International Journal of Cardiology 223 (2016) 101–107

Contents lists available at ScienceDirect

International Journal of Cardiology

journal homepage: www.elsevier.com/locate/ijcard

Paleopathology of cardiovascular diseases in South American mummies

Alexander N. Gabrovsky, Ph.D. [a,*,1], Kelsey D. O'Neill, B.S. [b,2], Enrique Gerszten M.D. [a,1]

[a] Department of Pathology, Medical College of Virginia Campus, Virginia Commonwealth University, USA
[b] Department of Biology, Virginia Commonwealth University, USA

ARTICLE INFO

Article history:
Received 22 July 2016
Accepted 7 August 2016
Available online 9 August 2016

Keywords:
Mummies
South America
Atherosclerosis
Cardiomegaly
Coca leaf

ABSTRACT

Background: Cardiovascular disease has emerged as the world's leading cause of death in the last century. An epidemiological focus of this disease that extends not only beyond the developed world but also far back into antiquity asks new questions about associated risk factors. Ancient mummies found in the Atacama desert are well preserved and show signs of cardiovascular disease as early as 1000 B.C. in Peru and Chile.
Method and results: Gross and histopathological examination of specimens shows atherosclerosis, cardiomegaly, endocarditis, and myocardial fibrosis.
Conclusion: In comparison to other ancient populations, less atherosclerosis has been noted in South American mummies. The chewing of coca leaves, a habitual cultural practice unique to the region, supports evidence of reduced cardiovascular risk among ancient people living in South America.

1. Introduction

> Pierce her soft soul, and rend her bleeding heart;Its quick pulsations paus'd, and, chill'd with dread,A livid hue her fading cheek o'erspread.– Helen Maria Williams, *Perú* (1784) [1]

Cardiovascular diseases are the leading causes of death throughout the world, and rates continue to rise in developing countries [2]. In 2012, 17.5 million people died from cardiovascular diseases; 7.4 million of these deaths were due to coronary heart disease [3]. An evolutionary perspective of cardiovascular disease, especially the study of its variations in expression among diverse human populations, can provide a global picture of this modern disease. Evolutionary studies of human disease have shaped our current understanding of the immune system and function [4]. The study of ancient disease, termed paleopathology, can be used as a tool to predict future trends in the evolving disease-scape among human populations. To better understand cardiovascular disease and its progression across time, this study examines evidence of cardiovascular diseases in South American mummies from ancient cultures of southern Peru and northern Chile from approximately 1000 BCE to 1500 CE in the area once ruled by the Inca Empire. Specific environmental factors, such as topography and diet, also impacted the cardiovascular health of ancient people. To explain less atherosclerosis in South American mummies compared to those of other ancient civilizations, the consequences of unique cultural practices in the Andean region are considered. Beneficial cardiovascular effects from habitual chewing of coca leaf might have functioned as a possible protective factor against plaque formation in this ancient population.

2. Mummies from the Ica Valley, Peru and the Azapa Valley, Chile

Under the auspices of the National Geographic Society and the Department of Pathology at the Medical College of Virginia, Virginia Commonwealth University, a multidisciplinary team of archeologists, anthropologists, and paleopathologists examined cultural artifacts and mummified remains excavated over a 40-year period from the Ica Valley in southern Peru and the Azapa Valley in northern Chile. These coastal valleys are the driest places on earth. The arid climate of the Atacama desert is suitable for the preservation of ancient burial contents. This present study concentrates mainly on the Azapa valley, a narrow stretch of land about 100 km, which lies between the Andes and the Pacific. Glacial meltwater from the Andes replenishes this dry ravine, or *quebrada*, and the Río San José bisects the valley during the summer months. The cordillera slopes of the Andes also provided a suitable environment for agricultural development, resulting in the establishment of eight, thriving cultures in this fertile region for nearly 8000 years.

Excavated remains from the Azapa valley were transferred to the Museo de Antropología y Arqueología de la Universidad de Tarapacá, Arica, Chile, and remains from the Ica valley were studied at the

* Corresponding author at: Paleopathology Research Lab, Department of Pathology, Medical College of Virginia, PO Box 980662, 1101 E. Marshall Street, Richmond, VA 23298-0662, USA.
E-mail address: alexander.gabrovsky@gmail.com (A.N. Gabrovsky).
[1] These authors take responsibility for all aspects of the reliability and freedom from bias of the data presented and their discussed interpretation.
[2] This author takes responsibility for all aspects of the reliability and freedom from bias of the data presented and their discussed interpretation.

http://dx.doi.org/10.1016/j.ijcard.2016.08.176
0167-5273/

Museo Regional de Ica, Perú. Radiographs of mummy bundles were obtained prior to autopsies, which were performed utilizing similar techniques as practiced in pathology today. The skeletal and organ systems were studied through gross and microscopic examination. Mummies were dated using archeological evaluation of cultural artifacts and were selectively confirmed by ^{14}C analysis. Tissues used in this study were transferred to the Paleopathology Research Laboratory at the Medical College of Virginia, Virginia Commonwealth University for further examination.

Many specimens in this study belong to the Cabuza culture, which thrived c. 300–1000 CE during the Middle Horizon period. Influenced by the Tiwanaku Empire, the Cabuza settled between the Ilo and Camarones valleys as agricultural-based communities that used irrigated fields to grow maize (Fig. 1), quinoa (Fig. 2), squash, beans, jicama, and coca, among others. The majority of burials were interred with food offerings reflecting their agricultural activities in this coastal valley. Artifact remains from the excavation also include grave offerings, such as decorated wooden spoons, carved *kero* cups, musical instruments carved from cane, ceramics with geometric elements, and elaborately woven textiles (Fig. 3). The Cabuza, among many other societies in the region, had unique cultural practices, such as intentional cranial deformation, trepanation, and the habitual chewing of coca leaves. Bodies of the dead were placed in fetal or crouching positions (Fig. 4), sometimes crowned with four-cornered hats, and then wrapped in woolen *unku* that were tied with rope made of *tortora* reeds (Fig. 5).

3. Gross and microscopic examination of the cardiovascular system in mummies

Sir Marc Armand Ruffer, considered a founder of paleopathology, developed a rehydration technique for examining microscopic sections of dessicated tissue [5]. Ruffer's solution is composed of ethyl alcohol, sodium carbonate, and formalin. Given the ability to rehydrate ancient tissue, mummified remains are suitable for organ identification and, if possible, determination of various disease processes. In this study, approximately 40% of the internal organs remained intact. The lungs, heart, liver, and kidneys are typically easy to identify. The pancreas and adrenal glands have never been detected in a mummy due to a higher amount of catalytic enzymes causing rapid postmortem autolytic changes.

3.1. Gross examination of the heart

The heart is one of the internal organs more likely to be preserved. Due to the lower amount of catalytic enzymes that originate from lysosomes, the heart is slow to undergo postmortem autolytic changes. Valves of the heart are especially resistant to autolytic destruction and can also be seen grossly. A complete heart of a 3-year-old female from the Cabuza culture (350 CE) was rehydrated. The child's heart is seen grossly and was injected with Hypaque 60 (meglumine diatrizoate 60%) contrast dye to visualize the coronary arteries and all right-sided chambers by fluoroscopy (Fig. 6). The foramen ovale and interventricular septum were closed, demonstrating that there were no congenital defects present.

Fig. 1. The burial of a male mummy included a collection of maize as a food offering.

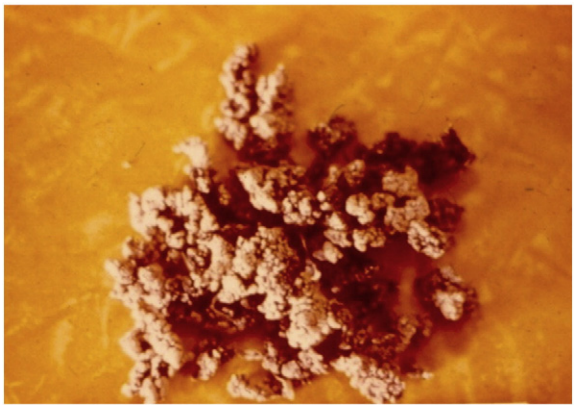

Fig. 2. Ancient specimen of *Chenopodium pallidicaule*, a species of goosefoot closely related to *Chenopodium quinoa*.

3.2. Microscopic examination of the myocardium

Autolytic changes in postmortem myocardium and the fragile nature of this tissue are common complications in identifying certain diseases of the heart. Some of these difficulties were demonstrated by Zimmerman [6], who did experimental studies of mummifying a heart with acute myocardial infarction from a recent autopsy and showed that it was nearly impossible to detect it in a mummy because necrotic tissue was indistinguishable from adjacent normal autolytic myocardial fibers. Healed infarcts, which contain a large amount of fibrous tissue, are much easier to identify. It is of interest that, using electron microscopy, we identified the bands of normal myocardium in a 12-year-old female mummy from the Cabuza culture (300–600 CE) (Fig. 7).

3.3. Blood vessels and cells

Large blood vessels are easy to identify due to the abundant amount of elastic tissue, which can also be detected by special stains. Grossly, dessicated blood is dark brown and the serum generally appears yellow. Red and white blood cells undergo autolytic changes in mummified tissue and are rarely identified. However, red blood cells are more likely to

Fig. 3. Textiles found near the coast in the burial site of a 50-year-old male.