

Tooth Reduction in the Orient

Received 27 July 1976

C. L. BRACE

INTRODUCTION

THERE is a general but tacit feeling among students of the prehistoric aspects of human evolution that little of interest has happened after the appearance of "modern man" about 35,000 years ago. For the palaeoanthropologist, the interesting research questions tend to be related to such problem areas as the emergence of modern from nonmodern form; identifying the antecedents of *Homo erectus*; and exploring the significance of differentiation among the earliest known hominids. This list is not intended to be complete. Rather its purpose is to demonstrate that palaeoanthropologists tend to be concerned with pre-Upper Palaeolithic problems.

On the other hand, students who focus on the adaptive significance of differences in modern human populations frequently deal with phenomena that simply reflect phenotypic plasticity and not real genetic change (Stini 1969; Frisancho 1975). This presumably is because the forces that have influenced phenotypic appearance in these instances have not impinged upon the human groups under study for enough generations to have resulted in a significant change in gene frequency. Where strong selective forces have been noted and where genuine genetic differences have been observed, it is clear that these have been able to reach their present state in two hundred, one hundred, or even fewer generations (Livingstone 1973; Black 1975). It should follow, then, that substantial differences in the nature of selective forces that have arisen in separate geographical areas during the last several thousand years should coincide with discernible biological differences in the associated populations.

It has been pointed out (Brace 1967*a*, 1967*b*) that major changes in the nature of the selective forces to have influenced prehistoric human populations are indicated by major cultural developments which can be readily identified in the archaeological record. Examples cited include the development of regular and

C. L. Brace is Professor of Anthropology in the Department of Anthropology at the University of Michigan, and Curator of Physical Anthropology in the Museum of Anthropology at the University of Michigan, Ann Arbor.

systematic hunting at the beginning of the Middle Pleistocene and the elaboration of tools and techniques in the Late Mousterian and early Upper Palaeolithic. But it was further noted (Brace and Mahler 1971) that the most profound changes in the nature of human culture adaptations have occurred after the end of the Pleistocene. If these cultural developments effected changes in the nature of the selective forces impinging upon the populations with which they are associated, then it was suggested that we should expect to find clearly recognizable biological responses in just those groups—but not in other modern groups which had not been affected by the cultural adaptations in question. Perhaps, then, some of the differences between modern human populations that have been called “racial” in nature are of relatively recent origin.

As one testable aspect of the larger picture, I chose to focus on changes in the dentition. Teeth have several advantages as objects for study. They are under relatively direct genetic control; they come into direct contact with the environment that determines their adaptive value; they are easy to measure and quantify; and they are the hardest and most readily preserved of all the parts of the skeleton, which means that there is a greater amount of material with which we can work. Along with several other anatomical features, the dentition has clearly undergone a marked reduction during the last 50,000 years. But it is clear that these reductions have not proceeded at the same rate in different populations. Nor are they without pattern.

Even before close examination, intuition suggests that each such morphological reduction follows a diminution in the survival significance of the possession of a full-sized manifestation of the organ in question. In the case of the dentition, there is a marked decrease in molar size that follows the reduction in primary dependency on an uncooked plant-product diet at the beginning of the Middle Pleistocene. Then with the beginnings of the Late Pleistocene technological proliferation in the Mousterian, there was a concomitant and dramatic reduction in front-tooth size. The suggestion was offered that this reduction was a consequence of a usurpation by the development of tools of a role formerly played by the front teeth (Brace 1964*a*, 1964*b*, 1967*a*, 1967*b*). (This interpretation has been questioned by Bailit and Friedlaender [1966] more for theoretical reasons than for the data manifestations cited. The theoretical issue is whether or not mutations can accumulate under conditions of relaxed selection and have a directional effect—reductive according to the original prediction [Brace 1963]. The data cited in their critique involved only the anterior teeth of groups used, and no attempt was made to correct for the possible contribution to their size by covariance with the post-canine dentition. The matter is still far from being resolved.)

It was further suggested that changes in the nature of selective forces affecting the human physique must have accompanied the development of an agricultural mode of subsistence wherever it occurred. Specifically, the prediction was tendered that the regular use of pottery would have greatly reduced the adaptive significance of maintaining a mid-Pleistocene-sized dentition (Brace and Mahler 1971). Pottery enables the users to reduce their food to a mushy or a liquid consistency where the larger size or even the existence of teeth is no longer absolutely necessary for survival.

The prediction was then put forward that those of the world's populations that

have been longest associated with an intensive agricultural way of life should be those in which tooth reduction had proceeded to the greatest extent. The prediction was confirmed by the data available from the Middle East and Europe. And it was also noted that a similar trend was discernible in the available data for the precontact populations of the Western Hemisphere. In the latter case, reduction had not proceeded to the extent visible in the Old World since the time depth for a fully agricultural way of life was considerably less.

When this suggestion was first proposed and tested, there simply was not enough information available to check it in the other major area of the world where the same pattern should also be apparent—namely East Asia. The research on which the present paper is based was undertaken in 1973 and 1974 in order to provide just such a test. While it does appear to confirm the original prediction, the data are hardly sufficient to constitute proof, and, at that, they are only partially analyzed at present. This, then, must be regarded as no better than a preliminary report.

THE DATA

Work in prehistoric archaeology in the Far East has not been pursued with anything like the intensity that has characterized such efforts in the Near East, Europe, and Mesoamerica. Even so, several lines of investigation have suggested that indigenous and *sui generis* cultural developments have occurred there which rival those of any other part of the world in complexity and antiquity. Most of the evidence suggests that China was an ancient and independent center for what has been called the food-producing revolution, although whether this was in North or South China or some combination or compromise is not yet determinable (Chang 1970). Furthermore, there are conflicting views which suggest a Southeast Asian primacy (Gorman 1971; Solheim 1972) or which stress the apparent antiquity of Jōmon pottery in Japan, and, in the present state of our ignorance, no firm conclusions can be sustained.

With this as a background, and in the light of what was repeated in summary form earlier in this paper, it should be possible to use dental data to sharpen our interpretive focus. Tables 1–6 present tooth size measurements from modern and Bronze Age collections from China, Thailand, and Indonesia. The measuring techniques are the standard ones described by Brace and Mahler (1971). Tables 1–2 and 4–5 record the mesial-distal and buccal-lingual mean measurements of the six groups along with the sample size and standard deviation for each tooth measured. Tables 3 and 6 show what has been called the cross-sectional areas for each of the teeth in each of the groups measured. These are calculated in each instance by multiplying the mesial-distal by the buccal-lingual dimensions of each tooth and then summing and calculating the mean in the usual manner.

It has been my pragmatic experience that the cross-sectional area shows less idiosyncratic variation between populations I have suspected to represent major differences in adaptation than do either the mesial-distal or buccal-lingual measurements when individually compared. In passing, it should be noted that the cross-sectional areas in Table 3 and Table 6 represent the areas for each tooth individually calculated and then averaged for the category indicated. The averages thus arrived at differ slightly from those computed by simply multiplying the mean mesial-distal

TABLE 1. MESIO-DISTAL (mm)

	MODERN CHINESE			MODERN THAI			MODERN JAVANESE		
	\bar{M}	S.D.	N	\bar{M}	S.D.	N	\bar{M}	S.D.	N
<i>Mandibular</i>									
I ₁	5.11	.43	29	5.49	.29	46	5.49	.39	29
I ₂	5.79	.40	39	6.13	.41	46	6.17	.40	32
C	6.76	.43	41	6.93	.42	51	7.02	.43	41
P ₁	6.82	.55	41	7.17	.47	51	7.26	.99	44
P ₂	6.84	.66	36	7.22	.44	51	7.17	.50	41
M ₁	10.64	.58	29	11.37	.63	44	11.50	.69	36
M ₂	10.43	.85	27	10.83	.65	48	10.69	.83	38
M ₃	10.16	.81	12	11.05	.89	40	11.02	.90	33
<i>Maxillary</i>									
I ¹	8.31	.41	35	8.50	.50	46	8.58	.54	19
I ²	6.83	.55	37	7.12	.56	50	7.02	.54	24
C	7.57	.48	40	7.84	.48	52	7.92	.51	31
P ¹	7.14	.49	40	7.35	.40	52	7.41	.50	34
P ²	6.64	.48	40	6.75	.35	50	6.99	.41	34
M ¹	10.22	.57	31	10.38	.52	54	10.54	.62	30
M ²	9.49	.62	30	9.65	.62	53	9.74	.66	31
M ³	8.72	.88	13	9.11	.73	43	8.40	1.15	24

NOTE: The modern Chinese were measured at the Queen Mary hospital in Hong Kong on material under the care of F. P. Lisowski of the Department of Anatomy. The modern Thai were measured at the Congdon Anatomical Museum, under the care of Sood Sangvichien. The modern Indonesians, principally Javanese from near Jogjakarta, were measured at the Gadjah Madah University Medical School in Jogjakarta under the care of Teuku Jacob.

TABLE 2. BUCCO-LINGUAL (mm)

	MODERN CHINESE			MODERN THAI			MODERN JAVANESE		
	\bar{M}	S.D.	N	\bar{M}	S.D.	N	\bar{M}	S.D.	N
<i>Mandibular</i>									
I ₁	5.86	.45	29	5.78	.42	46	5.79	.35	29
I ₂	6.23	.40	39	6.29	.42	46	6.21	.44	32
C	7.78	.59	41	7.64	.50	51	7.66	.63	41
P ₁	7.88	.52	41	8.03	.62	51	8.23	.89	44
P ₂	8.22	.57	36	8.38	.59	51	8.41	.43	41
M ₁	10.66	.57	29	10.86	.48	44	10.95	.61	36
M ₂	10.19	.65	27	10.42	.53	48	10.38	.72	38
M ₃	9.82	.50	12	10.30	.49	40	10.45	.87	33
<i>Maxillary</i>									
I ¹	7.21	.39	35	7.25	.42	46	7.26	.47	19
I ²	6.48	.47	37	6.53	.41	50	6.59	.44	24
C	8.25	.61	40	8.24	.57	52	8.30	.56	31
P ¹	9.40	.52	40	9.52	.62	52	9.78	.57	34
P ²	9.22	.60	40	9.38	.57	50	9.60	.53	34
M ¹	11.24	.55	31	11.44	.53	54	11.59	.69	30
M ²	11.22	.81	30	11.34	.66	53	11.54	.86	31
M ³	10.30	1.18	13	11.04	.59	43	10.70	1.55	24

TABLE 3. CROSS-SECTIONAL AREA (sq. mm)

	MODERN CHINESE			MODERN THAI			MODERN JAVANESE		
	\bar{M}	S.D.	N	\bar{M}	S.D.	N	\bar{M}	S.D.	N
<i>Mandibular</i>									
I ₁	29.97	3.82	29	31.82	3.30	29	31.87	3.46	29
I ₂	36.13	4.06	39	38.65	4.26	32	38.40	4.23	32
C	52.68	5.74	41	53.03	5.89	41	53.93	7.16	41
P ₁	53.82	6.05	41	57.76	7.24	44	60.43	16.94	44
P ₂	56.51	8.46	36	60.60	6.86	41	60.44	6.16	41
M ₁	113.60	10.96	29	123.64	10.93	36	126.23	14.01	36
M ₂	106.60	14.10	27	113.01	11.46	38	111.52	15.76	38
M ₃	99.86	10.87	12	114.15	13.53	33	115.84	18.02	33
<i>Maxillary</i>									
I ¹	59.93	5.16	35	61.71	6.05	19	62.39	6.60	19
I ²	44.32	5.42	37	46.59	5.62	24	46.36	5.34	24
C	62.58	7.26	40	64.77	7.47	31	65.89	7.56	31
P ¹	67.27	7.62	40	70.14	7.86	34	72.50	7.47	34
P ²	61.38	7.46	40	63.42	6.07	34	67.20	6.55	34
M ¹	115.52	10.60	31	119.00	10.57	30	122.53	13.54	30
M ²	106.49	11.13	30	109.79	12.31	31	112.84	14.98	31
M ³	90.41	17.23	13	100.84	11.96	24	91.17	22.23	24

TABLE 4. MESIO-DISTAL (mm)

	BRONZE CHINESE			BRONZE THAI			BRONZE JAVANESE		
	\bar{M}	S.D.	N	\bar{M}	S.D.	N	\bar{M}	S.D.	N
<i>Mandibular</i>									
I ₁	5.19	.36	134	5.35	.31	23	5.41	.41	10
I ₂	5.85	.43	170	6.05	.41	33	5.99	.36	11
C	6.86	.39	192	6.95	.49	41	7.14	.44	11
P ₁	6.87	.42	206	7.09	.60	42	7.39	.43	12
P ₂	6.80	.47	206	7.11	.50	45	7.30	.45	10
M ₁	11.05	.50	209	11.42	.55	49	11.67	.64	10
M ₂	10.70	.72	210	10.66	.63	48	11.29	.59	12
M ₃	10.63	.89	150	11.08	.67	43	11.20	.78	9
<i>Maxillary</i>									
I ¹	8.48	.53	222	8.46	.40	34	8.66	.39	9
I ²	6.99	.66	258	6.87	.73	31	6.82	.64	11
C	7.72	.45	302	7.72	.53	38	7.87	.56	10
P ¹	7.09	.41	314	7.24	.50	44	7.56	.43	11
P ²	6.51	.48	319	6.73	.49	48	7.31	.42	12
M ¹	10.11	.53	323	10.45	.56	52	10.72	.51	13
M ²	9.56	.59	308	9.45	.72	44	10.05	.64	13
M ³	8.83	.84	219	9.19	1.22	32	9.19	.88	9

NOTE: The Bronze Age Chinese were from the Shang dynasty tombs at An Yang, and are now housed under the care of H. M. Yang at the Academia Sinica, Taipei. The Bronze Age Thai were measured on the Non Nok Tha material in the Sood Sangvichien Prehistoric Museum and Laboratory in the Siriraj Hospital, Bangkok, under the care of Sood Sangvichien; additional Non Nok Tha material was made available at the Department of Anthropology, University of Nevada-Las Vegas, through the courtesy of Sheilaigh T. Brooks. Bronze Age Indonesians, excavated at Gilimanuk in Bali under the care of Teuku Jacob, were measured at the Gadjah Madah University Medical School in Jogjakarta.

TABLE 5. BUCCO-LINGUAL (mm)

	BRONZE CHINESE			BRONZE THAI			BRONZE JAVANESE		
	\bar{M}	S.D.	N	\bar{M}	S.D.	N	\bar{M}	S.D.	N
<i>Mandibular</i>									
I ₁	5.70	.36	134	5.96	.38	23	6.27	.58	10
I ₂	6.14	.38	170	6.32	.48	33	6.65	.60	11
C	7.80	.47	192	7.70	.56	41	8.05	.70	11
P ₁	7.95	.49	206	8.08	.61	42	8.22	.38	12
P ₂	8.26	.48	206	8.39	.59	45	8.55	.43	10
M ₁	10.89	.50	209	11.02	.52	49	10.90	.46	10
M ₂	10.50	.55	210	10.53	.54	48	10.72	.44	12
M ₃	10.22	.74	150	10.49	.61	43	10.51	.72	9
<i>Maxillary</i>									
I ¹	7.19	.43	222	7.30	.48	34	7.42	.44	9
I ²	6.46	.54	258	6.48	.61	31	6.64	.71	11
C	8.35	.53	302	8.17	.58	38	8.24	.68	10
P ¹	9.46	.51	314	9.39	.61	44	9.76	.52	11
P ²	9.26	.55	319	9.40	.52	48	9.51	.52	12
M ¹	10.38	.52	323	11.54	.51	52	11.73	.52	13
M ²	11.34	.62	308	11.21	.62	44	11.64	.60	13
M ³	10.80	.96	219	10.67	1.34	32	11.33	.52	9

TABLE 6. AREA (sq. mm)

	BRONZE CHINESE			BRONZE THAI			BRONZE JAVANESE		
	\bar{M}	S.D.	N	\bar{M}	S.D.	N	\bar{M}	S.D.	N
<i>Mandibular</i>									
I ₁	29.66	3.34	134	31.95	3.28	23	33.88	3.60	10
I ₂	35.98	4.04	170	38.35	4.84	33	39.82	3.68	11
C	53.58	5.46	192	53.70	6.81	41	57.50	6.77	11
P ₁	54.73	5.61	206	57.40	7.82	42	60.90	6.01	12
P ₂	56.25	6.20	206	59.72	6.95	45	62.54	6.50	10
M ₁	120.46	10.12	209	126.14	10.98	49	127.42	11.71	10
M ₂	112.58	12.43	210	112.60	10.91	48	121.19	10.51	12
M ₃	109.08	15.97	150	116.42	12.10	43	118.19	16.02	9
<i>Maxillary</i>									
I ¹	61.10	6.69	222	61.79	5.87	34	64.31	5.74	9
I ²	45.40	6.91	258	44.87	7.56	31	45.61	8.51	11
C	64.59	6.95	302	63.30	7.96	38	65.04	8.51	10
P ¹	67.19	6.83	314	68.13	7.71	44	74.00	7.72	11
P ²	60.41	7.16	319	63.42	7.24	48	69.62	7.05	12
M ¹	115.14	10.19	323	120.83	10.47	52	125.83	10.17	13
M ²	108.65	11.42	308	106.13	11.98	44	117.11	11.71	13
M ³	96.00	15.95	219	99.24	20.99	32	104.25	12.70	9

by the mean buccal-lingual measurements, although the difference probably is unimportant when comparing the mean figures of different populations. As an example, when the cross-sectional areas for the upper and lower dentitions of modern Chinese were computed and summed, the figure totalled 1154.87 when the averaged MD measurement was multiplied by the averaged BL measurement and accumulated tooth by tooth, while it totalled 1157.07 when the area was calculated for each tooth prior to summing and averaging.

Just as it has been my experience that combining mesial-distal and buccal-lingual dimensions gives more interpretable results than leaving them separate, so I have found in the present study that summing figures over the dental arches, both upper and lower, yields more consistent results than comparing populations tooth by tooth or one dental arch at a time. As can be seen in Tables 1-6, none of the mean differences is of great magnitude. Few differences would prove to be statistically significant, and, while the direction of difference is reasonably consistent with the theory proposed, even this would require a considerable degree of statistical ingenuity to demonstrate. When one simply adds up the averaged cross-sectional areas for each tooth category in both the upper and lower dentitions and uses a single average total for each population, the result is simply and almost seductively interpretable. Admittedly this blurs the adaptive difference between the front and the rear portions of the dentition, but the gain in interpretive simplicity is surely worth the risk of temporary possible misrepresentation.

The scheme displayed in Table 7, then, represents just such a possibly oversimplified attempt to come to grips with the dental adaptations demonstrated in a number of modern and prehistoric human populations. The three rough vertical blocks represent three crudely conceived geographical collages, the first being loosely European, the second Australasian, and the third aboriginal American. Horizontally the material is ordered in terms of average summed tooth areas decreasing in size from the top to the bottom. The intervals between horizontal groupings do not accurately represent the proportional size differences. Rank, then, is more important than height within a column in interpreting Table 7.

DISCUSSION

Sharing the bottom rung are modern South Chinese and Europeans, displaying, in terms of the data available, the greatest manifestation of dental reduction among the living peoples of the world. This suggests that late- and post-Pleistocene factors leading to dental reduction have been in operation for a longer time in South China and Europe than anywhere else in the world. Unfortunately, both area designations are crude to the point of being misleading, since they are blanket terms for large regions within which we might expect to find significant graded differences.

For example, the antiquity of the dependence on agriculture is clearly greater in the Middle East than it is in Northwest Europe, and if my proposed model has any merit, there should be a cline of tooth size running from a predicted European maximum in Scandinavia and the northern British Isles to a minimum in Asia Minor. Unfortunately, the data are inadequate to make a proper check, but incomplete evidence from Sweden (Lysell 1958) and the Aran Islands off the west coast of Ireland (Dockrell 1956) suggests that the teeth are larger than the averages

TABLE 7. AVERAGE SUMMED TOOTH AREAS

EUROPEAN		AUSTRALASIAN		ABORIGINAL AMERICAN	
Neanderthal	1518	Austral. S. Qnsld.	1530		
		Austral. Murray R.	1497		
		S. Aust. Swanport	1464		
		Tasmania	1444		
Wadi Halfa	1407	New Guin. E. High.	1395		
Skhül	1350	Bougainville	1359		
Early U.P. Eur.	1347				Dickson Mound 1315
Late U.P. Eur.	1267			Bronze Age Bali	1287
					Pecos 1254
Mesolith. Eur.	1237	Javanese	1240	Thai	1224
		Thai	1229	China	1191
		Japanese	1184		Aztec 1187
Euro-Amer.	1174				
European	1161	S. Chinese	1157		
12th-16th C. Europe	1083				

NOTE: Mean cross-sectional areas (MD × BL) were calculated for each category of tooth. For populations measured by the author, both right and left teeth were measured and a single average figure was calculated for each tooth category. The contribution of that individual to the population mean for any tooth category was considered to be a single instance even though it may have been a figure derived from two teeth. Obviously both the right and left antimeres are representatives of a single genotype. The average of both should be a better representative of that genotype than either would be alone. Where information was derived from the published literature, the cross-sectional area for a given tooth was taken to be the product of the mean mesial-distal and the mean buccal-lingual figures for that tooth. The summary tooth size figures in Table 7 were produced by adding up the mean cross-sectional areas of both maxillary and mandibular teeth to produce a single sum of the averages representing each population. Since it is difficult to impossible to assign many prehistoric specimens to one sex or the other, no attempt was made to separate by sex. The Neanderthal, Dickson Mound, and Aztec figures were calculated from Brace and Mahler 1971; Wadi Halfa from Greene et al. 1967; Skhül from McCown and Keith 1937; Early Upper Palaeolithic (Aurignacian, Szeletian, and Lower Perigordian), Late Upper Palaeolithic (Magdalenian, Gavettian, and Solutrean), and Mesolithic (including what has been called Epi-Palaeolithic in Italy) from Frayer 1976. I am grateful to David Frayer for making the data available for me even before the completion of his dissertation. The Euro-American figure was calculated from Black 1902; European from Miyabara 1916; 12th-16th century European from Twisselmann and Brabant 1960; New Guinea eastern highlands from Doran and Freedman 1974; Bougainville from Bailit et al. 1968; Japanese from Yamada 1932; and Pecos from Nelson 1938. The South Queensland measurements were made at the University of Queensland and the Queensland Museum, Brisbane, with the cooperation of W. B. Wood, Peter Lauer, and Michael Quinell; the Murray Valley measurements were made at the Australian Museum, the Macleay and Shellshear Museum in Sydney, the Murray Black Collections at the Australian Institute of Anatomy in Canberra and the University of Melbourne, the National Museum of Victoria, and the South Australian Museum in Adelaide; the Swanport material, measured in the South Australian Museum, is from a burial ground on the lower Murray River not far upstream from Adelaide, South Australia, and probably represents a single local group; the Tasmanian measurements were made in the Australian Institute of Anatomy, Canberra, the Tasmanian Museum, Hobart, the Queen Victoria Museum, Launceston, and the South Australian Museum, Adelaide. As is noted in the Acknowledgments, I am deeply indebted to many people for access to the materials in their charge. From further measurements not reported here there is an impressive gradation from southeastern Australia north and across the Torres Strait without break into the Fly River portion of the Gulf of Papua on the south coast of New Guinea. I suspect that this cline can also be explained by a parallel change in the antiquity of a nonpottery form of elaborated food-preparing, but demonstrating this will require the completion of analysis that is currently in progress.

reported in the sources cited in Table 7, while the incomplete evidence reported on Cochin and Yemenite Jews (Rosenzweig and Silberman 1967) suggests that their teeth are distinctly smaller.

In China, data are simply unavailable to make any even tentative assessments. It is a matter of general observation that northern Chinese are larger and more robust than southern Chinese, but we have no data on tooth size for North China, and hence cannot determine whether there is regional variation within China that might correlate with regional differences in the antiquity of the dependence upon elaborate methods of food preparation. The data do show a maximum degree of dental reduction in South China. This would suggest relatively great antiquity for intensive reliance upon agriculture and its associated food preparation techniques in the south, but in the absence of evidence from the north, we simply are not in a position to comment on the rival claims for antiquity between those who favor a northern and those who favor a southern focus for the antiquity of the development of a food-producing way of life. This is particularly unfortunate since our only Bronze Age material is from North China—specifically, from the Shang Dynasty tombs at An Yang in northern Honan Province.

We are forced, then, to use an areally nonspecific designation—China—and represent Bronze Age tooth size by the An Yang material and modern tooth size by a sample from Hong Kong. In China so considered, there has been measurable tooth size reduction in the last 4000 years. Using the data we do possess rather than bemoaning what we lack, the present study suggests that the greatest degree of dental reduction in the Orient, and hence the greatest antiquity of reliance upon an intensive agricultural lifeway, is to be found in China. And at present, it would seem that this process has been in operation longest and has gone farthest in South China.

Assuming that China, roughly considered—and South China probably—is the source of the development of intensive agriculture as a way of life in the Orient, then the South Chinese teeth reported in Tables 1–3 and 7 represent a maximum predicted response. Tooth measurements for other modern Asian populations, then, correspond nicely to the further predictions of the model. Intensive agriculture in Japan evidently developed under the influence of the mainland, but it has been a major factor of Japanese life for a shorter span of time (Treistman 1968), and, as is evident in Table 7, dental reduction has not proceeded quite to the same extent as in China. It is interesting to note that the Japanese teeth are just about the same size as those of the inhabitants of the Valley of Mexico at the point of contact almost 500 years ago, suggesting that in both instances the relaxation of the forces of selection had been in operation for about the same length of time.

Moving to the south, other oriental groups are predictably larger roughly proportional to their distance. Thus the Thai figure is larger than the Chinese, and the Javanese is larger than the Thai, but such expectations are conditioned by inferences we must make concerning the population history of Southwest Asia and Indonesia. If food-producing and food-preparing techniques entered the area strictly by diffusion, then the farther from China one goes the lesser would be the time depth and the lesser also the biological response. At the end of the line would be precontact Australia, where food producing techniques were never received or

developed and where, as can be seen from Table 7, an unabashedly unreduced dentition continued to survive.

But disembodied cultural diffusion to willing recipient populations simply does not square with what we know or can infer about Southeast Asian history. According to traditional views, north to south movement has indeed taken place in the form of colonization, migration, and out-and-out invasion. If the recipient areas had been entirely unoccupied previously, then the immigrant populations and their modern descendants would simply represent transplanted Chinese. This, too, is not the case, although several lines of evidence suggest that a large genetic component of the peoples of Southeast Asia and Indonesia is of northern origin (by which I mean southern Chinese). (If skin color is considered to be an adaptive trait, it is hard to interpret its oriental distribution in any other way [Brace 1964*b*]. This is also true for serological factors, even when their adaptive significance is not considered [Schanfield and Gershowitz 1973].)

It is true that the thrust of the present paper differs from that which has sought to push the primacy of Southeast Asia (Gorman 1969, 1970, 1971; Solheim 1970, 1972), but, on the other hand, it does not provide any positive support for the view that the principal source for the development of civilization (and its consequent impact) in Asia came mainly from northern China (Ho 1969, 1976). On the basis of the data actually at hand, I would concur with those who advocate caution in extending interpretations beyond what we can actually substantiate at present (Flannery 1973).

Although this can be no more than a guess, it is legitimate to suggest that the aboriginal pre-agricultural population of tropical Southeast Asia was heavily pigmented and large of tooth (Brace, in press *a*). The basis for such a suggestion is the appearance of the inhabitants of those parts of New Guinea where influence from the north and west has been minimal, and also, the appearance of the relict nonagricultural groups such as the Aeta of the Philippines, the Semang of the Malay Peninsula, and the Andaman Islanders. Tooth-size data are not available for the later groups, but the figures from Goroka and Lufa in the eastern highlands of New Guinea (combined in Table 7) are right in the middle of the Australian aboriginal range of variation (Brace, in press *b*).

An intensive agricultural mode of subsistence is capable of creating and sustaining much higher population densities than a hunting and gathering way of life. So even if the first agricultural immigrants were few and coexisted with the indigenes in the kind of regional mosaic similar to the situation recently discussed by Hutterer (1976), their expansion to represent a dominating element was simply a matter of time. A predictable consequence would be the eventual complete absorption of the original hunter-gatherers, which would serve to modify the Chinese appearance of the agricultural population. The modification should be visible in the form of greater pigmentation, as is indeed the case as one proceeds away from China toward Indonesia. As can be seen in Tables 1-3 and 7, this is paralleled by a proportional increase in tooth size.

The one discrepancy between this inferred history and the data in Tables 1-7 is the size of the teeth of the Bronze Age population from Non Nok Tha in Thailand. Modern Chinese are smaller than Bronze Age Chinese as expected (but subject to the ifs, ands, and buts previously discussed), and modern Indonesians (Javanese)

are smaller than Bronze Age Indonesians (Balinese). But modern Thai are slightly larger than Bronze Age Thai, although the difference is too small to be regarded as "significant." Still, the modern figure is not smaller than the Bronze Age one as it is elsewhere and as theory would lead us to expect. If, however, the Non Nok Tha population from northeast Thailand (Bayard n.d.) actually represented an immigrant group prior to their expansion and complete absorption of the aboriginal hunting and gathering people, the discrepancy would be explained.

Also evident in Table 7 are the parallels in the other major portions of the world influenced by separate and independent food producing/preparing traditions. The three populations listed as Aboriginal American are roughly contemporary, dating between A.D. 1000 and European contact early in the 16th century. The Aztec figure was derived from a population at San Juan Teotihuacan near Mexico City; the Pecos figure comes from a Pueblo Indian population in the state of New Mexico; and the Dickson Mound figure was from a precontact group of Indians from the state of Illinois. The Aztec figure represents the maximum degree of reduction recorded for any American Indian group, and it is evident that reduction is proportionately less the farther one goes from the locus of early high civilization in the Western Hemisphere. (I have collected some measurements which indicate that north of the utilization of agriculture in North America the teeth were substantially larger than those at Dickson Mound. Unfortunately the wear, especially at the front end of the dental arch, is so extensive that the measurements are not really comparable to those used in this paper.)

Turning to the Europeans recorded in Table 7, it should be noted that a substantial time depth is represented in contrast to the other two main blocs, Australasia and Aboriginal America. With one exception, time depth and size covary, with the oldest groups possessing the largest teeth. The one exception is the Wadi Halfa population. Although it is a Mesolithic group dating from 6000 to 9000 B.C., the teeth are larger than those of the "Neanderthaloids" from Mount Carmel of perhaps 35,000 B.C. Properly speaking the group should not be considered "European" at all since it comes from Nubia near the Egyptian border and lies outside the boundaries of the old Mousterian/Upper Palaeolithic culture area. Archaeological evidence from the latter suggests that the mode of life from western Europe through the Middle East had more elements in common at any one time during the Late Pleistocene than did the Middle East with Nubia. If this extended to food-processing techniques, as one suspects it did, then the selective pressures on the dentition of the ancestors of the Wadi Halfa population may have differed in important ways from those on the dentitions of the Upper Palaeolithic and Neanderthal ancestors of the European Mesolithic peoples.

This brings up a weakness in the technique of using summary tooth size figures as I have done in Table 7. It does not allow one to distinguish rates of change in different parts of the dental arch although, in general, even making such distinctions there is no real change in the ordering of Table 7. For example, when individual tooth-size measurements are assessed, it is apparent that the reason the summary figure for Wadi Halfa is larger even than that of the Skhūl group is that the molar teeth are larger even than those of the "classic" Neanderthals at the top of the column. And the reason that the summary figure for South Queensland Australian aborigines is even bigger than that for the Neanderthals is that their molars are

markedly larger yet than those from Wadi Halfa. Conversely, the classic Neanderthals maintain such a high position in Table 7 because the size of the anterior dentition greatly exceeds that of any more recent population.

If Wadi Halfa is removed from the first column, then the Late Pleistocene and post-Pleistocene course of the reduction of European teeth proceeds in a regular fashion as one approaches the present. I have argued that the development of a manipulative technology may have accounted for the relaxation of selective pressures on the forward end of the dental arch, but it is apparent that the back end of the dental arch had also undergone a marked reduction that started well before the end of the Pleistocene. Between the early and the late Upper Palaeolithic, European teeth had reduced from the "Neanderthaloid" dimensions of Skhül to the size of the teeth of modern Javanese. If my argument is consistent, some sort of food preparation technique must have been in use that reduced the previously mandatory amount of heavy-duty chewing. This is indeed a possibility. Movius (1966) has suggested, on the basis of the quantity, appearance, and distribution of heat-fractured river pebbles, that stone boiling was in use in the Perigordian at Abri Pataud in southern France. And from the quantity of heat-fractured rocks and basinlike "hearths" in the Aurignacian at Abri Pataud (and even at the Mousterian site of Combe Grenal, as I was able to observe myself), it is just possible that some kind of earth oven technique was being regularly used by populations in the northern reaches of the area of human habitation late in the Pleistocene.

Certainly the earth oven, as recently manifest in New Guinea and Oceania, is capable of reducing many foods to a soft consistency. If the evidence supports the use of earth ovens and/or stone boiling in the Upper Palaeolithic (and possibly in the preceding Mousterian), then the relaxation of the selective forces previously maintaining large molar size may have begun well before the end of the Pleistocene in the areas which were characterized by those cultures. This certainly would be consistent with the information shown particularly in the first column of Table 7.

Furthermore, if such food preparation techniques spread along with the Upper Palaeolithic as it moved eastward across Russia in the Late Pleistocene, then this relaxation of tooth-maintaining selective forces would also have been true for the inhabitants of the northerly portions of the Far East before the end of the Pleistocene and before the initial move across the Bering Straits into the New World. If, as the evidence suggests (Klein 1971), the arrival of this cultural manifestation in the northern parts of the Far East was substantially later than its initial development in the western parts of the Old World, then the first inhabitants of the New World should exhibit somewhat less dental reduction than their European contemporaries. Perhaps this is why the Dickson Mound group displays teeth that are somewhat larger than those of the Late Upper Palaeolithic in Europe.

These constitute a great many "ifs" and it will take years of devoted effort to turn them into positive or negative conclusions. One of the great lacks apparent in Table 7 is the absence of measurable dental material from the Late Pleistocene of eastern Asia. From the few scraps of teeth available (Chang 1968*a*), it would appear that dental reduction there, as in the western part of the Old World, had begun before the Pleistocene came to an end. (Late Pleistocene skeletal material from the Far East that has been tentatively equated in date and cultural development with the Late Pleistocene in Europe includes the three skulls from the Upper Cave at

Choukoutien. Of these only the male had a complete dentition when it was found, but the measurements were not included in the descriptive report [Weidenreich 1938-1939]. A reasonably good cast is available, however, and this yields a summary tooth-size figure of 1221. Realizing that my assessment is based upon measurements of a plaster cast, that the front teeth [especially the lowers] were heavily worn and hence appreciably smaller than they had been at the time of eruption, and that any use of this specimen constitutes relying upon a sample of one, it is still interesting to observe that the teeth were about the same size as those of the Mesolithic in Europe. It is possible that reduction of tooth size in the Late Pleistocene of the Far East had already proceeded to a considerable degree, and it is of interest to note that a recent archaeological assessment refers to the Upper Cave material as being Mesolithic [Chang 1968*b*: 67-68]. A still more recent assessment referring it again to the Late Pleistocene would simply emphasize the interpretation suggested here [Aigner 1972].) Subsequently, as the data here suggest, reduction was accelerated, as in other parts of the world, especially in just that area where agricultural civilization first came into prominence.

SUMMARY AND CONCLUSIONS

The suggestion has been offered that the teeth of modern human populations should exhibit a degree of reduction from their Pleistocene ancestral size proportional to the length of time the population in question has been associated with an agricultural subsistence economy. According to this view, it is not so much the practice of agriculture or the change in the nature of the diet that altered the action of selective forces as it was the development of cooking techniques that reduced the significance of maintaining the dentition at its earlier size level. This kind of culinary development is symbolized by but not restricted to the appearance of pottery in large quantities. Pottery allows food to be cooked to a consistency where chewing is not mandatory for survival. Under such conditions of relaxed selection, then, the prediction has been made that average tooth size would decrease as a consequence of the Probable Mutation Effect.

In previous studies, it was shown that dental reduction has proceeded to its greatest extent in just those areas where such conditions have been in existence for the longest period of time. The Middle East, with Europe following, shows the greatest degree of reduction, while dentitions in the Valley of Mexico show a similar but less marked trend, reflecting the fact that the food production and preparation complex was later in developing. At the time this earlier work was done, there were not sufficient data to run a check on the remaining portion of the world where the antiquity of the food-producing revolution was perhaps as great as the Middle East, namely the Far East.

The present study, then, was pursued in order to make just such a check. From the data collected, it is evident that dental reduction in Asia has proceeded to its greatest extent in South China, where tooth size is almost exactly the same as that now evident among Europeans. (I also received the subjective impression while I was doing the measuring that reduction in the presence of third molars attained a level of around 50 percent, as is reflected in the reduced number for M3's evident in Tables 1-3. But whether this was true agenesis or simply failure to erupt is a

question that can be answered only by checking the specimens with X-ray photographs.) Other populations show a lesser degree of reduction which varies in proportion to the cultural geographical distance from China. Japanese teeth, for example, are slightly larger than Chinese teeth. And the rest of the sequence goes in order of increasing size: Thai, Javanese, Melanesian, New Guinean and Australian, with the last, being uninfluenced by the post-Pleistocene developments north and west, showing absolutely no reduction at all.

Evidence for *in situ* dental reduction is also provided by two of the three late prehistoric populations available. In both China and Indonesia, modern teeth are smaller on the average than Bronze Age teeth, although in both instances it should be noted that the modern and Bronze Age populations do not come from the same parts of the country, so that the implications for reduction are tentative at best.

In the third instance where Bronze Age and modern teeth can be compared, that is, Thailand, the modern teeth are slightly larger. The Bronze Age Thai, however, are the next step up from the Bronze Age Chinese and may represent an immigration from the north. The modern Thai, then, might be the product of the hybridization of northern immigrants with a larger-toothed indigenous pre-agricultural population. Such an explanation, as has been noted, is at variance with the views recently being advocated by Solheim and his students (Solheim 1970, 1972). Although the interpretation toward which I lean resembles the more traditional view to some extent, it should be clearly recognized that my assumption of the existence of a larger-toothed indigenous hunting and gathering population remains unsupported hypothesis.

On the whole, sample sizes are not sufficient and the average differences between the adjacent steps of the model presented are too small to meet ordinary tests of statistical significance. The trends are clear, however, and it is evidence that dental reduction has proceeded to its greatest extent in just those parts of the Far East where high civilization has existed for the longest period of time. In this regard, the Orient presents a striking parallel to the course of development evident in Mesoamerica and the Near East. If the reader is not satisfied that this represents a further example of change that is the result of mutations accumulating under conditions of relaxed selection, then I offer the challenge to devise a better explanation.

ACKNOWLEDGMENTS

The research on which this paper is based was accomplished in spite of repeated refusals of support by the National Science Foundation. Partial funding was provided by the Horace H. Rackham School for Graduate studies at the University of Michigan in Ann Arbor; by the Department of Anthropology at the University of Auckland in New Zealand; and by Professor and Mrs. Gerald W. Brace. For access to crucial materials, I am indebted to Michael Quinnell and Roger Hardley of the Anthropology Division at the Queensland Museum; to Dr. Peter Lauer and Graham French at the University of Queensland Museum of Anthropology in Brisbane; to Dr. W. B. Wood, Department of Anatomy, University of Queensland; to Mr. Stanley Larnach and emeritus Professor N. W. G. Macintosh of the Department of Anatomy and the Shellshear Museum, University of Sydney; to Dr. Peter Stanbury at the Macleay Museum, University of Sydney; to Dr. David R. Moore and Dr.

James Specht, the Australian Museum, Sydney; to Robert Stone, the Australian Institute of Anatomy in Canberra; to Alan West and Alyson Schmidt of the National Museum of Victoria in Melbourne; to Professor L. J. Ray, Department of Anatomy, University of Melbourne; to Dr. Ronald L. Vanderwal at the Tasmanian Museum; to Drs. Alan G. Wallace and Gregory A. Doran of the Department of Anatomy, University of Tasmania, Hobart; to Frank Ellis, Director of the Queen Victoria Museum Launceston; to Drs. Murray Barrett and Tasman Brown, Department of Oral Biology, University of Adelaide Dental School; to Mance Lofgren, Western Australian Museum, Perth; to Professor Teuku Jacob, Gadjah Madah University Medical School, Jogjakarta; to Professor Sood Sangvichien, Siriraj Hospital Medical School, Bangkok; to Professor F. P. Lisowski, Department of Anatomy, Queen Mary Hospital, Hong Kong; to Professor C. C. Yu, Department of Anatomy, and Dr. W. C. Sung, Department of Anthropology, National Taiwan University; to Dr. H. M. Yang, Institute of History and Philology, Academia Sinica, Taipei; Drs. D. E. Yen and Y. Sinoto at the B. P. Bishop Museum in Honolulu; and to Professor Sheila T. Brooks of the Department of Anthropology, University of Nevada-Las Vegas. For help in recording and measuring, I am grateful to T. M. Brown and Roy Maeda. Finally, for help with a recalcitrant computer, I am especially indebted to Robert J. Hinton.

REFERENCES

- AIGNER, JEAN S.
1972 Relative dating of North Chinese faunal and cultural complexes. *Arctic Anthropology* 9(2): 36-79.
- BAILIT, H. L., S. J. DE WITT, and R. A. LEIGH
1968 The size and morphology of the Nasioi dentition. *Amer. Journ. Physical Anthro.* 28(3): 271-288.
- BAILIT, H. L., and J. S. FRIEDLAENDER
1966 Tooth size reduction: a hominid trend. *AA* 68(3): 665-672.
- BAYARD, D. T.
n.d. *Non Nok Tha: The 1968 Excavation: Procedure, Stratigraphy, and Summary of the Evidence*. Otago University Monographs in Prehistoric Anthropology, vol. 4. Dunedin, New Zealand. 77 pp. (Published 1971.)
- BLACK, F. L.
1975 Infectious diseases in primitive societies. *S* 187: 515-518.
- BLACK, G. V.
1902 *Descriptive Anatomy of the Teeth*. 5th ed. Philadelphia: S. S. White Dental Manufacturing Co.
- BRACE, C. L.
1963 Structural reduction in Evolution. *American Naturalist* 97: 39-49.
1964a The fate of the "classic" Neanderthals: a consideration of hominid catastrophism. *CA* 5: 3-43.
1964b A nonracial approach towards the understanding of human diversity. In *The Concept of Race*, ed. by A. Montagu, pp. 103-152. New York: The Free Press of Glencoe.
1967a Environment, tooth form, and size in the Pleistocene. *Journal of Dental Research* 46 (supplement): 809-816.
1967b *The Stages of Human Evolution: Human and Cultural Origins*. Englewood Cliffs, N.J.: Prentice-Hall. 116 pp.
in press a. Tooth size and Austronesian origins. In *Proceedings of the Second Eastern Conference on Austronesian Languages*, ed. by P. B. Naylor, Ann Arbor, Michigan, 4-5 May, 1976.
in press b. Tooth size clines in Australia. In *Festschrift honoring Professor J. B. Birdsall on his retirement*, ed. by Larry Mai.

- BRACE, C. L., and P. E. MAHLER
 1971 Post-Pleistocene changes in the human dentition. *Amer. Journ. Physical Anthro.* 34: 191-204.
- CHANG, KWANG-CHIH
 1968a Archaeology of ancient China. *S* 162: 519-526.
 1968b *The Archaeology of Ancient China*. Rev. ed. New Haven: Yale University Press. 483 pp.
 1970 The beginnings of agriculture in the Far East. *A* 44: 175-185.
- DOCKRELL, R. B.
 1956 Tooth size in Irish (Aran Island) families. *Report Europ. Orthodont. Soc.* 32: 200-216.
- DORAN, G. A., and L. FREEDMAN
 1974 Metrical features of the dentition and arches of populations from Goroka and Lufa, Papua, New Guinea. *Human Biology* 46: 583-593.
- FLANNERY, KENT V.
 1973 The Origins of Agriculture. *Annual Review of Anthropology* 2: 271-310.
- FRAYER, DAVID W.
 1976 *Evolutionary Dental Changes in Upper Paleolithic and Mesolithic Human Populations*. Ph.D. dissertation, Department of Anthropology, University of Michigan, Ann Arbor. 529 pp.
- FRISANCHO, A. R.
 1975 Functional adaptation to high altitude hypoxia. *S* 187: 313-319.
- GORMAN, C. F.
 1969 Hoabinhian: a pebble-tool complex with early plant associations in southeast Asia. *S* 163: 671-673.
 1970 Excavations at Spirit Cave, North Thailand. *AP* 13: 79-107.
 1971 The Hoabinhian and after: Subsistence patterns in Southeast Asia during the late Pleistocene and after. *World Archaeology* 2: 300-320.
- GREENE, D. L., G. H. EWING, and G. J. ARMELAGOS
 1967 Dentition of a mesolithic population from Wadi Halfa, Sudan. *Amer. Journ. Physical Anthro.* 27: 41-56.
- HO, PING-TI
 1969 The loess and the origin of Chinese agriculture. *American Historical Review* 75(1): 1-36.
 1976 *The Cradle of the East: An Inquiry into the Indigenous Origins of Techniques and Ideas of Neolithic and Early Historic China, 5000-1000 B.C.* Chicago: University of Chicago Press. 440 pp.
- HUTTERER, KARL L.
 1976 An evolutionary approach to the Southeast Asian cultural sequence. *CA* 17(2): 221-242.
- KLEIN, R. G.
 1971 The Pleistocene prehistory of Siberia. *Quaternary Research* 1: 133-161.
- LIVINGSTONE, F. B.
 1973 *Contributions in Human Biology 1. Data on the Abnormal Hemoglobins and Glucose-6-Phosphate Dehydrogenase Deficiency in Human Populations*. Technical Report No. 3, University of Michigan Museum of Anthropology, Ann Arbor. 289 pp.
- LYSELL, L.
 1958 A biometric study of occlusion and dental arches in a series of Medieval skulls from N. Sweden. *Acta Odontologica Scandinavica* 16: 177-203.
- MCCOWN, T. D., and A. KEITH
 1939 *The Stone Age of Mount Carmel*. Vol. II. *The Fossil Human Remains from the Levallois-Mousterian*. Oxford: Clarendon Press. 390 pp.
- MIYABARA, T.
 1916 An anthropological study of the masticatory system in the Japanese: the teeth. *Dental Cosmos* 58(7): 739-749.
- MOVIUS, H. S.
 1966 The hearths of the upper Périgordian and Aurignacian horizons at the Abri Pataud, Les Eyzies (Dordogne), and their possible significance. In *Recent studies in paleoanthropology*, ed. by J. D. Clark and F. C. Howell. *AA* 68, Part 2: 296-325.

NELSON, C. T.

1938 The teeth of the Indians of Pecos Pueblo. *Amer. Journ. Physical Anthro.* 23: 261-293.

ROSENZWEIG, K. A., and Y. ZILBERMAN

1967 Dental morphology of Jews from Yemen and Cochín. *Amer. Journ. Physical Anthro.* 26: 15-22.

SCHANFIELD, M. S., and H. GERSHOWITZ

1973 Nonrandom distribution of Gm haplotypes in East Asia. *American Journal of Human Genetics* 25(5): 567-574.

SOLHEIM, WILHELM G. II

1970 Northern Thailand, Southeast Asia, and world prehistory. *AP* 13: 145-162.

1972 An earlier agricultural revolution. *SA* 22 (April): 34-41.

STINI, W. A.

1969 Nutritional stress and growth: sex differences in adaptive response. *Amer. Journ. Physical Anthro.* 31: 417-426.

TREISTMAN, J. M.

1968 China at 1000 B.C.: a cultural mosaic. *S* 160: 853-856.

TWIESSSELMANN, F., and H. BRABANT

1960 Recherches sur les dents et les maxillaires d'une population d'âge Franc de Coxyde. *Bulletin du Groupement International pour la Recherche Scientifique en Stomatologie* 3: 99-171, 355-400.

WEIDENREICH, F.

1938- On the earliest representatives of modern mankind recovered on the soil of East Asia,

1939 *Peking Natural History Bulletin* 13: 161-174.

YAMADA, E.

1932 The anthropological study of the Japanese teeth. *Journ. Nippon Dental Assoc.* 25: 15-46, 101-132, 177-208, 255-286, 329-344, 450-481, 528-560, 609-656, 710-744, 774-812.