

# Atherosclerosis across 4000 years of human history: the Horus study of four ancient populations



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## Summary

**Background** Atherosclerosis is thought to be a disease of modern human beings and related to contemporary lifestyles. However, its prevalence before the modern era is unknown. We aimed to evaluate preindustrial populations for atherosclerosis.

**Methods** We obtained whole body CT scans of 137 mummies from four different geographical regions or populations spanning more than 4000 years. Individuals from ancient Egypt, ancient Peru, the Ancestral Puebloans of southwest America, and the Unangan of the Aleutian Islands were imaged. Atherosclerosis was regarded as definite if a calcified plaque was seen in the wall of an artery and probable if calcifications were seen along the expected course of an artery.

**Findings** Probable or definite atherosclerosis was noted in 47 (34%) of 137 mummies and in all four geographical populations: 29 (38%) of 76 ancient Egyptians, 13 (25%) of 51 ancient Peruvians, two (40%) of five Ancestral Puebloans, and three (60%) of five Unangan hunter gatherers ( $p=NS$ ). Atherosclerosis was present in the aorta in 28 (20%) mummies, iliac or femoral arteries in 25 (18%), popliteal or tibial arteries in 25 (18%), carotid arteries in 17 (12%), and coronary arteries in six (4%). Of the five vascular beds examined, atherosclerosis was present in one to two beds in 34 (25%) mummies, in three to four beds in 11 (8%), and in all five vascular beds in two (1%). Age at time of death was positively correlated with atherosclerosis (mean age at death was 43 [SD 10] years for mummies with atherosclerosis vs 32 [15] years for those without;  $p<0.0001$ ) and with the number of arterial beds involved (mean age was 32 [SD 15] years for mummies with no atherosclerosis, 42 [10] years for those with atherosclerosis in one or two beds, and 44 [8] years for those with atherosclerosis in three to five beds;  $p<0.0001$ ).

**Interpretation** Atherosclerosis was common in four preindustrial populations including preagricultural hunter-gatherers. Although commonly assumed to be a modern disease, the presence of atherosclerosis in premodern human beings raises the possibility of a more basic predisposition to the disease.

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## Introduction

When in the course of human history did atherosclerosis appear? Is it a disease of lifestyle? Of ageing? Of another cause? With the doubling of life expectancy across the developed world between 1800 and 2000,<sup>1</sup> atherosclerotic vascular disease has replaced infectious disease as the leading cause of death across the developed world.<sup>2</sup> A common assumption is that atherosclerosis is predominately lifestyle-related and that if modern human beings could emulate preindustrial or even preagricultural lifestyles, that atherosclerosis, or least its clinical manifestations, would be avoided.<sup>3</sup>

Human cultures residing in environments that are either very dry, hot, or cold have independently discovered how to mummify their dead. Thus, preindustrial or preagricultural cultures created the opportunity for a natural experiment—to study these ancient human beings with modern CT scanning to assess the extent of vascular calcifications in diverse environments and cultures. A common component of a mature atherosclerotic plaque,

vascular calcification in modern day human beings is pathognomonic for atherosclerosis.<sup>4</sup> Calcification consistent with atherosclerosis has been identified by CT scanning in the naturally mummified Iceman from present day Italy who lived around 3000 BCE (before common era).<sup>5</sup> More than a century ago, Johann Nepomuk Czermak<sup>6</sup> and Sir Marc Armand Ruffer<sup>7</sup> gave serious evidence for atherosclerosis in several autopsies of Egyptian mummies from around 1000 BCE. Our recent studies confirmed these findings of atherosclerosis in 20 of 44 Egyptian mummies who lived during several dynasties between 1981 BCE and 364 CE (common era).<sup>8,9</sup> However, ancient Egyptian culture and lifestyles might have had unique attributes relative to atherogenesis. Moreover, mummification in Egypt during the bulk of this time was primarily performed on elite Egyptians of high socioeconomic status.

We now ask whether atherosclerosis was common in other ancient societies, including those that had very different diet and genetic makeup to the people of

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ancient Egypt. The current HORUS study (named for Horus, the ancient Egyptian deity) addressed these and related questions by CT scanning the bodies of mummies from numerous geographically and chronologically disparate cultures.

**Methods**

**Study design**

137 mummies from populations of four disparate geographic regions were studied by whole body CT scanning: 76 ancient Egyptians (predynastic era, ca 3100 BCE, to the end of the Roman era, 364 CE, 13 excavation sites), 51 early intermediate to late horizon peoples in present day Peru (ca 200–1500 CE, five excavation sites), five Ancestral Puebloan of the Archaic and Basketmaker II cultures living in southwest America (ca 1500 BCE to 1500 CE, five excavation sites), and five Unangan people living in the Aleutian Islands of modern day Alaska (ca 1756–1930 CE,

one excavation site). These geographical areas were selected because of access to mummies with appropriate age and varied cultural attributes. Mummies were selected for imaging on the basis of their good state of preservation and the likelihood of being adults. Mummies were not selected for study in a random fashion.

Vascular findings have been previously reported for 52 of the 76 Egyptian mummies (mummies 1–52 in table 1).<sup>8,9</sup> We reviewed previously acquired whole-body X-ray CT scans of 24 additional Egyptian mummies from four US museums: the Metropolitan Museum of Art (New York, NY, USA), which had CT scanned their mummies in 1997 (n=13, Tomoscan M Mobile CT System, Philips Medical Systems, Eindhoven, Netherlands),<sup>10</sup> the Brooklyn Museum, New York, NY, USA (n=6, 64-CT Lightspeed VCT, GE Healthcare, Waukesha, WI, USA), the University of Pennsylvania Museum of Archaeology and Anthropology, Philadelphia, PA, USA

Population/sex/age (years)	Name (museum ID)	Population/culture	Period	Place of excavation	Vascular tissue present?	Heart	Atherosclerosis (vascular bed affected)
1*	Egypt/F/25–30	Unknown (JE59130(b))	Greco-Roman	332 BCE–364 CE	Edfu	✓	..
2*	Egypt/F/25–30	Unknown (SR3/636(b))	Late period	712–343 BCE	Unknown	✓	Intact
3*	Egypt/F/25–30	Mummy of Tarepet (SR4/11324(b))	Late period	712–343 BCE	Unknown	✓	..
4*	Egypt/M/25–30	Mummy of Nesimut (JE29705)	Third intermediate period	1070–712 BCE	Deir el-Bahri	..	..
5*	Egypt/M/25–30	Mummy of Paduimen (JE29706)	Third intermediate period	1070–712 BCE	Deir el-Bahri	..	..
6*	Egypt/F/25–30	Mummy of Amanit (SR3/895)	Middle Kingdom, Dynasty 11	2134–1991 BCE	Deir el-Bahri	..	Remnants
7*	Egypt/M/30–35	Mummy of Tauhert (JE26196(d))	Third intermediate period	1070–712 BCE	Deir el-Bahri	..	..
8*	Egypt/M/30–35	Unknown (SR4/11387(b))	Ptolemaic period	304–30 BCE	Akhmim	✓	..
9*	Egypt/M/30–35	Mummy of Tjanefer (JE296825)	Third intermediate period	1070–712 BCE	Deir el-Bahri	✓	Remnants Definite (aorta)
10*	Egypt/M/30–35	Mummy of Nesinebtawy (JE29685)	Third intermediate period	1070–712 BCE	Deir el-Bahri	..	Remnants
11*	Egypt/M/30–35	Mummy of Esankh (TR28.4.26.1(b)-2)	Third intermediate period	1070–712 BCE	Deir el-Bahri	✓	..
12*	Egypt/M/30–35	Unknown (TR4.10.14.13)	Ptolemaic period	304–30 BCE	Unknown	..	Intact
13*	Egypt/F/30–40	Mummy of Rai (JE26223(b))	New Kingdom	1550–1070 BCE	Deir el-Bahri	✓	Intact Definite (aorta)
14*	Egypt/F/45–50	Mummy of Shtwsk (SR1/4463(b))	Greco-Roman	332 BCE–364 CE	Dahshur	✓	Intact Probable (popliteal/tibial)
15*	Egypt/M/45–50	Mummy of Nesitanebetawy (TR28.4.26.13(b))	Third intermediate period	1070–712 BCE	Deir el-Bahri	..	Remnants
16*	Egypt/M/50–60	Mummy of Wedjarenes (SR4/11277(b))	Late period	712–343 BCE	Akhmim	✓	..
17*	Egypt/M/50–60	Mummy of Nesmin (SR4/11350(b))	Ptolemaic period	304–30 BCE	Akhmim	✓	Remnants Probable (popliteal/tibial)
18*	Egypt/M/50–60	Mummy of Djehet (SR4/11349(b))	Ptolemaic period	304–30 BCE	Akhmim	✓	Intact Definite (carotids, coronaries, aorta, popliteal/tibial)
19*	Egypt/M/50–60	Anonymous	New Kingdom, Dynasty 18	1550–1295 BCE	Thebes	✓	Remnants Definite (popliteal/tibial)
20*	Egypt/F/50–60	Anonymous	New Kingdom, Dynasty 18	1550–1295 BCE	Thebes	✓	Remnants Definite (aorta, iliac/femoral, popliteal/tibial)
21*	Egypt/M/>50	Unknown (JE59131(b))	Greco-Roman	332 BCE–364 CE	Edfu	✓	.. Probable (carotids, popliteal/tibial)
22*	Egypt/F/>60	Unknown (SR1/14425(b))	Ptolemaic period	304–30 BCE	Akhmim	✓	.. Probable (carotids, popliteal/tibial)
23*	Egypt/M/45–50	Mummy of Scribe Hatiaiy (JE31378(b))	New Kingdom	1570–1293 BCE	Thebes	✓	.. Definite (carotids, aorta, iliac/femoral, popliteal/tibial)
24*	Egypt/M/25–30	Mummy of Maiherpri (CG24100)	New Kingdom	1570–1293 BCE	Thebes	✓	Remnants
25*	Egypt/F/40–45	Mummy of Isis (JE27309(b))	New Kingdom	1293–1185 BCE	Thebes	✓	..

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Population/sex/age (years)	Name (museum ID)	Population/culture	Period	Place of excavation	Vascular tissue present?	Heart	Atherosclerosis (vascular bed affected)	
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26*	Egypt/M/50–55	Mummy of Unknown Man C (Nebsenu) (JE26216(b))	New Kingdom	1570–1293 BCE	Thebes	✓	Intact	..
27*	Egypt/M/25–30	Mummy of Unknown Man E (Poisoned Prince) (JE26218(b)+B47)	New Kingdom	1570–1293 BCE	Thebes	✓	Intact	Definite (aorta)
28*	Egypt/M/40–45	Unknown mummy with cartonnage (TR13.3.15.1(e))	Late period	ca 688–332 BCE	Asyut	✓	..	..
29*	Egypt/M/45–50	Unknown mummy with cartonnage (TR13.3.15.1(d))	Late period	ca 688–332 BCE	Asyut	✓	Intact	Definite (aorta, popliteal/tibial)
30*	Egypt/M/45–50	Unknown mummy with cartonnage (TR13.3.15.1(f))	Late period	ca 688–332 BCE	Asyut	✓	..	..
31*	Egypt/M/45–50	Mummy of Djedhor, Son of Nesihor (SR 4/11329(b))	Late period	380–343 BCE	Unknown	✓	Remnants	Probable (carotids, aorta, popliteal/tibial)
32*	Egypt/M/30	Unknown mummy covered with gilded and painted cart (TR4.1.1)	Greco-Roman	332 BCE–364 CE	Unknown	✓	..	..
33*	Egypt/F/40–50	Unknown Woman B (Tetisheri) (JE26225(b))	New Kingdom	1570–1293 BCE	Thebes, Deir el-Bahri	✓	Intact	Probable (carotids, aorta, iliac/femoral, popliteal/tibial)
34*	Egypt/F/40–45	Mummy of Ahmose-Henttamehu (JE26224(b))	Second intermediate period	1650–1567 BCE	Thebes, Deir el-Bahri	✓	Intact	Definite (aorta)
35*	Egypt/F/40–45	Unknown Woman A (Ahmose-Meritamun A) (JE26206(b))	Second intermediate period	1580–1550 BCE	Thebes, Deir el-Bahri	✓	Intact	Definite (carotids, coronaries, aorta, iliac/femoral, popliteal/tibial)
36*	Egypt/F/20–25	Mummy of Ahmose-Henutempet (JE26222(b))	Second intermediate period	1650–1567 BCE	Thebes, Deir el-Bahri	✓	Remnants	..
37*	Egypt/F/19	Mummy of a young woman with painted cloth covering (CG33281)	Roman period	30 BCE–364 CE	Saqqara	✓	Remnants	..
38*	Egypt/F/45–50	Unknown mummy with hair (PV.2010.44)	Unknown	Unknown	Fayoum	✓	Intact	Definite (aorta, iliac/femoral)
39*	Egypt/M/35–40	Unknown (PV.2010.45)	Unknown	Unknown	Fayoum	✓	Intact	..
40*	Egypt/M/45–50	Mummy of Nebsy (SR3/674(b))	New Kingdom	ca 1550–1070 BCE	Thebes	..	..	..
41*	Egypt/M/35–40	Mummy of Djedhor (SR4/11332(b))	Unknown	Unknown	Akhmim	✓	Intact	Definite (carotids, aorta)
42*	Egypt/F/45–50	Mummy of Tadibastet, daughter of Ankhfra-enemteper (SR3/634(b))	Third intermediate period	712–663 BCE	Unknown	✓	Intact	Probable (coronaries, aorta, iliac/femoral)
43*	Egypt/F/20–25	Mummy of Lady Shauenimes (SR4/11326(b))	Third intermediate period	945–745 BCE	Unknown	✓	Remnants	..
44*	Egypt/M/25–30	Mummy in linen bandages (JE56265(b))	Late period	ca 688–332 CE	Thebes, Deir el-Bahri	✓	..	Probable (popliteal/tibial)
45*	Egypt/?/12	Mummy of Tjayasetimu (EA20744)	Third intermediate period, Dynasty 22	ca 900 BCE	Thebes	✓	Intact	..
46*	Egypt/M/45–50	Mummy of Padiametet (EA6682)	Third intermediate period, Dynasty 25	ca 700 BCE	Thebes	✓	..	..
47*	Egypt/M/40–45	Mummy of Shepenmehyt (EA22814)	Saite period, Dynasty 26	ca 600 BCE	Thebes	✓	..	..
48*	Egypt/M/40–50	Mummy of Irthorru (EA20745)	Saite period, Dynasty 26	ca 600 BCE	Akhmim	✓	Remnants	..
49*	Egypt/?/10	Child (EA21809)	Roman period	ca 40–55 CE	Fayoum (Hawara)	..	..	..
50*	Egypt/M/20–25	Unknown (EA6713)	Roman period	ca 140–180 CE	?Thebes	✓	Remnants	..
51*	Egypt/M/45–55	Ka-i-nefer (EA21811)	Late intermediate period	ca 500 BCE	Unknown	✓	..	..
52*	Egypt/M/25–30	Gitbetah (EA21812)	Third intermediate period	745–718 BCE	Unknown	✓	Remnants	..
53	Egypt/M/50	Naturally mummified body (MMA 99.3.5)	Possibly predynastic period through first half of Old Kingdom	ca 3800–2500 BCE	Unknown	..	Intact	..
54	Egypt/M/45–50	Mummy of Khnumhotep (MMA 12.182.131c)	Middle Kingdom, Dynasty 12	ca 1981–1802 BCE	Meir	..	..	..

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Population/sex/age (years)	Name (museum ID)	Population/culture	Period	Place of excavation	Vascular tissue present?	Heart	Atherosclerosis (vascular bed affected)	
(Continued from previous page)								
55	Egypt/M/50	Mummy of Nesiamum (MMA 26.3.12)	Late period, Dynasty 25–26	ca 712–525 BCE	Thebes, Deir el-Bahri	✓	..	..
56	Egypt/M/40–45	Mummy of Nesmin (MMA 86.1.51)	Ptolemaic period	305–30 BCE	Akhmim	✓	Intact	Probable (carotids, iliac/femoral)
57	Egypt/F/40–45	Mummy of Nephthys (MMA 11.150.15c)	Middle Kingdom, Dynasty 12	ca 1981–1802 BCE	Meir	✓	..	Definite (iliac/femoral, popliteal/tibial)
58	Egypt/M/30–35	Mummy with panel portrait (MMA 11.139)	Roman period	80–100 CE	Fayum, Hawara	✓	..	..
59	Egypt/M/30–35	Mummy of Kharushere (MMA 86.1.35)	Third intermediate period, Dynasty 22	ca 825–712 BCE	Thebes, Sheikh Abd el-Qurna	✓	Intact	Probable (iliac/femoral)
60	Egypt/M/30–35	Mummy of Ukhhotep (MMA 12.182.132c)	Middle Kingdom, Dynasty 12	ca 1981–1802 BCE	Meir	..	..	..
61	Egypt/F/25–30	Mummy of Nefer (MMA 20.4)	Ptolemaic period	3rd century BCE or later	Unknown	✓	Remnants	..
62	Egypt/F/30	Mummy of Tasheriteniset (MMA 12.182.48c)	Ptolemaic period	305–30 BCE	Assiut	✓	..	..
63	Egypt/F/30–35	Mummy of Irtirutja (MMA 86.1.53)	Ptolemaic period	305–30 BCE	Akhmim	✓	Intact	Probable (carotids)
64	Egypt/M/4	Mummy of Amenemhat (MMA 19.3.208a-e)	New Kingdom, early Dynasty 18	ca 1550–1479 BCE	Thebes, Southern Asasif	..	..	..
65	Egypt/M/43–48	Mummy of Pum2 (UPM L-55-15A)	Ptolemaic period	304–30 BCE	Egypt	✓	..	..
66	Egypt/M/40–44	HAPI-Man (UPM E 16220A)	Late period	ca 688–332 CE	Abydos	✓	Remnants	Probable (carotids, iliac/femoral)
67	Egypt/F/29–33	Braided hair lady, MOWT (L33-002-006)	New Kingdom	ca 1550–1070 BC	Unknown	✓	..	..
68	Egypt/F/27–29	Kardatzke Mummy, MOWT (L53-001-006)	New Kingdom	ca 1550–1070 BC	Unknown	✓	..	..
69	Egypt/F/5	Seabury Seminary mummy aka Rhapsode Nier (8896*88**)	2nd century AD	100–200 CE	Unknown	✓	Intact	..
70	Egypt/F/30	Mummy with painted mask (MMA 25.3.219)	Roman period	270–280 CE	Thebes, Deir el-Bahri	✓	Remnants	Definite (carotids, aorta, iliac/femoral, popliteal/tibial)
71	Egypt/M/26–30	Mummy (“A. Man”) (52.128a-e)	Roman period, 3rd century	200–300 CE	Deir El Bahri	✓	Remnants	..
72	Egypt/M/19–24	Mummy of Thothirdes (37.1521.E a-c)	Late Period, Dynasty 26	664–525 BCE Carbon dating 768–545	Saqqara	✓	Intact	Definite (carotids)
73	Egypt/M/31–35	Mummy and Cartonnage of Hor (37.50E)	Third intermediate period, 2nd half Dynasty 25	712–664 BCE	Thebes	✓	..	Definite (iliac/femoral, popliteal/tibial)
74	Egypt/F/19–24	Inner Cartonnage of Gautseshenu (34.1223)	Third intermediate period Dynasty 25–26	700–650 BCE	Thebes	✓	Intact	..
75	Egypt/M/59	Mummy of Demetrios (11.600)	Greco-Roman 1st century	95–100 CE	Hawara	✓	Remnants	Probable (aorta, iliac/femoral)
76	Egypt/M/21–27	Mummy of Pasebakhaienipet (08-480.2a-c)	Third intermediate period	1070–945 BCE Carbon dating 1110–939 BCE	Thebes	✓	Intact	..
77	Peru/M/38–42	FA0060	Late intermediate period, Late Horizon	1000–1534 CE	Rinconada La Molina	✓	Remnants	Probable (aorta)
78	Peru/M/46–48	RT0688	Unknown	Unknown	Unknown	✓	..	..
79	Peru/F/40–44	FA 102	Late intermediate period, Late Horizon	1000–1534 CE	Rinconada La Molina	..	..	..
80	Peru/F/43–46	FA 036	Late intermediate period, Late Horizon	1000–1534 CE	Rinconada La Molina	..	..	..
81	Peru/F/47–49	PP 238	Late intermediate period, Late Horizon	1000–1534 CE	Pedrerros	✓	..	Probable (iliac/femoral, popliteal/tibial)
82	Peru/M/51–53	PP 614	Late intermediate period, Late Horizon	1000–1534 CE	Pedrerros	..	..	..
83	Peru/M/34–38	PP 487 E3	Late intermediate period, Late Horizon	1000–1534 CE	Pedrerros	..	..	..

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Population/sex/ age (years)	Name (museum ID)	Population/culture	Period	Place of excavation	Vascular tissue present?	Heart	Atherosclerosis (vascular bed affected)
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84	Peru/F/29–33	PP 508 E4	Late intermediate period, Late Horizon	1000–1534 CE	Pedrerros	..	..
85	Peru/?/7–9	FA 026	Late intermediate period, Late Horizon	1000–1534 CE	Rinconada La Molina	✓	Remnants ..
86	Peru/M/27–29	PP 604 E6	Late intermediate period, Late Horizon	1000–1534 CE	Pedrerros	..	..
87	Peru/F/43–46	FA 001	Late intermediate period, Late Horizon	1000–1534 CE	Rinconada La Molina	✓	..
88	Peru/?/?	FA 052	Late intermediate period, Late Horizon	1000–1534 CE	Rinconada La Molina	..	..
89	Peru/?/5–6	FA 074	Late intermediate period	1000–1476 CE	Huallamarca	✓	..
90	Peru/?/4–5	FA 04	Unknown	Unknown	Unknown	..	..
91	Peru/M/51–57	FA 040	Late intermediate period, Late Horizon	1000–1534 CE	Rinconada La Molina	✓	..
92	Peru/?/2–3	FA 051	Late intermediate period, Late Horizon	1000–1534 CE	Rinconada La Molina	..	..
93	Peru/F/32–38	FA 054	Late intermediate period, Late Horizon	1000–1534 CE	Unknown	..	..
94	Peru/M/43–46	FA 84	Late intermediate period, Late Horizon	1000–1534 CE	Unknown	✓	Definite (aorta, popliteal/tibial)
95	Peru/M/31–35	FA 41	Late intermediate period, Late Horizon	1000–1534 CE	Rinconada La Molina	✓	..
96	Peru/M/40–44	FA PP490 E7b	Late intermediate period, Late Horizon	1000–1534 CE	Pedrerros	✓	Remnants Probable (aorta, iliac/femoral)
97	Peru/M/40–44	FA 049	Late intermediate period, Late Horizon	1000–1534 CE	Rinconada La Molina	✓	..
98	Peru/F/51–57	FA 17	Late intermediate period, Late Horizon	1000–1534 CE	Rinconada La Molina	✓	..
99	Peru/M/53–57	FA 490 E7a	Late intermediate period, Late Horizon	1000–1534 CE	Pedrerros	✓	..
100	Peru/M/26–30	FA 068	Early intermediate to Middle Horizon	200–900 CE	Huallamarca	✓	Remnants Probable (aorta)
101	Peru/F/41–44	FA 085	Early intermediate to Middle Horizon	200–900 CE	Huallamarca	✓	..
102	Peru/F/?	FA 079	Early intermediate to late intermediate period	200–1476 CE	Huallamarca	..	..
103	Peru/?/?	FA 009	Late Intermediate Period, Late Horizon	1000–1534 CE	Huallamarca	..	..
104	Peru/M/48–51	FA 81	Early intermediate to late intermediate period	200–1476 CE	Huallamarca	✓	..
105	Peru/?/?	FA 73	Early intermediate to middle Horizon	200–900 CE	Huallamarca	..	..
106	Peru/M/45–49	FA 71	Early intermediate to late intermediate period	200–1476 CE	Huallamarca	..	..
107	Peru/F/38–41	FA 72	Early intermediate to Middle Horizon	200–900 CE	Huallamarca	..	..
108	Peru/?/?	FA 77	Late intermediate period	1000–1476 CE	Huallamarca	..	..
109	Peru/M/47–52	FA 70	Late intermediate period	1000–1476 CE	Huallamarca	✓	..
110	Peru/M/40–44	FA 76	Early intermediate to late intermediate period	200–1476 CE	Huallamarca	✓	..
111	Peru/M/53–57	FA69	Late intermediate period, Late Horizon	1000–1534 CE	Huallamarca	..	..
112	Peru/F/55–59	FA 74	Early intermediate to late intermediate period	200–1476 CE	Huallamarca	✓	Remnants ..

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Population/sex/ age (years)	Name (museum ID)	Population/culture	Period	Place of excavation	Vascular tissue present?	Heart	Atherosclerosis (vascular bed affected)
(Continued from previous page)							
113	Peru/M/45–49	FA 75	Late intermediate period, Late Horizon	1000–1534 CE	Huallamarca	..	..
114	Peru/F/59–60	FA 56	Late intermediate period, Late Horizon	1000–1534 CE	Unknown	✓	..
115	Peru/F/51–56	FA 62	Late intermediate period, Late Horizon	1000–1534 CE	Unknown	..	..
116	Peru/M/46–51	FA 59	Early intermediate to late intermediate period	200–1476 CE	Huallamarca	..	..
117	Peru/?/4–6	FA 10	Late intermediate period, Late Horizon	1000–1534 CE	Unknown	..	..
118	Peru/M/41–44	FA 78	Early intermediate to late intermediate period	200–1476 CE	Huallamarca	✓	Probable (iliac/femoral, popliteal/tibial)
119	Peru/M/37–40	FA 80	Early intermediate to late intermediate period	200–1476 CE	Huallamarca	✓	Probable (aorta, popliteal/tibial)
120	Peru/?/4–6	FA 50	Late intermediate period, Late Horizon	1000–1534 CE	Rinconada La Molina	..	..
121	Peru/M/19–23	FA 67	Late intermediate period	1000–1476 CE	Huallamarca	✓	..
122	Peru/?/3–5	FA 25	Unknown	Unknown	Unknown	..	..
123	Peru/M/39–45	FA065A	Late intermediate period, Late Horizon	1000–1534 CE	Unknown	..	..
124	Peru/M/47–51	FA 135	Late intermediate period	1000–1476 CE	Huallamarca	✓	..
125	Peru/?/4–5	FA 053	Late intermediate period, Late Horizon	1000–1534 CE	Unknown	..	..
126	Peru/M/54–59	PP490E-7c	Late intermediate period, Late Horizon	1000–1534 CE	Pedrerros	✓	Probable (carotids)
127	Peru/F/27–29	FA 06B	Late intermediate period	1000–1476 CE	Unknown	..	..
128	Ancestral Puebloans/F/26–30	UPM 29-43-365	Archaic to Basketmaker II	1500 BCE–500 CE	SE Utah, Red Canyon, Cave	✓	..
129	Ancestral Puebloans/M/22–26	UPM 29-43-375	Archaic to Basketmaker II	1500 BCE–500 CE	SE Utah, Lake Canyon	✓	Remnants
130	Ancestral Puebloans/M/18–23	UPM 29-43-378	Archaic to Basketmaker II	1500 BCE–500 CE	SE Utah, Colorado River Canyon, Cave	✓	Remnants
131	Ancestral Puebloans/F/46–51	UPM 29-43-381	Archaic to Basketmaker II	1500 BCE–500 CE	SE Utah, Deep Canyon, Cave	✓	Remnants
132	Ancestral Puebloans/?/18–22	UPM 29-43-379	Pueblo	1200 CE–1500 CE	SE Utah, or SW Colorado	✓	..
133	Unangan/F/47–51	USNM-386381	Unangan	1900 CE	Aleutian Islands	✓	Remnants
134	Unangan/F/25–29	USNM-386379	Unangan	1900 CE	Aleutian Islands	✓	Definite (coronaries, aorta, iliac/ femoral)
135	Unangan/M/18–24	USNM-386376	Unangan	1900 CE	Aleutian Islands	✓	..
136	Unangan/?/4–5	USNM-386389	Unangan	1900 CE	Aleutian Islands	..	..
137	Unangan/M/40–44	USNM-17482	Unangan	1850 CE	Aleutian Islands	✓	Definite (aorta, iliac/femoral, popliteal/tibial)

Mummies 1–44, 52 were from the Egyptian Museum, Cairo, Egypt; mummies 45–50, from the British Museum, London, UK; mummy 51, from the Nelson-Atkins Museum of Art, Kansas City, MI, USA; mummies 53–64, 70, from the Metropolitan Museum of Art (MMA), New York, NY, USA; mummies 65, 66, 128–132, from the University of Pennsylvania Museum of Archaeology and Anthropology (UPM), Philadelphia, PA, USA; mummies 67, 68, from the Museum of World Treasures (MOWT), Wichita, KS, USA; mummies 71–76, from the Brooklyn Museum, New York, NY, USA; mummies 77–127, from the Museo de Sitio Puruchuco—Arturo Jimenez Borja, Lima, Peru; and mummies 133–137, from the National Museum of Natural History (Smithsonian Institution; USNM), Washington, DC, USA. Period years are as specified by the respective museums. BCE=Before Common Era. CE=Common Era. F=female. M=male. ?=not known. \*Findings from mummies 1–52 have been previously reported.<sup>9</sup>

Table 1: Demographic and cardiovascular findings

(n=2, Somatom Sensation 64 CT scanner, Siemens, Florsheim, Germany), and the Museum of World Treasures of Wichita, KS, USA (n=2, GE Lightspeed-16, GE Healthcare, Waukesha, WI, USA).

The 51 mummies in Peru were housed at the Museo de Sitio Puruchuco—Arturo Jimenez Borja, Lima, and were specifically imaged for this study in Lima in February and May, 2012, at the Instituto Nacional de Ciencias Neurológicas (n=40, Siemens Somatom Sensation 64-slice scanner) or the Hospital de Emergencias José Casimiro Ulloa (n=11, Philips Brilliance CT 64 slice scanner).

The five Ancestral Puebloan mummies from the Hazzard–Hearst collection of the University of Pennsylvania Museum of Archaeology and Anthropology had been excavated mainly from caves in southwest Utah, and were previously imaged (Siemens Somatom Sensation 64 CT scanner).

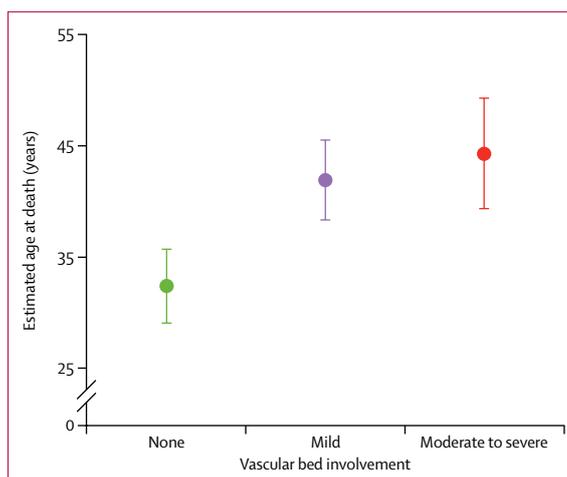
The five mummies from the Aleutian Islands were of the Unangan hunter-gatherer culture and had been collected from the Warm Cave on the Kagamil Island volcano located 500 miles off the Alaskan mainland in the Aleutian Islands by Captain Ernest Hennig in 1874<sup>11</sup> and Ales Hrdlicka in 1936.<sup>12</sup> They are housed in the Smithsonian Institution's National Museum of Natural History (Washington, DC, USA), where they were previously imaged (single slice Siemens AR.SP CT scanner).<sup>13</sup>

### Procedures

For mummies imaged prospectively for this study, a consistent scan protocol was used.<sup>8,9</sup> Images were interpreted by a consensus of seven experienced cardiovascular imaging physicians (RCT, AHA, MLS, JDS, LSW, MIM, and GST) focusing on identification of cardiovascular tissue and the presence or absence of calcification in the vessel walls and heart. Image reformatting and interpretation were predominately done on an Apple platform OsiriX DICOM viewing software (version 5.5.1–64-bit and 3.7.1–64-bit).

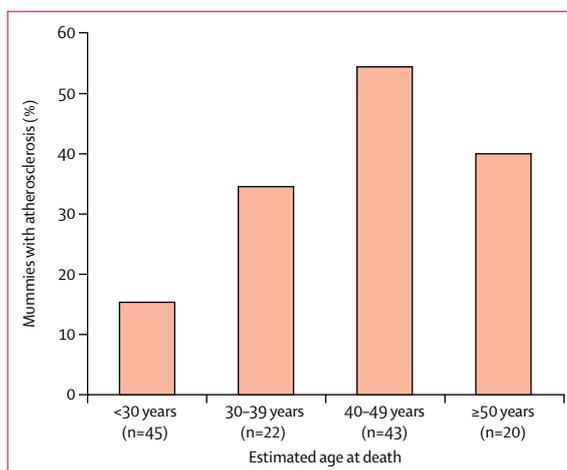
As previously described, vascular tissue and the heart, when present, were identified by their typical anatomical positions in the body and relation to contiguous structures, enhanced by the use of three-dimensional multi-planar reformatting and maximum intensity projection reconstructions.<sup>8,9</sup> Calcification in the wall of a clearly identifiable artery was regarded as diagnostic of atherosclerosis.<sup>4</sup> Calcification along the expected course of an artery was judged to be probable atherosclerosis. Vascular regions were divided into the five distinct beds modified from the method of Allison and colleagues:<sup>14</sup> the carotid, coronary, aortic, iliac or femoral, and popliteal or tibial (termed peripheral) vascular beds.

Identifying information was obtained by an extensive search of museum and other databases by a team of experienced archeologists and experts in mummy restoration, when possible. Determination of sex was

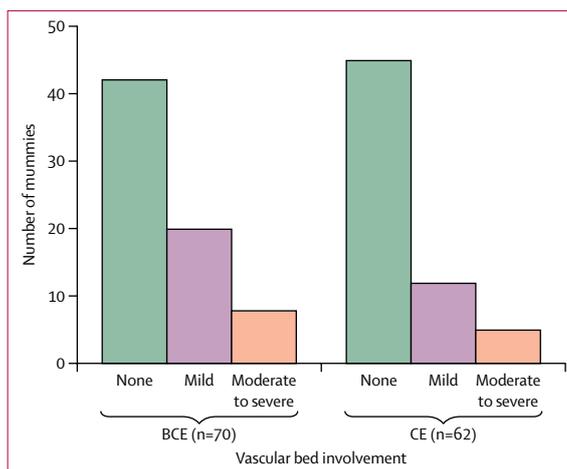


**Figure 1: Mean estimated age at death of the mummies in the three categories of atherosclerosis**

Error bars show 95% CI.

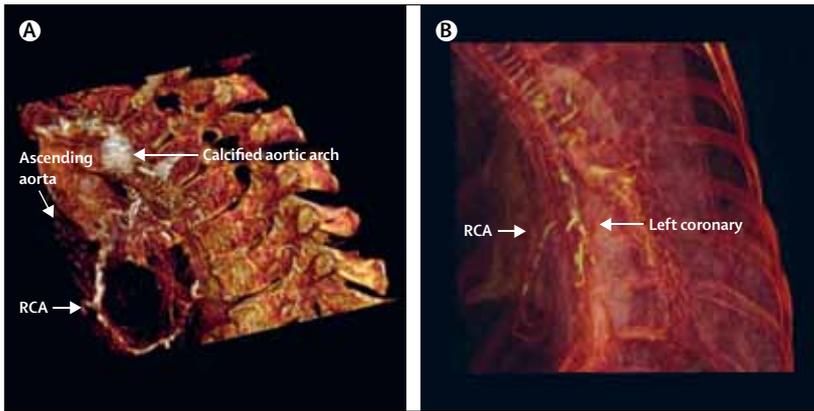


**Figure 2: Frequency of atherosclerosis by age group**

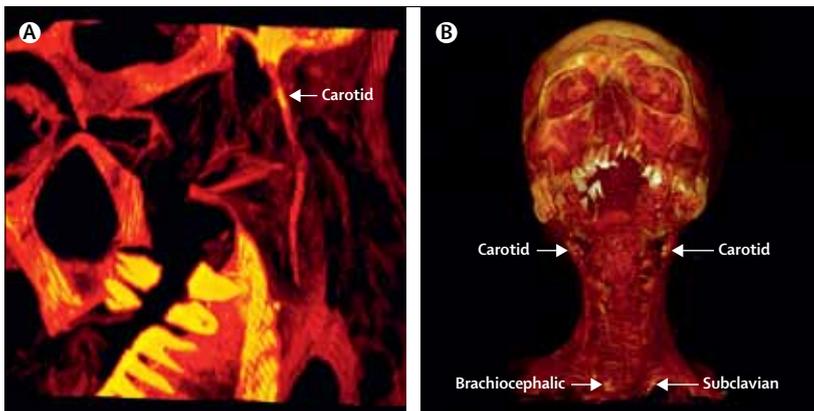


**Figure 3: Severity of atherosclerosis in mummies from before the common era (BCE) and the common era (CE)**

None=no vessel involvement. Mild=one to two vascular beds affected. Moderate to severe=three to five vascular beds affected.



**Figure 4: Coronary artery disease**  
Sagittal three-dimensional (3D) volume rendered (A) and sagittal oblique 3D volume rendered (B) CT reconstruction of two mummies with coronary calcifications. (A) Coronary calcifications in the mummy of a Unangan woman (mummy 133) aged 47–51 years who lived in the late 19th century CE and was found on Kagamil Island of the Aleutian Islands. (B) Coronary artery calcifications in the mummy of Ahmose-Meritamun (mummy 35), an Egyptian princess aged 40–45 years who lived about 1580–1550 BCE and was found near modern day Luxor. RCA=right coronary artery. CE=common era. BCE=before common era.



**Figure 5: Carotid disease**  
Sagittal three-dimensional (3D) maximum projection rendered (A) and coronal 3D volume rendered (B) CT reconstruction showing carotid artery disease. (A) Carotid calcifications in the mummy of an Unangan woman (mummy 134) aged 25–29 years, who lived in the late 19th century CE and was found on Kagamil island in the Aleutian Islands. (B) Bilateral carotid, bilateral subclavian, and brachiocephalic calcification of Hatyai (mummy 23), a male Egyptian scribe aged 40–50 years, who lived during the New Kingdom (1570–1293 BCE) and was found near modern day Luxor. CE=common era. BCE=before common era.

attempted by biological anthropological assessment of the genital or reproductive organs (when present) and the morphology of both pelvis and skull. Age was estimated by analysis of the architectural changes in the clavicle, femur and humerus, and cranial suture closures for 124 of the mummies.<sup>15,16</sup> The CT images of the 13 mummies from the Metropolitan Museum of Art were available for viewing on radiographic film only, and age and sex were obtained from the museum's previous study.<sup>10</sup>

Social, cultural, environmental, dietary, and other lifestyle information was generally unavailable for individual mummies, but multiple anthropological and archaeological resources were used in an attempt to reconstruct risk factors that are currently believed to predispose to development of atherosclerosis.

### Statistical analysis

Statistical analysis was done with SPSS software (version 17 for Windows). The null hypothesis was rejected at  $p < 0.05$ , which was regarded as significant. To access the independent predictors of the level of atherosclerosis (none, mild, or moderate to severe), we did ordinal logistic regression using the variables age, sex, and time period of life (CE vs BCE) as predictor variables. We also did sensitivity analyses in only the mummies who had arteries identified on CT, adjusting for non-Egyptian mummies, and altering the outcome to definite atherosclerosis.

### Role of the funding source

The sponsors of the study had no role in study design, data collection, primary data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the final content of the report and the decision to submit for publication.

### Results

Table 1 shows the demographic and cardiovascular findings of the 137 mummies. The Egyptian mummies generally had better preservation of soft tissues because of embalming techniques. Mummies from the other cultures were naturally mummified without evident evisceration or embalming. Age at death and sex could not be established in four mummies because of poor preservation. In another mummy, age, but not sex could be established, resulting in an age estimate being available for 132 of the mummies. Sex could not be established in an additional 12 mummies because of their youth. Mean age at death was 36 (SD 15) years (range 2.5 to >60 years). Of the 121 mummies in whom sex could be established, 77 were male and 44 were female. The mean age at death did not differ significantly by sex (38 [SD 12] years vs 40 [11] years;  $p=NS$ ).

Probable or definite atherosclerosis was seen in 47 (34%) of 137 mummies, 25 of the 47 mummies had definite and 22 had probable atherosclerosis. Those with atherosclerosis were older at time of death (43 [SD 10] years vs 32 [15] years;  $p < 0.0001$ ). Mean age was 36.8 (SD 13) years for the ancient Egyptians, 37.1 (17) years for the ancient Peruvians, 28.1 (12) years for the Ancestral Puebloans, and 28.6 (18) years for the Unangan. Atherosclerosis was present in all four populations: 29 (38%) of 76 Egyptians, 13 (25%) of 51 Peruvians, two (40%) of five Ancestral Puebloans, and three (60%) of five Unangan ( $p=NS$  between populations). Although these differences are not statistically significant, the numbers of mummies in the Ancestral Puebloans and Unangan groups are, of course, small. Among mummies identified as women, 17 (39%) of 44 had atherosclerosis, as did 30 (39%) of 77 men. Overall, probable or definite atherosclerosis was present in the aorta in 28 (20%) mummies, iliofemoral arteries in 25 (18%), popliteal or

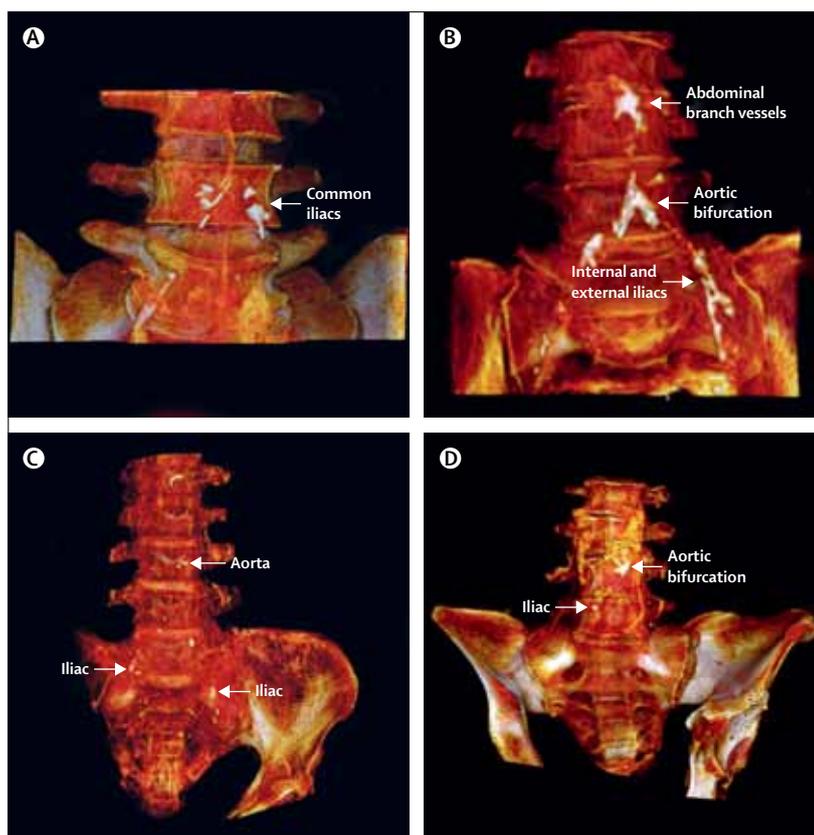
tibial arteries in 25 (18%), carotids in 17 (12%), and coronary arteries in six (4%). Of five vascular beds examined, atherosclerosis was present in one or two beds in 34 (25%) mummies, in three to four beds in 11 (8%), and in all five beds in two (1%). Mean age was 32 (SD 15) years for mummies with no atherosclerosis, 42 (10) years for those with atherosclerosis in one or two beds, and 44 (8) years for those with atherosclerosis in three to five beds ( $p < 0.0001$ ; figure 1).

In our ordinal logistic regression model, age was associated with increased odds of atherosclerosis severity, defined as no beds (none), one to two beds (mild), and three to five beds (moderate to severe); per 10 year increase in age, odds ratio [OR] 1.69, 95% CI 1.19–2.40). Thus, the odds of increasing atherosclerosis severity increases by about 69% per decade of life. There were no significant associations by sex (male vs female, OR 0.68, 95% CI 0.31–1.50), or by the historical time period (CE vs BCE, OR 0.68, 0.31–1.48). In a sensitivity analysis in which mummies without identifiable arteries ( $n=40$ ) were excluded, age continued to be a significant predictor of increased risk of atherosclerosis severity grade (per 10 year increase in age, OR 1.77, 95% CI 1.22–2.56), with sex and time period being non-significant. Similarly, after adjusting for mummy location (Egypt vs Americas), age continued to be significant (per 10 year increase in age, OR 1.65, 95% CI 1.15–2.36), with sex, time period, and location being non-significant. A further sensitivity analysis was done in which only definite atherosclerosis was evaluated, excluding probable atherosclerosis, and in this model age continued to be a significant predictor (per 10 year increase in age, OR 1.64, 95% CI 1.14–2.35) with sex and time period being non-significant. Figure 2 shows the increase in atherosclerosis severity observed with increasing age groups and figure 3, severity of atherosclerosis observed in mummies who lived before and during the common era.

Examples of coronary atherosclerosis in two of the mummies who had involvement of all five vessel beds is shown in figure 4: a Unangan woman aged 47–51 years (mummy 133, late 19th century CE) and Ahmose-Meritamun, an Egyptian Princess aged 40–45 years (mummy 35, second intermediate period, 1580–1550 BCE). Figure 5 shows the carotid atherosclerosis of Unangan mummy 134 and the carotid, subclavian, and brachiocephalic atherosclerosis of Hatiay, a male Egyptian scribe, aged 40–50 years (mummy 23, New Kingdom, 1570–1293 BCE). Figure 6 shows examples of atherosclerosis of the aortic bifurcation or common iliac artery, or both, in mummies from each of the four geographical regions. Rotational movies of the reconstructions are included as videos 1–3.

## Discussion

Atherosclerosis was prevalent in mummies from many cultures across four disparate geographical regions over several time epochs. Our findings are consistent with



**Figure 6: Iliac and aortic bifurcation calcifications**

Coronal three-dimensional (3D) volume rendered CT reconstructions of four mummies with calcifications in the distal aorta and iliac arteries. (A) Aortic and iliac calcification in the mummy of an Unangan woman (mummy 133) aged 47–51 years, who lived during the late 19th century CE and was found on Kagamil island of the Aleutian Islands. (B) Aortic and iliac calcification in the mummy of an Egyptian woman (mummy 38) aged 45–50 years, of unknown era from ancient Egypt, who was found in the Fayoum Oasis. (C) Aortic and iliac calcification in the mummy of an Ancestral Puebloan woman (mummy 131), aged 46–51 years, of the Basket Maker culture (1500 BCE to 500 CE), found in a cave in Deep Canyon, southeast Utah, USA. (D) Aortic and iliac calcification in the mummy of a woman from ancient Peru (mummy 101), aged 41–44 years, of the Early intermediate to Middle Horizon (200–900 CE), excavated from Huallamarca (near Lima), Peru. CE=common era. BCE=before common era.

previous autopsy studies of atherosclerosis in several ancient Egyptians,<sup>6,7,17</sup> autopsies of two Unangan men, one estimated to be age 40–59 years and the other 45–57 years, who were collected from the same cave and time period as the five Unangans in the current sample,<sup>18,19</sup> and of an Inuit woman in her 50s living on St Lawrence Island in the Bering Sea around 400 CE (panel).<sup>20</sup>

In modern day human beings, Allison and colleagues<sup>14</sup> found atherosclerosis to be commonplace using whole body CT scanning in a cross-sectional study of 650 asymptomatic people. Atherosclerosis with calcification was ubiquitous in men by age 60 years and in women by 70 years, as indicated by the presence of calcification in at least one of five beds assessed: carotid, coronary, proximal aorta, distal aorta, and iliac vessels. By the age of 50 years, atherosclerosis was present in all five beds in 82% of men and 68% of women.

The MESA investigators<sup>21</sup> found in a population of 976 asymptomatic men and women older than 65 years

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that abdominal aortic calcification was common among the four ethnicities studied: non-Hispanic whites (97%), Chinese (96%), Hispanics (91%), and African-Americans (80%). Traditional risk factors (age, smoking, diabetes, hypertension, family history of coronary artery disease, and measured dyslipidaemia) predicted the presence of calcification. In the PDAY autopsy study<sup>22</sup> of a large multiethnic US sample, all those aged 15–19 years (n=614) had early stage aortic atheromas, and more than 50% had coronary lesions.

**Panel: Research in context**

**Systematic review**

We searched PubMed and Google Scholar using variations of the keywords “mummy atherosclerosis”, “ancient atherosclerosis”, “mummy autopsy”, and “mummy CT scanning”, reviewing relevant original and review articles and their citations. We also crosschecked our results with an extensive independent, partially overlapping database of CT scans in mummies that one of the authors (SLC) had done in preparation for a master’s thesis. We assessed the quality of the evidence specifically related to cardiovascular disease by review of figures and the details of the descriptions of the CT scan. We also considered the reliability and previous work of the authors. Autopsy studies done as long ago as the mid-19th century showed atherosclerosis in ancient Egyptians.<sup>6,7,17</sup> Also, in more recent times, Zimmerman undertook autopsies and described atherosclerosis in the mummies of two Unangan men from the same cave as our Unangan mummies and of an Inuit woman who lived around 400 CE.<sup>18–20</sup> A previous study using CT scanning showed atherosclerotic calcifications in the aorta of the Iceman, who is believed to have lived about 3200 BCE and was discovered in 1991 in a high snowfield on the Italian–Austrian border.<sup>5</sup> We previously described atherosclerotic calcifications on CT scan in some ancient Egyptian mummies.<sup>8,9</sup>

**Interpretation**

Our findings greatly increase the number of ancient people known to have atherosclerosis and show for the first time that the disease was common in several ancient cultures with varying lifestyles, diets, and genetics, across a wide geographical distance and over a very long span of human history. These findings suggest that our understanding of the causative factors of atherosclerosis is incomplete, and that atherosclerosis could be inherent to the process of human ageing.

What were the lives like of these ancient people, and how might it have affected known risk factors for atherosclerosis? Table 2 summarises diet and lifestyles of the four populations.<sup>23–27</sup> The ancient Egyptians and Peruvians were farmers with domesticated animals, the Ancestral Puebloans forager-farmers, and the Unangans hunter-gatherers without agriculture. The Peruvians and Ancestral Puebloans predated the written word and were thus prehistoric cultures. None of the cultures were known to be vegetarian. Physical activity was probably prominent in all of these civilisations without animal or vehicle transport.

The diets of these peoples were quite disparate, as were the climates. Indigenous food plants varied greatly over the wide geographical distance between these regions of the world. Fish and game were present in all of the cultures, but protein sources varied from domesticated cattle among the Egyptians to an almost entirely marine diet among the Unangans. Mummified Egyptians were generally of higher social status than were those not mummified, and the wealthy tended to have more sophisticated embalming; those mummified might have had greater access to animal food sources, which included domesticated cattle, sheep, pigs, and ducks.<sup>23</sup> David and colleagues<sup>24</sup> have postulated that ancient mummified Egyptians, being of higher socioeconomic status, consumed a diet particularly high in saturated fat. Ancient Peruvians living near Lima also had access to irrigated farmland where they harvested many foodstuffs including corn, potato, sweet potato, tarwi, manioc, peanuts, beans, bananas, and hot pepper. Domesticated guinea pigs and ducks were available and Andean deer, birds, and frogs were hunted.<sup>25</sup> The two Ancestral Puebloan mummies (mummies 130 and 131) with atherosclerosis could only be dated over an extended time period, 1500 BCE to 500 CE. During this time, the Ancestral Puebloans transitioned from being hunter-gatherers to farmer-foragers growing corn and squash.

	Egyptians <sup>23,24</sup>	Peruvians <sup>25</sup>	Ancestral Puebloans <sup>26</sup>	Unangan/Aleuts <sup>27</sup>
Diet characterisation	Farmers, animal domestication	Farmers, animal domestication	Forager-farmers	Hunter-gatherers
Food examples	Farmed wheat, barley, dates, figs, olive, beans, pomegranates, radishes, onions, cucumber, lettuce, cabbage; made beer, wine	Farmed corn, potato, sweet potato, manioc, beans, bananas, hot pepper	Farmed maize (corn) and squash; collected pine nuts, seeds, amaranth, grasses	Marine (as below); collected berries; no agriculture
Protein sources	Domesticated cattle, sheep, goats, pigs, hyenas, ducks, geese; hunted quail, pheasants; fished	Domesticated alpaca, guinea pigs, ducks; hunted Andean deer and birds; collected crayfish; fished	Hunted rabbit, mice, big horn sheep, mule deer with the Atlatl (ancient spear thrower); fished	Hunted (from kayak or baidarka) marine mammals (seal, sea lion, sea otter, whales); collected shellfish, sea urchins, eggs; fished
Landscape	Nile River within Sahara desert	Coastal desert valleys	Colorado Plateau, elevation 5000 feet	Volcanic islands with harsh cold, windy marine climate
Housing	Above-ground homes of mud bricks; a few elite had limestone homes	Above-ground mud homes	Subterranean single family homes (pithouses)	Subterranean homes (barabaras)
Smoke exposure	Cooked with wood or coal in yard or on roof	Those living along the coast cooked outside with wood and alpaca dung	Used fire for warmth and cooking in pithouses	Used fire for warmth and cooking in barabaras; used seal oil lamps for light in barabaras

**Table 2: Diet and lifestyles of the four populations**

Protein was obtained from rabbits, rodents, deer, and big horn sheep. Hunting was performed with spears as they predated the bow and arrow.<sup>26</sup> Mummy 131, which had atherosclerosis in four vessel beds, had been found in a cave with a large basket and a buckskin sack. The Unangan people developed the kayak during their 9000 years populating the Aleutian Islands. The Aleutians represent the volcanic outcroppings of the southern terminus of the 1000 mile Bering land bridge between Asia and the Americas, hence they can be called survivors of the Bering land bridge.<sup>27</sup> The Unangan's diet was predominately marine, including seals, sea lions, sea otters, whale, fish, sea urchins, and other shellfish and birds and their eggs. They were hunter-gatherers living in barabaras, subterranean houses to protect against the cold and fierce winds.<sup>27</sup>

Common to all populations was the use of fire for warmth and cooking. Cooking was often done outdoors by the ancient Peruvians and Egyptians but indoors over a fire among the Ancestral Puebloans. The Unangans in particular, were exposed to smoke within their living quarters. Entry into a barabara was through a hole in the roof via a slated timber, through which the inhabitant climbed. Seal and whale oil lamps lit and heated their subterranean sod homes. Laughlin<sup>27</sup> described the soot inside as so heavy at times that children's faces needed to be wiped from the accumulated soot in the morning. In his two autopsies of Unangan<sup>18,19</sup> and of the Inuit woman,<sup>20</sup> all of whom had atherosclerosis, Zimmerman described extensive pulmonary anthracosis in each. Although cigarette smoking was not part of these four ancient populations, the need for fire and thus smoke inhalation could have played a part in the development of atherosclerosis.

All four populations lived at a time when infections would have been a common aspect of daily life and the major cause of death. Antibiotics had yet to be developed and the environment was non-hygienic. In 20th century hunter-foragers-horticulturalists, about 75% of mortality was attributed to infections, and only 10% from senescence.<sup>28</sup> The high level of chronic infection and inflammation in premodern conditions might have promoted the inflammatory aspects of atherosclerosis.<sup>29</sup> This would be consistent with the accelerated atherosclerosis experienced by modern day patients with rheumatoid arthritis and systemic lupus erythematosus.<sup>30</sup> Future study of the genetic variants of innate immunity in these historical populations could reveal antagonistic pleiotropies, in which gene variants that enhance immunity had delayed adverse effects at later ages when natural selection is weaker.

In considering the limitations of our study, we used calcification as a marker of atherosclerosis and do not have pathological confirmation that calcifications in these mummies represents atherosclerosis. However, arterial calcifications on imaging studies in patients are deemed characteristic for clinical atherosclerosis.<sup>4</sup> Also, the

calcifications occurred at the same locations as in modern human beings and their appearance is the same.<sup>8,9</sup> Previous studies involving autopsies of mummies in two of the four populations, the Egyptians and Unangan, have shown atherosclerosis in these populations.<sup>6,7,18–20</sup>

The quality of soft tissue preservation varied greatly among the mummies. Additionally, the Egyptian mummies primarily underwent artificial mummification which often involved the removal of a variable number of vessels and organs (in the other three cultures, mummification was natural). In a subset of mummies, vessels were not identifiable by CT because they had either been removed or had disintegrated over time. Thus, at times we noted calcification along the expected course of an artery, but without visualising a vessel we interpreted the atherosclerosis as probable, since the vessel itself was not seen. For analytic purposes, these were combined and interpreted as representing atherosclerosis. We also have only a fairly small number of mummies from both the Unangan and Ancestral Puebloans, precluding the opportunity to estimate the incidence of atherosclerosis in these cultures. The sample size of 137 represents a wide cross-section of four cultures, but lacks the statistical power to adequately compare potential differences in the incidence and severity of atherosclerosis between men and women and between different cultures.

In conclusion, atherosclerosis was common in four preindustrial populations, including a preagricultural hunter-gatherer population, and across a wide span of human history. It remains prevalent in contemporary human beings. The presence of atherosclerosis in premodern human beings suggests that the disease is an inherent component of human ageing and not characteristic of any specific diet or lifestyle.

#### Contributors

RCT, AHA, GPL, LSW, MLS, JDS, MIM, Ae-HNe-d, JN, CEF, and GST contributed to the conception, design, and implementation of the study. AHA, GPL, BF, DTM, JMM, CMV, GAe-M, IB, SLC, and AHN provided access to mummies and archaeological correlations. MA-TS and SLC assessed the age of the mummies from CT data. RCT, AHA, LSW, MLS, JDS, MIM, and GST interpreted the CT scans for vascular calcification. RCT, AHA, MIM, and GST assembled the data and did statistical analysis. RCT, AHA, GPL, LSW, MLS, JDS, MA-TS, MIM, BF, DTM, JMM, SLC, GAe-M, IB, MIM, Ae-HNe-d, JN, CEF, and GST contributed to the interpretation of the data and drafting of the report.

#### Conflicts of interest

We declare that we have no conflicts of interest.

#### Acknowledgments

Funding for the study was supplied by the National Endowment for the Humanities (#HJ-50069-12), the Paleocardiology Foundation, Siemens, the National Bank of Egypt, and the St Luke's Hospital Foundation of Kansas City. The study also would not have been possible without the generosity of numerous museum and medical personnel who aided in the CT scanning or provided essential CT images or anthropological data. We thank the Metropolitan Museum of Art for generously providing us with full access to the data that they had gathered for their 1997 study.<sup>10</sup> We also thank Kevin F Kennedy of the Saint Luke's Mid America Heart Institute for statistical analysis, John N Makaryus and Amgad N Makaryus of the North Shore LIJ Health System for providing the CT data for mummies 71–76, Jon Kardatzke of the Museum of World Treasures, Wichita, KS, for access to the CT data for mummies 68 and 69, Sallam Lotfy Mohamed of

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#### References

- 1 Oeppen J, Vaupel JW. Broken limits of life expectancy. *Science* 2002; **296**: 1029–31.
- 2 WHO. The top 10 causes of death. Fact sheet N°310. Updated June, 2011. <http://www.who.int/mediacentre/factsheets/fs310/en/index.html> (accessed Dec 31, 2012).
- 3 O'Keefe JH, Cordain L. Cardiovascular disease resulting from a diet and lifestyle at odds with our Paleolithic genome: how to become a 21st-century hunter-gatherer. *Mayo Clin Proc* 2004; **79**: 101–08.
- 4 Stary HC, Chandler AB, Dinsmore RE, et al. A definition of advanced types of atherosclerotic lesions and a histological classification of atherosclerosis. A report from the Committee on Vascular Lesions of the Council on Arteriosclerosis, American Heart Association. *Circulation* 1995; **92**: 1355–74.
- 5 Murphy WA Jr, Nedden Dz Dz, Gostner P, Knapp R, Recheis W, Seidler H. The iceman: discovery and imaging. *Radiology* 2003; **226**: 614–29.
- 6 Czermack J. Description and microscopic findings of two Egyptian mummies. Meeting of the Academy of Science. *S B Akad Wiss Wien* 1852; **9**: 27.
- 7 Ruffer MA. On arterial lesions found in Egyptian mummies (1580 BC–535 AD). *J Pathol Bacteriol* 1911; **16**: 453–62.
- 8 Allam AH, Thompson RC, Wann LS, Miyamoto ML, Thomas GS. Computed tomographic assessment of atherosclerosis in ancient Egyptian mummies. *JAMA* 2009; **302**: 2091–103.
- 9 Allam AH, Thompson RC, Wann LS, et al. Atherosclerosis in ancient Egyptian mummies: the Horus study. *J Am Coll Cardiol Img* 2011; **4**: 315–27.
- 10 Mininberg DT. The Museum's mummies: an inside view. *Neurosurgery* 2001; **49**: 192–99.
- 11 Dall WH. On the remains of later prehistoric man obtained from caves in the Catherina archipelago, Alaskan territory and especially from the caves of the Aleutian Islands. Washington, DC: Smithsonian Institution, 1878.
- 12 Hrdlicka A. The Aleutian and Commander Islands and their inhabitants. Philadelphia, PA: Wistar Institute of Anatomy and Biology, 1945.
- 13 Jonsdottir B. CT scanning of Aleutian mummies. In: Frohlich B, Harper AB, Gilberg R. To the Aleutians and beyond: the anthropology of William S. Laughlin. Copenhagen: Publications of the National Museum Ethnographic Series, Volume 20, the National Museum of Denmark, 2002: 155–167.
- 14 Allison MA, Criqui MH, Wright CM. Patterns and risk factors for systemic calcified atherosclerosis. *Atheroscler Thromb Vasc Biol* 2004; **24**: 331–36.
- 15 Buikstra JE, Ubelaker DH. Standards for data collection from human skeletal remains. Arkansas Archeological Survey Research Series No. 44. Fayetteville, AR: Arkansas Archeological Survey, 1994.
- 16 Walker RA, Lovejoy CO. Radiographic changes in the clavicle and proximal femur and their use in the determination of skeletal age at death. *Am J Phys Anthropol* 1985; **68**: 67–78.
- 17 Long AR. Cardiovascular renal disease: a report of a case three thousand years ago. *Arch Pathol (Chic)* 1931; **12**: 92–94.
- 18 Zimmerman MR, Yeatman GW, Sprinz H, Titterington WP. Examination of an Aleutian mummy. *Bull NY Acad Med* 1971; **47**: 108.
- 19 Zimmerman MR, Trinkaus E, LeMay M, et al. The paleopathology of an Aleutian mummy. *Arch Pathol Lab Med* 198; **105**: 638–41.
- 20 Zimmerman MR. The paleopathology of the cardiovascular system. *Texas Heart Inst J* 1993; **20**: 252–57.
- 21 Allison MA, Budoff MJ, Nasir K, et al. Ethnic-specific risks for atherosclerotic calcification of the thoracic and abdominal aorta (from the Multi-Ethnic Study of Atherosclerosis). *Am J Cardiol* 2009; **104**: 812–17.
- 22 Strong JP, Malcom GT, McMahan CA, et al. Prevalence and extent of atherosclerosis in adolescents and young adults: implications for prevention from the Pathobiological Determinants of Atherosclerosis in Youth Study. *JAMA* 1999; **281**: 727–35.
- 23 Darby WJ, Ghalioungui P, Grivatti L. Food: the gift of Osiris. Vol 1. London: Academic Press, 1957.
- 24 David R. The art of medicine—atherosclerosis and diet in ancient Egypt. *Lancet* 2010; **175**: 718–19.
- 25 Antunez de Mayolo S. La Nutrición en el Antiguo Perú. Lima, Peru: Banco Central de Reserva del Perú, 1981.
- 26 Downum CE, ed. Hisat'sinom. Ancient peoples in a land without water. Santa Fe, NM: School for Advanced Research Press, 2012.
- 27 Laughlin WS. Aleuts: survivors of the Bering land bridge. New York, NY: Holt, Rinehart and Winston, 1980.
- 28 Finch CE. Evolution of the human lifespan and diseases of aging: roles of infection, inflammation, and nutrition. *Proc Natl Acad Sci USA* 2010; **107** (suppl 1): 1718–24.
- 29 Finch CE. The biology of human longevity. Inflammation, nutrition, and aging in the evolution of lifespans. Amsterdam: Academic Press, 2007.
- 30 Missala I, Kassner U, Steinhagen-Thiessen E. A systematic literature review of the association of lipoprotein(a) and autoimmune diseases and atherosclerosis. *Int J Rheumatol* 2012; **2012**: 480784.