Historical Perspectives

The Paleopathology of the Cardiovascular System

M.R. Zimmerman, MD, PhD

Paleopathology, the study of disease in ancient remains, adds the dimension of time to our study of health and disease. The oldest preserved heart is from a mummified rabbit of the Pleistocene epoch, over 20,000 years old. Cardiovascular disease has been identified in human mummies from Alaska and Egypt, covering a time span ranging from approximately 3,000 to 300 years ago. An experimental study suggests that the potential exists for identifying a wide range of cardiovascular pathologic conditions in mummified remains. The antiquity and ubiquity of arteriosclerotic heart disease is considered in terms of pathogenesis. ***(Texas Heart Institute Journal 1993;20:252-7)***

Paleopathology, the study of the evidence of disease in ancient human and animal remains, adds the dimension of time to our study of health and disease. Pathogenic organisms and mechanisms—and the patterns of disease they cause—evolve just as do larger organisms, including the hosts and vectors of disease. Paleopathologic studies have given us insight into the antiquity and evolution of congenital, traumatic, nutritional, degenerative, and infectious disease,[1] while suggesting that cancer may be a relatively recent disease.[2] Mummies, defined as bodies preserved either naturally or artificially, hold a great potential for paleopathologic examination. Postmortem examinations can be performed on mummies, and the diagnoses of many disorders can be made with relative accuracy and confidence.[3]

Rehydration of desiccated tissues is accomplished by overnight immersion of small samples in a solution of water, alcohol, and sodium carbonate, a technique developed in Egypt in 1921 by the father of modern paleopathology, Sir Marc Armand Ruffer.[4] The rehydrated tissue is processed for microscopic examination in the same fashion as fresh tissue. Nuclear detail is usually minimal or lacking, but, in general, skin and connective tissues are reasonably well preserved. The state of preservation of internal organs over long periods of time is somewhat variable, depending on mummification rites, entombment, and environmental conditions.[5] A number of mummies have shown preservation of the heart and major blood vessels, which has enabled paleopathologists to gain insight into the antiquity of disorders affecting the cardiovascular system.

Alaskan Mummies

The oldest preserved bodies from Alaska are 20,000-year-old mammals of the late Pleistocene epoch. Among several specimens that I examined in 1975, from the American Museum of Natural History in New York City, was a rabbit in which the viscera were easily identifiable and grossly appeared to be well preserved, and which showed preservation of the general architecture of the liver but no trace of histologic structure in the other organs, including the heart.[6]

The preservative effect of freezing and subsequent mummification lasts much longer than previously suspected. However, the tissue destruction observed does suggest that a significant period of time elapsed between the death of the animals and their entombment in the permafrost, countering a popular notion that Arctic mammals were killed and preserved instantaneously by a catastrophic climatic change.

Naturally frozen bodies of ancient human beings have also been found in Alaska. The oldest one, dating to about 400 AD, was that of a 53-year-old Eskimo woman found on St. Lawrence Island in the Bering Sea.[7,8] In October of 1972, a frozen body washed out of a low beach cliff on the island, which is about 130 miles from mainland Alaska. The body was transported to Fairbanks, where it was

Key words: *Cardiovascular diseases; mummies; paleopathology*

From: *The Department of Pathology and Laboratory Medicine, Hahnemann University; and the Department of Anthropology, University of Pennsylvania; Philadelphia, Pennsylvania*

Address for reprints: *Michael R. Zimmerman, MD, PhD, M.S. 113, Hahnemann University, Broad and Vine, Philadelphia, PA 19102*

thawed, and George Smith, of the National Park Service and University of Alaska, and I performed a complete autopsy.

The internal organs were somewhat desiccated, a process that continues even in the frozen state. There was a moderate degree of aortic and coronary atherosclerosis, visible grossly as yellow streaking in the brown vessels, and confirmed on microscopy (Fig. 1). There was no evidence of myocardial infarction, acute or healed. The well-preserved valves and chambers were normal.

Death was determined to have been traumatic; in addition to gross and microscopic evidence of skull fractures, the smaller bronchi of both lungs were packed with moss that formed casts of the bronchi. The histologic finding of aspirated moss associated with hemorrhage suggested that accidental burial and suffocation played a significant role in this woman's death. Our conclusion was that she had been buried alive in a landslide or earthquake, and asphyxiated. Aspiration of foreign material into the bronchi associated with hemorrhage is known to occur in accidental inhumation, and has been demonstrated in persons who fall into or are buried in coal heaps. Nor is it unusual for red blood cells to be preserved for extended periods; preserved erythrocytes have been reported in the tissues of Peruvian and North American Indian mummies, and in 6,000-year-old Egyptian mummies.[9]

In 1980, several other frozen Eskimo bodies were recovered from a site in Barrow, the northernmost community in Alaska.[10,11] An entire family had been trapped while asleep, crushed and frozen in their house on a bluff overlooking the Arctic Ocean. Spring storms can break up the ice and force it onto the shore with tremendous destructive force, a phenomenon known by the Eskimos as *ivu.*

Dr. Arthur Aufderheide of the University of Minnesota-Duluth and I were confronted with a mass of sleeping robes, bodies, and bones. Radiographs and computed-tomographic scans allowed us to sort out 5 bodies. These radiologic studies also demonstrated the difficulties of interpretation in ancient bodies; frozen pleural fluid was at first interpreted as aerated lung tissue. Three of the bodies were sub-adults reduced to skeletons. The other 2 bodies were intact and extraordinarily well preserved. On the basis of where they were found in the house, the intact bodies were named the Northern Body (NB) and the Southern Body (SB). A radiocarbon date on the NB was 1520 AD ± 70, well before white contact in the area (and in most of the New World).

The NB, a 25- to 30-year-old female, was found on the sleeping platform in the house, wrapped in her sleeping robes. The entire right hemithorax was crushed, indicated in part by multiple rib fractures. Although the computed-tomographic scan seemed to indicate that the lungs were inflated, autopsy revealed collapsed lungs and bilateral frozen pleural effusions containing many bubbles. Analysis of the fluid revealed traces of hemoglobin, confirming a hemopneumothorax.

The heart showed a slight dilatation of the right side, probably caused by obstructed pulmonary blood flow through the crushed and collapsed lungs. The young woman's coronary arteries were free of disease (Fig. 2).

As in the case of the St. Lawrence Island woman, the lungs were intensively anthracotic, attributed to the heating of the house with small, smoky seal-oil lamps. It was the duty of the women to trim the lamp at night, and sleeping next to the lamp increased their exposure to smoke, resulting in severe anthra-

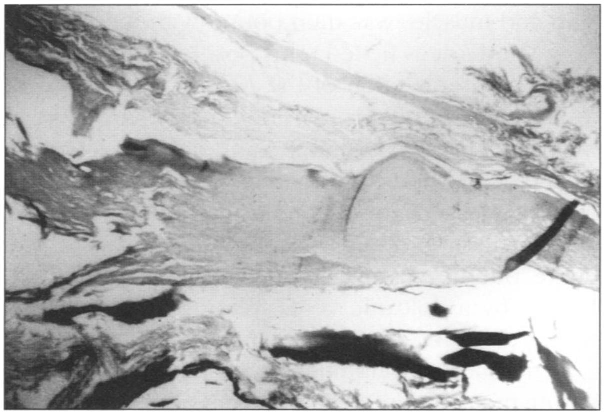

Fig. 1 *A coronary artery of a 53-year-old Eskimo woman who died 1,600 years ago, showing atherosclerosis. (H + E orig. x95)*

(From: Zimmerman MR, Smith GS,[7] courtesy of the New York Academy of Medicine.)

Fig. 2 *A normal coronary artery from a young Eskimo woman who died 500 years ago. (H + E orig. x32)*

cosis at an early age. Although anthracotic pigment is relatively innocuous, the introduction of cigarette smoking to Alaska during World War II has created a synergistic effect, and lung cancer is a major health problem for modern Eskimo women.

The bladder was markedly dilated and the stomach empty. Similar findings in the other adult, the SB, led to the conclusion that the catastrophe occurred early in the morning, trapping the sleeping family.

The other woman, did, however, try to escape. Her body was found in the doorway, with her boots in one hand and a roof beam across her chest. There were multiple fractures of both right and left ribs and both lungs were collapsed.

The SB was 42 to 45 years of age, so she had more time to acquire evidence of disease. Her lungs and lymph nodes were even more severely anthracotic, and she had atherosclerosis involving the aorta (Fig. 3) and coronary arteries. The mitral valves showed focal calcification (Fig. 4), for which the differential diagnosis includes rheumatic valvulitis (unlikely, since there was no shortening or fusion of the chordae tendineae) and calcific mitral stenosis (again unlikely, since the calcification was out on a leaflet rather than in the ring, and since she was too young for this disease). The most likely choice was a healed bacterial endocarditis, even considering the odds against survival before the advent of antibiotic agents. Pleural adhesions suggested a previous bout of pneumonia, as a source for bacteremia. The kidneys showed evidence of healed tubular necrosis, suggesting that she had survived a serious illness earlier in life.

Both the NB and the SB showed severe osteoporosis, the bone spicules being remarkably thinned and decalcified. Osteoporosis is a major health problem for modern Eskimos, the most likely cause being the traditional high-protein diet, which results in metabolic acidosis and consequent calcium loss from the bones.

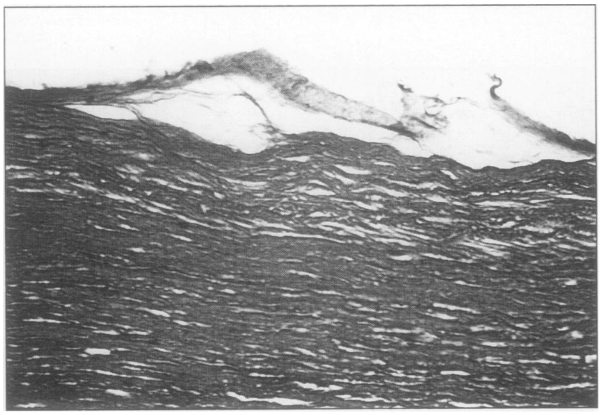

Fig. 3 *The aorta of a middle-aged Eskimo woman, dead for 500 years, shows atherosclerosis. (H + E orig. x32)*

(From: Zimmerman MR, Aufderheide AC,[10] with permission of the University of Wisconsin Press.)

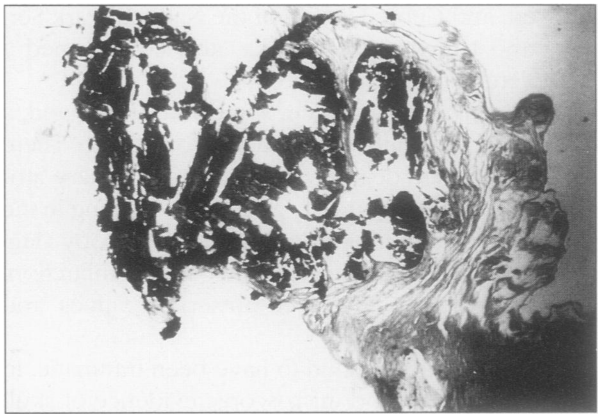

Fig. 4 *The mitral valve of the same middle-aged woman shows a focus of calcification consistent with bacterial endocarditis. (H + E orig. x8)*

(From: Zimmerman MR, Aufderheide AC,[10] with permission of the University of Wisconsin Press.)

The bodies have now been reburied in accordance with the wishes of the elders, and the artifacts and records of the studies have formed a modest museum display in the town hall in Barrow, as a memorial to this family and to the human ability to survive in hostile environments.

Artificially prepared 18th-century mummies have been recovered from the Aleutian Islands. The technique of mummification varied with the social status of the deceased. The bodies of tribal leaders and hunters were eviscerated through an abdominal incision, and removal of fat was completed by putting the body in running water. The body, reduced to skin and muscle, was then bound with the hips, elbows, and knees flexed. This position being the habitual leisure position of the Aleuts, the binding of the mummy bundle is considered to be an effort to maintain the deceased in a comfortable position.

The flexed body was then air dried and wrapped in the deceased's best clothes and various layers of seal, sea lion, or otter skins, and fiber matting. The entire bundle was then removed to a burial cave heated by a volcanic vent, creating a preservative warm, dry atmosphere.

A number of mummies were removed from the Aleutian chain in the late 19th and early 20th centuries and donated to the Smithsonian Institution and the Peabody Museum at Harvard University. Aside from determination of blood groups, the mummies remained uninvestigated at the Smithsonian until a group that I directed examined one, a middle-aged male, in 1969.[12] The mummy of a middle-aged female from the Peabody[13] has also been examined. Both appear to have been commoners, as neither had been eviscerated.

Both mummies were examined initially by roentgen ray, and then unwrapped. The anterior thoracic and abdominal walls were removed and the internal organs identified and removed.

The various tissues were sampled and rehydrated for histologic examination. In the Smithsonian mummy, the general fascicular architecture of the heart was preserved, and seen scattered throughout the tissue were small aggregates of crystalline material ranging from 50 to 200 microns in diameter. These contained numerous gram-negative bacilli and were considered to be abscesses.

The pulmonary architecture was generally well preserved, showing a moderate amount of anthracosis and some fibrosis, coalescence of alveoli, and an increase in elastic tissue. A number of abscesses, again containing gram-negative bacilli, were seen, particularly in the pleural areas, as well as in the kidneys. A section of the right lower lobe showed complete loss of the normal architecture, the tissue consisting of amorphous material containing free gram-negative bacilli and scattered small abscesses. Examination of the aorta and other arteries showed atherosclerotic plaques.

Death was concluded to be due to a right-lower-lobe pneumonia, probably caused by *Klebsiella pneumoniae*, with bacteremic spread to the heart, other lobes of the lungs, and kidneys. Other findings included anthracosis, again due to open cooking and heating fires in the home.

The Aleut mummy from Harvard University's Peabody Museum was a middle-aged woman, who also showed evidence of atherosclerosis, as well as previous pneumonia and anthracosis. The kidneys, like those of the SB from Barrow, showed evidence of healed acute tubular necrosis, probably related to an episode of shock in the course of her pneumonia. The cause of death could not be determined.

Egyptian Mummies

The heart is usually present in Egyptian mummies, because part of the funerary mythology was the weighing of the heart against the feather of truth by the god Maat. Failure of the heart, literally, to "measure up" (a virtuous heart would prove lighter than the feather) condemned the deceased to an unhappy afterlife in a part of the underworld inhabited by snakes, 3-headed monsters, and other evil creatures.[14]

Previous archeologic and paleopathologic studies have documented the antiquity of cardiovascular disease in Egypt. Sudden deaths depicted in reliefs or described in inscriptions in Egyptian tombs have been diagnosed as evidence of coronary artery disease and myocardial infarction[15] and cerebrovascular accident.[16] This historical evidence is well substantiated by the finding of atherosclerosis in many Egyptian mummies.[17] Severe aortic atherosclerosis was seen in the Pharaoh Merneptah,[18,19] and Ruffer[4] found involvement of all arteries, large and small, to be very common among the hundreds of mummies he examined. Long[20] demonstrated coronary artery disease, myocardial fibrosis, and arteriolar nephrosclerosis in a 3,000-year-old Egyptian mummy. Shaw[21] noted involvement of the superior mesenteric artery in the mummy of Har-mosĕ, a singer of the 18th Dynasty. A recent autopsy of a mummy from the collection of the University of Pennsylvania Museum revealed severe atherosclerosis of the aorta and diffuse arteriolar sclerosis on microscopic examination,[3] but my examination of the remains of 50 mummies in a tomb in Upper Egypt revealed atherosclerosis in only one.[22]

Radiologic studies have detected calcification of vessels in Amenhotep and Ramses II,[23] but a radiologic survey of Egyptian mummies in European and British museums detected such changes in only 4 of 88 adult mummies.[24] This low figure probably reflects the inadequacy of radiologic evaluation for this disorder.

The diagnosis of the sequelae of atherosclerosis, e.g., thrombosis, embolization, and myocardial or pulmonary infarction, has not been made in any mummy. This is surprising in view of the historic and anatomic evidence of atherosclerosis but may be the result of a problem in preservation, as discussed below.

An Experimental Study of Mummification

The difficulties of diagnosis of pathologic conditions in modern tissue specimens are immensely magnified in studying ancient remains. An approach to this matter was undertaken by an experimental study, in which small tissue specimens from cadavers undergoing postmortem examination were desiccated, rehydrated, and examined histologically.[5,25] The specimens were dried in an oven, rehydrated, and processed. Fresh tissues were used as controls. A variety of tissues (including cardiac tissues) and of disease processes were studied by this technique.

In normal myocardium, the outlines of the fibers were preserved, although cross striations were not well seen. Examination of a severely atherosclerotic and thrombosed coronary artery showed excellent preservation of the atherosclerosis and calcification after mummification and rehydration. The thrombus was reduced to eosinophilic material indistinguishable with hematoxylin and eosin from a mummified postmortem blood clot. Phosphotungstic acid hematoxylin diffusely stained the material within the lumen: the red blood cells and fine detail of the fibrin were no longer seen, but the mesh-like fibrin pattern remained.

An acute myocardial infarction was essentially undiagnosable, the mummified necrotic tissue being distinguished from the adjacent autolyzed myocardium only by a few fragmented neutrophils (Fig. 5). The necrosis of muscle in an acute infarct is in essence a process of in situ autolysis, and diagnosis of an acute infarct in a mummified heart would have to be based on the finding of the remains of a neutrophilic infiltrate—a difficult matter at best in the experimental setting, and probably impossible in a naturally or artificially preserved mummy.

The fibrosis of a mummified healing myocardial infarct was seen as a lighter-staining eosinophilic area with a decreased number of nuclei. Trichrome staining showed the fibrosis and peripheral organization well. Chronic passive congestion of the lungs, liver, and spleen was well displayed, particularly the hemosiderin pigment present, which retained a marked avidity for the iron stain.

This study indicated that the diagnosis of an acute myocardial infarction is probably not possible in a mummified body. Strong presumptive evidence, including coronary artery disease or thrombosis, myocardial scarring, and chronic visceral congestion, should be preserved and allow for the assignment of atherosclerotic heart disease as the cause of death in mummified bodies, in either the archeological or forensic setting.[26]

Conclusions

Natural or artificial mummies have proved to be excellent subjects for paleopathologic examination. Conditions in the Arctic would seem to provide for excellent preservation of soft tissues, but bodies are in fact preserved there only under extraordinary circumstances. The frozen ground makes winter burials impossible, and the permafrost layer, being only a few centimeters below the surface, discourages deep burials even in summer. Cycles of freezing and thawing tend to bring summer burials to the surface, exposing remains to the ravages of climate and animals.

Studies of Arctic mummies do point out a major focus of paleopathology, the reconstruction of ancient disease patterns. Rare finds such as those described above give us a glimpse into the prehistoric Arctic and show health hazards shared by past and present inhabitants of a once-remote area. Some of the cardiovascular diseases discovered in these mummies, such as bacterial endocarditis and myocardial abscesses, have well-known natural histories and are relatively easily explained in the context of the Arctic ecosystem.

We have also seen that ancient Eskimos, far removed from the stresses of modern technological society, suffered from coronary artery disease, a process that has also been well documented as far back as dynastic Egypt, by both historical and anatomic evidence. This anatomic evidence in Alaska not only confirms the antiquity of arteriosclerotic heart disease but also its occurrence in a preliterate society that lacks the historical evidence seen in Egypt.

Various factors have been implicated in the pathogenesis of atherosclerosis, including diets high in cholesterol and saturated fat, hypercholesterolemia, hypertension, diabetes, salt intake, lack of physical activity, and cigarette smoking.[27] Cigarette smoking usually does not apply in the consideration of ancient populations, and most of these other factors are not amenable to documentation in paleopathologic specimens, although hypertension is suggested by the occasional finding of arteriolar nephrosclerosis.[20] Heavy physical activity was most often a major feature of life in antiquity. The Eskimo diet was almost entirely meat, as attested to by their severe osteoporosis, while the Egyptian diet contained meat only at occasional festival times; yet the finding of atherosclerosis in both groups suggests that diet alone may not be a critical factor. If stress is a factor in this disease, perhaps the lesson is that stress is a component of life shared by all human societies.

Fig. 5 *An acute myocardial infarct, experimentally mummified, is essentially indistinguishable from autolyzed myocardium. (H + E orig. x80)*

References

1. Zimmerman MR, Kelley MA. Atlas of human paleopathology. New York: Praeger, 1982.
2. Zimmerman MR. An experimental study of mummification pertinent to the antiquity of cancer. Cancer 1977;40:1358-62.
3. Cockburn A, Cockburn E, eds. Mummies, disease and ancient cultures. Cambridge: University Press, 1980.
4. Ruffer MA. Studies in the paleopathology of Egypt. Chicago: University of Chicago Press, 1921.

5. Zimmerman MR. Paleopathologic diagnosis based on experimental mummification. Am J Phys Anthropol 1979;51:235-54.
6. Zimmerman MR, Tedford RH. Histologic structures preserved for 21,300 years. Science 1976;194:183-4.
7. Zimmerman MR, Smith GS. A probable case of accidental inhumation of 1,600 years ago. Bull N Y Acad Med 1975;51:828-37.
8. Masters PM, Zimmerman MR. Age determination of an Alaskan mummy: morphological and biochemical correlation. Science 1978;201:811-2.
9. Zimmerman MR. Blood cells preserved in a mummy 2000 years old. Science 1973;180:303-4.
10. Zimmerman MR, Aufderheide AC. The frozen family of Utqiagvik: the autopsy findings. Arctic Anthropol 1984;21:53-63.
11. Zimmerman MR. Paleopathology in Alaskan mummies. Am Sci 1985;73:20-5.
12. Zimmerman MR, Yeatman GW, Sprinz H, Titterington WP. Examination of an Aleutian mummy. Bull N Y Acad Med 1971;47:80-103.
13. Zimmerman MR, Trinkaus E, LeMay M, et al. The paleopathology of an Aleutian mummy. Arch Pathol Lab Med 1981;105:638-41.
14. Boisaubin EV. Cardiology in ancient Egypt. Tex Heart Inst J 1988;15:80-5.
15. Bruetsch WL. The earliest record of sudden death possibly due to atherosclerotic coronary occlusion. Circulation 1959;20:438-41.
16. Rowling JT. Pathological changes in mummies. Proc R Soc Med 1961;54:409-15.
17. Sandison AT. Degenerative vascular disease in the Egyptian mummy. Med Hist 1962;6:77-81.
18. Smith E. The unwrapping of Pharaoh. Br Med J 1908;1:342-3.
19. Shattock SG. Report on the pathology of King Menephtah. Lancet 1909;1:319.
20. Long AR. Cardiovascular renal disease: report of a case three thousand years ago. Arch Pathol 1931;12:92-4.
21. Shaw AFB. A histological study of the mummy of Har-mosĕ, the singer of the eighteenth Dynasty (circa 1490 B.C.) J Pathol Bacteriol 1938;47:115-23.
22. Zimmerman MR. The mummies of the tomb of Nebwenenef: paleopathology and archeology. J Am Res Center Egypt 1977;14:33-6.
23. Harris JE, Wente EF, eds. An x-ray atlas of the royal mummies. Chicago: University of Chicago Press, 1980.
24. Gray PHK. Radiography of ancient Egyptian mummies. Med Radiogr Photogr 1967;43:34-44.
25. Zimmerman MR. Histological examination of experimentally mummified tissues. Am J Phys Anthropol 1972;37:271-80.
26. Zimmerman MR. The mummified heart: a problem in medicolegal diagnosis. J Forensic Sci 1978;23:750-3.
27. Cotran RS, Kumar V, Robbins SL. Robbins pathologic basis of disease. 4th ed. Philadelphia: WB Saunders, 1989:568-9.