ANTHROPOLOGICAL SCIENCE
Vol. 119(1), 67–79, 2011

On the origin of pre-Angkorian peoples: perspectives from cranial and dental affinity of the human remains from Iron Age Phum Snay, Cambodia

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Received 11 May 2010; accepted 30 July 2010

Abstract This article presents the results of an assessment of the morphological affinities of the skeletal remains from a large mortuary assemblage, dated to Iron Age, in Phum Snay, a village in Banteay Meanchey Province, northwest Cambodia. The purpose of the research is to address the origin of these pre-Angkorian people. Multivariate comparisons using cranial and dental metrics, as well as dental nonmetric traits, demonstrate that the characteristic affinities intermediate between the early Holocene Hoabinhian groups akin to Australo-Melanesians and the present-day people in the mainland Southeast Asia. This finding suggests that the ancient people of Phum Snay preserved genetic traits of early indigenous populations, whereas modern mainland Southeast Asians, including Cambodians, were more affected by gene flow from later migrants from East Asia into this region.

Key words: Phum Snay, Cambodia, human remains, pre-Angkorian

Introduction

Phum Snay is a village located along National Route 6 between Siem Reap (the center of the ancient great state of Angkor) and the Thai border in Preah Neat Prey District, Banteay Meanchey Province, northwest Cambodia (Figure 1). Roadworks in the village during 2000 accidentally uncovered a large number of prehistoric burials and artifacts. The Banteay Meanchey Archaeological Project (BMAP) team, led by O'Reilly, Pheng, and Thuy from the Royal University of Fine Arts, Phnom Penh, conducted archaeological excavations at the site of Phum Snay during 2001 and 2003, in collaboration with colleagues from the University of Otago, New Zealand, and James Cook University, Australia (O'Reilly and Pheng, 2001; O'Reilly et al., 2004, 2008; Domett and O'Reilly, 2009). The mortuary assemblages, which were dated to the Iron Age (or pre-Angkorian period) with C14 dates ranging from *c.* 350 BC to 200 AD (O'Reilly et al., 2006), bear similarities with contemporaneous mortuary ritual in northeast Thailand including the discovery of black, streak-burnished wares known widely as Phimai black (O'Reilly et al., 2004, 2008). In addition, some of the interments contained rice silica. In contrast to the mortuary assemblages in Thailand, the graves at Phum Snay contained many weapons. Some of these were most likely hunting weapons, such as iron projectile points, while others, such as long (> 1 m) swords, found only interred with males, may have had military applications. The human skeletal remains from Phum Snay also show some striking differences to those in northeast Thailand, including a high rate of cranial trauma and artificial tooth deformation (Domett and Buckley, 2006; Domett and O'Reilly, 2009).

The skeletal remains of 23 individuals were uncovered during the excavation and are currently housed at the Royal University of Fine Arts, Phnom Penh. Aside from these archaeologically recovered remains, many skeletons were exposed by the recent extensive looting of the archaeological remains at Phum Snay. These skeletons, which indubitably come from Phum Snay, were collected by the local monks and are stored at the temples of Wat Leu in Phum Snay village and at Wat Bo in Siem Reap. The majority of Phum Snay skulls are characterized by low and wide faces, with broad nasal openings and rectangular orbital margins, and protruding glabella. Figure 2 displays a representative male cranium from the site of Phum Snay.

The aim of this paper is to explore the biological relationships of the people of Phum Snay to surrounding populations dating from the prehistoric to modern times. The cranial and dental morphological data and an assessment of their morphometric affinities are presented here in order to address the issue of the origin of this group of pre-Angkorean people.

Materials

Phum Snay skeletons

The skeletal remains used in this analysis comprise three major collections, one from specimens uncovered during the 2001–2003 excavations by the BMAP team, and the others

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Published online 1 October 2010
in J-STAGE (www.jstage.jst.go.jp) DOI: 10.1537/ase.100511

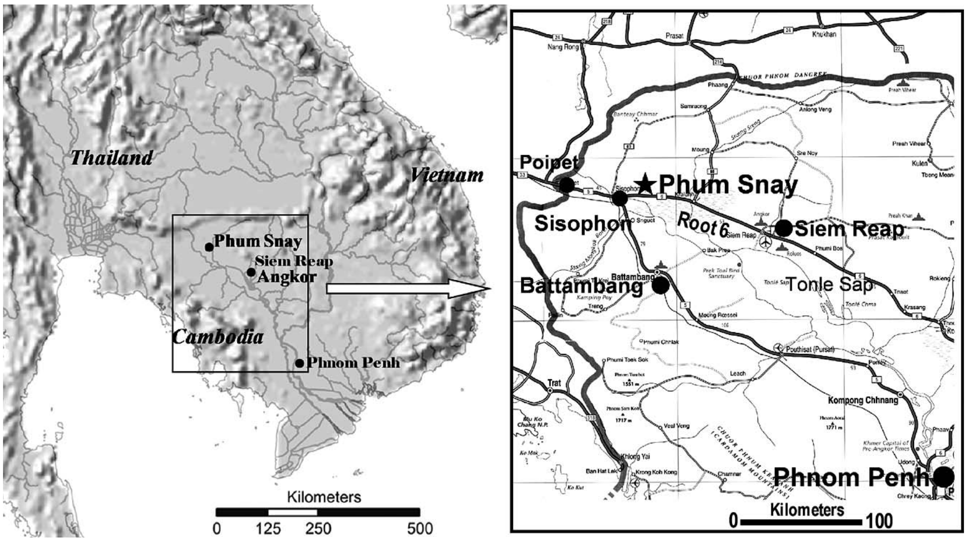

Figure 1. Location of the Phum Snay site in Cambodia.

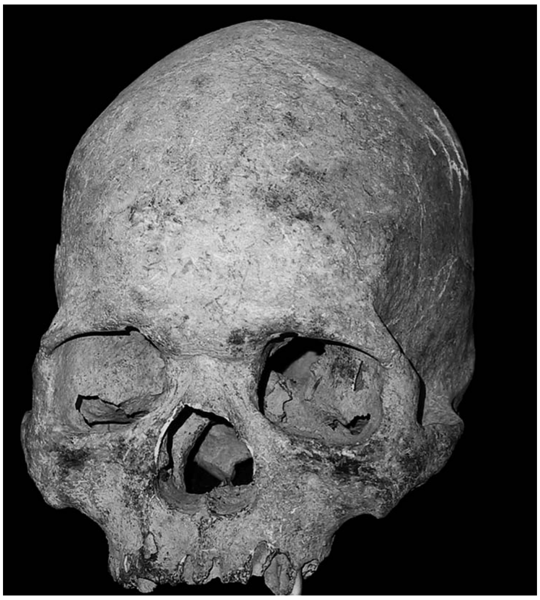

Figure 2. Representative adult male skull from the Phum Snay site.

housed at Wat Bo and at Wat Leu. The excavated material included 19 individuals from which cranial and dental data were recorded. From the other collections, cranial measurements were taken from 44 specimens and dental metric and nonmetric data were recorded for 88 maxillae and 105 mandibles. The amount of information recovered from the dental remains was limited, especially with the incisors due to the pre-mortem tooth ablation and/or tooth filing that was performed on the anterior teeth.

Cranial and dental trait data

Twenty-seven cranial measurements were undertaken following Martin's definitions (Bräuer, 1988). Yamaguchi's (1973) method was utilized for six facial flatness measurements. Metric dental traits were represented by the mesiodistal and buccolingual crown diameters of all teeth except for the third molars. The measurements were taken as maximum diameters according to Fujita's system (1949). Nonmetric dental data were scored using protocols and criteria of 21 traits given in Matsumura (1995). All traits were scored for both sexes on the basis of presence/absence to facilitate statistical comparison. Crown measurements and observations of nonmetric traits were undertaken for teeth on the right side, or antimere substitutions when necessary.

Comparative samples

Using the cranial metric, dental metric and nonmetric data sets, multivariable statistical procedures were undertaken to assess the population affinities between the Phum Snay sample and ethnically and chronologically different groups.

The comparative samples are listed in Table 1 and Table 2, which also includes a summary of comparative archaeological samples from Vietnam, Laos, Thailand, Malaysia, Indonesia, China, and Japan, as well as modern samples from East/Southeast Asia and the Pacific, to be used for cranial, dental metric, and/or dental nonmetric comparisons.

Only samples identified as male were used for the cranial and odontometric data analysis as many of the comparative datasets are exclusively male, although sexual differences might exist. The nonmetric dental data were compiled from both sexes due to the low to minimal sexual dimorphism expected for the traits compared (Turner et al., 1991). As large sample sizes are required for comparisons of the nonmetric traits (based on the frequency of trait presence), it was necessary to combine some neighboring ethnic groups with small sample sizes.

Statistical procedures

Comparisons of cranial and dental morphology were made between the Phum Snay remains and the modern Cambodian or geographically neighboring modern population samples within mainland Southeast Asia including Vietnam,

Table 1. Comparative prehistoric cranial and dental samples from East/Southeast Asia

Sample	Locality	Period	Remark	Cranial metrics	n^1	Facial flatness	n^1	Dental metrics	n^1	Dental nonmterics	n^1	Storage[3]
1 Mai Da Nuoc	Site in Thanh Hoa Prov., northern Vietnam	Early Holocene (Late Hoabinhian Culture, *c.* 8000 BP)	Cuong, 1986	Cuong, 1986	1	H.M.	1	—	—	—	—	IAH
2 Hoabinhian Vietnam	Vietnam	Late Pleistocene–Early Holocene (Hoabinhian Culture)	Sites of Mai Da Nuoc, Mai Da Dieu, Dong Truong, Du Sang and Lang Bon	—	—	—	—	H.M.	6	—	—	IAH, LAM, CSPH
3 Bac Son	Northern Vietnam	Early Holocene (Bac Son Culture *c.* 8000–7000 BP)	Sites of Pho Binh Gia, Lang Cuom, and Cua Gi	H.M.	8	H.M.	8	Matsumura and Hudson, 2005	8	—	—	MHO
4 Con Co Ngua	Site in Than Hoa Prov., northern Vietnam	Early Neolithic (Da But Culture, sample dated to *c.* 5000 BP)	Patte, 1965; Thuy, 1990; Bui, 1991	Cuong, 2003	19	H.M.	7	Matsumura et al., 2001	20	—	—	IAH
5 Tam Hang & Tam Pong	Sites in northern Laos	Early Holocene	Mansuy and Colani, 1925; Huard and Saurin, 1938	H.M.	4	H.M.	4	H.M.	8	—	—	MHO
6 Early Holocene Vietnam & Laos	Vietnam and Laos	Early Holocene including Neolithic	Composite sample of groups Nos. 1–5	—	—	—	—	—	—	Matsumura and Hudson, 2005	76	—
7 An Son	Site in Long An Prov., southern Vietnam	Late Neolithic (*c.* 3500 BP)	Cuong, 2006	H.M.	4	H.M.	4	H.M.	7	—	—	LAM
8 Dong Son	Northern Vietnam	Early Metal Age (Dong Son Culture, 3000–1700 BP)	Cuong, 1996	Cuong, 1996	10	H.M.	21	Matsumura et al., 2001	20	Matsumura et al., 2001	46	IAH, CSPH
9 Gua Cha	Site in Kelantan Prov., Malaysia	Hoabinhian-Neolithic (*c.* 8000–3000 BP)	Sieveking, 1954; Bulbeck, 2000a	H.M.	1	H.M.	1	Matsumura and Hudson, 2005	9	—	—	UCB
10 Guar Kepah	Site in mainland Penang, Malaysia	Early Holocene (Hoabinhian Culture)	Callenfels, 1936; Mijsberg, 1940	—	—	—	—	Matsumura and Hudson, 2005	11	—	—	—
11 Mesolithic Flores	Flores Island	Early Holocene (Mesolithic, *c.* 7000–4000 BP)	Sites of Liang Momer, Linag Toge, Liang X, Gua Alo, Aimere, Sampung and Gua Nempong (Jacob, 1967)	—	—	—	—	Matsumura and Pookajorn, 2005	5	—	—	—
12 Early Flores & Malay	Flores Island and Malaysia	Hoabinhian/Mesolithic-Neolithic	Composite sample of groups Nos. 9–11	—	—	—	—	—	—	Matsumura and Hudson, 2005	52	—
13 Leanng Codong	Site in Sulawesi Island	Early Metal Age	Verhoeven, 1958; Jacob, 1967; Bulbeck, 2000b	—	—	—	—	—	—	Matsumura and Hudson, 2005	100	—
14 Ban Chiang	Site in Udon Thani Prov., Thailand	Neolithic-Bronze Age (*c.* 3500–1800 BP)	Gorman and Charoenwongsa, 1976	Pietrusewsky and Douglas, 2002 (M51[2]: Hanihara, 1993)	27	H.M.	15	—	—	H.M.	75	UHW, SAC
15 Weidun (& Songze)	Site in Jiangsu Prov., Sth China	Neolithic (Majiabang Culture, *c.* 7000–5000 BP)	Chang, 1986; Nakahashi and Li, 2002; teeth includes Songze series	Nakahashi et al., 2002.	29	Nakahashi et al., 2002.	29	Matsumura, 2002	48	Matsumura, 2002	111	—
16 Anyang	Site in Henang Prov., China	Bronze–Iron Age (*c.* 3300 BP)	IHIA and CASS, 1982	Han and Qi, 1985	42	H.M.	26	H.M.	60	H.M.	81	AST
17 Jiangnan	Jiangnan Prov., southern China	Zhou-Western Han (2770–1992 BP)	Nakahashi and Li, 2002	Nakahashi et al., 2002	18	Nakahashi et al., 2002	—	Matsumura, 2002	14	—	—	—
18 Jomon	Japan	Neolithic (Middle–Latest Jomon Culture, *c.* 5000–2300 BP)	Akazawa and Aikens, 1986	Hanihara, 1993	113	Hanihara, 2000	31	Matsumura, 1989	210	Matsumura, 1989	711	—

[1] n = sample size; [2] M = Martin's cranial measurment number; [3] Storage: institutions of materials studied by H.M. (H. Matsumura) AST = Academia Sinica of the Republic of China in Taipei; BMNH = Department of Paleontology, Natural History Museum, London; CSPH = Center for South East Asian Prehistory, Hanoi; IAH = Department of Anthropology, Institute of Archaeology, Hanoi; LAM = Long An Museum, Vietnam; MHO = Laboratoire d'Anthropologie Biologique, Musée de l'Homme, Paris; NMP = Department of Archaeology, National Museum of the Philippines, Manila; NTW = Department of Anatomy, National Taiwan University; SAC = Princess Maha Chakri Sirindhorn Anthropology Centre, Bangkok; UCB = Department of Biological Anthropology, University of Cambridge; UHW = Department of Anthropology, University of Hawaii; UMPH: Department of Dental Anatomy, University of Medicine and Pharmacy at Ho Chi Minh City, UTK: University Museum, University of Tokyo.

Table 2. Comparative modern cranial and dental samples from East/Southeast Asia and West Pacific

Sample	Remark (M = Martin's no.)	Cranial metrics	n^1	Facial flatness	n^1	Dental metrics	n^1	Dental nonmterics	n^1	Storage[2]
19 Vietnam	—	H.M.	27	H.M.	25	H.M.	52	H.M.	99	MHO, UMPH
20 Cambodia	—	H.M.	12	H.M.	12	—	—	—	—	MHO
21 Laos	—	Cuong, 1996	17	H.M.	10	H.M.	34	—	—	MHO
22 Thailand	—	Sangvichien, 1971	85	Hanihara, 2000	30	Matsumura, 1994	46	Matsumura, 1994	110	MUB
23 Myanmar	cranial metrics M17, 45, 48, 51 by H.M. ($n^1 = 21$)	Pietrusewsky, 1981	16	Hanihara, 2000	102	H.M.	30	H.M.	50	BMNH
24 Java	cranial metrics M17, 45, 48, 51 by H.M. ($n^1 = 20$)	Pietrusewsky, 1981	73	Hanihara, 2000	62	H.M.	45	—	—	BMNH, UCB
25 Celebes	cranial metrics M17, 45, 48, 51 by H.M. ($n^1 = 6$)	Pietrusewsky, 1981	41	Hanihara, 2000	28	—	—	—	—	—
26 Moluccas	cranial metrics M17, 45, 48, 51 by H.M. ($n^1 = 8$)	Pietrusewsky, 1981	78	Hanihara, 2000	28	—	—	—	—	—
27 Sumatra	cranial metrics M17, 45, 48, 51 by H.M. ($n^1 = 8$)	Pietrusewsky, 1981	43	Hanihara, 2000	13	H.M.	24	—	—	BMNH, UCB
28 Sunda	composite sample of group Nos. 24-27	—	—	—	—	—	—	H.M.	119	—
29 Dayak	Borneo	Yokoh, 1940	12	Hanihara, 2000	72	Matsumura and Hudson, 2005	42	Matsumura and Hudson, 2005	74	—
30 Philippines	—	Suzuki et al., 1993	8	H.M.	8	H.M.	41	—	—	NMP, UTK
31 Atayal	cranial metrics M45, 48, 51, 55 by H.M. ($n^1 = 41$)	Pietrusewsky and Chang, 2003	36	H.M.	30	H.M.	50	H.M.	79	NTW
32 Bunun	cranial metrics M45, 48, 51, 55 by H.M. ($n^1 = 23$)	Pietrusewsky and Chang, 2003	26	H.M.	16	H.M.	28	H.M.	45	NTW
33 Hainan	cranial metrics M48, 51, 55 by H.M. ($n^1 = 24$)	Howells, 1989	45	H.M.	24	H.M.	85	H.M.	128	NTW
34 Northern China	Manchurians	Hanihara, 1993	26	Hanihara, 2000	66	Matsumura, 1994	100	Matsumura, 1994	104	—
35 Japan	dental data includes the early modern specimens	Hanihara, 1993	140	Hanihara, 2000	138	Matsumura, 1994	178	Matsumura, 1994	254	UTK
36 Australia	—	Hanihara, 1993	53	H.M.	21	Matsumura and Hudson, 2005	63	Matsumura and Hudson, 2005	101	BMNH
37 Melanesia	Fiji, Tongans; New Hebrides; New Guinea	Hanihara, 1993	18	Hanihara, 2000 (New Guinea)	156	—	—	—	—	—
38 Loyalty	—	H.M.	17	H.M.	18	Matsumura and Hudson, 2005	39	Matsumura and Hudson, 2005	62	MHO
39 New Britain	—	—	—	—	—	Matsumura and Hudson, 2005	95	Matsumura and Hudson, 2005	188	—

[1] n = sample size; numbers in parentheses are sample sizes of cranial materials measured by Matsumura in remarks; [2] Storage: institutions of materials studied by H.M. (H. Matsumura) (abbreviations: see Table 1 footnote).

Thailand, and Laos. In order to compare the resemblance or dissimilarity to group averages of these samples, deviation diagrams were drawn using standardized cranial or dental measurements. The standard deviation data were then used from the Thai sample as it provides the largest sample size among the four groups. In the comparisons of nonmetric dental traits, frequencies of presence data were schematized using line graphs.

Next, the morphological affinities of the Phum Snay skull and dental samples were analyzed using all available comparative samples listed in Table 1 and Table 2, encompassing a wide geographic area and chronological span. Similarities in cranial and dental shapes were estimated by Q-mode correlation coefficients (Sneath and Sokal, 1973) using cranial and dental metrics. The cranial data set selected for this calculation were a subset of 16 measurements (Martin's method number: M1, M8, M9, M17, M43(1), M43c, M45, M46b, M46c, M48, M51, M52, M54, M55, M57, M57a), as these were the most commonly provided among the comparative samples. The dental data used for the analysis comprised 28 crown diameters (14 mesiodistal and 14 buccolingual diameters). The measurement data were then standardized using standard deviations of the Thai sample, which were then used to draw a deviation diagram, based on the grand means of all comparative samples. To evaluate population affinities based on the presence/absence frequencies of 21 nonmetric traits, C.A.B. Smith's distances (Berry and Berry, 1967), often referred to as 'mean measure of divergence' values, were computed.

Lastly, the neighbor-joining method (Saitou and Nei, 1987) was applied to the distance matrix of the Q-mode correlation coefficients and the matrix of Smith's distances, respectively, to aid in the interpretation of intersample phenotypic affinities. This procedure was driven using the software package Splits Tree version 4.0 provided by Huson and Bryant (2006).

Results

Cranial measurements

Cranial measurements and facial flatness measurements and indices for Phum Snay are given in Table 3. For cross-reference of cranial size, data recorded or cited for male modern Southeast Asian samples from Cambodia, Vietnam, Laos, and Thailand are also presented in Table 3. A comparison of the standardized deviations of the 18 cranial measurements and five indices of the Phum Snay males and the comparative samples are depicted in Figure 3. In order to standardize the measurements, data from modern Thai were used; therefore the horizontal zero line indicates the Thai averages. The differences in overall patterns are not remarkable between the Vietnamese and Cambodians, whose deviations are, in range, under 1.0 from the Thai. The Laos remains differed from these samples in terms of shorter and lower cranial vaults and of more protruding nasal bones and maxillae. As compared with the four modern samples, the Phum Snay sample bears little resemblance to any group, even to the modern Cambodians. The Phum Snay people are characterized as possessing a wider face with broad nasal openings, and larger maxillary alveoli. In most of the measurements relating to these features, the differences are highly significant from each other, as shown in Table 3.

Figure 4 presents the results from the neighbor-joining method applied to the distances of the Q-mode correlation coefficients based on 16 cranial measurements from 33 population samples encompassing Southeast Asian samples and other more geographically remote samples. The unrooted tree diagram resulting from this analysis branches into two major clusters at the top and bottom. These include: (1) East Asians and many of the Southeast Asians ranging from Late Neolithic to modern times; and (2) Australo-Melanesians and early Holocene Southeast Asians including Hoabinhian and early Neolithic, respectively. The peoples of Atayal, Dayak, and the Philippines, as well as the modern Cambodian, Laos and Thai peoples, occupy an intermediate phenetic position between these two major clumps. The Phum Snay people were also scattered intermediately in this tree, but lay closer to the later cluster consisting of the Australo-Melanesian and Hoabinhian samples.

Crown measurements

Dental crown measurements comprising mesiodistal (MD) and buccolingual (BL) diameters are presented in Table 4. For comparative dental metric data, the modern Cambodian sample was not utilized due to the poor preservation of teeth from the skeletal collection studied. The standardized deviations comparing the Phum Snay male sample with the modern male samples from Vietnam, Laos, and Thailand (base zero line) are represented in Figure 5. In respect of the overall patterns of deviation lines, Phum Snay is considerably different from the Laos sample. In the patterns of mesiodistal diameters, the Phum Snay data somewhat resemble the modern samples from Vietnam and Thailand, while those patterns in buccolingual diameters exhibit little similarity to each other.

The neighbor-joining method was applied to the Q-mode correlation matrix, calculated using the 28 crown diameters of 30 comparative population samples from the area expanding to East/Southeast Asia and the Pacific region, to generate an unrooted tree (Figure 6). An array of modern East and Southeast Asians occupy the top of the ordination. The Early Metal Age Dong Son Vietnamese and Neolithic Weidung and Songze from Southern China also branched out from this cluster. On the opposite, lower side there is a loose grouping of mainland Hoabinhian Vietnamese including Bac Son, Malays, Australian Aborigines, and Melanesians, as well as the Neolithic Vietnamese such as Con Co Ngua and An Son. The Phum Snay sample neighbored this major cluster.

Nonmetric tooth traits

Frequencies of the 21 nonmetric dental traits for Phum Snay and two modern samples from Vietnam and Thailand are summarized in Table 5 and Figure 7. The comparative data from modern Cambodia and Laos samples are not provided due to the small sample size. As compared with these two samples, the low frequencies of shovel-shaped incisors and deflecting wrinkle in the lower first molars, and the high frequency of the seventh cusp in the lower first molars are most remarkable in the Phum Snay sample. A few other

Table 3. Cranial measurements (mm) and indices of Phum Snay and four comparative modern Southeast Asian samples (males)

Population	Phum Snay						Cambodia				Vietnam				Laos[1]				Thailand[2]			
Sex	Males			Females			Males				Males				Males				Males			
Martin's no. and measurement	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*P*	*n*	Mean	SD	*P*	*n*	Mean	SD	*P*	*n*	Mean	SD	*P*
1 Max. cranial length	31	176.0	5.1	30	170.1	6.7	11	171.6	6.2	*	27	175.7	4.9		*17*	*167.9*	*4.7*	***	85	173.1	6.0	*
5 Basion–nasion length	31	99.1	3.8	28	95.9	3.1	10	99.6	3.5		27	99.8	4.8		*17*	*96.0*	*2.9*	**	84	99.4	4.8	
8 Max. cranial breadth	33	139.5	5.7	30	134.6	6.2	11	141.7	5.2		27	140.5	4.9		*16*	*144.5*	*4.8*	***	85	142.8	5.3	***
9 Min. frontal breadth	31	97.7	4.1	29	95.2	4.1	12	94.8	4.9		27	95.1	5.1	*	*17*	*94.1*	*3.1*	***	85	93.0	4.1	***
10 Max. frontal breadth	23	118.8	4.4	18	113.8	5.7	12	118.3	4.2		27	117.6	5.1		10	120.1	4.6		84	117.3	5.2	
12 Max. occipital breadth	24	107.2	5.4	20	104.1	7.4	12	105.2	4.7		27	105.3	5.4		10	107.3	2.2		85	107.0	5.6	
17 Basion–bregma height	30	138.4	4.4	28	133.0	3.8	11	137.3	5.2		27	138.0	4.3		*17*	*132.7*	*3.5*	***	84	136.9	5.6	
29 Frontal chord	31	112.4	4.0	29	108.4	3.7	12	111.7	5.3		26	113.5	5.0		—	—	—		85	111.8	4.9	
30 Parietal chord	31	113.3	5.7	29	108.9	7.4	11	109.5	7.7		27	110.1	4.7	*	—	—	—		85	107.8	6.3	***
31 Occipital chord	30	97.0	5.6	30	96.0	6.1	11	92.5	5.1	*	27	98.2	6.4		—	—	—		85	98.6	5.6	
40 Basion–prosthion length	27	99.4	4.5	20	96.3	3.7	9	99.0	6.2		27	96.2	4.6	*	*17*	*89.2*	*4.7*	***	65	95.2	4.8	***
43 Upper facial breadth	31	110.2	3.4	27	104.6	3.0	12	106.1	4.4	***	27	107.1	3.5	***	10	107.1	1.3	**	85	104.7	4.5	***
45 Bizygomatic breadth	19	136.1	4.6	15	127.3	4.4	10	132.9	3.4		27	136.9	4.8		*17*	*131.1*	*4.2*	***	84	133.1	5.8	
46 Bimaxillary breadth	22	108.4	4.9	18	101.6	4.7	12	101.6	5.8	***	27	103.9	4.1	***	*17*	*97.7*	*3.1*	***	84	99.1	5.7	***
48 Upper facial height	29	67.4	3.9	22	63.3	3.9	10	68.8	2.9		26	69.2	3.3		*17*	*67.8*	*4.4*		60	70.9	4.9	***
51 Orbital breadth	30	41.0	1.5	28	38.8	1.9	12	42.1	1.2	*	27	41.5	1.4		*17*	*42.7*	*1.9*	***	85	41.4	1.9	
52 Orbital height	30	33.0	1.8	27	32.7	2.0	12	33.7	1.7		27	34.7	2.0	***	*17*	*33.5*	*1.7*		85	33.7	1.7	
54 Nasal breadth	28	29.2	2.0	27	27.9	1.5	12	27.8	1.5	*	27	26.9	1.6	***	*17*	*26.3*	*1.7*	***	84	27.3	2.0	***
55 Nasal height	29	49.8	4.4	27	47.6	4.7	12	50.9	2.2		27	51.7	2.6		*17*	*51.3*	*2.4*		85	52.5	3.2	***
60 Upper alveolar length	28	54.9	3.0	19	52.1	3.4	8	53.6	6.0		25	52.4	2.5	***	—	—	—		64	52.7	3.4	**
61 Upper alveolar breadth	27	69.6	3.4	25	65.4	2.8	11	66.0	4.1	**	25	65.7	3.2	***	—	—	—		62	65.5	4.0	***
8:1 Cranial index	31	79.2	3.9	30	79.3	5.2	11	82.7	5.1	*	27	80.0	3.8		*16*	*86.1*	—	***	85	82.6	4.1	***
48:45 Upper facial index	19	49.0	3.3	15	49.0	3.5	9	51.6	2.2	*	26	50.6	2.0	*	*17*	*51.7*	—	***	60	53.1	3.0	***
43(1) Frontal chord	23	103.1	4.2	—	—	—	12	99.0	3.6	**	25	99.1	3.4	***	10	99.0	1.3	**	30	96.9	3.1	***
43c Frontal subtense	23	17.0	3.9	—	—	—	12	16.5	3.0		25	15.6	4.1		10	16.4	2.1		30	15.4	1.8	
57 Simotic chord	23	10.2	1.5	—	—	—	12	8.5	2.0	**	25	9.1	2.3		10	10.2	1.5		30	8.0	1.5	***
57a Simotic subtense	23	2.9	0.9	—	—	—	12	2.6	0.7		24	2.6	0.9		10	4.2	0.6	***	30	2.8	0.9	
46b Zygomaxillary chord	21	107.6	4.9	—	—	—	12	101.7	5.4	***	25	103.5	4.6	**	10	103.8	3.7	*	30	100.6	4.7	***
46c Zygomaxillary subtense	21	21.6	3.6	—	—	—	11	22.2	5.3		25	20.4	3.0		10	24.1	4.0		30	22.0	2.7	
43c:43(1) Frontal index	23	16.5	3.5	—	—	—	12	16.5	2.6		25	15.7	3.9		10	16.6	2.2		30	15.9	1.8	
57a:57 Simotic index	23	29.1	8.8	—	—	—	12	30.8	7.4		24	29.2	9.0		10	41.2	2.7	***	30	35.3	10.1	*
46c:46b Zygomaxillary index	21	20.1	3.7	—	—	—	11	21.8	4.6		25	19.7	2.9		10	23.2	4.0	*	30	21.9	2.4	*

[1] Laos: data italics cited from Cuong (1996); [2] Thai: cranial data cited from Sangvichien (1971), and the facial flatness data from Hanihara (2000).

P is the probability of *t*-test difference from Phum Snay: * significant at 5% level, ** 1% level, *** 0.5% level.

traits for Phum Snay also significantly differed from one another but to a lesser degree.

The neighbor-joining method was applied to the Smith's distance matrix based on the 21 nonmetric trait data of 22 comparative population samples from the area encompassing Southeast Asia to the Pacific region (Figure 8). In this branching pattern, the Phum Snay sample, as well as the Island Southeast Asians such as Dayak and Sunda, occupy a position intermediate between the clump of mainland East/Southeast Asian samples and the aggregation of early Holocene Southeast Asians and Australo-Melanesian samples.

Discussion

In comparing the Phum Snay data set with modern population samples from Cambodia and/or from surrounding countries such as Thailand, Vietnam, and Laos, differences are apparent in both the cranial and dental morphology. The interpretation of this difference is a crucial issue in the discussion of the population history of this region. There are two possible interpretations to explain how the morphological inconsistency arose between the early Metal Age and these modern populations. The first is that the morphological change was the result of modernization or some environmental adaptation through the two millennia in an initially monophyletic group. The modernization in skeletal morphology is represented by reduced robusticity, including reductions of dentofacial size, which is due to the reduction of mastication structures with the softening of foods consumed (e.g. Brace, 1963; Dahlberg, 1963; Wolpoff, 1971). However, the Phum Snay people possess a relatively wider and lower facial skeleton and larger alveoli, though these features are not signs of 'remarkable' robusticity, as compared with modern samples. The skeletal facial characteristics differed in proportion rather than in absolute size, as demonstrated in deviation diagrams. In addition, the differences

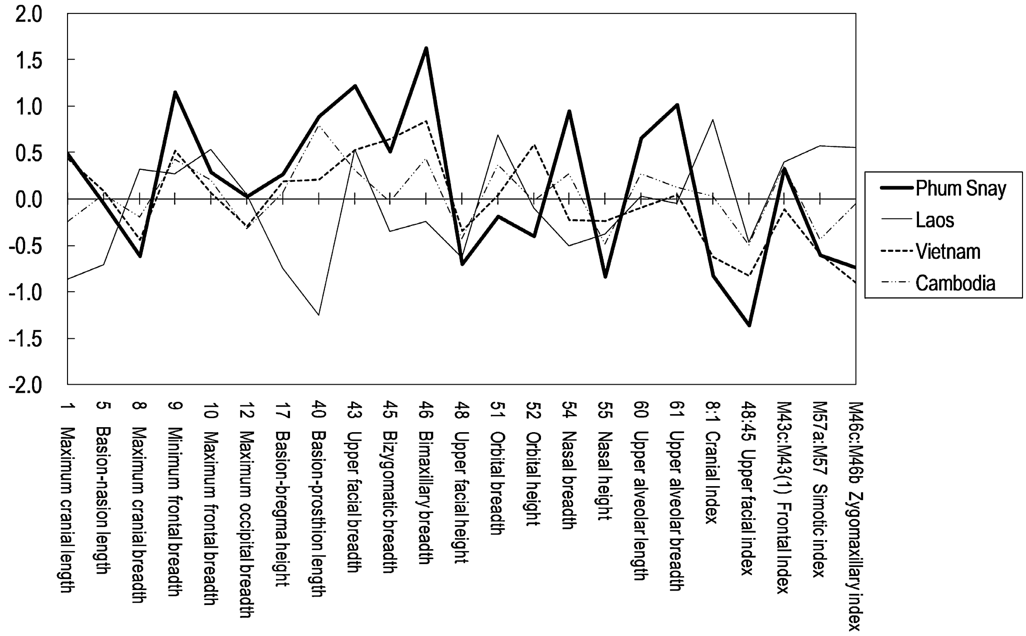

Figure 3. Deviation diagram from modern Thai males based on 18 cranial measurements and indices of Phum Snay and comparative modern Southeast Asian samples.

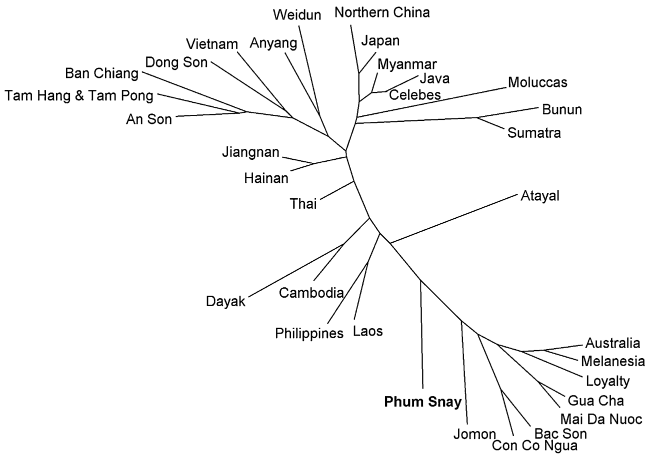

Figure 4. An unrooted tree of the neighbor-joining method applied to the distance matrix of Q-mode correlation coefficients, based on 16 cranial measurements (males).

from surrounding modern population samples were detected in dental datasets consisting of two different phenotypic morphological features represented by metric and nonmetric traits batteries. Although in univariable comparisons of dental measurements only a few numbers of tooth kinds show significant differences between the Phum Snay and surrounding modern samples from Thai and Vietnam, the patterns of standardized means in the deviation diagrams are very different from each other, especially in buccolingual diameters. In comparisons of nonmetric tooth traits among these population samples, the considerable differences were detected in shovel shape incisors, deflecting the wrinkle and seventh cusp of lower first molars. Both the tooth size proportion and nonmetric dental traits are thought to be formed strongly under genetic control and developed in the young childhood, which are more conservative against environmental factors than the bone tissue (e.g. Bowden and Goose, 1969; Mizoguchi, 1977; Townsend and Brown, 1978; Hanihara and Ueda, 1979; Hanihara and Hanihara, 1989). The differences in these dental characteristics are not particularly suggestive of genetic consistency between the Phum Snay and surrounding modern populations. This leads to a hypothesis that there is a possible genetic discrepancy between the people of Phum Snay and later surrounding modern inhabitants.

To address the interpretation from the perspective of genetic lineage, it is useful to summarize long-term arguments on the population history of Southeast Asia. In terms of Hoabinhian/Mesolithic foragers, which were widely expanding over mainland Southeast Asia during the late Pleistocene and early Holocene, the majority of analyses of skeletal materials have demonstrated Australo-Melanesian characteristics in cranial morphology, despite issues associated with using subadult or incomplete material (e.g. Duckworth, 1934; Mijsberg, 1940; Trevor and Brothwell, 1962; Jacob, 1967). These skeletons of the pre-ceramic period may represent some of the early indigenous settlers of Southeast Asia, which are of crucial importance in understanding the population history of Southeast Asia, suggesting the possibility that the first modern human colonizers of mainland Southeast Asia and the Australian subcontinent were ancestral to modern day Australo-Melanesians in the region.

Based upon these findings, despite complex migration processes and the intermixing of populations since prehistoric times (Lertrit et al., 2008), in general terms, Southeast Asia is thought to have been initially occupied by such indigenous people that later exchanged or admixed genes

Table 4. Dental crown measurements of Phum Snay and three comparative modern Southeast Asian samples (males)

	Phum Snay						Vietnam				Laos				Thailand			
	Males			Females			Males				Males				Males			
	n	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*P*	*n*	Mean	SD	*P*	*n*	Mean	SD	*P*
Mesiodistal diameters (mm)																		
UI1	3	8.79	0.68	5	8.25	0.32	19	8.73	0.44		2	8.27	0.07		20	8.31	0.70	
UI2	2	6.80	0.49	3	7.58	0.64	18	7.14	0.50		4	7.02	0.48		29	7.01	0.46	
UC	11	8.08	0.49	7	7.71	0.38	21	8.11	0.43		8	7.67	0.37		38	8.09	0.54	
UP1	17	7.41	0.57	12	7.32	0.31	33	7.58	0.52		15	7.29	0.51		41	7.58	0.61	
UP2	18	7.13	0.55	13	6.85	0.35	33	7.08	0.43		19	6.71	0.38	**	41	7.15	0.91	
UM1	17	10.55	0.42	14	10.25	0.58	50	10.53	0.46		28	10.34	0.41		39	10.44	0.56	
UM2	18	9.69	0.68	13	9.55	0.60	42	9.61	0.51		26	9.03	0.61	***	41	9.69	0.55	
LI1	5	5.49	0.47	6	5.00	0.30	19	5.49	0.32		2	5.29	0.51		25	5.56	0.40	
LI2	10	6.23	0.35	10	5.79	0.34	23	6.07	0.34		1	6.19	0.00		26	6.20	0.42	
LC	25	7.12	0.56	17	6.82	0.36	25	7.14	0.38		9	7.14	0.32		38	7.01	0.49	
LP1	37	7.30	0.50	32	7.14	0.49	26	7.43	0.47		14	6.98	0.39	*	43	7.39	0.52	
LP2	39	7.43	0.55	35	7.14	0.57	24	7.61	0.43		11	7.06	0.36	*	43	7.41	0.50	
LM1	35	11.69	0.68	34	11.52	0.40	31	11.63	0.45		17	11.47	0.54		34	11.59	0.52	
LM2	39	11.04	0.65	38	10.75	0.53	25	10.98	0.84		20	10.42	0.64	***	39	10.98	0.67	
Buccolingual diameters (mm)																		
UI1	3	7.41	0.34	6	7.00	0.39	5	8.06	0.49		2	7.26	0.42		23	7.29	0.36	
UI2	3	6.71	0.32	4	6.32	0.52	4	7.07	0.42		4	6.45	0.28		32	6.64	0.47	
UC	12	8.59	0.59	7	7.70	0.49	13	8.57	0.54		8	7.95	0.17	**	39	8.36	0.53	
UP1	17	9.51	0.63	13	9.45	0.37	33	9.67	0.52		15	9.34	0.51		40	9.63	0.61	
UP2	19	9.55	0.59	13	9.09	0.64	33	9.46	0.51		19	9.20	0.52		39	9.49	0.61	
UM1	20	11.99	0.51	14	11.56	0.60	49	11.68	0.61	*	28	11.62	0.54		42	11.62	0.56	*
UM2	19	11.90	0.65	14	11.35	0.70	41	11.64	0.72		26	11.61	0.74		41	11.71	0.62	
LI1	8	6.20	0.50	9	5.60	0.20	9	5.93	0.51		2	6.22	0.10		24	5.91	0.29	*
LI2	11	6.62	0.36	11	6.03	0.24	12	6.30	0.49		3	5.92	0.27	**	29	6.30	0.43	*
LC	24	7.94	0.58	17	7.31	0.50	12	8.35	0.44	*	9	7.44	0.45	*	41	7.85	0.35	
LP1	35	8.21	0.60	32	7.88	0.47	25	8.25	0.55		14	7.99	0.52		42	8.29	0.50	
LP2	38	8.69	0.52	35	8.36	0.53	24	8.66	0.48		11	8.31	0.49	*	46	8.56	0.52	
LM1	38	11.04	0.64	37	10.71	0.48	33	10.87	0.57		19	10.78	0.57		38	10.84	0.47	
LM2	40	10.60	0.63	39	10.26	0.52	29	10.38	0.63		20	10.01	0.64	***	44	10.51	0.41	

P is the probability of *t*-test difference from Phum Snay: * significant at 5% level, ** 1% level, *** 0.5% level.

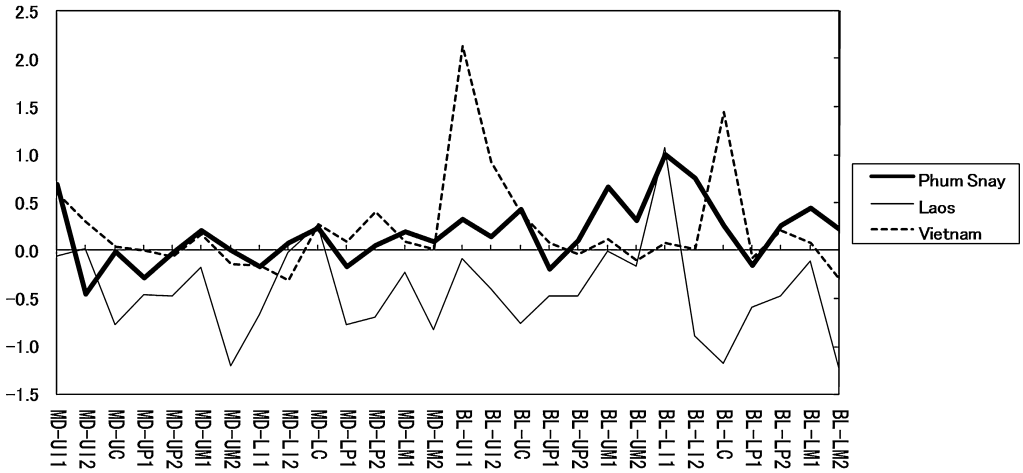

Figure 5. Deviation diagram from modern Thai males based on 28 dental crown diameters of Phum Snay and comparative modern Southeast Asian samples (MD: mesiodistal diameter; BL: buccolingual diameter).

with immigrants from North and/or East Asia, leading to the formation of present-day Southeast Asian populations (Callenfels, 1936; Mijsberg, 1940; Von Koenigswald, 1952; Coon, 1962; Jacob, 1967; Brace et al., 1991). This model is known as the 'immigration' or 'two-layer' model, as a scenario of understanding the peopling Southeast Asia. Among some recent cranial and dental analyses, a few researchers have criticized this model, suggesting that Southeast Asians are the product of long-standing continuity (the regional continuity or local evolution model) uninterrupted

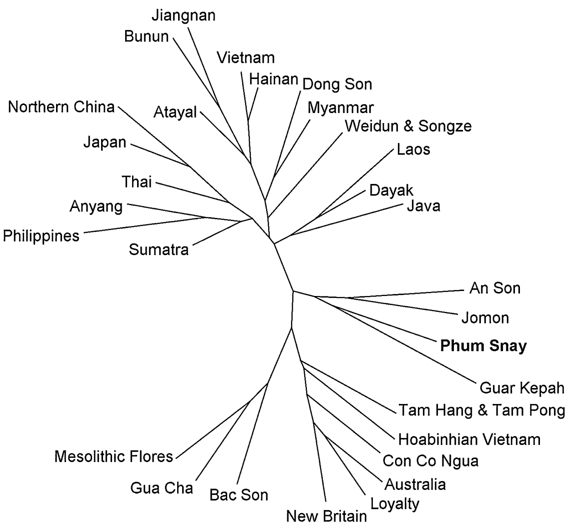

Figure 6. An unrooted tree of the neighbor-joining method applied to the distance matrix of Q-mode correlation coefficients, based on 28 dental crown diameters (males).

by significant admixture with people from north (e.g. Turner, 1990; Hanihara, 1994; Pietrusewsky, 1994).

This hypothesis has recently received some support from genetic research in which Negrito and non-Negrito populations of Southeast and East Asia are historically united via a single primary wave of entry to the region; however, no timeline is provided for this (HUGO Pan-Asian SNP Consortium, 2009). Furthermore, this particular study also suggests that Southeast Asia was a major geographic source of East Asian populations—a model that has to date received little support from prehistorians.

However, some recent studies have validated the 'two-layer' hypothesis based on the analysis of new skeletal findings from several Hoabinhian sites such as Gua Gunung from Malaysia (Matsumura and Zuraina, 1995, 1999), Moh Khiew from Thailand (Matsumura and Pookajorn, 2005), and Mai Da Nuoc, Hang Muoi, and Hang Cho from Vietnam (Cuong, 1986; Bulbeck et al., 2007; Matsumura et al., 2008a). These studies demonstrate considerable cranial and dental features akin to Australian and/or Melanesian samples, suggesting close biological ties, ensuring the reasonableness of the belief that available Hoabinhian material characterizes populations descended from the first anatomically modern human colonizers of Southeast Asia and the Australian subcontinent. Nonetheless, it is important to note that a broad comparisons of dental traits conducted by Matsumura and Hudson (2005) highlighted a close affinity between Hoabinhian and Australo-Melanesian samples on the one hand, but identified a northern source for contemporary Southeast Asians on the other hand. This observation supports an immigration, rather than regional continuity, model for the origins of modern Southeast Asians. Hanihara (2006), who once rejected the two-layer hypothesis, re-examined cranial data from a wide geographical area and found that the two-layer model is partially viable.

Today the immigration hypothesis has gained theoretical support from the fields of historical linguistics and archaeology, which have linked the pre-modern dispersion of the Austronesian, Austroasiatic, Daic (Tai-Kadai), Miao-Yao (Hmong-Mien), and Sino-Tibetan (Tibeto-Burman) language families with the expansion of rice-cultivating people during the Neolithic period and early Iron Age (Renfrew, 1987, 1989, 1992; Bellwood, 1991, 1993, 1997; Bellwood et al., 1992; Blust, 1977, 1996a, b; Glover and Higham, 1996; Higham, 1998, 2001; Bellwood and Renfrew, 2003;

Table 5. Frequencies of 21 nonmetric dental traits in Phum Snay and two comparative modern Southeast Asian samples (sexes combined)

Trait	Tooth	Phum Snay			Vietnam				Thailand			
		O	A	Freq.	O	A	Freq.	*P*	O	A	Freq.	*P*
Shovelling	UI1	17	7	41.2%	41	34	82.9%	***	48	35	72.9%	*
Shovelling	UI2	12	6	50.0%	39	19	48.7%		56	32	57.1%	
Double shovelling	UI1	18	2	11.1%	41	6	14.6%		52	1	1.9%	
Double shovelling	UI2	12	0	0.0%	40	1	2.5%		62	0	0.0%	
Dental tubercle	UI1	19	3	15.8%	38	1	2.6%		54	1	1.9%	*
Dental tubercle	UI2	15	1	6.7%	36	2	5.6%		61	2	3.2%	
Spine	UI1	18	5	27.8%	40	10	25.0%		52	17	32.7%	
Interruption groove	UI2	11	2	18.2%	29	5	17.2%		61	24	39.3%	
Winging (bilateral)	UI1	16	2	12.5%	41	4	9.8%		51	14	27.5%	
De Terra's tubercle	UP1	41	4	9.8%	60	16	26.7%	*	69	14	21.7%	
Double rooted	UP1	54	38	70.4%	50	25	50.0%	*	41	21	51.2%	
Double rooted	UP2	41	8	19.5%	49	3	6.1%		43	4	9.3%	
Carabelli's trait	UM1	58	15	25.9%	92	26	28.3%		79	18	22.8%	
Hypocone reduction	UM2	75	8	10.7%	75	15	20.0%		79	8	10.1%	
Sixth cusp	LM1	65	13	20.0%	63	15	23.8%		63	16	25.4%	
Seventh cusp	LM1	69	11	15.9%	66	2	3.0%	**	72	5	6.9%	
Protostylid	LM1	67	2	3.0%	65	1	1.5%		70	8	11.4%	
Deflecting wrinkle	LM1	45	4	8.9%	53	19	35.8%	***	42	13	31.0%	**
Groove pattern Y	LM1	49	29	59.2%	57	43	75.4%		60	43	71.7%	
Groove pattern X	LM2	73	18	24.7%	65	21	32.3%		79	28	35.4%	
Hypoconulid reduction	LM2	71	31	43.7%	66	25	37.9%		71	34	47.9%	

O: number of observed teeth; A: number of affected teeth; Freq: frequency (%); *P* is the probability of chi-square test difference from Phum Snay: * significant at 5% level, ** 1% level, *** 0.5% level.

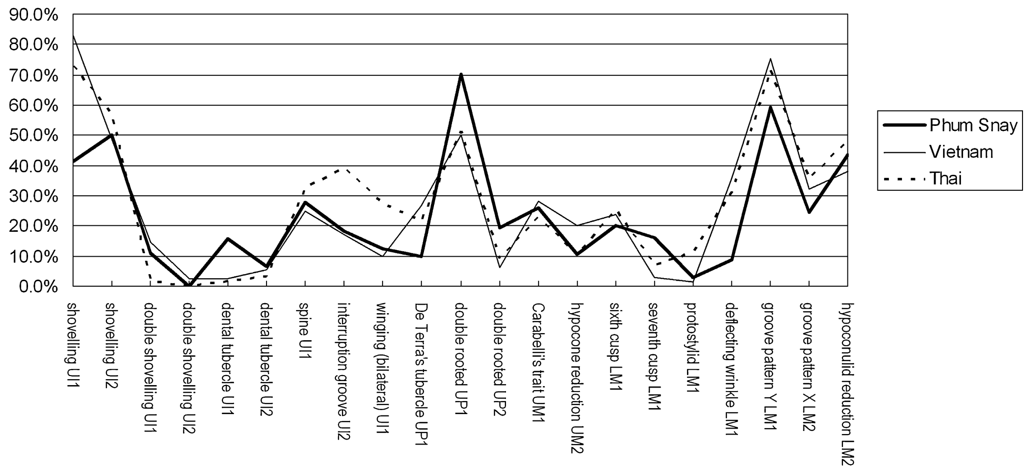

Figure 7. Frequency diagram of 21 nonmetric dental traits in the Phum Snay and comparative modern Indochina Southeast Asian samples (sexes combined).

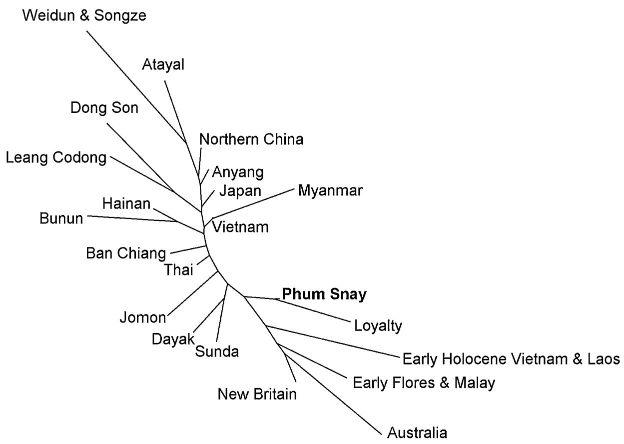

Figure 8. An unrooted tree of the neighbor-joining method applied to the Smith's distance matrix, based on 21 nonmetric dental trait frequencies.

Diamond and Bellwood, 2003). Research in historical linguistics suggest that south China or Taiwan was a major center of linguistic diversification and appears to have been the ultimate source of the language families of Southeast Asia. With the exception of Sino-Tibetan which also spread to the north and west, these language families expanded primarily to the east and south. The archaeological record suggests that the origins of Neolithic farming societies were in the Yangzi basin in the early Holocene, followed by their subsequent expansion into Southeast Asia (Yan, 1991; Crawford and Chen, 1998; Chen, 1999; Bellwood, 2001; Lu, 2006).

Turning to studies of human remains in mainland Southeast Asia, cases of drastic population change or large-scale admixture with North/East Asians are especially evident in northern Vietnam. Some cranial and dental traits exhibited by early indigenous Hoabinhian people were retained even until the early Neolithic period such as the Da But sequences, which display a large morphological gap with early Metal Age Dong Son people (Matsumura et al., 2001, 2008b; Matsumura and Hudson, 2005; Matsumura, 2006). This inconsistency of skeletal morphology was reconfirmed in a current study, in which the Da But cultural people (represented by the Con Co Ngua series) were separated out from the Metal Age Dong Son people (see Figure 4, Figure 6, Figure 8). It has been concluded that the close resemblance of Dong Son people with recent East Asians was due to a large gene flow by new immigrants from areas to the north or east of northern Vietnam during the early Metal Age or just before, in the late Neolithic (Matsumura et al., 2008b).

Given this perspective, in order to process a more comprehensive interpretation of the affinity of the prehistoric population of Phum Snay, the present study undertook multivariable comparisons using the samples from an area encompassing other remote East/Southeast Asian and Pacific regions including chronologically different specimens. The prehistoric people of Phum Snay are characterized by cranial and dental features that are intermediate between many of the present-day East/Southeast Asians and early Holocene samples including the pre-Neolithic Hoabinhian and early Neolithic Southeast Asian settlers. In fact, among the groups intermediately positioned, the people of Phum Snay were aligned more towards the early Hoabinhian and early Neolithic groups than with the modern samples. Taking all cranial and dental affinities that have been depicted into consideration, it seems the best interpretation is that the Phum Snay people were less affected by the substantial gene flow by diffusion of East Asians from northern or eastern peripheral areas, as compared with contemporary Iron Age Dong Son Vietnamese and more modern people in the Indochina region. As discussed in historical linguistic and archaeological studies, the immigrants theoretically dispersed from east or north since the late Neolithic period or at the latest Iron Age (Yan, 1991; Crawford and Chen, 1998; Higham and Lu, 1998; Chen, 1999; Bellwood, 2001). Recent mitochondrial DNA analysis by Lertrit et al. (2008) suggests such an early genetic contribution, perhaps by Austroasiatic-speaking people, even into Bronze–Iron Age groups in what is now northeastern Thailand. The paucity of evidence of gene flow from immigrants to the people of ancient Phum Snay, compared to in the early Metal Age northern Vietnam and northern Thai people, is possibly due to the more southern, and inland, locality of the Phum Snay people in the Indochina Peninsula. Although direct comparison with modern Cambodian people was made here only using cranial metrics, the results imply a 'gradual' gene flow from a northern source after the Prehistoric period at Phum Snay and into the subsequent Angkorian period.

Acknowledgments

The authors are indebted to the late Mr. Hor Lat and Mr. Pheng Sytha, the Royal University of Fine Arts in Phnom Penh, for permission to study Phum Snay specimens at the University. We are pleased to acknowledge the considerable aid of Dr. Christophe Pottier, l'École Française d'Extrême-Orient for our research in Siem Reap.

Thanks are also due to Dr. Bui Phat Diem and Dr. Vuong Thu Hong, the Long An Provincial Museum, Dr. Chris Stringer, Department of Palaeontology, the Natural History Museum, London, Dr. Hoang Tu Hung, Faculty of Odonto-Stomatology, the University of Medicine and Pharmacy at Ho Chi Minh City, Mr. Korakot Boonlop, the Princess Maha Chakri Sirindhorn Anthropology Centre, Bangkok, Dr. Nguyen Kim Thuy and Dr. Nguyen Lan Cuong, the Vietnamese Institute of Archaeology, Hanoi, Dr. Nguyen Viet, the Center for Southeast Asian Prehistory, Hanoi, Dr. Philippe Mennecier, Departement Hommes, Musée de l'Homme, Paris, Dr. Michael Pietrusewsky, Department of Anthropology, University of Hawaii, Dr. Robert Foley, Department of Biological Anthropology, the University of Cambridge, Dr. Gen Suwa, the University Museum of the University of Tokyo, Dr. Tsai Hsi-Kue, National Taiwan University, College of Medicine, Dr. Wang Daw-Hwan, IHP, Academia Sinica, Taipei, and Dr. Wilfred Ronquillio, Archeology Division, National Museum of the Philippines for permission to study the comparative cranial and/or dental specimens.

This research was funded in part by Grant-in-Aid in 2003–2005 (No. 15405018) and 2008–2010 (No. 20370096, No. 20520666) from the Japan Society for the Promotion of Science, by the Toyota Foundation in 2006–2007 (No. D06-R-0035), and by a James Cook University Merit Research Grant in 2003.

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