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Health Indicators in Skeletons from Iron Age Central Thailand: A Preliminary Report from the Site of Phromthin Tai, Lopburi Province
ตัวบ่งชี้สุขภาพอนามัยบนกระดูกมนุษย์สมัยเหล็กในภาคกลางของประเทศไทย: รายงานเบื้องต้นจากแหล่งโบราณคดีพรหมทินใต้ จังหวัดลพบุรี

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Abstract
Little has been published about the health of individuals living in Central Thailand during the Iron Age (ca. 2500 – 1500 BP). The site of Phromthin Thai provides an opportunity to examine indicators of systemic stress and signs of compromised health during this time period using human skeletal remains. Twenty-six Iron Age skeletons from the site were examined for indicators of systemic stress or compromised health in the form of porotic hyperostosis, cribra orbitalia, linear enamel hypoplasia, dental caries, and trauma. These results were compared with data from the Ban Pong Manao site in Central Thailand and from two sites in different parts of Northeast Thailand to determine whether frequencies of these indicators varied significantly at Phromthin Tai. We found that the skeletons from Phromthin Tai exhibited generally low frequencies of most of these skeletal indicators, and that the prevalence of most of these indicators were similar to that reported for Ban Pong Manao in Central Thailand, and Ban Chiang and Noen U-Loke in Northeast Thailand. The main difference was a surprisingly low frequency of dental caries compared to the other three sites, which may relate to some unknown difference in the diet.

งานการศึกษาวิจัยเกี่ยวกับสุขภาพอนามัยของผู้คนสมัยเหล็ก (ประมาณ ๑,๕๐๐ – ๒,๕๐๐ ปีมาแล้ว) ในภาคกลางที่มีการตีพิมพ์นับว่ายังมีไม่มาก แหล่งโบราณคดีพรหมทินใต้ได้เปิดโอกาสให้พวกเราศึกษาตรวจสอบเรื่องราวเกี่ยวกับสุขอนามัยโดยพิจารณาจากตัวบ่งชี้สุขภาพต่าง ๆ ซึ่งปรากฏหรือทิ้งร่องรอยไว้บนกระดูกมนุษย์ที่ถูกฝังไว้ในช่วงสมัยเหล็ก ตัวอย่างกระดูกที่ศึกษามาจากผู้ตายจำนวน ๒๖ คน ตัวบ่งชี้สุขภาพอนามัยที่เราศึกษาได้แก่ร่องรอยความพรุนบนกะโหลกศีรษะ (porotic hyperostosis) ร่องรอยความพรุนบนกระดูกบนเพดานเบ้าตา (cribra orbitalia) ร่องรอยความผิดปกติบนเคลือบฟัน (linear enamel hypoplasia) โรคฟันผุ (dental caries) และร่องรอยบาดแผล (trauma) เรานำผลการศึกษาไปเปรียบเทียบกับข้อมูลและผลการศึกษาสุขอนามัยของผู้คนสมัยเหล็กจากแหล่งโบราณคดี

บ้านโป่งมะนาวในภาคกลางและแหล่งโบราณคดีอีก ๒ แหล่ง (แหล่งโบราณคดีบ้านเชียงและแหล่งโบราณคดีเนินอุโลก) ในภาคตะวันออกเฉียงเหนือที่มีการศึกษามาแล้ว จากผลการศึกษา เราพบว่าโครงกระดูกของผู้คนสมัยที่แหล่งโบราณคดีพรหมทินใต้โดยทั่วไปมีร่องรอยตัวบ่งชี้สุขอนามัยค่อนข้างต่ำ ซึ่งคล้ายหรือใกล้เคียงกับสุขอนามัยของผู้คนสมัยเดียวกันที่แหล่งโบราณคดีบ้านโป่งมะนาวในภาคกลางและแหล่งโบราณคดีบ้านเชียงและแหล่งโบราณคดีเนินอุโลกในภาคตะวันออกเฉียงเหนือ สิ่งที่แตกต่างกันอย่างน่าประหลาดก็คือผู้คนที่แหล่งโบราณคดีพรหมทินใต้มีร่องรอยโรคฟันผุน้อยหรือต่ำกว่าผู้คนจากแหล่งโบราณคดี ๓ แหล่งที่นำมาเปรียบเทียบ

Keywords: Bioarchaeology, Iron Age, Phromthin Tai, Lopburi | โบราณคดีเชิงชีววิทยา, สมัยเหล็ก, พรหมทินใต้, ลพบุรี

Introduction

Little has been published about the health of individuals living in Central Thailand during the Iron Age, which lasted from approximately 2500 – 1500 BP (Higham and Thosarat 1998, Rispoli 2022). For the purposes of this study, "health" refers to the presence of skeletal markers indicative of pathology or systemic stress, such as cribra orbitalia, porotic hyperostosis, linear enamel hypoplasia, fractures and dental caries. When discussing studies from other sites in Thailand, the term "health" also includes information on adult stature, life expectancy, and other indicators. Most of what is known about systemic stress and skeletal or dental pathology during the Iron Age in Central Thailand comes from an unpublished master's thesis examining such indicators at Ban Pong Manao (Lerdpipatworakul 2009), and an unpublished PhD dissertation that addressed stress indicators and conducted dietary isotopic analysis of skeletons from four Iron Age sites in the area (Liu 2012). These four sites included Phromthin Tai and Ban Pong Manao, along with Ban Mai Chaimongkol and Kao Sai On-Noen (Liu 2012), but only Phromthin Tai and Ban Pong Manao had an Iron Age skeletal sample of greater than 10 individuals that were suitable for study (Liu 2012). Furthermore, Liu's (2012) frequencies from Phromthin Tai and Ban Pong Manao included observations made while some of the skeletons were still *in situ*. These skeletons were left partially excavated and on display as part of local public archaeology initiatives, making it challenging to identify more subtle skeletal and dental indicators of stress and potentially impacting the reported frequencies.

Northeastern Thailand has more published bioarchaeological research about Iron Age sites than Central Thailand (e.g. Dhavale et al. 2017, Higham 2007, Pedersen et al. 2019, Pietrusewsky and Douglas 2002, Wangthongchaicharoen 2013) and from sites that were likely similarly dependent on rice agriculture as was Phromthin Tai (d'Alpoim Guedes et al. 2019, Higham 2007:609, Liu 2018, Pietrusewsky and Douglas 2002). However, the degree of cultural similarity between the neighboring areas of Northeastern and Central Thailand during the Iron Age is still unclear. Higham and Rispoli (2014) have attempted to integrate the sequences of cultural development in both northeastern Thailand and the neighboring Lopburi region of Central Thailand, where Phromthin Tai is located, to better understand the relationship between the two areas. Using mostly artifactual evidence, they conclude that the Iron Age was a time of fundamental cultural change in both regions, with a flood of prestige goods flowing in via far-ranging trade networks, and a trade relationship that involved production of copper at several sites in Lopburi, which was then traded to the Northeast probably in exchange for salt. Phromthin Tai was likely involved in this exchange network, given the evidence of copper smelting and a mold for making copper ingots at the site (Lertcharnrit 2014).

During the Iron Age in Central Thailand, people permanently inhabited a wide array of open geographic settings, including lowland areas near rivers or tributaries of major rivers, high terraces, and highlands. They subsisted on hunting and collecting wild plants and animals (terrestrial and fresh-water animals), and farming millet and rice (Chanthasi 2015, d'Alpoim Guedes et al. 2019). There is also evidence of craft production, such as shell and stone bracelet production and metalworking (like copper mining and smelting), that link the communities to long-distance trade and exchange networks (Lertcharnrit 2019). The increase in the number and size of sites dating to this time period suggests that population density was higher than during previous periods such as the Neolithic and Bronze Age (see, for example, Rispoli 2022). Climate was generally stable throughout the period and remained similar in different parts of Thailand, as seen from faunal and floral remains discovered at archaeological sites across Thailand (Higham and Thosarat 1998). However, more zooarchaeological, archaeobotanical, and geoarchaeological studies are needed to support and refine these arguments.

Unlike many parts of the world that tend to see declining health with the transition to agriculture, such was not the case in at least some parts of Thailand (Domett and Tayles 2006). In the Mun River Valley, for example, health seems to have generally improved between the Bronze Age (3400 – 2500 BP) and the Iron Age. Domett and Tayles (2006) compared two sites from this area situated in similar environments – Ban Lum Khao from the Bronze Age, and Noen U-Loke from the Iron Age – and found a number of indicators of improved health. In particular, the Iron Age site had slightly lower overall mortality for individuals under the age of 15, particularly between the ages of 5-9 years, and less evidence of growth disruption in the form of linear enamel hypoplasia. Young adult female deaths (ages 15-29) were nearly twice as common in the Bronze Age sample as were male deaths, and more than twice the death rate compared to females at Iron Age Noen U-Loke (Domett and Tayles 2006). Males were also taller in the Iron Age sample by approximately 4.6 cm, suggesting better health during childhood, although the female sample was too small to properly determine whether the trend applied to both sexes. Fractures appeared to be more common for the Bronze Age Ban Lum Khao sample as well, particularly of the radius and ulna. Caries rates were fairly equivalent between the two time periods, at between 4.5-4.8% of adult individuals when counted by affected tooth, although a higher proportion of caries were periapical in the Iron Age. The main indicator of potentially poorer health for the Iron Age sample comes in the form of evidence of systemic infection. Iron Age Noen U-Loke showed substantially poorer preservation than Ban Lum Khao, and yet showed a prevalence for periostitis suggesting systemic infection in the sample (excluding neonates) of 7.7% versus 3.4%. The difference was not statistically significant, but given the preservation differences, the rates at Noen U-Loke were likely higher than observed. Domett and Tayles (2007) suggest that increased long-distance trade relationships could be a factor in introducing more infectious disease in the Iron Age (citing O'Reilly 2000), and there is considerable evidence for such interactions from more recent research in the area (Carter 2013, 2015; Higham and Rispoli 2014).

Douglas and Pietrusewsky (2007) examined the agricultural transition considerably north of the Mun River at Ban Chiang and Non Nok Tha. The Non Nok Tha sequence began around 4500-5000 BP and its occupation and cemetery use lasted until the end of the Bronze Age. Ban Chiang overlaps with Non Nok Tha for about 400 years during the Bronze Age, and lasted until about 1800 BP in the late Iron Age. Leading up to the Iron Age at the Non Nok Tha site, Douglas and Pietrusewsky (2007) note some improvements in health over time. There are fewer children in the cemetery as time goes on, and the estimated life expectancy at birth increased from 27 to 37 years by the later period. Dental pathology frequencies increased over time when measured by tooth count, including antemortem tooth loss, alveolar resorption, and caries. Frequencies of non-specific systemic stress indicators such as linear enamel hypoplasia and cribra orbitalia also declined over the period, and stature increased in both sexes (Douglas and Pietrusewsky 2007). As was the case for the Mun River Valley, infectious diseases increased from the earlier to the later time period in the lead up to the Iron Age.

Health at Ban Chiang remained relatively steady between the early and late periods, with some minor exceptions (Douglas and Pietrusewsky 2007). The site straddles the boundary between the late Bronze Age and the Iron Age while agriculture was intensifying, but statistically significant differences between the early and late periods are few. Importantly, there was very little difference in stature between males or females (Douglas and Pietrusewsky 2007), with an increase between the early and late groups averaging less than 1 cm in both sexes, perhaps indicating a fairly consistent health environment for children who survived to adulthood. For comparison to the Mun River Valley further south, stature averaged 166 cm at Ban Chiang compared to 169 at Noen U-Loke during the same time period (Douglas and Pietrusewsky 2007, Domett and Tayles 2006). As for other indicators, Douglas and Pietrusewsky (2007) note a decrease in alveolar resorption and caries, but an increase in antemortem tooth loss and cribra orbitalia during the late period. Cribra orbitalia increases from ca. 9% to 40% between the early and late periods, although the samples are small. This could indicate problems during childhood with nutrition, parasites, or malaria, but the effect does not seem to have been severe enough to reduce stature attainment in adulthood, at least for those who survived. By contrast, dental caries rates by tooth count decline over time, from 7.3% to 4.3% (Douglas and Pietrusewsky 2007). The caries rate by tooth during the late period/Iron Age is a very similar 4.8% at Noen U-Loke (Domett and Tayles 2006). These data suggest fairly limited change in health between the earlier and later periods at Ban Chiang, and some similarities between Iron Age Noen U-Loke and the corresponding period at Ban Chiang.

The goal of this study is to gain a better understanding of health in Lopburi Province during the Iron Age by analyzing skeletons from the site of Phromthin Tai and comparing them to three other sites in Thailand. The skeletons from Phromthin Tai were scored for systemic stress indicators, dental caries, and fractures, and compared to the Ban Pong Manao site in Central Thailand as well as the Ban Chiang and Noen U-Loke sites in Northeast Thailand, to determine whether living at Phromthin Tai appears to have affected individuals any differently than living in either of the two sites from Northeast Thailand during the Iron Age.

The Site of Phromthin Tai

Phromthin Tai (แหล่งโบราณคดีพรหมทินใต้) lies 20 km northeast of the city of Lopburi in the Lam Maleng Valley, a local component of Central Thailand’s Eastern Chao Phraya River Valley (Figure 1). Stratigraphic evidence suggests continuous occupation of Phromthin Tai from the late Bronze Age to the Historic Period, or approximately 2700 – 1200 BP (Lertcharnrit 2006, 2014). Thirty-six (36) individuals were excavated from a 6 x 6 meter excavation unit (PTT-S2/S3) in 2007, at depths ranging from 165 cm to 285 cm below datum.

Fig. 1 Map showing location of the Phromthin Tai site in relation to two other nearby sites with Iron Age burials, and the two comparative sites of Ban Chiang and Noen U-Loke from Northeast Thailand. Map prepared by Nannabhat Niyomsap.

Although the burials are found in Iron Age deposits, dating them precisely is difficult due to soil homogeneity and past human disturbance. Calibrated radiocarbon dates from carbonized seeds in non-burial contexts at Phromthin Tai suggest considerable activity between 2200 BP and 1450 BP (d'Alpoim Guedes et al. 2019). Additionally, mortuary practices found at Phromthin Tai fit well with those at other sites (e.g. Non Ban Jak on the Khorat Plateau) dating to the later Iron Age (Higham et al. 2014). Some mortuary similarities include the practice of extended supine burials, the consumption of a wide variety of ornaments as grave goods (e.g., glass and stone beads, bronze ornaments) across sex and age, as well as the interment of the dead in or around houses, namely "residential burials" (e.g. Adams and King 2011, White and Eyre 2011).

As was true for other sites in the area, Phromthin Tai was connected to long-distance trade networks (Lertcharnrit 2019). Carter (2013:413) argues that during the Iron Age, the Phromthin Tai community likely participated in multiple, wide-ranging stone and glass bead exchange networks, some with connections to Vietnam and India (Carter 2013:259). Agate and carnelian ornaments also connect Phromthin Tai to other communities in west-central, southern, and northeastern Thailand (Carter 2015, Bellina 2017), suggesting greater involvement in exchange networks than many other Iron Age communities in Southeast Asia, and the potential for interaction, whether direct or indirect, with northeastern sites.

Comparative Sites

As noted above, the information published about Iron Age skeletons from other settlements in Central Thailand has been limited. The three sites that are closest to Phromthin Tai all overlap in time and also produced burials. However, neither Non Pa Wai (Rispoli et al. 2013), nor Non Mak

La appear to have produced any burials from the Iron Age (Pigott et al. 1997; Rispoli et al. 2013). Fourteen burials from Nil Kham Haeng clearly belong to the Iron Age, probably between 2200 BP and well into the 2nd millennium BP (Rispoli et al. 2013), but no details about stress indicators in the skeletons have been published. Most of what we know about skeletal lesions and systemic stress come from the unpublished sources noted above, and only Ban Pong Manao provides a reasonably sized skeletal sample (51 skeletons) for comparison in the Central region. Data from this site are challenging to interpret, however, because the two researchers disagree on the frequencies of caries, linear enamel hypoplasia, cribra orbitalia, and the number of fractures (Table 1). These disagreements likely reflect differences in methodological approach between the researchers, and perhaps some differences in the specific set of skeletons examined.

Site	N	Author	Caries % of Teeth	LEH % of Teeth	Cribra % of Orbits	PH % of Individuals	Fractures # Individuals
Ban Pong Manao[1]	51	Lerdpipatworakul (2009)	8.5%	1.0%	16.7%	--	5
Ban Pong Manao[2]	49	Liu (2012)	2.1%	0.6%	0.0%	5.3%	2
Ban Mai Chaimongkol[3]	10	Liu (2012)	6.6%	0.9%	20.8%	0.0%	0
Promthin Tai[4]	35	Liu (2012)	0.0%	6.2%	0.0%	0.0%	1

[1]Only 6 individuals (8 orbits) scored for cribra. Fractures are reported to a left ulna (SQ1,B2), a humerus (SQ1,B8), a tibia and four foot phalanges (SQ1,B11), a right MC5 (SQ3,B9), and a proximal hand phalanx (SQ18,B3).
[2]Twenty-seven (27) orbits scored for cribra. 19 cranial vaults scored for PH. One showed pitting but no thickening. One individual had a fracture of a distal ulna, the other a right distal ulna and fifth metacarpal.
[3]Twenty-four (24) orbits scored for cribra with three individuals affected. 13 cranial vaults were scored for PH. No fractures in the Iron Age sample.
[4]Fifteen (15) orbits scored for cribra. 12 cranial vaults were scored for PH. One left clavicle fracture described.

Table. 1 Skeletal Indicators in Iron Age Central Thailand - Previous Studies (Lerdpipatworakul 2009; Liu 2012).

The archaeological site Ban Pong Manao is a natural mound located in the eastern highland area of east-central Thailand (about 180 meters above modern sea level), approximately 90 km east of the site Phromthin Tai. It is flanked by small streams in the north and the south, with a slight slope from the east to the west. Excavations at the site reveal two periods of human occupation and use (Natapintu 2007). The earliest period dates between 3,500-3,000 BP. The later period Iron Age occupation dates to 2,800-1,500 BP. Over 100 burials associated with diverse kinds of grave goods (e.g., personal ornaments, ceramic vessels, metal tools, spindle whorls, turtle carapaces) were uncovered during excavations (Lerdpipatwarakul 2009), some of which had been looted, and others left partially excavated and on display. People at the site subsisted on a variety of natural resources, and had intra-regional and inter-regional contacts with other groups of people (see for more details in Natapintu 2007).

In addition to Ban Pong Manao, we have chosen two sites in Northeast Thailand for pilot comparison as they contain data available for comparative study from two different areas in the Northeast. Ban Chiang is located in the northeastern Thai province of Udon Thani, and Noen U-Loke is located considerably south of Ban Chiang, in the Mun River Valley, and is geographically closer to Phromthin Tai (Figure 1). Both sites date to the Iron Age or have Iron Age components (Pietrusewsky and Douglas 2002; Tayles et al. 2007). Furthermore, information about individual burials/skeletons is available for both sites (Higham et al. 2007, Pietrusewsky and Douglas 2002). Evidence indicates rice agriculture was practiced during the Iron Age at both of these sites (Higham 2007:609; Pietrusewsky and Douglas 2002), as was the case for Phromthin Tai, and both show evidence of metallurgy (Higham 2002:204, White and Hamilton 2009), as is also true for Phromthin Tai.

The Ban Chiang site produced burials from three periods (Pietrusewsky and Douglas 2002): The Early Period (4100-2900 BP), Middle Period (2900-2300 BP) and Late Period (2300 BP – 1800 BP). The Late Period lies firmly in the timespan of the Iron Age in Central Thailand, but the Middle Period is late Bronze Age to early Iron Age. It is not until Middle Period VII that iron is found with burials at Ban Chiang, so we followed the lead of King and Norr (2006) and combined Middle Period VII, Middle Period VIII, and the two Late Periods into an Iron Age sample for the site. This produced 36 Iron Age burials of which 24 skeletons provided relevant data on systemic stress indicators, dental caries, and fractures. These data come from raw data published by Pietrusewsky and Douglas (2002: Appendix E). Iron Age individuals from Ban Chiang were buried with limited numbers of exotic artifacts, perhaps suggesting low levels of status differentiation. Although most graves contained pottery of some sort, and many contained bones of animals, only eight burials (25%) had metal artifacts, mostly in the form of bronze anklets and bracelets (Pietrusewsky and Douglas 2002: Appendix C). Four (13%) had objects that included iron, and only one had glass beads. None of the burials had agate or carnelian beads. Thus, Ban Chiang does not seem to have been as heavily involved in long-distance exchange as was apparently the case for Phromthin Tai (Carter 2015) and this could have impacted their health.

Noen U-Loke is located in the southwestern part of Thailand's Khorat Plateau (Higham 2002). Noen U-Loke was a moated settlement surrounded by as many as five moats during the Iron Age, and the site covered an area of 12 hectares (Wichakana 1991, cited in Higham 2002). Burials at the site date from 2200 BP to 1600 BP (Talbot 2007) and the excavations produced a relatively large sample of 120 skeletons. Data for comparison are those provided by Domett and Tayles (2006), Halcrow et al. (2016), and Tayles et al. (2007). Many of the burials from Noen U-Loke are quite rich in burial goods, including agate ornaments, carnelian beads, gold beads, bronze ornaments, and iron tools (Higham 2002), suggesting greater involvement in long-distance trading networks, similar to Phromthin Tai.

Materials And Methods

Thirty-five (35) burials were excavated from the PTT-S2/S3 unit at Phromthin Tai, representing at least 36 individuals (Table 2). Fourteen (14) of the 36 skeletons were left *in situ* as part of a public archaeology initiative, and were subsequently buried during severe flooding in the rainy season of 2010. Portions of four of these skeletons (Burials 19, 24, 26 and 29) had been removed prior to the flooding, while the rest remained on display. Demographic information on age and sex is available for some of these display burials based on *in situ* observation prior to the flooding, however the analytical sample of skeletons from this site is comprised of those burials that were fully or partially removed for study (20 adults, 6 nonadults). Most of the bones were broken in one or more places, and the skulls tended to be in many pieces. Many of the skeletons were also quite fragile. This is likely due to the depth of the burials and the weight of the earth above (Figures 2A and 2B).

Burial	Sex	Sex Certainty	Depth*	In Collection?	Left In Situ?	Notes
1	?	--	165	Yes	No	
2	M	Medium	190	Yes	No	
3	F	Medium	199	Yes	No	
4	?	--	205	Yes	No	
5	M	High	222	Yes	No	
6	Nonadult	--	227	Yes	No	
7	F	Low	248	Yes	No	
8	M	Medium	239	Yes	No	
9	M**	Low	237	No	Yes	Lower limbs only
10	M	Low	254	Yes	No	
11	?	--	249	No	Yes	Femora only
12	M	High	267	Yes	No	
13	F**	Medium	243	No	Yes	Cranium/maxilla only
14	M**	Medium	275	No	Yes	Lower half of body
15	M	Medium	217	Yes	No	
16	M	High	235	Yes	No	
17	Nonadult	--	230	Yes	No	
18	Nonadult	--	252	Yes	No	
19	Nonadult	--	247	Yes	Yes	Most left in situ
20	F	High	241	Yes	No	
21	M	High	243	Yes	No	
22	M	Medium	250	Yes	No	
23	Nonadult	--	230	Yes	No	
24	?	--	242	Yes	Yes	Most left in situ
25	M	Low	238	Yes	No	
26	?	--	273	Yes	Yes	Part left in situ
27	?	--	256	No	Yes	Lower limbs, possibly more
28	?	--	254	No	Yes	Lower limbs only
29	M	Medium	254	Yes	Yes	Lower body, lower limbs in situ
30	?	--	268	No	Yes	Partial skeleton
31	?	--	--	No	Yes?	No burial record
32	?	--	249	No	Yes	Most of skeleton in situ
33A	M	High	222	Yes	No	
33B	Nonadult	--	222	Yes	No	Identified during analysis
34	?	--	285	No	No	
35	?	--	270	No	Yes	Misc scattered bones

*Centimeters below datum

**Sex estimate from Chin-Hsin Liu's field notes; skeletons subsequently buried in flooding event.

Table. 2 List of Burials Excavated from PTT-S2/S3

Fig. 2 2A (left): Skeleton of Burial 12 *in situ*. This was one of the display skeletons that was partially excavated in 2007 and later fully removed. It is one of the more complete skeletons at the site. 2B (right): Skull of Burial 20 showing fragmentation and deformation. Source: Photos by Scott Burnett 2011.

Sex estimation was accomplished using standard pelvic and cranial indicators (Buikstra and Ubelaker 1994). The confidence of these estimates is reported as high, medium, or low. Confidence is a subjective assessment that reflects the number of observable traits present in each skeleton, as well as the consistency of the scores. Measurements were used to help clarify the sexes of some skeletons by means of discriminant function or logistic regression equations created from samples of modern Thai individuals. Measurements were never used alone to estimate sex, but only as supporting evidence. Equations for humeral epicondylar breadth and humeral vertical head diameter were taken from İşcan et al. (1998). Equations for talar length, breadth, and height were taken from Mahakkanukrauh et al. (2014). However, the bones most likely to be complete and unbroken were the digital bones of the hands. Therefore, logistic regression equations were generated for this study based on measurements of finger bones using data from 192 modern Thai skeletons housed at Chiang Mai University (see Table 3 for the equations used and Appendix for a description of the methods used to create the equations).

Measure	Female N	Male N	Logit Equation	Female %	Male %	Overall %
MC3 Base Width (L)	96	96	2.149*MC3BW - 28.707	82.3%	82.3%	82.3%
MC4 Base Width (L)	92	94	2.326*MC4BW - 25.626	83.7%	78.7%	81.2%
MC5 Base Width (L)	92	92	2.188*MC5BW - 27.744	82.6%	80.4%	81.5%
PP1 Base Width (L)	87	94	3.148*PP1BW - 47.265	89.7%	89.4%	89.5%
PP3 Base Width (L)	93	94	3.106*PP3BW - 46.592	86.0%	87.2%	86.6%
IP3 Base Width (L)	91	95	3.202*IP3BW - 41.499	83.5%	88.4%	86.0%

MC3, MC4, MC5 Base Width Measurements follow Case et. al. 2015.

PP1, PP3, and IP3 base widths are taken on a mini-osteometric board with the posterior side up and long axis perpendicular to the board

Table. 3 Logistic regression equations for hand bones derived from modern Thai skeletons.

Ages of nonadult skeletons at Phromthin Tai were assessed using a variety of indicators of skeletal maturity and dental eruption (Baker et al. 2005; Buikstra and Ubelaker 1994; Fazekas and Kosa 1978; Merchant and Ubelaker 1977; Rissech et al. 2008; Saunders et al. 1993; Scheuer and Black 2004; Todd and D'Errico 1926). The ages of adult skeletons were assessed using information on skeletal maturity (Krogman and İşcan 1986) as well as pubic symphysis changes based on the Suchey-Brooks method (Buikstra and Ubelaker 1994) and auricular surface changes (Meindl and Lovejoy 1989). Dental wear was also scored (Smith 1984), and the dentitions of those skeletons with no pelvic indicators present for aging were compared to those with these indicators present in order to place adult individuals into young adult (ca. 20-34), middle adult (35-49), or old adult (50+) categories based on relative dental wear.

Skeletal Stress Indicators, Caries, and Fractures

Three systemic stress indicators were assessed. Cribra orbitalia (CO), porotic hyperostosis (PH) and dental linear enamel hypoplasias (LEH) were scored to provide information about nutritional and/or disease stress, and perhaps other causes of non-specific stress, experienced primarily during childhood (Ham et al. 2020, Vlok et al. 2021, Walker et al. 2009, Zuckerman et al. 2014). In addition, dental caries were assessed for information about the cariogenicity of the local diet (Marklein et al. 2019), particularly in the teen and adult years, and because caries-related abscesses have been an important cause of early mortality in the past (Clarke 1999). Antemortem fractures with signs of healing were identified in order to better understand susceptibility to accident and interpersonal violence at all ages (Walker 2001).

Cribra orbitalia and porotic hyperostosis were scored following procedures outlined in Buikstra and Ubelaker (1994: Figs. 106a-f). Frequencies are based on the number of affected individuals compared to the total number who could be scored for the condition. An individual was considered to express the condition if they showed a score beyond the Grade 1 or "barely discernible" level. A Grade 2 minimum was selected because the "barely discernible" grade may be treated as absent by some researchers, and because the fragmentary nature of the skulls means that some barely discernible indicators would likely be missed. We also required at least half of an orbit or parietal bone to be present on at least one side in order for these conditions to be scored.

It is very difficult to identify a specific cause for cribra orbitalia and porotic hyperostosis. Porosity of the cranial vault or the orbital roof can be caused by anemia or scurvy, and porous lesions caused by surface deposits of bone can be found in cases of rickets, while osteomalacia can lead to fine pitting and porosity of the cranium as well (Brickely and Ives 2008, Ortner and Ericksen 1997, Ortner and Mays 1998, Zuckerman et al. 2007). Even if anemia is determined to be the most likely cause, there is some debate about the type of anemia most likely to lead to PH and CO - iron-deficiency versus megaloblastic anemia (Oxenham and Cavill 2010; Sullivan 2005; Walker et al. 2009). Anemia is also often a side effect of scurvy, so the two may co-occur (Weinstein et al. 2001, Brickley 2018). In areas where malaria is endemic, anemia caused by malaria or genetic polymorphisms such as thalassemia are also potential causes (Techataweewan 2021, Vlok et al. 2021). Criteria for attempting to distinguish these different etiologies are still being discussed in the literature (Brickley 2018, Klaus 2017, Zuckerman et al. 2014) but most of these discussions have occurred after the data for Phromthin Tai and the comparative sites were collected, and therefore these data may represent a mix of etiologies. By limiting our scoring to Grade 2 or higher, we have increased the probability that the cause is anemia versus scurvy, but no further attempt was made to distinguish these different causes of CO or PH at Phromthin Tai.

Linear enamel hypoplasia was scored on the anterior teeth of the mandible and maxilla with the aid of a 10x hand lens. In addition to scoring the presence or absence of LEH in each tooth, the number of LEH lines per tooth was tabulated, and the distance from the cemento-enamel junction to the occlusal border of the hypoplastic line was measured using Mitutoyo digital calipers. These measurements were used to estimate age at LEH formation based on Reid and Dean (2000). Dental wear on some of the older individuals may have obscured some LEH lines. Linear enamel hypoplasias are a form of developmental defect in dental tissues that may arise from diverse etiological factors, including genetic conditions, local insults such as trauma, or systemic physiological disturbances including malnutrition and disease (e.g. Larsen 2015, Patel et al. 2019, Seow 2014). Documented episodes of malnutrition have been correlated with elevated rates of LEH both human and non-human primates (e.g. Zhou and Corruccini 1998, Guatelli-Steinberg and Benderlioglu 2006), but the multitude of potential etiological factors means that LEH is generally considered a non-specific indicator of developmental disturbance (Guatelli-Steinberg 2015). Both localized trauma to the developing tooth germ and genetic conditions affecting dental development are relatively rare. Accordingly, most LEH is likely to result from systemic physiological disturbances justifying its use as general measure of nutritional status and health (Bereczki et al. 2019).

Trauma was scored by visual examination of each bone for presence of bony callus and/or morphological change to a bone's shape consistent with a healed fracture. Presence of fractures was noted by individual. Given the fragmentary nature of the collection, no attempt was made to identify unhealed fractures, nor to calculate frequencies based on the number of elements. Fracture location was noted to help distinguish fractures that more likely resulted from violence than accident (Judd 2008, Martin and Harrod 2015, Walker 2001).

Dental caries were scored by means of visual examination of all teeth followed by closer inspection with a 10x hand lens where warranted. Frequencies are reported both by the number of individuals affected, and by the number of permanent teeth. Individuals were included in the sample if they had at least one tooth present. While caries are multifactorial in origin, with both intrinsic (e.g. sex, saliva composition, and flow rate) and extrinsic (e.g. diet composition, oral hygiene) correlates (e.g. Lukacs, 2017; Yildiz et al. 2016), Turner (1979) suggested that there is a strong tendency for caries frequencies to correlate with subsistence strategy, though with much overlap in frequencies (see

Marklein et al. 2019). Generally speaking, caries frequencies are relatively lower in foraging groups, higher in mixed subsistence groups, and highest in agricultural groups where carbohydrate-rich domesticated plants are frequently consumed (Turner 1979). Interestingly, this pattern does not appear to hold consistently during the intensification of rice agriculture in Southeast Asia (Larsen 2015, Tayles et al. 2000). Nevertheless, caries remains an important tool to help understand past diet (Larsen 2015; Temple 2016), though a linear relationship between caries and subsistence should not be directly assumed (Marklein et al. 2019).

Because the data from Phromthin Tai and the three comparative sites were all collected by different individuals, interpretation of results are made at a more general level than if the same researchers were involved due to likely variation in methods employed. Furthermore, it is important to keep in mind that there have been some fundamental changes in the methods for collection, as well as the interpretation, of certain skeletal stress indicators such as cribra orbitalia and linear enamel hypoplasia over the past two decades that were not known to the researchers who published much of the comparative data used here. Finally, comparisons with the skeletons from Ban Pong Manao are hampered by differences in reported frequencies from two different studies of the site. However, Liu (2012) included observations of skeletons that remained in situ at the time of her study, and therefore the data from Lerdpipatworakul (2009) are used for the following comparisons.

Statistical Methods
Statistical comparison of site frequencies are made using an online tool for calculating Fisher's Exact statistics (Uitenbroek 2000). Fisher's Exact test was selected because it is more accurate than Chi-square when calculating the p-value in small samples (McDonald 2009). Two-sided p-values are used because the authors did not have an *a priori* expectation that any of the sites should show more evidence of systemic stress than any other. In all cases, the null hypothesis is that the two samples have the same population frequency, and the alternative hypothesis is that they do not.

Results

Sex and age information for the skeletons from Phromthin Tai is provided in Table 2 and Tables 4-6. These data indicate that the current skeletal sample is not representative of a normal population, based on the sex ratio and theoretical age-at-death distributions (Milner et al. 1989). There are too many males, too few nonadults, and too many young adults (Table 6). The sex ratio for Phromthin Tai skeletons was 77% male and 23% female. By contrast, Ban Pong Manao, Ban Chiang and Noen U-Loke have sex ratios nearer to 50/50. Neither Phromthin Tai nor the two comparative sites are representative of a normal population in terms of their age distributions (Table 6). Ban Pong Manao, Ban Chiang and Phromthin Tai have fewer than expected nonadult skeletons, and all four sites have too many teen and young adult individuals compared to expectations (Milner et al. 1989).

Burial Number	Age Est. (years)	Range (years)	Indicators
Burial 6	1	0.7 - 1.3	Some neural arch fusions, dental development
Burial 17	9.5	7.5-11.5	Dental development
Burial 18	5	3.5 - 6.5	Dental development, neural arch fusions C2, femur length = 215 mm
Burial 19	11	8.5-13.5	Dental development
Burial 23	4	3-5	Dental development, C2 dens fusion, femur length = 202 mm
Burial 33B	1	0.5 - 1.5	Femur length estimate = 131 mm, talus neck constriction

Table 4 Non-Adult Skeletons from Phromthin Tai and Their Age Estimates.

Burial	Auricular	Suchey-Brooks	Age Upper Limit	Age Lower Limit	Highest Molar Wear Grade	Highest Other Wear Grade	Age Group
1	4+	--	--	Lumbar epiph ring	--	--	Middle Adult
2	--	--	--	Medial clavicle	7	7	Old Adult
3	3	--	--	S1 epiph ring	--	--	Young Adult
4	--	--	--	--	5	--	Middle Adult
5	2	1	IP ramus fusing	Iliac crest	3	5	Young Adult
7	5	--	--	Medial clavicle	4	4	Middle Adult
8	--	--	--	Iliac crest	5	5	Middle Adult
10	5	--	--	Dist Tib & Fib	--	--	Middle Adult
12	2.5	< 5	Clavicle fusing	--	3	4	Young Adult
13*	--	--	M3 unerupted	M2 erupted	--	--	Teen+
14*	--	--	--	Lumbar osteophytosis	--	--	Adult
15	--	--	--	Prox humerus	--	--	Adult
16	1	1	Clavicle unfused	Iliac crest	2	2	Young Adult
20	2	2	Clavicle fusing	Iliac crest	3	3	Young Adult
21	2	1	Clavicle fusing	Iliac crest	--	--	Young Adult
22	--	--	--	Dist humerus	--	--	Adult
24	--	--	--	--	--	3	Young Adult
25	--	--	--	M3 erupted	--	4	Middle Adult
26	--	--	--	Iliac crest	--	1	Young Adult
29	--	--	--	Prox humerus	--	4	Middle Adult
33A	5	4	--	Vert epiph rings	--	--	Middle Adult

*Age estimate from Chin-Hsin Liu's field notes; skeletons buried in flooding event.
Note: Highest molar wear grade from mandibular M1 except B4 (mand. M2), B5 (max. M1), and B16 (mand. M2).

Table 5 Age Assessment for Phromthin Tai Adults.

Group	Sample (n)	Males	Females	< 6 years	< 15 years	Teen & Young Adult	Middle Adult	Old Adult
--	--	Out of All Sexed Adults		Out of All Skeletons		Out of Age-Categorized Adults Only		
Promthin Tai	28	77%	23%	14%	21%	50%	44%	6%
Ban Pong Manao	51	56%	44%	4%	6%	87%	13%	0%
Noen U-Loke	120	53%	47%	39%	44%	53%	27%	20%
Ban Chiang	36	48%	52%	22%	28%	48%	48%	5%
Expectations: High Fertility	--	~50%	~50%	~54%	~59%	~31%	~14%*	~55%*
Expecations: Low Fertility	--	~50%	~50%	~36%	~41%	~21%	~11%*	~68%*

Note: Comparative data from Tayles et al. (2007), Domett & Tayles (2006), Pietrusewsky & Douglas (2002)
*inexact comparison because Milner et al. (1989) oldest adult category is over age 45 instead of 50 and older.

Table 6 Demographic Representativeness of Phromthin Tai and Comparative Samples.

Non-specific Stress Indicators

Cribra orbitalia and porotic hyperostosis of Grade 2 or higher were only found in two individuals at Phromthin Tai (Fig. 3, Table 7). The overall frequency for cribra orbitalia is 17%, and the frequency for porotic hyperostosis is 12.5%. The sample sizes are small here - only six of the 26 skeletons available for analysis could be assessed for cribra orbitalia, and only eight could be assessed for porotic hyperostosis. At the other Central Thailand site of Ban Pong Manao, the frequency of cribra orbitalia was reported as 16.7%, essentially identical to that at Phromthin Tai (Table 1). Among the northeastern sites, the Iron Age skeletons from Ban Chiang exhibited a seemingly higher frequency of cribra orbitalia at 29%, but the difference is not statistically significant, likely due to the small sample sizes (FET, $p > 0.99$). At Noen U-Loke, data are only available for nonadult skeletons. Two nonadult skeletons were examined and cribra orbitalia was not found. These results suggest that Phromthin Tai had no more cribra orbitalia or porotic hyperostosis than individuals from the same period at Ban Pong Manao or the sites in the Northeast.

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Fig. 3 Left superior eye orbit of the only individual in the sample with any evidence of cribra orbitalia (Burial 17, Age ~9.5 years). The right orbit was also affected (not pictured). Source: Photo by Scott Burnett 2015.

Burial	Sex	Age Group	Cribra	Porotic Hyperostosis	LEH Number Max per Tooth	Caries	Trauma
1	?	Middle Adult	--	--	--	0	No
2	M	Old Adult	No	No	2	0	No
3	F	Young Adult	--	--	--	--	No
5	M	Young Adult	No	No	1	0	No
6	?	Non-Adult	--	--	--	--	No
7	?	Middle Adult	No	No	0	0	No
8	M	Middle Adult	--	--	3	0	3 Lower Rt. Ribs
10	M	Middle Adult	--	--	--	--	No
12	M	Young Adult	No	Grade 1**	2	0	No
15	M	Adult	--	--	--	--	No
16	M	Young Adult	--	--	1	0	No
17A	?	Non-Adult	Grade 3	Grade 1**	0	0	No
17B*	?	Young Adult?	--	--	--	0	--
17C*	?	Middle Adult?	--	--	--	0	--
18	?	Non-Adult	--	--	--	--	No
19	?	Non-Adult	--	--	2	0	--
20	F	Young Adult	--	--	1	0	Lt. Clavicle, Lt. Ribs 2, 3
21	M	Young Adult	--	--	--	--	No
22	M	Middle Adult	--	Grade 2	--	--	Lt. Parietal
23	?	Non-Adult	No	Grade 1**	--	Deciduous	No
24	?	Young Adult	--	--	--	0	--
25	M	Middle Adult	--	Grade 1**	--	--	No
26	?	Young Adult	--	--	1	Permanent	No
29	M	Middle Adult	--	--	1	0	No
33	M	Middle Adult	--	--	--	--	No
33B	?	Non-Adult	--	--	--	--	No

*Additional teeth found with provenienced skeleton.

**Grade 1 is "barely discernible" and was excluded in the comparative analysis (see methods).

Table 7 Skeletal indicators and trauma identified among Phromthin Tai skeletal samples.

Linear enamel hypoplasias were much more common than cribra orbitalia or porotic hyperostosis at Phromthin Tai (Table 7). Nine of 11 individuals (82%) with anterior teeth exhibited at least one LEH. Three individuals (Burials 2, 12, 19) had two LEHs on one or more teeth, and one individual had three (Burial 8). In terms of the timing of LEH development on the canine teeth, 60% of the defects occurred between ages 2.0 and 2.5 years, and 80% between the ages of 2.0 and 3.0 years (Table 8). None were found after age 3.5 years. LEH formation is often said to be associated with weaning and postweaning stress (Goodman and Martin 2002:26). However, the dental enamel is also growing at its fastest rate from 1.5 – 2.5 years of age (Reid and Dean 2000), and the dentition is more sensitive to systemic stress during the formation of the middle sections of the anterior teeth (Hillson 2014). Thus, at Phromthin Tai we primarily see LEH occurring at developmentally sensitive ages.

Burial Number	Maxillary Canine R Measures (mm)	Maxillary Canine L Measures (mm)	Max Canine Age Range (years)	Mandibular Canine R Measures (mm)	Mandibular Canine L Measures (mm)	Mandibular Canine Age Range (years)	Summary (years)
B2 (1st)	0	0	--	nd	3.00	2.0 - 2.5	2.0 - 3.5
B2 (2nd)	--	--	--	--	6.50	3.0 - 3.5	
B5 (1st)	3.51	0	2.0 - 2.5	nd	0	--	2.0 - 2.5
B7	0	0	--	0	0	--	None
B8 (1st)	1.41	1.58	1.7 - 2.0	Y	2.83	2.0 - 2.5	1.7 - 3.5
B8 (2nd)	1.80	2.80	2.0 - 2.5	Y	5.00	2.5 - 3.0	
B8 (3rd)	3.31	3.03	2.0 - 2.5	Y	6.87	3.0 - 3.5	
B12 (1st)	3.21	3.48	2.0 - 2.5	3.86	3.95	2.0 - 2.5	2.0 - 3.0
B12 (2nd)	5.03	5.07	2.5 - 3.0	5.52	5.63	2.5 - 3.0	
B19 (1st)	2.79	nd	2.0 - 2.5	2.29	nd	1.5 - 2.0	1.5 - 3.0
B19 (2nd)	4.83	nd	2.5 - 3.0	3.28	nd	2.0 - 2.5	
B20	nd	0	--	nd	4.10	2.0 - 2.5	2.0 - 2.5
B26	nd	nd	--	2.88	nd	2.0 - 2.5	
B29	nd	nd	--	nd	3.60	2.0 - 2.5	2.0 - 2.5

Note: 0= no evidence of LEH, nd = no data due to tooth absence, tooth damage, calculus, etc., Y = LEH evident but unable to measure due to calculus obscuring the CEJ

Table 8 Age ranges for LEH lines on canine teeth of Phromthin Tai burials.

The number of individuals with LEH identified at Phromthin Tai appears elevated compared to the number in the three comparative sites. At Ban Pong Manao, results were reported by tooth count rather than by individual, so they are not comparable (Table 1). At Ban Chiang, only about 39% of the Iron Age skeletons exhibited LEH, and at Noen U-loke 54% were affected (Pietrusewsky and Douglas 2002; Tayles et al. 2007). The difference between Ban Chiang and Phromthin Tai is near enough to significance (FET, $p = 0.052$) that it could be meaningful, particularly considering the small sample size at Phromthin Tai. The difference between Noen U-loke and Phromthin Tai is not significant ($p = 0.108$). It should be noted, however, that although comparison of enamel hypoplasia frequencies between groups or subgroups has been common practice in bioarchaeological studies for many years (Armelagos et al. 2009, Lambert 2000, Hodges 1987), Hillson (2014) has cautioned against comparing frequencies between groups based on macroscopic scoring. Variation in sensitivity of different parts of the tooth crown to development of enamel hypoplasia, and variation in dental wear among samples means that comparisons may not be meaningful. Therefore, the more interesting result from Phromthin Tai may not be the not-quite-significant, apparently higher LEH frequency at Phromthin Tai compared to Ban Chiang, but the fact that LEH lines seem to be confined to an age range during which the teeth are most sensitive to developmental disturbance, and they are not found much outside that range.

Caries Analysis

There were surprisingly few dental caries observed in the Phromthin Tai sample. Out of 185 observable permanent teeth, only one tooth exhibited evidence of caries. This is a frequency by tooth of 0.54%. Only one of 15 skeletons with at least one permanent tooth present was affected, for an individual frequency of 7%. Burial 23 also exhibited caries affecting two adjacent teeth, but they were deciduous – a canine and 1st molar. Burial 23 had a mixed dentition, and the permanent teeth showed no evidence of caries.

At Ban Pong Manao, caries rates were higher than at Phromthin Tai. The frequency by tooth count for Ban Pong Manao is reported as 8.6%, which is significantly higher than that found at Phromthin Tai (FET, $p = 0.0004$). At first glance, caries rates at the Ban Chiang site appear to be higher than at Phromthin Tai as well. Pietrusewsky and Douglas (2001) report that during the Middle and Late Periods at Ban Chiang (2900 BP – 1800 BP), which they combined in their analysis, caries rates by the tooth count method are 7.6%. However, when the sample at Ban Chiang is further reduced to just those skeletons likely to have been from the Iron Age, the caries frequency declines to just 2.2% of teeth. Although that value is still four times higher than at Phromthin Tai, the difference is not significant (FET, $p = 0.372$). When considered by individual, the results are also similar, with 25% of the Iron Age Ban Chiang sample affected versus 7% at Phromthin Tai, a difference that is also not significant (FET, $p = 0.329$). Thus, it appears that during the Iron Age at Ban Chiang, the diet may have changed in some way that reduced the risk of caries in the population, bringing it closer to Phromthin Tai's caries frequency. One possibility is an increased reliance on rice with low cariogenicity (see Tayles et al. 2000) and reduced reliance on sticky carbohydrates such as yams and taro, which Halcrow et al. (2013) have noted are highly cariogenic foods.

Comparison of caries rates between Phromthin Tai and Noen U-Loke must be done slightly differently because caries rates are reported among adults aged 15 and older at Noen U-Loke, rather than among all permanent teeth. At Noen U-Loke, 46 out of 956 adult teeth (4.8%) were affected by caries (Tayles et al. 2007). The frequency by individual was 42.3% at the site, with 23 out of 54 individuals affected. At Phromthin Tai, only one out of 175 adult teeth were affected (0.57%), and only one out of 12 adults (8.3%). For these two sites, the differences are statistically significant, both by tooth count (FET, $p = 0.0031$) and by individual (FET, $p = 0.0432$). The younger age of our sample is likely a contributing factor, because the frequency of caries by tooth in older adults at Noen U-Loke is twice as high as in younger adults, and adults over the age of 50 make up a smaller proportion of the Phromthin Tai sample. Nevertheless, the caries frequency at Phromthin Tai is low by any standards, falling into the range that is more common for foraging groups than for horticulturalists or intensive agriculturalists (Turner 1979).

Fracture Analysis

The fracture risk appears to have been fairly low at Phromthin Tai, and there is little evidence for trauma related to interpersonal violence. Though many skeletons are incomplete, evidence for trauma was only found on three of 19 adult individuals (16%) with at least some skeletal material present (two males, one female). One adult was represented by only dental remains (Burial 24) and was excluded. The fractures found involved a total of five ribs, one clavicle, and one parietal. All were antemortem fractures with evidence of healing. The affected female had a fracture of her clavicle, plus the second and third ribs (Fig. 4). These fractures likely occurred in a single event, and may have come from falling on the shoulder (Robinson 1998). The affected male had three rib fractures, all were lower ribs and at least two were adjacent to each other, again suggesting a single incident. The cranial trauma might have been caused by interpersonal violence or an accident. Whatever the cause, this fracture was minor and is well-healed. Among the five nonadult skeletons that could be examined for skeletal fractures, none were found. Combining adults and children, fractures were found in three of 24 individuals.

Fig. 4 Healed clavicle fracture in Burial 20. Source: Photo by Scott Burnett 2011.

There appear to have been even fewer fractures at Ban Pong Manao. Lerdpipatworakul (2009) reports only five individuals with fractures among the 48 adults at the site (ca. 10%). Most of these fractures are to the extremities. Four individuals had fractures to the upper limbs (ulna, humerus, MC5 and a proximal hand phalanx) and one had fractures of the tibia and four foot phalanges. The MC5 fracture affects the middle third of the shaft of the bone with severe angulation and is most likely due to an accident rather than punching a person or object (de Jonge et al. 1994, Gudmundsen and Borgen 2009). The ulna fracture affects the distal third of the shaft without significant angulation and involvement of the radius is not mentioned, so it could be defensive (Judd 1015). It appears to be well-healed. The pattern of fractures appears to be quite different from that found at Phromthin Tai where all fractures identified affected the axial skeleton.

Among the Ban Chiang Iron Age skeletons, a similar proportion of individuals appear to have been affected by trauma as were found at Phromthin Tai. Pietrusewsky and Douglas (2002) report that four individuals from the Iron Age period exhibited fractures, including the clavicle of a child, three lower ribs in a male skeleton, fracture of a right MC5 in a male, and fracture of a hyoid in a male. A fifth individual was listed with a possible fracture to the hamulus of the hamate, but it is described as a hypoplastic hamulus, which can be a developmental condition (Poznanski 1984:192). Ban

Chiang and Phromthin Tai are similar in terms of both the frequency of fracture (four of 24 skeletons compared to three of 24 skeletons) and the location of the trauma present. A clavicle fracture, and a series of three broken lower ribs, were found in both samples. The only fracture missing from the Ban Chiang Iron Age sample is a cranial fracture. The MC5 fracture from Ban Chiang affects the proximal base, and is likely related to a fall (de Jonge et al. 1994, Gudmundsen and Borgen 2009). The healed hyoid fracture may relate to violence, as fracture of the hyoid is a common result of one person choking another, but can also result from falls (Bux et al. 2006; Maxeiner 1999) or other direct trauma to the neck (Porr et al. 2012).

Incidences of trauma are even fewer at Noen U-Loke than at either Phromthin Tai or Ban Chiang. Although the skeletal sample is much larger at Noen U-Loke, only two possible incidences of fracture are reported (Tayles et al. 2007: Table 17.11). There is an old adult female with a collapsed vertebral body, perhaps related to low bone mineral density, and another female whose skull was cleaved nearly in half. It is not certain whether the damage to the skull was done ante- or post-mortem, but there appear to have been at least three blows to the head with an axe (Tayles 2003). Despite this one particularly violent event, skeletal evidence from these three Iron Age sites suggests a relatively low level of interpersonal violence.

Discussion And Conclusions

Neither Phromthin Tai nor the three comparative sites are representative of a normal population in terms of their overall sex and age distributions (Table 6). Phromthin Tai has too many males, Ban Pong Manao, Ban Chiang, and Phromthin Tai have fewer than expected nonadult skeletons, and all four sites have too many teen and young adult individuals (Table 6, Milner et al. 1989). The bias in the sex ratio at Phromthin Tai could be caused by sampling error due to the small size of the excavation unit (6 m x 6 m) or purposeful segregation of individuals by sex during part of the Iron Age. Further excavation would be necessary to answer this question.

Low adult life expectancy might be an explanation for the age distributions at these sites if relatively good childhood health was followed by very poor adult survivability. Such situations are possible, if lethal intersite violence involving only the adults were active, or if adult occupations were unusually dangerous or subjected adults to environmental conditions that shortened lifespans. However, if very low adult life expectancy was occurring, it should be associated with a high fertility rate, and most likely, early childbirth (Walker et al. 2006). The sample of teen deaths seems insufficient at any of the three sites to suggest a consistent trend toward early pregnancy and a large number of pregnancy-related teen deaths (Current Study Tables 4 and 5; Pietrusewsky and Douglas 2002; Tayles et al. 2007: Table 17.4), although it is possible that such deaths might have been treated differentially in burial and placed elsewhere. However, we believe this age distribution is reflective of the ease of aging young adults from developmental markers compared to the challenges of aging middle and older adults where the pelvis or skull must be used. When preservation is poor, as at Phromthin Tai, the skull and pelvis may not preserve well enough for accurate aging, while many young adults can be aged more easily by means of markers of skeletal development. Many of the skeletons identified as simply “adult” at these sites may in fact be middle and older adults.

The people living at Phromthin Tai exhibited low levels of skeletal stress indicators that manifest as cribra orbitalia or porotic hyperostosis. In this respect, they are quite similar to both the Ban Pong Manao and Ban Chiang populations. Low frequencies of these conditions might be interpreted as evidence that nutritional stresses such as scurvy or nutrition-related anemias (Ortner and Ericksen

1997, Oxenham and Cavill 2010, Walker et al. 2009), severe parasitic infection resulting in anemia (Sullivan 2005), and/or problems with malaria and the genetic polymorphisms that protect current populations from malaria (Techataweewan 2021, Vlok et al. 2021) were not a serious problem for the people living at these sites during the Iron Age. However, the osteological paradox (Wood et al. 1992) cautions that we should consider other possibilities – that a disproportionate number of these individuals might have died from such conditions before they developed cranial lesions, and the surviving adults were unlikely to experience these stresses long enough to develop identifiable lesions. Furthermore, given the non-representativeness of these samples, particularly when it comes to low numbers of nonadult skeletons, it is likely that there was some degree of burial segregation at these sites, and children who survived long enough to develop lesions, but are not represented among the fewer-than-expected nonadult burials that were excavated, might also be buried elsewhere.

One area in which Phromthin Tai seems, at first glance, to show a higher frequency of one of these skeletal stress indicators than its contemporaries is in the frequency of LEH. Raw frequency scores are higher for Phromthin Tai than for the two northeastern sites, although neither of these differences quite reaches statistical significance. It is likely that we identified more LEH because of our use of a 10x hand lens in scoring. Furthermore, as noted above, comparisons of frequencies between samples face several other challenges of comparability. Regardless, the stresses that led to LEH formation seem to have been rather limited at Phromthin Tai to the period between ages 1.5 and 3.5 years, with 80% occurring between the ages of 2-3 years. Low numbers of LEH lesions per individual suggest that stresses were not chronic, although as was noted for cribra orbitalia and porotic hyperostosis, it is possible that individuals from who suffered from diseases or conditions that might have led to enamel hypoplasias may have died as young children and not been included in our sample of permanent teeth.

The caries results are somewhat surprising as only one individual exhibited evidence of caries in a permanent tooth. Such low levels of caries are usually seen only in foraging groups (Turner 1979). It suggests that the Phromthin Tai diet was likely high in rice, which has low cariogenicity (Tayles et al. 2000). This conclusion finds some support from the work of Liu (2012) who discovered through isotopic analysis that Promthin Tai showed a greater reliance on C3 foods (of which rice is an example) than several other sites in Central Thailand, including nearby Non Mak La. However, Noen U-Loke also appears to have relied heavily on rice (Boyd 2007; Talbot 2007) and skeletons there showed a significantly higher frequency of caries than those at Phromthin Tai. This suggests that there may be something else about the diet that differed, perhaps the quantity of starchy root crops of higher cariogenicity such as yams and taro (Halcrow et al. 2013), though other intrinsic or extrinsic factors may be at play.

The younger age profile and relatively small sample size at Phromthin Tai could also be factors in the low caries frequency, but this would not explain the significantly lower frequency at Phromthin Tai compared to Ban Pong Manao, the other Central Thailand site, because Ban Pong Manao has a higher proportion of young adults than does Phromthin Tai (Table 6). Liu (2012) argues that Ban Pong Manao likely relied on a broad spectrum diet (citing Lerdpipatworakul 2009), consuming hunted and gathered foods from the local area in addition to cultivated food. Liu (2012) notes evidence for rice at the site in the form of rice-tempered pottery, but that the location of Ban Pong Manao in the uplands would make wet rice cultivation unlikely (citing Eyre 2006). A significant difference in the diets of these two communities might explain the substantial difference in caries rates.

Trauma appears to be a relatively minor concern for all four Thai sites in the study. Noen U-Loke exhibits the least trauma, seemingly much lower than at Ban Chiang, Ban Pong Manao, or Phromthin Tai given the much larger number of skeletons excavated there. Violent trauma is, at worst, only a minor concern at all four sites, though not completely missing. Each of the four sites has at least one example of trauma that could more likely result from interpersonal violence than accident, though in three of the cases accident is also a possibility.

Finally, it should be kept in mind that the burials we studied at Phromthin Tai come from a relatively small 36 sq. meter excavated area and might not be representative of the wider cemetery. However, we believe this sample and the data it provides serves as a starting point for understanding life and health during the Iron Age in east-central region of Thailand. We hope that future excavators in the region will conduct similar analyses to assess whether the patterns reported here are found, and if differences between sites in Central Thailand exist, such as those few differences seen between Phromthin Tai and Ban Pong Manao, that research is carried out to try to explain their significance.

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References

Adams, RL and King, SM (2011) Residential burial in global perspective. *Archaeological Papers of the American Anthropological Association* 20(1): 1-16.

Armelagos, GJ, Goodman, AH, Harper, KN and Blakey, ML (2009) Enamel hypoplasia and early mortality: Bioarcheological support for the Barker hypothesis. *Evolutionary Anthropology: Issues, News, and Reviews: Issues, News, and Reviews* 18(6): 261-271.

Baker, BJ, Dupras, TL and Tocheri, MW (2005) *The Osteology of Infants and Children.* College Station: Texas A&M University.

Bellina, B (2017) *Khao Sam Kaeo: An Early Port-City between the Indian Ocean and the South China Sea*. Paris: Ecole française d'Extrême-orient.

Bereczki, Z, Teschler-Nicola, M, Marcsik, A, Meinzer, NJ and Baten, J (2019) Growth disruption in children: Linear enamel hypoplasias. In R Steckel, CS Larsen, CA Roberts, and J Baten (eds) *The Backbone of Europe: Health, Diet, Work, and Violence over Two Millennia*. Cambridge: Cambridge University Press, 175-197.

Brickley, MB (2018) Cribra orbitalia and porotic hyperostosis: A biological approach to diagnosis. *American Journal of Physical Anthropology* 167(4): 896-902.

Brickley, MB and Ives, R (2008) *The Bioarchaeology of Metabolic Bone Disease*. San Diego: Elsevier Academic Press.

Buikstra, JE and Ubelaker, DH (1994) *Standards for Data Collection from Human Skeletal Remains*, Arkansas Archaeology Research Series 44. Fayetteville: Arkansas Archaeological Survey.

Carter, AK (2013) Trade, Exchange, and Sociopolitical Development in Iron Age (500 BC–AD 500) Mainland Southeast Asia: An Examination of Stone and Glass Beads from Cambodia and Thailand. PhD Thesis, University of Wisconsin, Madison.

Carter, AK (2015) Beads, exchange networks and emerging complexity: a case study from Cambodia and Thailand (500 BCE–CE 500). *Cambridge Archaeological Journal* 25:733-757.

Chanthasi, S (2015) An Analysis of Mammal Bones, Rodent Bones, and Poultry Bones from the Archaeological Site of Phromthin Tai, Lopburi. Bachelor's thesis, Department of Archaeology, Silpakorn University, Bangkok.

Clarke, JH (1999) Toothaches and death. *Journal of the History of Dentistry,* 47**:** 11-13.

de Jonge, JJ, Kingma, J, Van der Lei, B and Klasen, HJ (1994) Fractures of the metacarpals. A retrospective analysis of incidence and aetiology and a review of the English-language literature. *Injury* 25(6):365-369.

d'Alpoim Guedes, J, Hanson, S, Higham, C, Higham, T and Lertcharnrit, T (2019) The wet and the dry, the wild and the cultivated: subsistence and risk management in ancient Central Thailand. *Archaeological and Anthropological Sciences* 11(12):6473-6484.

Dhavale, N, Halcrow, SE, Buckley, HR, Tayles, N, Domett, KM and Gray, AR (2017) Linear and appositional growth in infants and children from the prehistoric settlement of Ban Non Wat, Northeast Thailand: Evaluating biological responses to agricultural intensification in Southeast Asia. *Journal of Archaeological Science: Reports,* 11**:** 435-446.

Domett, K and Tayles, N (2006) Human biology from the bronze age to the iron age in the Mun River valley of northeast Thailand. In: M Oxenham and N Tayles (eds.) *Bioarchaeology of Southeast Asia.* Cambridge University Press: Cambridge, 220-240.

Fazekas, István Gyula and Ferenc Kósa. 1978. *Forensic Fetal Osteology*. Akadémiai Kiadó, Budapest.

Goodman, AH (1998) The biological consequences of inequality in antiquity. In AH Goodman and TL Leatherman (eds*) Building a New Biocultural Synthesis: Political-Economic Perspectives on Human Biology*. Ann Arbor: University of Michigan Press, 147-169.

Goodman, AH and Martin, DL (2002) Reconstructing health profiles from skeletal remains. In: RH Steckel and JC Rose (eds.) *The Backbone of History: Health and Nutrient in the Western Hemisphere.* Cambridge: Cambridge University Press, 11-60.

Guatelli-Steinberg, D (2015) Dental stress indicators from micro- to macroscopic. In JD Irish and GR Scott (eds) *A Companion to Dental Anthropology*. New York: Wiley-Blackwell, 450-464.

Guatelli-Steinberg, D and Benderlioglu, Z (2006) Linear enamel hypoplasia and the shift from irregular to regular provisioning in Cayo Santiago Rhesus monkeys (*Macaca mulatta*). *American Journal of Physical Anthropology* 131: 416-419.

Gudmundsen, TE and Borgen, L. (2009). Fractures of the fifth metacarpal. *Acta Radiologica* 50(3): 296-300.

Halcrow, SE, Harris, NJ, Tayles, N, Ikehara-Quebral, R and Pietrusewsky, M (2013) From the mouths of babes: dental caries in infants and children and the intensification of agriculture in Mainland Southeast Asia. *American Journal of Physical Anthropology* 150: 409-420.

Halcrow, SE, Tayles, N and King, CL (2016) Infant and child health and disease with agricultural intensification in mainland Southeast Asia. In MF Oxenham and Buckley, HR (eds) *The Routledge Handbook of Bioarchaeology in Southeast Asia and the Pacific Islands*. New York: Routledge, 158-186.

Higham, CF and Thosarat, R (1998) *Prehistoric Thailand: From Early Settlement to Sukhothai*. Bangkok: River Books.

Higham, CF (2002) *Early Cultures of Mainland Southeast Asia*. Chicago: Art Media Resources.

Higham, CF, Thosarat, R and Talbot, S (eds.) (2007) *The Origins of the Civilization of Angkor, Volume 2: The Excavation of Noen U-Loke and Non Muang Kao.* Bangkok: Thai Fine Arts Department.

Higham, CF, Cameron, J, Chang, N, Castillo, C, O'Reilly, D, Petchey, F and Shewan, L (2014) The excavation of Non Ban Jak, Northeast Thailand - A report on the first three seasons. *Journal of Indo-Pacific Archaeology* 34:1-41.

Higham, CF and Rispoli, F (2014) The Mun Valley and Central Thailand in prehistory: integrating two cultural sequences. *Open Archaeology* 1(1):2-28.

Hillson, S (2014) *Tooth Development in Human Evolution and Bioarchaeology*. Cambridge: Cambridge University Press.

Hodges, DC (1987) Health and agricultural intensification in the prehistoric valley of Oaxaca, Mexico. *American Journal of Physical Anthropology*, 73(3): 323-332.

İşcan, MY, Loth, SR, King, CA, Shihai, D and Yoshino, M (1998) Sexual dimorphism in the humerus: a comparative analysis of Chinese, Japanese and Thais. *Forensic* Science *International* 98: 17-29.

Judd, MA (2008) The parry problem. *Journal of Archaeological Science* 35(6): 1658-1666.

King, CA and Norr, L (2006) Palaeodietary change among pre-State Metal-Age societies in Northeast Thailand: a study using bone stable isotopes. In M Oxenham and N Tayles (eds) *Bioarchaeology of Southeast Asi*a. Cambridge: Cambridge University Press, 241-262.

Krogman, WM and İşcan, MY (1986) *The Human Skeleton in Forensic Medicine.* Springfield: Charles C. Thomas.

Lambert, PM (2000) Life on the periphery: health in farming communities of interior North Carolina and Virginia. In PM Lambert (ed) *Bioarchaeological Studies of Life in the Age of Agriculture: A View from the Southeast*. Tuscaloosa: University of Alabama Press, 168-194.

Larsen, CS (2015) *Bioarchaeology: Interpreting Behavior from the Human Skeleton*, 2nd edition. Cambridge: Cambridge University Press.

Lerdpipatworakul, T (2009) The Study of Prehistoric Human Skeletal Remains from Ban Pong Manao Archaeological Site, Pattananikom District, Lop Buri Province. M.A. Thesis. Department of Archaeology, Silpakorn University, Bangkok.v

Lertcharnrit, T (2006) The moated site of Promtin Tai and the transition from Late Prehistory to Early History in Central Thailand. In EA Bacus, I Glover, and VC Pigott (eds) *Uncovering Southeast Asia's Past: Selected Papers from the 10th International Conference of the European Association of Southeast Asian Archaeologists*. Singapore: National University of Singapore Press, 258-265.

Lertcharnrit, T (2014) Phromthin Tai: an archaeological perspective on its societal transition. In S Murphy and N Revire (eds) *Before Siam: Essays in Art and Archaeology*. Bangkok: River Books, 118–131.

Lertcharnrit, T (2019) Imported and Exported Trade Goods: Archaeological Evidence from Central Thailand. *Journal of Anthropology, Sirindhorn Anthropology Center* 2(2): 119-147.

Liu, C-H (2012) Human Skeletal Health and Dietary Assessment of Metal Age Central Thailand: The Impact of Changing Social Complexity and Regional Variation*.* PhD thesis, University of Florida, Gainesville.

Liu, C-H (2018) Human foodways, metallurgy, and landscape modification of Iron Age Central Thailand. *Asian Perspectives,* 57(1)**:** 83-104.

Marklein, KE, Torres-Rouff, C, King, LM and Hubbe, M (2019) The precarious state of subsistence: reevaluating dental pathological lesions associated with agricultural and hunter-gatherer lifeways. *Current Anthropology,* 60(3)**:** 341-368.

Martin, DL and Harrod, RP (2015). Bioarchaeological contributions to the study of violence. *American journal of physical anthropology* 156: 116-145.

McDonald, JH (2009) *Handbook of Biological Statistics*, 2nd ed. Baltimore, Maryland. : Sparky House Publishing.

Meindl, RS and Lovejoy, CO (1989) Age changes in the pelvis: implications for paleodemography. In MY İşcan (ed) *Age Markers in the Human Skeleton*, Springfield: Charles C. Thomas, 137-168.

Merchant, VL and Ubelaker, DH (1977) Skeletal growth of the protohistoric Arikara. *American Journal of Physical Anthropology* 46(1): 61-72.

Milner, GR, Humpf, DA and Harpending, HC (1989) Pattern matching of age ‐ at ‐ death distributions in paleodemographic analysis. *American Journal of Physical Anthropology* 80(1):49-58.

Natapintu, S (2007) *รากเหง้าบรรพชนคนไทย: พัฒนาการทางวัฒนธรรมก่อนประวัติศาสตร์* [Roots of Ancestors of Thai People: An Evolution of Prehistoric Culture]. Bangkok: Matichon.

O'Reilly, DJW (2000) From the Bronze Age to the Iron Age in Thailand: Applying the heterarchical approach. *Asian Perspectives* 39: 1-19.

Ortner, DJ and Ericksen, MF (1997) Bone changes in the human skull probably resulting from scurvy in infancy and childhood. *International Journal of Osteoarchaeology,* 7(3)**:** 212-220.

Ortner, DJ and Mays, S (1998) Dry-bone manifestations of rickets in infancy and early childhood. *International Journal of Osteoarchaeology,* 8(1)**:** 45-55.

Oxenham, MF and Cavill, I (2010) Porotic hyperostosis and cribra orbitalia: the erythropoietic response to iron-deficiency anaemia. *Anthropological Science,* 118(3)**:** 199-200.

Patel, A, Aghababaie, S and Parekh, S (2019) Hypomineralisation or hypoplasia? *British Dental Journal,* 227(8)**:** 683-686.

Pedersen, LT, Domett, KM, Chang, NJ, Halcrow, SE, Buckley, HR, Higham, CF, O'reilly, DJW and Shewan, L (2019) A bioarchaeological study of trauma at Late Iron Age to protohistoric Non Ban Jak, Northeast Thailand. *Asian Perspectives,* 58(2)**:** 220-249.

Pietrusewsky, M, and Douglas, MT (2002) *Ban Chiang, A Prehistoric Village Site in Northeast Thailand, Volume 1: The Human Skeletal Remains*. Philadelphia: The University of Pennsylvania Museum of Archaeology and Anthropology.

Pigott, VC., Weiss, AD and Natapintu, S (1997) The archaeology of copper production: Excavations in the Khao Wong Prachan Valley, central Thailand. In R Ciarla and F Rispoli (eds) *South-East Asian Archaeology, 1992: Proceedings of the 4th International Conference of the European Association of Southeast Asian Archaeologists*. Rome: Instituto italiano per l'Africa e l'Orient, 119-157.

Porr, J, Laframboise, M and Kazemi, M (2012) Traumatic hyoid bone fracture–a case report and review of the literature. *The Journal of the Canadian Chiropractic Association* 56(4): 269-274

Poznanski, AK (1984) *The Hand in Radiologic Diagnosis, with Gamuts and Pattern Profiles*. St. Louis: WB Saunders.

Reid, DJ and Dean, MC (2000) The timing of linear hypoplasias on human anterior teeth. *American Journal of Physical Anthropology* 113(1): 135-139.

Rispoli, F, Ciarla, R and Pigott, VC (2013) Establishing the prehistoric cultural sequence for the Lopburi region, central Thailand. *Journal of World Prehistory* 26(2): 101-171.

Rispoli, F (2022) The Iron Age in Central Thailand. In: CFW Higham and N Kim (eds.) *The Oxford Handbook of Early Southeast Asia.* Oxford: Oxford University Press, 578-596.

Rissech, C, Schaefer, M and Malgosa, A (2008) Development of the femur—implications for age and sex determination. *Forensic Science International* 180(1) :1-9.

Saunders, S, Hoppa, R and Southern, R (1993) Diaphyseal growth in a nineteenth century skeletal sample of subadults from St Thomas' Church, Belleville, Ontario. *International Journal of Osteoarchaeology* 3(4): 265-281.

Scheuer, L and Black, S (2004) *The Juvenile Skeleton*. New York: Academic Press.

Seow, WK (2014) Developmental defects of enamel and dentine: challenges for basic science research and clinical management. *Australian Dental Journal,* 59(s1)**:** 143-154.

Smith, B. Holly. 1984. Patterns of molar wear in hunter–gatherers and agriculturalists. *American Journal of Physical Anthropology*, 63(1):39-56.

Talbot, S (2007) The analysis of the mortuary record. In C Higham, R Thosarat and S Talbot (eds) *The Origins of the Civilization of Angkor, Volume 2: The Excavation of Noen U-Loke and Non Muang Kao*. Bangkok: Thai Fine Arts Department, 305-351.

Tayles, N, Domett, K and Nelsen, K (2000) Agriculture and dental caries? The case of rice in prehistoric Southeast Asia. *World Archaeology* 32(1): 68-83.

Tayles, N (2003) Murder or mortuary behaviour? An Iron Age enigma from northeast Thailand. *International Journal of Osteoarchaeology* 13(4): 197-206.

Tayles, N, Halcrow, S and Domett, K (2007) The people of Noen U-Loke. In C Higham, R Thosarat, and S Talbot (eds) *The Origins of the Civilization of Angkor, Volume 2: The Excavation of Noen U-Loke and Non Muang Kao*. Bangkok: Thai Fine Arts Department, 234-304.

Techataweewan, N, Mann, RW, Vlok, M, Ruengdit, S, Panthongviriyakul, C and Buckley, HR (2021) Thalassemia major in a 49-year-old Thai female: Gross and X-ray examination of dry bone. *International Journal of Osteoarchaeology,* 31(5)**:** 866-880.

Temple, DH (2016) Caries: The Ancient Scourge. In JD Irish and GR Scott (eds) *A Companion to Dental Anthropology*. New York: Wiley-Blackwell, 433-449.

Todd, TW and D'Errico, J Jr. (1926) The odontoid ossicle of the second cervical vertebra. *Annals of Surgery* 83(1): 20-31.

Turner, CG (1979) Dental anthropological indications of agriculture among the Jomon people of central Japan. X. Peopling of the Pacific. *American Journal of Physical Anthropology* 51(4): 619-635.

Uitenbroek DG. (2000) Fisher's exact. SISA. Available at: http://www.quantitativeskills.com/sisa/statistics/fisher.htm. [accessed November 2017].

Vlok, M, Buckley, HR, Miszkiewicz, JJ, Walker, MM, Domett, K, Willis, A, Trinh, HH, Minh, TT, Nguyen, MHT, Nguyen, LC, Matsumura, H, Wang, T, Nghia, HT and Oxenham, MF (2021) Forager and farmer evolutionary adaptations to malaria evidenced by 7000 years of thalassemia in Southeast Asia. *Scientific Reports,* 11**:** 5677.

Walker, PL (2001) A bioarchaeological perspective on the history of violence. *Annual Review of Anthropology* 30(1): 573-596.

Walker, PL, Bathurst, RR, Richman, R, Gjerdrum, T and Andrushko, VA (2009) The causes of porotic hyperostosis and cribra orbitalia: A reappraisal of the iron deficiency anemia hypothesis. *American Journal of Physical Anthropology* 139(2): 109-125.

Weinstein, M, Babyn, P and Zlotkin, S (2001) An orange a day keeps the doctor away: scurvy in the year 2000. *Pediatrics,* 108(3)**:** e55-e55.

Wichakana, M (1991) Prehistoric sacrifices at Noen U-Loke. *Muang Boran* 16(4): 69-79.

Wangthongchaicharoen, N (2013) Recently discovered infant jar burials from Wat Pho Srinai, Ban Chiang, northeastern Thailand. In: MJ Klokke and V Degroot (eds.) *Materializing Southeast Asia's Past: Proceedings of the 12th International Conference of the European Association of Southeast Asian Archaeologists.* Amsterdam: Amsterdam University Press, 91-106.

White, JC and Hamilton, EG (2009) The transmission of early bronze technology to Thailand: new perspectives. *Journal of World Prehistory,* 22(4)**:** 357-397.

White, JC and Eyre, CO (2011) Residential Burial and the Metal Age of Thailand. *Archaeological Papers of the American Anthropological Association,* 20(1)**:** 59-78.

Zhou, L and Corruccini, RS (1998) Enamel hypoplasias relating to famine stress in living Chinese. *American Journal of Human Biology,* 10(6)**:** 723-733.

Zuckerman, MK, Garofalo, EM, Frohlich, B and Ortner, DJ (2014) Anemia or scurvy: A pilot study on differential diagnosis of porous and hyperostotic lesions using differential cranial vault thickness in subadult humans. *International Journal of Paleopathology,* 5**:** 27-33.

Appendix: Logistic Regression Equations for Sex Estimation

Logistic regression equations to assist with sex estimation from the Phromthin Tai burials were developed using a sample of 192 Thai skeletons (96 females, 96 males) from the Chiang Mai area. These skeletons were originally measured for an unpublished study of size variation within the upper limb using measurements from the left side. Logistic regression equations were only developed for measurements that would add to information about the sexes of the Phromthin Tai skeletons. These included the base widths of MC3, MC4, and MC5, following the instructions for these measurements described in Case et al. (2015), and measurements for PP1 base width, PP3 base width, and IP3 base width that were developed for the purposes of the project. The phalanges were identified to the correct ray following the approach recommended in Case and Heilman (2006). All three phalangeal base width measurements were taken on a mini-osteometric board with the posterior side of the bone facing up and the long axis of the phalanx perpendicular to the long axis of the mini-osteometric board. The measurements are best accomplished by holding the distal end of the bone between two fingers so that it projects beyond edge of the board and remains in contact with the stationary upright, and then closing the movable upright until it makes contact. This prevents the orientation of the long axis of the bone from shifting when the movable upright makes contact.

Logistic regression equations were generated for each variable using SPSS Version 25. See Table 3 for the resulting equations. When the measurement is plugged into the formula, a value below zero indicates a probable female, and a value above zero indicates a probable male. Estimated accuracy of these equations for modern Thai individuals from the Chiang Mai area ranges between 81.5% - 82.3% for the three metacarpal base measurements, and 86.0% - 89.9% for the three phalangeal base measurements. Of course, these results may be somewhat less accurate when applied to Iron Age individuals from Thailand.