

Dental Indicators of Health in Early Neolithic and Iron Age Skeletons from Taiwan

Michael Pietrusewsky^{*}, Adam Lauer^{**}, Cheng-hwa Tsang^{***},
Kuang-ti Li^{****}, Michele Toomay Douglas^{*****}

ABSTRACT

This study introduces, for the first time, data recorded in some of the oldest Neolithic skeletons from Taiwan and investigates biocultural implications of changes in subsistence in the earliest Neolithic and later Iron Age Taiwan. Human skeletons from two archaeological sites in Taiwan are included. The first skeletal series is from the Nankuanli East (NKLE) site ($n = 23$ individuals) located in the Tainan Science Park, Tainan City in southwestern Taiwan. The NKLE skeletons are associated with the Tapenkeng culture (ca. 5000 years BP), the earliest Neolithic cultural sequence in Taiwan. The second skeletal series from Taiwan is from the Shisanhang (SSH) site ($n = 23$ individuals), an Iron Age site (ca. 1800-500 years BP) located in northwestern Taiwan. The main objectives of this study are to 1) document selected indicators of oral/dental (antemortem tooth loss - AMTL, dental caries, alveolar resorption, alveolar defects, dental calculus, and dental attrition) and physiological (linear enamel hypoplasia-LEH) health in the NKLE skeletons, 2) examine differences between male and female NKLE skeletons, 3) compare health in the early Neolithic and Iron Age Taiwan, and 4) place the prehistoric skeletons from Taiwan in a broader regional perspective.

A relatively high frequency of LEH (51.3%), an indicator of infant and childhood health, was observed in the NKLE adult anterior teeth, indicating there was significant childhood stress experienced by the earliest Neolithic inhabitants of Taiwan. Relatively low frequencies of AMTL (0.3%), dental caries (1.9%), and alveolar defects (1.0%), and moderate levels of alveolar resorption (8.8%) and dental calculus (8.3%) were observed in the NKLE skeletons. Contrary to expectations, no significant sex differences were observed for most of the indicators of health in the NKLE series. However, compared to adult females, the frequency of

^{*} Professor, Department of Anthropology, University of Hawai'i at Mānoa, Honolulu. mikep@hawaii.edu

^{**} Doctoral Candidate, Department of Anthropology, University of Hawai'i at Mānoa, Honolulu. alauer@hawaii.edu

^{***} Research Fellow, Institute of History and Philology, Academia Sinica, Taipei. tsang@mail.ihp.sinica.edu.tw

^{****} Associate Research Fellow, Institute of History and Philology, Academia Sinica, Taipei.

kuang@mail.ihp.sinica.edu.tw

^{*****} Affiliate Graduate Faculty, Department of Anthropology, University of Hawai'i at Mānoa, Honolulu. toomaydoug@charter.net

advanced attrition was significantly higher in adult males, a difference that is likely related to age, diet, and subsistence practices. Overall, the dental health of the NKLE skeletons was good.

Also contrary to expectations, the frequencies of childhood stress (LEH), dental caries, AMTL and alveolar defects are similar in the NKLE and SSH series. Significantly higher frequencies of dental calculus and alveolar resorption are noted in the SSH series, consistent with the transition to advanced food processing techniques. The frequency of advanced dental attrition (7.9%) in the NKLE skeletons was higher than in SSH skeletons suggesting use of teeth as tools in the early Neolithic and an increased reliance on softer more processed foods and the use of metal tools in the Iron Age. Although not statistically significant, the higher frequency of LEH (51.3%) observed in the NKLE skeletons compared to those from the SSH site (37.1%) suggests improvement in childhood health in the Iron Age. Overshadowing the mostly minor differences, many of which may be attributed to differences in diet, hygiene, and cultural practices, are the overwhelming similarities in dental health between the early Neolithic and later Iron Age skeletons. The evidence presented in this study confirms archaeological evidence that the prehistoric inhabitants of both sites shared a similar subsistence economy broadly based on farming, fishing and the hunting and gathering of marine and terrestrial resources.

Regional comparisons of dental health indicators suggest the earliest Neolithic inhabitants of Taiwan experienced more childhood physiological stress (LEH) than that observed in other series. Overall, the frequencies of several indicators of oral infection (e.g., AMTL, dental caries, and alveolar defects) in the NKLE and SSH skeletons are among the lowest reported, indicating good dental health for Taiwan's prehistoric inhabitants, a finding that may also reflect a non-agricultural subsistence economy or diets low in starch and sugars and/or the cariostatic nature of marine diets. Given the small samples used in this study, these conclusions must be viewed with caution. Future research, involving additional skeletons from the Nankuanli East site as well as other sites from Taiwan, will expand on the research reported in this study.

Key Words : dental pathology, linear enamel hypoplasia, Nankuanli, Shisanhang, Neolithic and Iron Age Taiwan

Recent excavations in the Tainan Science Park (TSP), located in Shanhua, Xinshi, and Anding Districts in Tainan City, southwestern Taiwan, provide ample evidence that the Tapenkeng (named after the Tapenkeng site in northern Taiwan) culture, which includes cord-marked and incised pottery, represents the earliest Neolithic culture in Taiwan appearing approximately 3500-3000 BC (Chang 1969; Tsang 1995, 2005). The unique features of this new culture and its relatively rapid spread around the island suggest its likely source was from the neighboring coastal southeastern China (Bellwood 2005; Jiao 2007; Tsang, 2010, 2012).

Thus far, archaeological work at the TSP has identified at least 80 sites, extending from about 5,000 years BP to the first Han Chinese settlements of a few hundred years BP. In addition to a rich record of cultural and faunal material, human skeletons of approximately 2,000 individuals have been recovered from these sites. Two of the earliest Neolithic sites within the TSP complex are Nankuanli and Nankuanli East (NKLE). Extended supine burials accompanied by pottery, ornaments, and shell-bracelet funerary objects constitute the predominant mortuary pattern observed for these early Neolithic cultures. In addition to ceramic ware (i.e. jars and bowls), the archaeological evidence includes the presence of rice, foxtail millet, domesticated dogs, wild boars, deer, fish, shellfish, reaping knives made of shell, fishing sinkers, ground adzes and projectile points (Bellwood 2006; Li 2013; Tsang 2005). The major subsistence base of these early cultures included extensive marine exploitation, hunting, collecting wild plant seeds, as well as early farming involving the cultivation of small grains, root and fruit crops commencing at least 5,000 years ago.

The Neolithic people on both sides of the Taiwan Strait have figured prominently in the search for the homeland of Austronesian speakers and the dispersal of agriculturalists from southern China into the Pacific (Bellwood 2005; Jiao 2007; Tsang 2010, 2012). It is now widely assumed that the indigenous groups living in Taiwan prior to the major immigration of Han Chinese beginning in the 17th century are the likely descendants of these early Neolithic cultures of Taiwan.

Beginning approximately 2000 years BP, Taiwan's indigenous cultures entered the Iron Age. Several regional Iron Age cultures, such as the Shisanhang culture found in coastal regions of northwestern Taiwan, are represented by this period (Tsang 2000). The Shisanhang ceramic tradition included many more forms of pottery, including bottles, bowls, basins and globular cooking pots. In addition to tools made of stone, bone, and antler, evidence of an iron-smelting furnace and a workshop were identified indicating the people possessed knowledge of metal working. There is also evidence of long-distance trade with the Chinese during Tang and Song dynasties for exotic goods, such as agate beads and ornaments, bronze artifacts, Chinese coins, glass beads and bracelets, gold ornaments, porcelain, and silver objects, etc. (Tsang 2000). While cereal crops such as rice and millet formed a part of the subsistence base, hunting, marine and riverine fishing and collecting of marine resources were dominant characteristics of this subsistence economy (Pietrusewsky and Tsang 2003).

Bioarchaeological research in other regions of the world, especially the Western Hemisphere, has reported increased prevalence of dietary stress and disease following the

transition to intensified agriculture (e.g., Cohen and Armelagos 1984; Cohen and Crane-Kramer 2007; Larsen 2002, 2006; Rose et al. 1991; Steckel and Rose 2002). In such regions, the frequencies of indicators of systematic stress (e.g., linear enamel hypoplasia (LEH) and cribra orbitalia) and dental indicators such as dental caries, antemortem tooth loss (AMTL), and alveolar defects have been reported to increase significantly in response to malnutrition, infectious diseases, and changes in diet following the transition to agriculture. Likewise, dental attrition is found to generally decline following the transition from foraging to farming. With the exception of dental attrition, a different and more complex pattern has emerged in bioarchaeological research in Southeast Asia. Here the absence of evidence for a deterioration in health associated with the transition to sedentism and the intensification of agriculture was attributed to the relative noncariogenicity of rice and the retention of broad-spectrum subsistence strategies (Domett and Tayles 2007; Douglas and Pietrusewsky 2007; Halcrow et al. 2013; Oxenham 2004; Oxenham et al. 2006; Pietrusewsky and Douglas 2002). For example, for the Ban Chiang people of Thailand, while AMTL and dental abscesses increased over time signaling a decline in health; LEH, dental caries, and alveolar resorption decreased over time suggesting an improvement in health.

Using LEH and several indicators of oral-dental health, this study examines systematic stress and health during the early Neolithic and later Iron Age Taiwan in association with the transition to agriculture. Limited comparisons are also made to other skeletal assemblages from surrounding regions.

This is the first study of the NKLE skeletons from the TSP and the first systematic study of stressors and indicators of oral-dental health in skeletons representing Taiwan's earliest Neolithic period. A preliminary study of health and disease in human skeletons from the Iron Age Shisanhang site was reported by Pietrusewsky and Tsang (2003). Another study of the Shisanhang skeletons (Liu et al. 2013) that examined dental pathology (dental caries, AMTL and dental abscessing), LEH, cribra orbitalia and porotic hyperostosis in the skeletons from this site, was not available at the time this study was undertaken. While studies of health in East Asia using human skeletons are still rare, this void is beginning to be addressed (e.g., Pechenkina and Oxenham 2013).

Three hypotheses that examine the impact of agricultural economies in prehistoric Taiwan are tested. The first is based on the general observation that differences in diet (Larsen 1997; but see Lukacs 2008) explain differences in dental health. Females, who generally consume more plant carbohydrates and less meat than males, are expected to exhibit higher frequencies of dental caries and related dental indicators of health such as dental abscesses, dental calculus, and AMTL.

Second, it is predicted that subsistence economies of Iron Age Taiwan will be associated with an increase in systematic stress and certain dental indicators of health when compared to the earliest Neolithic communities in Taiwan. Thus, frequencies of childhood stress (LEH), dental caries, AMTL, alveolar defects, and dental calculus should increase from early Neolithic to later Iron Age Taiwan.

Third, previous work has demonstrated that agricultural societies generally use their teeth and jaws less vigorously than hunter-gatherer and foraging societies resulting in less macroscopically visible tooth wear from early to later Holocene times (Larsen 1997, 2002). This hypothesis predicts less advanced dental wear in the Iron Age skeletons relative to the early Neolithic series from Taiwan.

Limited comparisons of the Nankuanli East data with other skeletons, modern and prehistoric, from surrounding regions are made in discussing these results. While the comparative skeletal series examined do not represent the same temporal period as the Nankuanli East skeletons, they provide important regional as well as temporal perspectives for discussing the health of Taiwan's earliest indigenous peoples.

SKELETAL ASSEMBLAGES FROM TAIWAN

Nankuanli East (NKLE) Site

The Nankuanli East (NKLE) site is located five hundred meters east of the Nankuanli site on the flood plains of Shanhua District, Tainan City, in southwestern Taiwan. Salvage excavations at NKLE in 2002 – 2003 recovered approximately 82 burials (42 adults and 40 subadults) and extensive archaeological materials that are very similar to those recovered from the Nankuanli site.

Given that the skeletons from this and all the TSP sites suffered extensive postmortem damage due to 7-8 meters of overlying sediment, very few of the bones from the infracranial skeleton and none of the crania are complete. Further, given the manner in which these burials were excavated¹, only the skulls and teeth could be prepared for detailed examination. Twenty-three of the most complete and best preserved adult skulls from the NKLE site that were freed from the rest of the skeleton for further cleaning and possible restoration are used in the present study (Table 1). Seventeen individuals (9 males and 8 females) died as young adults (20-35 years of age) and six (5 males and 1 female) as middle-aged (35-50 years of age) adults. A selection of skeletons showing the state of preservation and completeness of these remains prior to this study are presented in Figures 1 and 2. A very limited number of observations were made in-situ in the infracranial skeleton and will be reported in a future paper.

¹ After the burials were exposed and cleaned, the exposed bones were treated with B-72 glue and then covered with 1-2 cm layer of soft plastic prior to being removed en-bloc. Once the skeleton and the underlying block of earth and sediments had been cut out of the ground, the entire mass was coated with several layers of fiberglass for transport to a storage facility. Later, in the storage facility, these fiberglass coffins were inverted and sawn open to expose the underlying dirt, which was then removed using dental picks and brushes. Once the dried bone had been exposed more glue was applied to consolidate the integrity of the bones. Thus, at the time of our study, the view presented by the intact skeletons was the opposite of that seen during fieldwork. Given that the majority of the burials at the NKLE site were interred in the supine position (lying on the back with the face upward or turned to the side) our initial view of them in the laboratory was the prone position.

Table 1: Age and sex distribution of the Nankuanli East skeletons

Age/Sex	Male ¹	Female ²	Total
Young Adult (20 - 35 yrs.)	9	8	17
Middle-aged Adult (35 - 50 yrs.)	5	1	6
Total	14	9	23

¹ The male burials used in this study: NKLE-D3-B2, NKLE-E3-B1, NKLE-E3-B2, NKLE-E3-B5, NKLE-E4-B4, NKLE-F3-B3, NKLE-F5-B11, NKLE-F5-B19, NKLE-F5-B25, NKLE-F5-B26, NKLE-F5-B27, NKLE-F5-B29, NKLE-F5-B39, NKLE-F5-B40.

² The female burials used in this study: NKLE-D3-B3, NKLE-D4-B1, NKLE-E6-B1, NKLE-F3-B1, NKLE-F5-B6, NKLE-F5-B14, NKLE-F5-B20, NKLE-F5-B32, NKLE-F5-B33.



Fig. 1: Some of the adult male burials from the NKLE site showing state of preservation and completeness prior to this study.

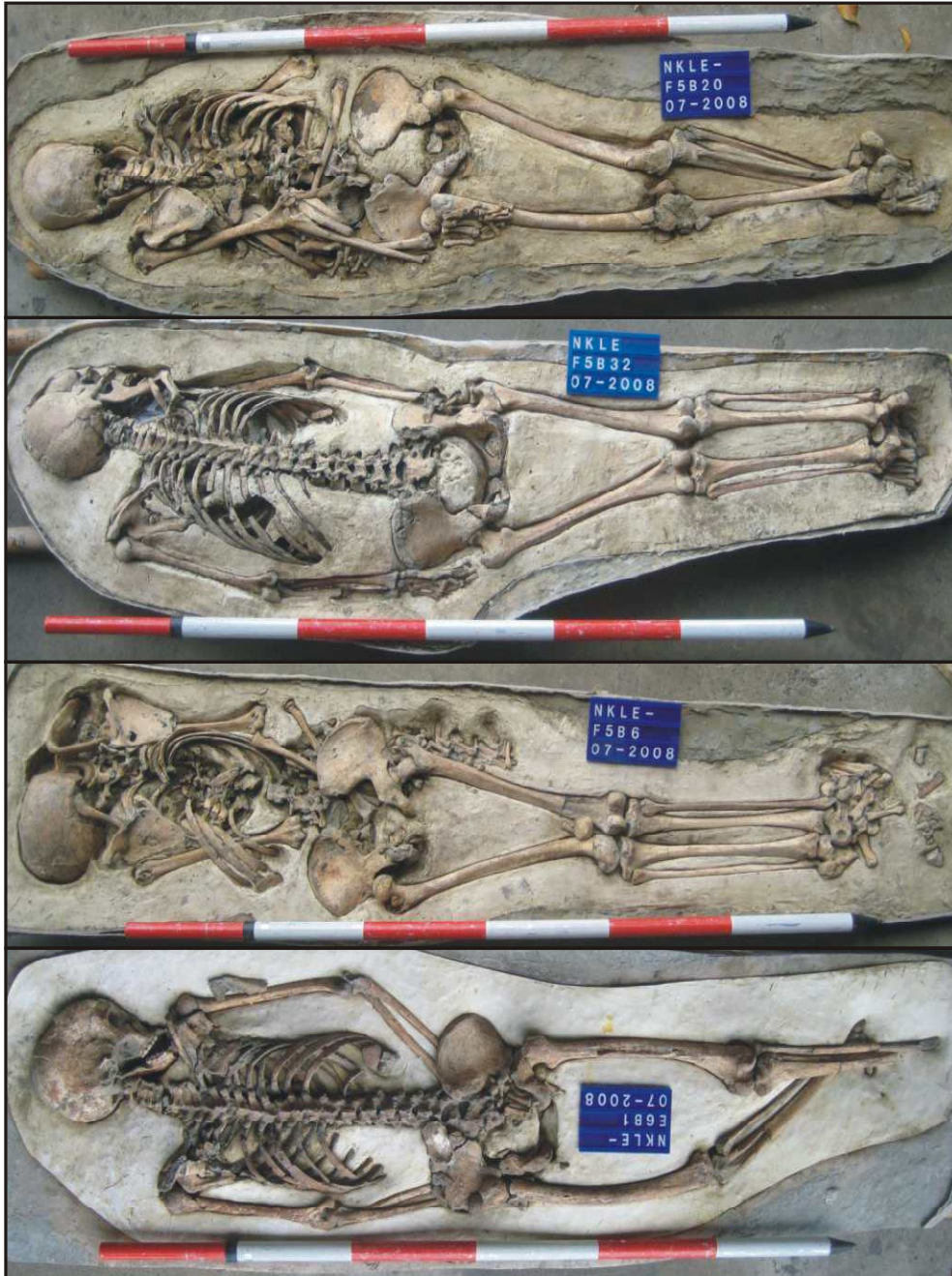


Fig. 2: Some of the adult female burials from the NKLE site showing state of preservation and completeness prior to this study.

Shisanhang (SSH) Site

The Shisanhang (SSH) site, which dates from approximately 1800 – 500 years BP, is located on the northwestern coast of Taiwan near the modern Bali District New Taipei City, near the mouth of the Danshui River (Tsang 2000; Yang 1961). More than 200 hundred well preserved human burials, many in the flexed position with heads facing southwest, have been removed from the site.

A total of 23 of the best preserved and most complete adult skeletons from the SSH site are used in this study (Pietrusewsky and Tsang 2003). Eighteen of the specimens examined died as young adults (20-35 years of age) and five were middle-aged adults (35-50 years).

Comparative Skeletal Assemblages

Selected skeletal assemblages from the region that compliment the two series from Taiwan are used for comparison (Table 2). The approximate location of these series and those from Taiwan are shown in the map in Figure 3.

Table 2: Comparative adult (15 years and older) skeletal series arranged temporally

Skeletal Series	Location	Dates (years BP)	Total Individuals	References
Con Co Ngua (Da But Period)	Northern Vietnam	5500 - 6000	71	Oxenham (2000); Oxenham et al. (2002, 2006)
Nankuanli East	Southwestern Taiwan	ca. 5000	23	Tsang (2005)
Middle to Final Jomon	Japan	5000 - 2300	186	Temple (2007a,b)
Khok Phanom Di	Central Thailand	4000 - 3500	67	Tayles (1999)
Early Ban Chiang	Northeast Thailand	4100 - 2900	63	Douglas (1996); Pietrusewsky and Douglas (2002)
Anyang	Northern China	3100	56	Li (1977)
Late Ban Chiang	Northeast Thailand	2900 - 1800	32	Douglas (1996); Pietrusewsky and Douglas (2002)
Yayoi	Japan	2500 - 1300	521	Temple (2007a); Temple and Larsen (2007)
Metal Age/Dong Son Period	Northern Vietnam	2500 - 1700	45	Oxenham (2000); Oxenham et al. (2002, 2006)
Shisanhang	Northwestern Taiwan	1500 - 1000	23	Tsang (2000)
Atayal	Taiwan	modern	36	Howells (1989)



Fig. 3: Map showing the approximate locations of the skeletal series used in the study.

Da But, Neolithic Vietnam

The Da But period skeletons (5500 – 6000 BP) is represented by dental remains of 71 adults from Con Co Nguia in Thanh Hoa province in Vietnam, a site that is approximately 30 km from the current coast (Oxenham et al. 2002, 2006). The inhabitants of this site have been described as sedentary foragers who subsisted on a range of food items including shellfish, fish, and land animals (buffalo and pig).

Middle to Final Jomon, Japan

The Middle to Final Jomon (5000 – 2300 BP) skeletal assemblages, from Honshu Island, Japanese Islands (Temple 2007a, 2007b), represent prehistoric people whose subsistence strategy included foraging, hunting and fishing, and plant cultivation / procurement (Akazawa 1986, 1999; Habu 2004; Imamura 1996). The Jomon are believed to be the descendants of Pleistocene nomads who migrated to the Japanese Islands sometime prior to approximately 16,000 BP (Kobayashi 2004).

Khok Phanom Di, Thailand

Khok Phanom Di is a coastal estuary site located near the Gulf of Thailand with early evidence of rice cultivation. A total of 154 individuals were recovered from this site, which has been dated from 4000 – 3500 BP. In addition to early evidence of rice production there is abundant evidence that the prehistoric inhabitants of this site relied heavily on marine food sources (Tayles 1999).

Ban Chiang, Thailand

A total of 142 individuals were recovered from Ban Chiang, a pre-metal to early Iron-Age (4100 – 1800 BP) site located in northeast Thailand (Pietrusewsky and Douglas 2002; White 2008). The skeletons used in this paper are from the Early Period (ca. 4100 – 2900 BP) and Late Periods (ca. 2900 – 1800 BP). Associated faunal remains from this site include dogs, chickens, cattle, and pigs. The subsistence base for those buried at Ban Chiang indicates a mixed agricultural and foraging economy. Evidence of domesticated water buffalo, indicative of the beginning of wet-rice agriculture appears approximately 2900 BP (Douglas 1996; Pietrusewsky and Douglas 2002).

Anyang, Northern China

Bronze Age (eleventh century BCE) male crania from 'sacrificial pits' excavated prior to World War II from Shang Dynasty tombs at Anyang, Henan Province, northern China (Li 1977) are located in Academia Sinica, Taipei, Taiwan. The frequency of caries in the Anyang series is taken from Turner (1979).

Yayoi, Japan

The people of the Yayoi Period (2500 – 1300 BP) represent the earliest wet-rice dependent agriculturalists who migrated to Japan from present day Korea and northern China beginning approximately 2500 BP. Limited comparative data are available for early to late Yayoi skeletons from southern Honshu, north Kyushu and Tanegashima Island (Temple 2007a; Temple and Larsen 2007).

Metal Age Vietnam

The skeletons representing Metal Age Vietnam, including the most developed and well known Dong Son period, include 68 individuals from 11 separate sites in the Red

(2200 – 1700 BP), Ma, and Ca (2500 – 1700 BP) river areas of Vietnam (Oxenham et al. 2006). The Dong Son people were sophisticated agriculturalists, raising rice and buffalo.

Atayal, Taiwan

The Atayal are the second largest surviving indigenous tribe in Taiwan. The modern skulls are those of Atayal slain in the Wushe incident in 1930. The skulls located in Academia Sinica (Taipei) were collected by Takeo Kanaseki in 1932 (Howells 1989:109). Caries prevalence in the Atayal teeth is taken from Turner (1979).

METHODS

The methods used to determine age-at-death and sex follow standard osteological procedures described in Buikstra and Ubelaker (1994) and Pietrusewsky and Douglas (2002). More detailed methodological information on the dental indicators of health summarized in this paper is discussed in Pietrusewsky and Douglas (2002). Additional comments will be introduced in the appropriate section when discussing the results. The chi-square statistic with Yates' correction was used to test for significant differences (Thomas 1986).

TOOTH ABLATION

Some observations, especially of the anterior teeth, were not permitted due to the cultural modification of teeth. Tooth ablation was observed in all of the adult individuals from the NKLE site. The predominant pattern observed (22/23, 95.7%) was the intentional removal of both maxillary lateral incisors and canines well before the time of death. One individual, a middle-aged adult male, exhibited a slightly different pattern where both maxillary lateral incisors were missing but the maxillary canines were present. In two of the 22 individuals exhibiting tooth ablation, the roots of the left canine teeth remained in the alveolus. In one other individual the roots of the left lateral incisor and both maxillary third premolars remained in the alveolus. None of the mandibular anterior teeth had been removed prior to death. Examples of tooth ablation in the NKLE dentitions are shown in Figures 4 - 6.



Fig. 4: NKLE F5 B26, a middle-aged male. Maxillary and mandibular teeth exhibiting marked and uneven wear. A dental caries is present on the distal surface of the left mandibular second molar.



Fig. 5: NKLE D3 B2, a young adult male. Maxillary teeth exhibiting marked attrition and tooth ablation of the maxillary lateral incisors and canines.



Fig. 6: NKLE E3 B1, a young adult male. The maxillary dentition showing tooth ablation of the lateral incisors and canines, shovel-shaped central incisors, and moderate wear of occlusal surfaces of the first molars.

RESULTS

Dental enamel hypoplasia, antemortem tooth loss, dental caries, and alveolar bone loss in the skeletons from NKLE area reported on a per tooth/tooth socket basis. The frequencies of the dental indicators in the NKLE series are given in Table 3. The frequencies of these dental indicators for the SSH site and the other comparative series are given in Tables 4 - 6.

Dental Enamel Hypoplasia

Developmental defects of enamel (DDE), or dental enamel hypoplasia, which have various manifestations including pits, bands, depressions, discoloration, or linear defects (furrows) of the enamel surface result from a disruption of enamel development (phase of amelogenesis) during infancy and early childhood (Goodman and Rose 1991; Hillson 1996, 2005). Dental enamel hypoplasias are a non-specific indicator of childhood stress because a single cause can rarely be attributed to a specific defect. Disruption of enamel development is associated with a variety of stressors affecting the mother and/or growing child including malnutrition, metabolic disorders, acute and chronic infections, physical trauma, and hereditary conditions (Goodman and Rose 1990, 1991; Goodman et al. 1984; Hillson 2008).

In this study the most common form of dental enamel hypoplasia was linear enamel hypoplasias (LEH), generally visible as one or more transverse furrows or grooves of varying depths on the crown surfaces of teeth. For that reason, our reporting is limited to LEH. Linear enamel hypoplasias in the NKLE teeth ranged in severity from slight to moderate grooves and often there was more than one defect per tooth. The number of defects per tooth was not recorded. Here, we report the incidence of one or more defects per tooth. While all teeth are scored for the presence/absence of these disruptions, they are more frequent in the incisor and canine teeth. The frequency of LEH in the NKLE maxillary and mandibular incisor and canine teeth, sexes combined, is 51.3% (Table 3). Although not statistically significant, a higher frequency of LEH is observed in adult males (57.1%) than in adult females (44.1%). Overall, LEH are observed in the canine and incisor teeth of thirteen males (13/14, 92.9%) and eight (8/9, 88.9%) females. A few examples of LEH observed in the NKLE teeth are presented in Figures 7 - 9.

Table 3: Frequencies¹ of dental indicators in Nankuanli East adult teeth/sockets

Indicator	Male		Female		Total		Significance ³
	A/O ²	%	A/O ²	%	A/O ²	%	
LEH ⁴	48/84	57.1	30/68	44.1	78/152	51.3	n.s.
AMTL	1/421	0.2	1/277	0.4	2/698	0.3	n.s.
Caries	6/345	1.7	5/233	2.1	11/578	1.9	n.s.
Alveolar resorption ⁵	26/250	10.4	9/148	6.1	35/398	8.8	n.s.
Alveolar defect	4/314	1.3	1/208	0.5	5/522	1.0	n.s.
Calculus ⁵	14/315	4.4	30/216	13.9	44/529	8.3	*
Attrition ⁶	40/342	11.7	5/231	2.2	45/573	7.9	*

¹ Frequencies include right and left sides combined, where applicable.

² A/O = affected/observed.

³ n.s. denotes no significant difference between the frequencies for males and females when tested using chi-square with Yates' correction at $p < 0.05$ and 1 degree of freedom.

* denotes significant difference between the frequencies for males and females when tested using chi-square with Yates' correction at $p < 0.05$ and 1 degree of freedom.

⁴ Frequencies for maxillary and mandibular canine and incisor teeth only.

⁵ Frequencies of moderate and severe expressions.

⁶ Advanced (pulp exposure or wear to the root).



Fig. 7: NKLE D4 B1, a young adult female. The maxillary central incisors exhibit LEH.



Fig. 8: NKLE E3 B1, a young adult male. Anterior view of the maxillary central incisors exhibiting linear enamel hypoplasias and tooth ablation.



Fig. 9: NKLE F3 B1, young adult female. Anterior view of the anterior mandibular teeth; the left canine and adjacent lateral incisor exhibit multiple LEH.

Antemortem Tooth Loss (AMTL)

The loss of teeth before death (antemortem tooth loss - AMTL) can be attributed to several causes indicative of pathological processes including periodontal disease, carious lesions, and alveolar defects. Tooth ablation, or the ritual removal of teeth during the lifetime of an individual, is not included in the reported frequencies of AMTL. The overall frequency of AMTL in the dentitions from the NKLE site, sexes combined, is 0.3%, an extremely low frequency (Table 3). There is no significant difference between male dentitions (0.2%) and female dentitions (0.4%).

Dental Caries

Dental caries is a demineralization of the tooth structures caused by organic acids produced by bacterial processes involved in the fermentation of dietary carbohydrates (Hillson 2008:313). The overall frequency of carious teeth (1.9%) in the NKLE teeth, sexes combined, is low. There is no significant difference in the frequency of carious teeth observed in males (1.7%) and females (2.1%) from this site (Table 3). Some examples of dental caries in the NKLE teeth are shown in Figures 7, 10, and 11.



Fig. 10: NKLE F5 B33, a young adult female. Occlusal view of mandibular teeth. A carious lesion is visible in the left second molar and there is moderate to marked dental attrition.



Fig. 11: NKLE F5 B6, a young adult female. Dental caries are present in the maxillary left first and second molars.

Alveolar Bone Loss

Two distinct types of bone loss from the alveolar process are recorded in the NKLE series. The first type, referred to in this study as alveolar resorption, is related to the removal of alveolar bone due to inflammation of the supporting tissues of the teeth associated with periodontal disease (Hillson 2008). The second type of alveolar bone loss is concentrated around the apex of the tooth roots, originating from infections of pulp, so-called periapical inflammation; a term that has been suggested to replace the older and somewhat incorrect designation, periapical dental abscess (Dias and Tayles 1997; Hillson 2008; Oxenham et al. 2006). While we have adopted the term alveolar defect for this type of bone loss in the present paper, it is referred to as dental abscess in previous work (e.g., Steckel and Rose 2002).

Alveolar Resorption

In this study, alveolar resorption is scored as the amount (none, slight, moderate, and marked) of tooth root exposed above the alveolar bone margin (see Figure 12 for an example). The overall frequency of advanced (moderate and marked expressions) levels of resorption of the alveolus in the NKLE series is 8.8% (Table 3). No significant difference is reported for the frequency of resorption in adult male alveoli (10.4%) and female alveoli (6.1%) from NKLE.

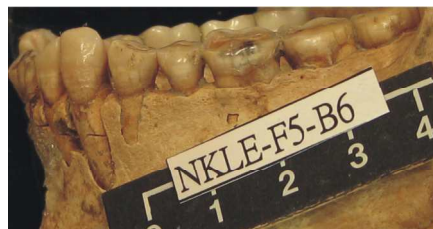


Fig. 12: NKLE F5 B6, a young adult female. Linear enamel hypoplasias are present on the left canine and incisor teeth. There is slight alveolar resorption in the molar region.

Alveolar Defects

The frequency of alveolar defects, or periapical inflammation, in the NKLE series is 1.0% of tooth sockets (Table 3 and Figure 13). There is no significant difference in the frequency of alveolar defects in the adult male sockets (1.3%) and female sockets (0.5%).



Fig. 13: NKLE F5 B29, a middle-aged male. Alveolar defects (periapical abscesses) are observed exposing the roots of the maxillary left first and second molars and third premolar.

Dental Calculus

One of the most common dental diseases in the living is dental plaque, a dense accumulation of microorganisms and associated extracellular material on the tooth's surface (Hillson 2008). Dental calculus is calcified or mineralized dental plaque, composed primarily of calcium phosphate mineral salts deposited between and within remnants of formerly viable microorganisms (White 1997). Dental calculus accumulates at the base of a living plaque deposit that attaches to the tooth surface. Two forms of calculus are generally recognized, supragingival (on the tooth crowns and sometimes roots) and subgingival (a less obvious layer that primarily coats the surface of the root), only the latter occurs coincident with periodontal disease (Hillson 2008; White 1997). Dental calculus, both supra- and subgingival occurs in the majority of adults worldwide. Levels of calculus and location are affected by oral hygiene habits, diet (carbohydrate consumption), and systemic disease (Hillson 2008; White 1997).

Given the difficulty of differentiating between the two kinds of calculus, a distinction between these two kinds of dental calculus was not made in this study. In the NKLE teeth, dental calculus was mainly confined to the tooth crown and cemento-enamel junction. The overall frequency of advanced (moderate and marked as described in Brothwell 1981, Figure 6.14b) calculus build-up in the NKLE teeth is 8.3% (Table 3). A significantly higher frequency of calculus was observed in NKLE female teeth (13.9%) compared to NKLE male teeth (4.4%). Some examples of dental calculus observed in the NKLE teeth are shown in Figures 14 and 15.



Fig. 14: NKLE F5 B33, a young adult female. Left mandibular teeth exhibiting marked dental calculus deposits.



Fig. 15: NKLE F5 B27, a middle-aged male. Anterior mandibular teeth exhibiting dental calculus deposits and moderate tooth wear.

Dental Attrition

Tooth-on-tooth wear that results in wear facets on the teeth involved is described as attrition (Hillson 2008). In the NKLE series occlusal wear was recorded on an absent, slight, moderate, and marked gradient reflecting the exposure of the dentin as wear progresses. The overall incidence of advanced dental attrition, tooth wear that exposes the dentin (moderate) and pulp cavity (marked), is 52.1% in the NKLE adults. A lower, but not statistically significant, frequency of advanced dental attrition is observed in adult female teeth (43.3%) than in adult male teeth (57.6%) from NKLE (Table 3). Several examples of tooth wear in the NKLE dentitions are shown in Figures 7 - 10, 15, and 16.



Fig. 16: NKLE D3 B2, a young adult male. Occlusal view of mandibular teeth that exhibit moderate wear.

DISCUSSION

Nankuanli East Health

Given the limitations of the NKLE sample, our observations of health are restricted to linear enamel hypoplasia and dental pathology. Data for stature, cribra orbitalia (porotic hyperostosis), and evidence of infection and trauma are not available for the NKLE series. Overall, a relatively high frequency of LEH was observed in the canine and incisor teeth in both sexes, suggesting significant childhood stress was experienced by these early Neolithic inhabitants. While not significant, a slightly higher frequency of linear enamel hypoplasia was observed in Nankuanli East males compared to females. Overall, the dental health of the NKLE skeletons is relatively good; frequencies of AMTL, dental caries, alveolar defect, dental calculus, and alveolar resorption are low. The significantly higher frequency of advanced dental attrition observed in the males is likely related to age, diet, and subsistence practices that included hunting, fishing and collecting as well as early farming. While these differences may be attributable to small sample size and younger age-at-death of females, there may also be environmental considerations.

Males have less mineralized plaque than females. Given that the accumulation of calcified dental plaque is age-related, this is an unexpected observation since the majority of the females are young adults. Hygiene habits, diet, cultural practices, and general stress may account for this observed sex difference. Thus, there is some support for the first hypothesis that predicted frequencies of dental caries and related dental indicators of health such as AMTL, alveolar defects and dental calculus would be higher in females than males due to differences in diet.

Early Neolithic and Iron Age Taiwan Comparisons

In this section, comparisons of health are made between the early Neolithic NKLE and the Iron Age SSH skeletons. Although the overall frequency of dental enamel hypoplasia in the Nankuanli East series is somewhat higher (51.3%) compared to the Shisanhang (37.1%), the difference is not significant (Table 4). However, given the prevalence of deliberate tooth ablation in the NKLE series, the 'per tooth' presence of LEH is underscored suggesting the difference in frequency between the two sites would be greater and perhaps significantly greater. There is a decline in childhood stress over time, perhaps as a result of improved food processing techniques (e.g., boiling) because of improved ceramic vessels, better weaning foods, resulting in less weaning stress and less contamination of food in later Iron Age Taiwan.

Table 4: Regional comparison of LEH in canine and incisor teeth

Sample	A/O ¹	%	Significance ²
Nankuanli East, SW Taiwan	78/152	51.3	
Jomon, Japan ³	487/1054	46.2	n.s.
Khok Phanom Di, C Thailand	130/297	43.8	n.s.
Early Ban Chiang, NE Thailand	34/254	13.4	*
Yayoi, Japan ⁴	292/965	30.3	*
Late Ban Chiang, NE Thailand	10/81	12.3	*
Shisanhang, NW Taiwan	69/186	37.1	n.s.

¹ A/O =affected/observed; % = frequency of occurrence. Includes maxillary and mandibular teeth.

² n.s. denotes no significant difference when the NKLE frequencies are compared to other series using chi-square with Yates' correction at $p < 0.05$ and 1 degree of freedom.

* denotes significant difference when the NKLE frequencies are compared to other series using chi-square with Yates' correction at $p < 0.05$ and 1 degree of freedom.

³ Frequency of LEH taken from Table 3 in Temple (2007b) for Middle to Final Jomon skeletal series from Honshu Island.

⁴ Frequency is based on a pooled Yayoi series from Temple (2007a:151).

The prediction (hypothesis 2) of an increase in certain dental indicators of health associated with the transition from early Neolithic to later Iron Age Taiwan is only partially substantiated in these results. As expected, significantly higher frequencies of alveolar resorption and dental calculus, reflecting differences in oral hygiene, diet, and periodontal disease, were observed in the SSH series compared to NKLE. Also, as expected, significantly lower levels of advanced attrition were observed in the Iron Age series from Taiwan compared to the early Neolithic series. These temporal changes are consistent with a transition from an abrasive or fibrous diet and/or use of the teeth as tools in the early Neolithic to an increased reliance on softer more processed foods and metal for tools in the Iron Age.

However, several other indicators of dental health such as AMTL, dental caries and alveolar defects in the NKLE and SSH series reveal few differences. Identical frequencies of AMTL were observed in the NKLE and SSH series (Table 5). Likewise, though not significant, a slightly lower frequency (1.0%) of dental caries was recorded in the SSH series compared to NKLE. Very similar frequencies of alveolar defects were observed in the two series. These results fail to confirm the second hypothesis, suggesting there is no temporal increase in reliance on cereals or change in emphasis between millet and rice; rather, the subsistence base remained very broad, including marine, riverine and terrestrial resources.

Perhaps more remarkable than these mostly minor differences, which may be attributable to differences in diet and oral hygiene, is the overall similarity in dental health between the early Neolithic skeletons from NKLE and the later Iron Age skeletons from

SSH. The archaeological evidence suggests that Taiwan's earliest Neolithic inhabitants, like those who settled at the Nankuanli East site in southwestern Taiwan, possessed well-developed coastal adaptive strategies (Li 2013). While the NKLE settlers were among Taiwan's first farmers, which included the cultivation of millet, their mode of subsistence was heavily dependent on intensive marine exploitation and the hunting of terrestrial mammals (dog, deer and wild boar) and birds (Li 2013; Tsang 1995). Likewise, although there is evidence that the diet of the Iron Age settlers at SSH, a site located near the sea and rivers, included rice (Tsang 2000), the collection of shellfish and terrestrial hunting were considered to be very important in their diets. Despite the fact that the inhabitants of the NKLE and SSH sites are separated by at least 3000 years and assigned to different cultural periods in Taiwan, both appear to have relied heavily on marine resources in their subsistence strategies. The similarities in dental health for the early settlers at these sites, which were found in the present study, agree with this interpretation.

Table 5: Regional comparison of dental infection in teeth/sockets (sides combined)

Sample	Antemortem Tooth Loss		Carious Lesions		Alveolar Defect	
	A/O ¹	%	A/O	%	A/O	%
Da But, Vietnam ²	69/1430	4.8*	14/951	1.5	22/1430	1.5
Nankuanli East, SW Taiwan	2/698	0.3	11/578	1.9	5/522	1.0
Jomon, Japan ³			398/4869	8.2*		
Khok Phanom Di, C Thailand	183/2047	8.9*	139/1282	10.8*	122/2047	6.0*
Early Ban Chiang, NE Thailand	64/1012	6.3*	60/826	7.3*	44/850	5.2*
Anyang, China ⁵			177/5100	3.5		
Late Ban Chiang, NE Thailand	25/312	8.0*	10/235	4.3	22/234	9.4*
Yayoi, Japan ⁴			123/1108	11.1*		
Metal Age Vietnam	46/1518	3.0*	26/1152	2.3	39/1518	2.6
Shisanhang, NW Taiwan	2/633	0.3	6/585	1.0	4/598	0.7
Atayal, Taiwan ⁵			50/378	13.2*		

¹ A/O =affected/observed teeth.

* denotes significant difference when the NKLE frequencies are compared to other series using chi-square with Yates' correction at $p < 0.05$ and 1 degree of freedom.

² The number of affected teeth was determined from Oxenham (2000) and Oxenham et al. (2006).

³ Calculated from data in Table 6 in Temple (2007b).

⁴ Calculated from data in Table 5 in Temple and Larsen (2007).

⁵ Frequencies from Turner (1979).

Regional Comparisons

In this section, comparisons are made between skeletons from Southeast Asia, Japan, and China that have similar subsistence economies and temporally overlap the NKLE and SSH skeletons. Although the sample size is small, frequency of LEH recorded in the NKLE teeth is the highest among the comparative series. A comparably high frequency of LEH is observed in the Middle to Final Jomon series (46.2%), a series whose subsistence base includes foraging, hunting and fishing, as well as plant cultivation.

Slightly lower frequencies of LEH are reported for Khok Phanom Di (43.8%), and Shisanhang (37.2%). Significantly lower frequencies of LEH are reported for Yayoi agriculturalists and the Ban Chiang skeletal series. Although a single cause can rarely be assigned to a specific hypoplastic defect, nutritional deficiencies, metabolic disorders, and infectious diseases experienced during childhood, are among the possible causes of dental enamel hypoplasias. The relatively high frequency of this indicator suggests that the early Neolithic inhabitants in this region experienced relatively high levels of physiological stress during childhood.

Although comparisons are limited, the prevalence of indicators of oral infection; AMTL, dental caries, and alveolar defects for the NKLE and SSH series are among the lowest reported (Table 5), suggesting generally good dental health for these prehistoric inhabitants of Taiwan. Significantly higher frequencies of AMTL were observed for the Neolithic and early metal age skeletons from Thailand and Vietnam. The frequencies of carious lesions in the NKLE and SSH series, while among the lowest reported, are not significantly different from those for the Neolithic and Metal age series from Vietnam and the Chinese Bronze-Age series from Anyang (Table 5). The equally low frequencies of alveolar defects observed in the NKLE and SSH series are consistent with observations in the Neolithic and Metal Age series from Vietnam. Significantly higher frequencies for this dental indicator are reported for skeletons from Thailand.

Differences in diet (particularly carbohydrate content) and subsistence patterns have been linked to caries frequencies. Caries is generally rare until the adoption of agriculture (Larsen 1995, 1997; Larsen et al. 1991) and when fermentable carbohydrates from cultivated crops were added to the diet (Hillson 2008). Although Tayles et al. (2000) have recently made the case that low rates of carious lesions may be associated with rice-dominated agricultural communities (as opposed to other grains such as corn), the unusually low frequencies of dental infections observed in the NKLE series may also reflect a non-agricultural subsistence economy, or a diet low in starches and sugars. Several authors (e.g., Kelley et al. 1991; Larsen et al. 1991) have reported the cariostatic nature of marine diets. The coastal locations and archaeological evidence for both NKLE and SSH sites indicates that both fishing and exploitation of marine resources were important components of the subsistence patterns for these early inhabitants of Taiwan. It is also of note that the Neolithic and Metal Age inhabitants of Vietnam, described as foragers and agriculturalists whose subsistence base included marine resources, have similarly low frequencies of dental caries and alveolar defects as the early Neolithic and later Iron Age skeletons from Taiwan.

Compared to NKLE a significantly higher frequency of alveolar resorption is reported for the SSH series (Table 6). Although a different method was used, the slightly higher frequency (13.2%) reported for Ban Chiang is not significant. The overall frequency of dental calculus observed in the NKLE series is considerably lower than the frequency for SSH (28.9%) and those reported for Ban Chiang and the two Vietnamese series (Table 6). The frequencies of advanced alveolar resorption and dental calculus observed in the NKLE series are among the lowest reported (Table 6). Higher frequencies of dental calculus have been attributed to a more alkaline oral environment, which may be associated with several factors including the chewing of betel nut (*Areca catechu*), a diet high in carbohydrates, or poor dental hygiene. Although not reported here, the majority of the NKLE teeth exhibit evidence of staining, which may or may not be caused by the use of betel nut. The SSH teeth have no evidence of dental staining.

Table 6: Regional comparison of alveolar resorption, calculus, and attrition (sides combined)

Sample	Alveolar Resorption ¹		Calculus ¹		Attrition ²	
	A/O ³	%	A/O	%	A/O	%
Da But, Vietnam ⁴			211/951	22.2*		
Khok Phanom Di, C. Thailand	—	—	—	—	112/1272	8.8
Nankuanli East	35/398	8.8	44/529	8.3	45/573	7.9
Early Ban Chiang, NE. Thailand	92/657	14.0	158/663	23.8*	35/642	5.5
Late Ban Chiang	24/239	10.0	95/255	37.3	45/307	14.7
Shisanhang, Taiwan	130/508	25.6*	162/560	28.9*	4/584	0.7*

¹ Frequencies of moderate and marked expressions.

² Advanced attrition (pulp exposure or wear to the roots).

³ A/O =affected/observed.

⁴ Slight, medium and heavy calculus (Oxenham, 2000).

* denotes significant difference when the NKLE frequencies are compared to other series using chi-square with Yates' correction at $p < 0.05$ and 1 degree of freedom.

Of the skeletons available for comparison, significantly higher frequencies of advanced dental attrition were reported for the NKLE and Ban Chiang series (Table 6). In addition to diet, cultural practices such as betel nut chewing, and the use of teeth in task-related activities may contribute to advanced dental attrition rates. Comparisons of the NKLE and SSH skeletons from Taiwan show these two skeletal series within the range of other coastal communities in the region with good dental health but with evidence of more childhood stress. Additional skeletal evidence is necessary to examine the possible causes of this, including evidence for infectious disease and anemia.

CONCLUSIONS

With the exception of a slightly higher frequency of dental calculus in females, there are very few sex differences in the frequencies of oral-dental indicators of health observed in the Nankuanli (NKLE) skeletons. Comparisons of the early Neolithic skeletons from NKLE with the later Iron Age Shisanhang (SSH) series reveal very similar frequencies of dental caries, AMTL, and alveolar defects. Only the frequencies of advanced dental calculus and alveolar resorption are found to be significantly higher in the SSH series. Comparisons of the oral-dental indicators of health in the prehistoric skeletons from Taiwan with other regional skeletal series suggest the early inhabitants of Taiwan had good oral-dental health with low frequencies of dental caries, AMTL, alveolar defect, advanced alveolar resorption, and dental calculus. Only the frequencies of LEH and advanced dental attrition are observed to be among the highest for the NKLE series. The higher than expected frequency of LEH suggests that early Neolithic inhabitants of Taiwan very likely experienced considerable nonspecific physiological stress, including the possibility of infectious diseases and/or metabolic disorders, during early childhood. The overwhelming similarities in dental health between the early Neolithic skeletons from NKLE and the later Iron Age skeletons from SSH, likely the result of sharing a similar subsistence economy based on fishing and the hunting and gathering of marine and terrestrial resources, is worthy of future investigation. Because of the limited size of the samples used in this study, these conclusions must be viewed with caution. It is hoped that future research involving additional skeletons from the Nankuanli East site as well as other sites in the Tainan Science Park and Taiwan will augment the research reported here.

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臺灣新石器時代早期及鐵器時代人骨健康的牙齒指標

Michael Pietrusewsky^{*}, Adam Lauer^{**}, 臧振華^{***}, 李匡悌^{****},
Michele Toomay Douglas^{*****}

摘要

本研究論述若干從臺灣新石器時代人類遺骸中所獲得的資訊，並探討臺灣最早的新石器時代及較晚的鐵器時代人類生業改變的生物文化意涵。本研究的樣本來自兩個考古遺址。其中一批，共 23 個個體，是來自臺灣臺南市臺南科學園區內的南關里東（NKLE）遺址。該遺址屬於大盆坑文化，為臺灣最早的新石器時代文化，年代約距今 5000 年前。另一批，共 23 個個體，是來自臺灣北部的十三行遺址，年代約距今 1800—500 年前，屬於鐵器時代。

本研究的目的有四：1) 紀錄南關里東遺址人骨所呈現的一些口腔病徵及生理健康之指標，包括生前牙齒脫落、齲齒、齒槽骨萎縮、齒槽骨缺損、牙結石、牙齒磨耗，以及線狀齒釉發育不全。2) 檢視南關里東遺址人骨的性別差異。3) 比較臺灣新石器時代早期及鐵器時代的人類健康狀況。4) 將臺灣史前時代的人骨放在更大的區域中來觀察。

研究的結果顯示：作為嬰兒及兒童健康指標的線狀齒釉發育不全現象，在南關里東遺址成人門齒上出現的頻率相當高（51.3%），說明這些臺灣新石器時代早期人類在其童年時曾經承受生理的壓力。此外，這批人骨在生前牙齒脫落、齲齒、齒槽骨缺損等方面，出現的頻率都相當低，分別是 0.3%、1.9%，及 1.0%；在齒槽骨萎縮及牙結石方面的出現頻率，則屬中等級，分別為 8.8% 及 8.3%。出乎意料的是，在南關里東的人骨中，上述的健康指標，都沒有顯著的性別差異。不過，成年男性的牙齒磨耗，明顯高於成年女性。可能與年齡、飲食，及生活方式有關。整體而言，南關里東人骨的健康狀況，相當不錯。

同樣令人意外的是：南關里東與十三行兩處遺址，在線狀齒釉發育不全、齲齒、生前牙齒脫落，及齒槽骨缺損等方面的頻率，沒有太大差別。但是十三行遺址的牙結石及齒槽骨萎縮的頻率則明顯較高，這可能與當時食物處理技術精緻化的轉變有所關連。此外，南關里東人骨的牙齒磨耗頻率（7.9%）高過十三行遺址的人骨，說明在新石器時代

^{*} 夏威夷大學人類學系教授。mikep@hawaii.edu

^{**} 夏威夷大學人類學系博士候選人。alauer@hawaii.edu

^{***} 中央研究院歷史語言研究所研究員。tsang@mail.ihp.sinica.edu.tw

^{****} 中央研究院歷史語言研究所副研究員。kuang@mail.ihp.sinica.edu.tw

^{*****} 夏威夷大學人類學研究所兼職教師。toomaydoug@charter.net

早期，牙齒仍然被當作是一種工具，但是到了鐵器時代，因為食用較多加工柔軟的食物，而且有了鐵器作為工具，減低了牙齒的磨耗。

在南關里東遺址的人骨中，線狀齒釉發育不全的頻率為 51.3%，高於十三行遺址的 37.1%，似乎顯示在鐵器時代，兒童的生理健康狀況已有所改善。不過，這兩個數字在統計學上的意義並不明顯。我們如果不去注意那些可能是由於飲食、衛生或文化作為所造成的微小差異，南關里東與十三行兩處遺址人骨的牙齒健康狀況其實肯定是相似的。

本研究所呈現的結果支持考古證據所顯示的：兩處遺址的居民同樣都是採行農業、漁業，以及開採海域與陸域資源為基礎的生業經濟。而大區域的比較顯示，臺灣新石器時代早期居民較其它地區遺址的居民承受了更大的生理壓力。

總而言之，南關里東與十三行人骨口腔中若干指標的頻率，包括生前牙齒脫落、齲齒、齒槽骨缺損，都是報導資料中的最低者，說明臺灣史前居民具有良好的牙齒健康。這種情形似乎也反映了一種非農業的生業經濟，或是食用低澱粉、低糖，以及/或者具有止齲性質的海洋性食物。不過，由於本研究所使用的樣本數偏少，必須審慎看待這個研究結果。未來的研究，包括對南關里東及其他遺址更多人骨的研究，當會對本研究的資料有所擴充。

關鍵詞：牙齒病理、線狀齒釉發育不全、南關里東、十三行、臺灣新石器時代及鐵器時代