrical equations are population specific. To determine the age of the specimen the ectocranial sutures were assessed (6), while discriminant function equations for South African populations were used in the determination of both the sex and population affinity of the specimen (7,8). Morphological traits were also used to assess the sex and population affinity of the specimen.

The specimen was seen as having a large, rugged cranium with large supraorbital ridges, and showed marked muscle lines with a prominent external occipital protuberance, which developed into an occipital hook. Below the sloping forehead are rounded orbits, which are placed relatively low on the facial area, and which have rounded (blunt) margins. The zygomatic arches were large and laterally arched. The mandible was robust with a unilateral ramus flexure and an undercut chin. Most of these traits are typically male. The morphological traits used for population affinity produced an equal number of traits for whites and blacks, while the discriminant function equations classified the specimen as probably white. The ectocranial suture method estimated the specimen to be between the ages of 34 and 68 years.

Mummified Brain Analysis

Materials and Methods

CT scans of the skull, with mummified brain *in situ* (2 mm thick nonoverlapping slices), were taken with a Phillips Brilliance 6 CT multislice machine at the Donald Gordon Medical Centre, Parktown, South Africa, to determine the extent of preservation of the mummified brain. Following this, the foramen magnum was enlarged using a dental drill and the mummified brain carefully removed. The external surface of the brain was photographed with a digital camera under studio lighting. CT scans of the mummified brain *ex situ* were taken in coronal, sagittal, and horizontal planes (1 mm thick nonoverlapping slices), and the CT scans examined for identifiable subcortical structures. The volume of the mummified brain and the endocranial volume were calculated from the CT scans.

Following the CT scanning, the majority of the temporal lobe of the left hemisphere of the mummified brain was dissected free from the remainder and softened by soaking in 15% glycerol in

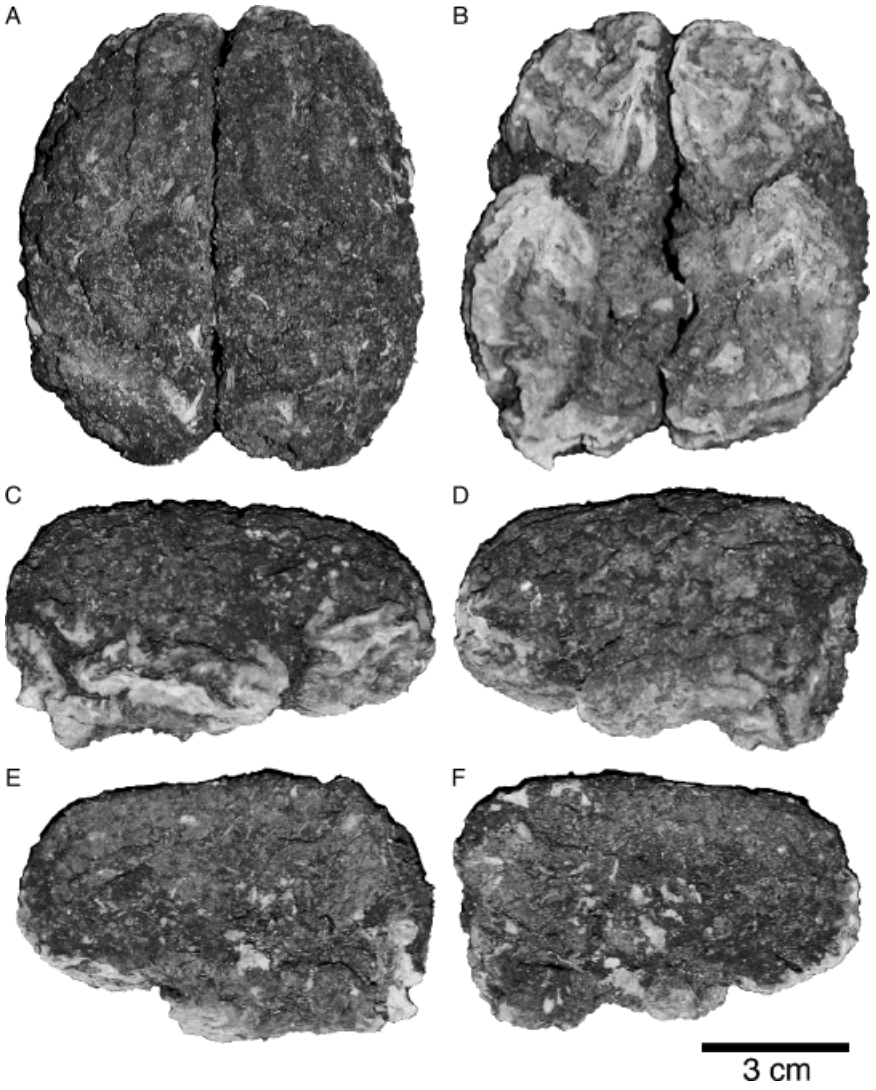

FIG. 2—*Photographs of the mummified brain following removal from the endocranium. (A) dorsal view, (B) ventral view, (C) lateral view of right hemisphere, (D) lateral view of left hemisphere, (E) mid-sagittal view of right hemisphere, (F) midsagittal view of left hemisphere. Note the size of the brain, being c. 8.5 cm in the antero-posterior dimension, 5 cm in the dorso-ventral dimension, and 8 cm in the medio-lateral dimension. This is greatly reduced in size in comparison with the normally hydrated human brain. The arrangement of the cerebral lobes and several sulci and gyri are apparent. Portions of the cerebellum and the mass that was presumably the diencephalon and the upper brainstem are apparent on the mid-sagittal views. The occipital lobes appear to be somewhat flattened, indicating the brain was possibly lying prone during the mummification process.*

0.1 M phosphate buffer for 2 weeks. When the tissue was softened a block of tissue incorporating the middle temporal gyrus was cut from the temporal lobe and fixed in 10% buffered formalin. Following 2 days' fixation, this gyral block was embedded in paraffin wax and the tissue sectioned at a thickness of 10 μm on a rotary microtome. The sections were mounted on glass slides and dried in an oven set at 37°C. The sections of tissue were stained for hematoxylin and eosin to reveal basic tissue structure, cresyl violet to reveal any remaining Nissl bodies, and the Marsland, Glees, and Erickson method for myelin staining in paraffin-embedded tissue. The staining regimes used were those outlined in Bancroft and Stevens (9). Following dehydration, clearing, and coverslipping, the sections were examined and photographed digitally at low and high power using conventional light microscopy techniques.

Results

The extracted mummified brain was a dark gray color on the dorsal surface, and a lighter gray on the ventral surface. The dorsal surface appeared to be covered by a hard deposit external to the brain, perhaps a mineralized deposit through weathering. Both cerebral hemispheres were present, as two separate blocks; however, the lobar arrangement of each hemisphere was readily seen. The brain itself had undergone a dramatic size reduction during the mummification process. The endocranial volume of the specimen was calculated to be 1323.5 cm^3, which is close to the average modern human cranial capacity of 1350 cm^3 (10). The volume of the mummified brain was calculated to be 232.4 cm^3, *c*. 18% of the endocranial volume, which is normally mostly filled by the soft tissue of the brain.

The gyral and sulcal pattern typical of the cerebral cortex of the adult human brain was observable on the outer surface (Fig. 2). On the dorso-lateral surface the superior, middle, and inferior frontal gyri, the superior, middle, and inferior temporal gyri, pre- and postcentral gyri, and the lateral and central sulci were visible. On the median sagittal surface the presumptive lateral ventricle, the cingulate gyrus and the parieto-occipital gyrus were observed. On this surface there was a mass of mummified tissue that appeared to

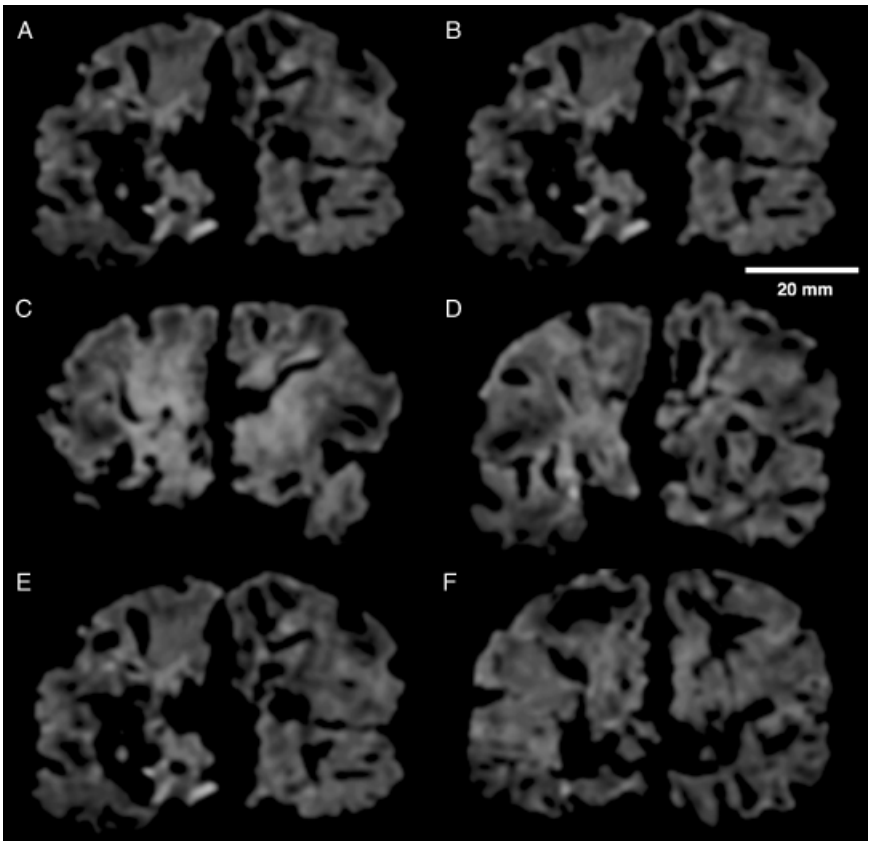

FIG. 3—*CT scans of the mummified brain in a coronal plane. The scans run from anterior (A) to posterior (F). The gyri and sulci are evident in the CT slices; however, the normally apparent internal structures of the brain are not readily identifiable. Masses of mummified tissue internally in panels B–F appear to represent the remains of the corpus striatum, diencephalon, and upper brainstem. The temporal lobe can be clearly seen to appear on the right in (C) and for both hemispheres in (D). The large spaces evident in these scans do not appear to represent the normal ventricular pattern of the human brain and are probably artifacts due to cracking of the neural tissue during the mummification process.*

be the remnants of the caudate nucleus, diencephalon, and upper brainstem. On the antero-inferior surface of the frontal lobe the orbital sulci and gyri were visible. The uncus was also visible. Portions of the cerebellum could be discerned on the postero-inferior surface of the desiccated brain. An endocast made of the internal surface of the endocranium provided confirmation of these superficially observable structures.

CT scanning of the brain in the various planes demonstrated that no internal structures of the brain had been preserved as identifiable entities during the mummification process. Structures such as the ventricles, folia of the cerebellum, compartments of the brainstem, corpus striatum, hippocampal complex, and diencephalon were not seen. The gyral and sulcal pattern was readily observed with CT scanning and closely matched the observations made visually on the external surface of the brain (Fig. 3). Despite the gyri and sulci being apparent, there was no clear distinction between the gray and white matter of the cerebral cortex as usually seen in CT scans of the *in situ* normal human brain (11).

Histological Appearance of the Mummified Cerebral Cortex

The microanatomy of the mummified neural tissue of a portion of the temporal lobe of the cerebral cortex was examined with hematoxylin and eosin, cresyl violet, and silver staining. The mummified neural tissue was seen to be amorphous and fragmented, providing the appearance of connective tissue with numerous lacunae. All stains were weakly positive, but individual neurons, neuroglia, myelin sheaths, cortical layers, blood vessels, and meningeal layers were not visible (Fig. 4). The hematoxylin and eosin stain showed an eosinophilic background, indicating the presence of remnants of cytoplasmic structures. There were areas that were basophilically stained indicating the remnants of proteins (Fig. 4*A*). The cresyl violet stain revealed what appeared to be remnants of Nissl bodies (Fig. 4*B*, *D*). The myelin stain, though revealing the presence of degraded biological matter, revealed no myelin sheaths (Fig. 4*C*). There appears to have been a postmortem contamination of the brain tissue by organisms with extremely thick cell walls and a granular cytoplasm (Fig. 4*A*, *E*). These are potentially either fungal spores or cysts produced in the lifecycle of a parasite (3) and were found close (within 100 μm) to the surface of the mummified cerebral cortex.

Discussion

Skull

The determination of age, sex, and population affinity are of fundamental importance in forensic anthropology (12). Although the determination of sex is essentially an either/or decision, the estimation of age, and population affinity do not have such simple and clear-cut divisions (13). When there are only skeletal remains, the difficulties associated with identification are increased (14). In the case of an isolated skull, only an uncertain estimate of sex and population affinity may be given, unless the skull in question shows traits that are extreme variants of the characteristics typical to any one group (15). This is unlikely, however, because absolute

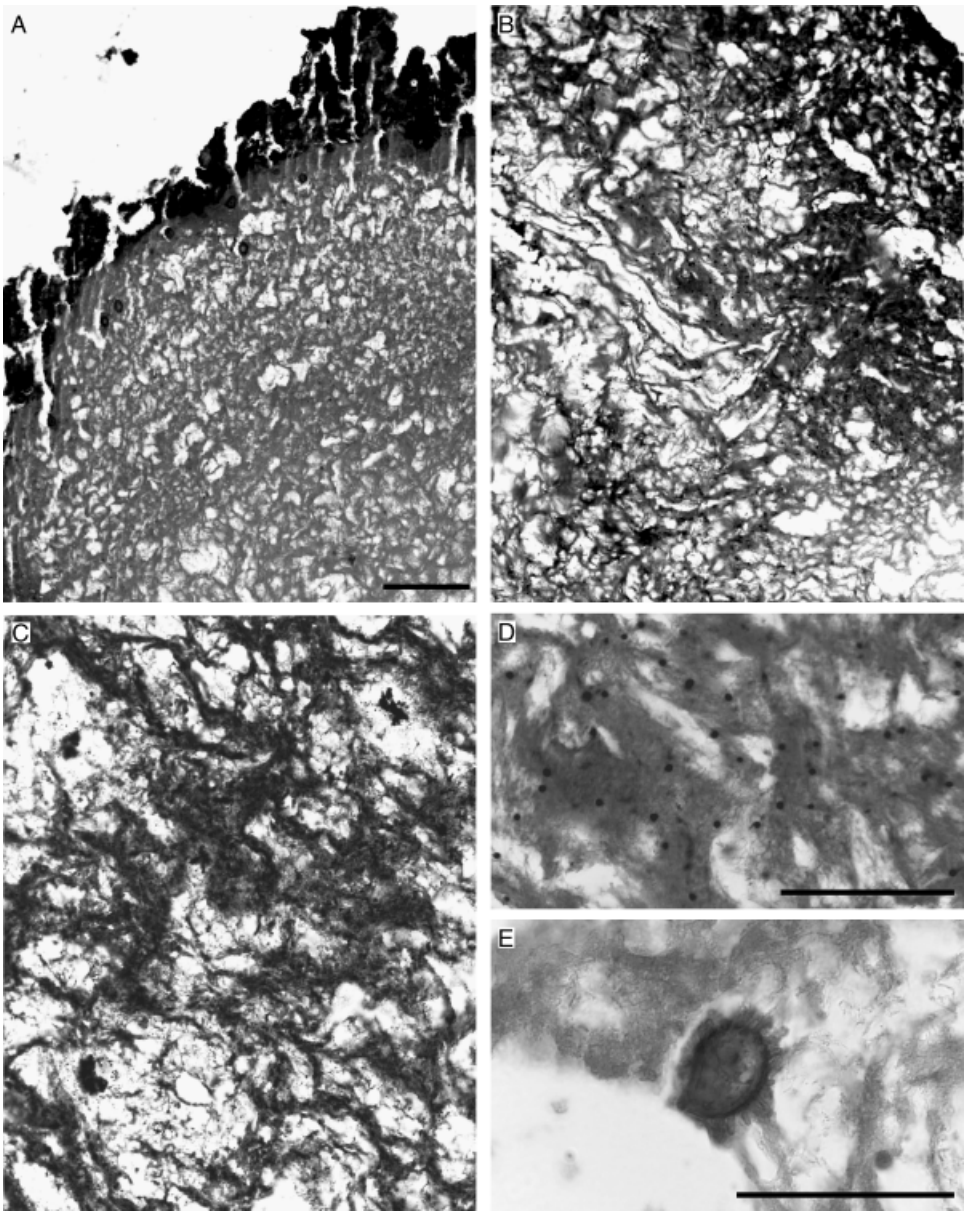

FIG. 4—*Photomicrographs of histologically stained portions of the mummified cerebral cortex of the middle temporal gyrus of the temporal lobe. (A) Hematoxylin and eosin staining. (B) Cresyl violet staining. (C) Silver staining. (D) Higher power micrograph of the cresyl violet stain revealing the intensely stained potential remnants of Nissl bodies. (E) Higher power micrograph of the hematoxylin and eosin stain showing the thick-walled organisms found in the mummified neural tissue. These are also evident at much lower power in (A) Scale bar in (A) = 200 μm and applies to (A), (B), and (C). Scale bar in (D) = 100 μm. Scale bar in (E) = 50 μm.*

differences in the crania of different sexes or population groups are not common and there are many intermediate forms (16). Therefore no single trait should be used to make an assessment of sex or population affinity (17). Despite these potential shortcomings in assignment of particular features to an isolated skull, our observations indicated that the skull and mummified brain of this specimen probably belonged to a white male, aged between 34 and 68 years.

The Naturally Mummified Brain

The discovery of the naturally preserved brain within the cranium of this forensic case was unusual in that very few reports of such cases have been made previously, and we could find no evidence of similar cases from sub-Saharan Africa (18). Moreover, the environment in which the specimen was found is unique, in that it was not buried, and it was neither in the arid desert conditions leading to preservation through desiccation (3,4), nor was it preserved in the damp conditions that lead to preservation in the state of adipocere (5). The present specimen resulted from preservation in the open savannah grassland in a region with moderate average rainfall, and high average summer temperatures and humidity with many sizeable thunderstorms. Because of the available information of the case, the time since death could not be calculated as the person has not been identified as yet and does not match any of the individuals in the missing persons databank. Further studies into the antiquity of the specimen will allow discussion of the conditions of the mummification.

The present specimen is similar to those described by Radanov et al. (4) and Gerszten and Martinez (3), in that it was hard, dry, and brittle. As with these other cases, the cerebral hemispheres, including gyral and sulcal patterns, were well preserved. The

dramatic reduction in size is another similarity. Structures such as the cerebellum and brainstem are often difficult to observe (3), and this was case for the present specimen. The degree of preservation of the cellular architecture of the brain has differed among studies (3–5,18); however, most studies recognize some cellular structures. In the present study the tissue was completely degenerated, with perhaps only Nissl bodies remaining from the original microstructure. Gerszten and Martinez (3) reported the presence of postmortem contamination by microorganisms. They proposed that these were most likely to be the fungal species *Microsporidia*. Although the structures seen in the tissue of this specimen are oval shaped, like those of *Microsporidia*, the *Microsporidia* have an anteriorly projecting apparatus (19), which is absent in the organisms seen here. These microorganisms remain to be identified for the present specimen.

We suggest that the present specimen became preserved because of hot and dry conditions at the time of death (2) with a significant water concentration gradient occurring between the brain and the environment (20). Mummification of soft tissue may occur as rapidly as within 2 weeks postmortem (21), but a period of *c*. 12 weeks appears more standard (22). The substantial degeneration of cellular structure, and the microorganism contamination, both indicate a period closer to 12 weeks for mummification. In the present case, only the brain tissue was preserved, and this implies that the conditions necessary for mummification may have occurred specifically within the cranium (4). The present specimen appears to have been extensively burnt in a bush fire. If the foramen magnum had been blocked (either by tissue or other material), it is possible that the interior of the cranium became very hot, leading to rapid fluid loss from the brain; however, there is no evidence of yellow staining of the bone that occurs when bone that is still flesh-covered burns (23). This indicates that the soft tissue had already decomposed and that the brain would have already been preserved. At this time it is unclear how the presently described specimen may have come to be, but future investigation of potentially similar cases in sub-Saharan Africa may reveal important clues.

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References

1. David AR. Disease in Egyptian mummies: the contribution of new technologies. Lancet 1997;349:1760–3.
2. Aufderheide AC, Munoz I, Arriazza B. Seven Chinchirro mummies and prehistory of northern Chile. Am J Phys Anthropol 1993;91:189–201.
3. Gerszten PC, Martinez AJ. The neuropathology of South American mummies. Neurosurgery 1995;36:756–61.
4. Radanov S, Stoev S, Davidov M, Nachev S, Stanchev N, Kirova E. A unique case of naturally occurring mummification of human brain tissue. Int J Legal Med 1992;105:173–5.
5. Tkocz I, Bytzer P, Bierring F. Preserved brains in medieval skulls. Am J Phys Anthropol 1979;5:197–202.
6. Meindl RS, Lovejoy CO. Ectocranial suture closure: a revised method for the determination of skeletal age at death based on the lateral-anterior sutures. Am J Phys Anthropol 1985;68:57–66.
7. Steyn M, Iscan MY. Sexual dimorphism in the crania and mandibles of South African whites. Forensic Sci Int 1998;98:9–16.
8. Iscan MY, Steyn M. Craniometric determination of population affinity in South Africans. Int J Legal Med 1999;112:91–7.
9. Bancroft JD, Stevens A. Theory and practice of histological techniques. 3rd ed. New York: Churchill Livingstone; 1990.
10. De Miguel C, Henneberg M. Variation in hominid brain size: how much is due to method? HOMO 2001;52:3–58.
11. Gado MH, Rao KCVG. Normal cranial CT anatomy. In: Lee SH, Rao KCVG, editors. Cranial computed tomography and MRI. 2nd ed. New York: McGraw-Hill Book Company; 1987:71–103.
12. Graw M, Czarnetzki A, Haffner HT. The form of the supraorbital margin as a criterion in identification of sex from the skull: investigations based on modern human skulls. Am J Phys Anthropol 1999;108:91–6.
13. White TD. Human osteology. 2nd ed. San Diego: Academic Press; 2001.
14. Johnson DR, O'Higgins P, Moore WJ, McAndrew TJ. Determination of race and sex of the human skull by discriminant function analysis of linear and angular dimensions. Forensic Sci Int 1989;41:41–53.
15. Keen JA. A study of the differences between male and female skulls. Am J Phys Anthropol 1950;8:65–78.
16. Bass WM. Human osteology: a laboratory and field manual. 4th ed. Columbia: Missouri Archaeological Society; 1995.
17. Haun SJ. Brief communication: a study of the predictive accuracy of mandibular ramus flexure as a singular morphologic indicator of sex in an archaeological sample. Am J Phys Anthropol 2000;111:429–32.
18. Aufderheide AC. The scientific study of mummies. Cambridge: Cambridge University Press; 2003.
19. Franzen C. Microsporidia: how can they invade other cells? Trends Parasitol 2004;20:275–9.
20. Aturaliya S, Lukasewycz A. Experimental forensic and bioanthropological aspects of soft tissue taphonomy: 1. factors influencing post-mortem tissue desiccation rate. J Forensic Sci 1999;44:893–6.
21. Reichs KJ Forensic osteology. Advances in the identification of human remains. 2nd ed. Springfield, IL: Charles C. Thomas; 1998.
22. Iscan MY. Global forensic anthropology in the 21st century. Forensic Sci Int 2001;117:1–6.
23. Krogman WM, Iscan MY The human skeleton in forensic medicine. Springfield, IL: Charles C. Thomas; 1986.

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