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Dental Paleopathology and Agricultural Intensification in South Asia: New Evidence From Bronze Age Harappa

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ABSTRACT Patterns of dental disease among Bronze Age people of the Indus Valley Civilization are currently based on early and incomplete reports by non-specialists. This deficiency precludes accurate diachronic analysis of dental disease and its relationship with increasing agriculturalism in the Indian subcontinent. The objective of this paper is to document prevalence of dental disease at Harappa (2500–2000 B.C.), Punjab Province, Pakistan, comparatively evaluate the Harappan dental pathology profile, and use these data to assess theories regarding the dental health consequences of increasingly intensive agricultural dependence.

Pathological conditions of the dentition included in the study are abscesses, ante-mortem tooth loss (AMTL), calculus, caries, hypoplasia, hypercementosis, pulp chamber exposure, and alveolar resorption. The Harappan dentition exhibits a dental pathology profile typical of a population whose subsistence base is agriculture. Dental caries at Harappa are present in 6.8% (n = 751) of the teeth and 43.6% (n = 39) of the more completely preserved dental specimens. The use of a caries correction factor is recommended to permit an estimate of caries induced AMTL in calculating the caries prevalence. All dental lesions are present at higher rates in this Harappan study sample than were reported in previous investigations, and important differences in prevalence of dental disease occur between the genders. Prevalence of dental disease increases in the greater Indus Valley as subsistence becomes more intensive and as food preparation and storage technology becomes more efficient.

While abundant human skeletal remains have been discovered among Bronze Age sites of the Indus Valley Civilization, the dental anthropology of these ancient populations of the Indian subcontinent has never been fully reported. This situation precludes diachronic analysis of dental disease and an assessment of its relationship with increasing agriculturalism in South Asia. The objectives of this paper are to document prevalence of dental disease among prehistoric inhabitants of Harappa, to compare the Harappan dental pathology profile with other prehistoric skeletal series within and outside the Indian subcontinent, and to use these comparisons to test theories predicting the dental health consequences of increasingly intensive agriculturalism.

The findings reported here are crucial in several ways to understanding how subsistence and dietary change are related to changing patterns of dental disease. Though similar data have been presented for numerous prehistoric skeletal series from the Americas (Hodges, 1987; Larsen, 1984; Powell, 1988), Europe (y'Edynak and Fleicsh, 1983; Frayer, 1987, 1989; Molnar and Molnar, 1985), Asia (Turner, 1979), and Africa (Armelagos, 1969; Greene, 1972; Machiarelli, 1989), these data yield conflicting results, are heavily biased toward specific regions of the world and do not include a comprehensive analysis of dental pathology

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among prehistoric populations of the Indian subcontinent (Cohen and Armelagos, 1984). The data presented here for Harappa will permit the first diachronic assessment of the consequences of agricultural intensification for dental health in South Asia.

Recent studies of the relationship between subsistence activities and diet, and the prevalence of dental afflictions by age, sex, and social status among contemporary African hunter-gatherers and their horticultural neighbors (Walker and Hewlett, 1990), have direct and important implications for the interpretation of dental lesions among prehistoric human populations. As each region of the world has its own distinctive biological, geological, and chemical attributes, each human population is characterized by unique cultural patterns and genetic composition (Hildebolt et al., 1988, 1989). Taken together, these multiple variables and their interactions are directly responsible for interpopulation differences in dental health that accompany increasingly intensive agriculture. The significance of these new South Asian dental pathology data is that they will assist in identifying biological responses to increased agriculture that are shared by Harappans and other populations. A comparative perspective will also permit detection of any unique or distinctive trends in dental disease that may accompany agricultural intensification in South Asia.

While human skeletal remains were recovered from the Indus Valley site of Mohenjo-daro in the 1920s and 1930s (Fig. 1), both skeletal and dental remains were inadequately studied (Guha and Basu, 1938; Sewell and Guha, 1931). Previous excavations of the cemetery at Harappa also yielded human skeletons, including some from wooden coffins (Mughal, 1968; Vats, 1940; Wheeler, 1947), but rarely were these valuable remains subjected to exhaustive anthropological study (Bose, 1963). Human skeletons excavated at Harappa prior to partition are still curated at the Anthropological Survey of India, Calcutta, where they were analyzed by the Survey's officers. Publication of the Survey's *Memoir* on the human remains from Harappa (Gupta et al., 1962) witnessed lengthy delays and gave little attention to paleopathology in general and paleodontology in particular. This situation is quite unfortunate since extensive dental remains were recovered from the initial excavations at Harappa (Lukacs, 1982, 1984). Dutta's (1972) adoption of a population concept in the analysis of Harappan cranial morphology was subsequently applied to odontometric characteristics of Harappan molar teeth (Dutta, 1983a,b). Pal's (1981) survey of dental disease in ancient India includes tabulations based upon previously excavated skeletal remains from Harappa. General comments on the dental condition of the Harappan skeletons recovered from Kalibangan are provided by Sharma (1969–1970), and from earlier excavations at Harappa and Mohenjo-daro by Kennedy (1980; Lovell and Kennedy, 1989). Valuable descriptive details and statistical analysis of Harappan dental health conditions and dental morphology were routinely omitted from most of these earlier investigations.

It is perhaps surprising that our understanding of prehistoric dental variability in the Indian subcontinent is more complete for pre-Harappan (Neolithic and Chalcolithic Mehrgarh, Baluchistan: Lukacs 1983a, 1985a, 1988; Lukacs and Hemphill, 1991b; Lukacs and Minderman, 1991) and post-Harappan (Inamgaon, western India: Lukacs, 1983b, 1985b; Sarai Khola and Timargarha, Pakistan: Lukacs 1983c) populations than it is for the Harappans themselves. This incomplete picture of Harappan dental health was part of the rationale behind the inception of the University of California Expedition's excavations at Harappa. This analysis of Harappan dental pathology, and its role in comparatively testing theories relating changes in subsistence and diet to dental health, will fill a crucial gap in the spatial and temporal database for dental paleopathology.

MATERIALS AND METHODS

The prehistoric mound of Harappa is located on the southern floodplain of the Ravi River on the southwest margin of the modern town of Harappa, in Punjab Province, Pakistan (Fig. 2). An old meander of the Ravi River passes just north of the main mound of Harappa, though today the active channel of this river is situated 5 km to the north.

Dental remains were excavated during the winter 1987 and 1988 field seasons from an area previously referred to as Cemetery R-37, located south of the citadel (AB mound). Cemetery excavations were under the direction of Jonathan Mark Kenoyer (University of Wisconsin—Madison). Burial position is usually extended, supine, with

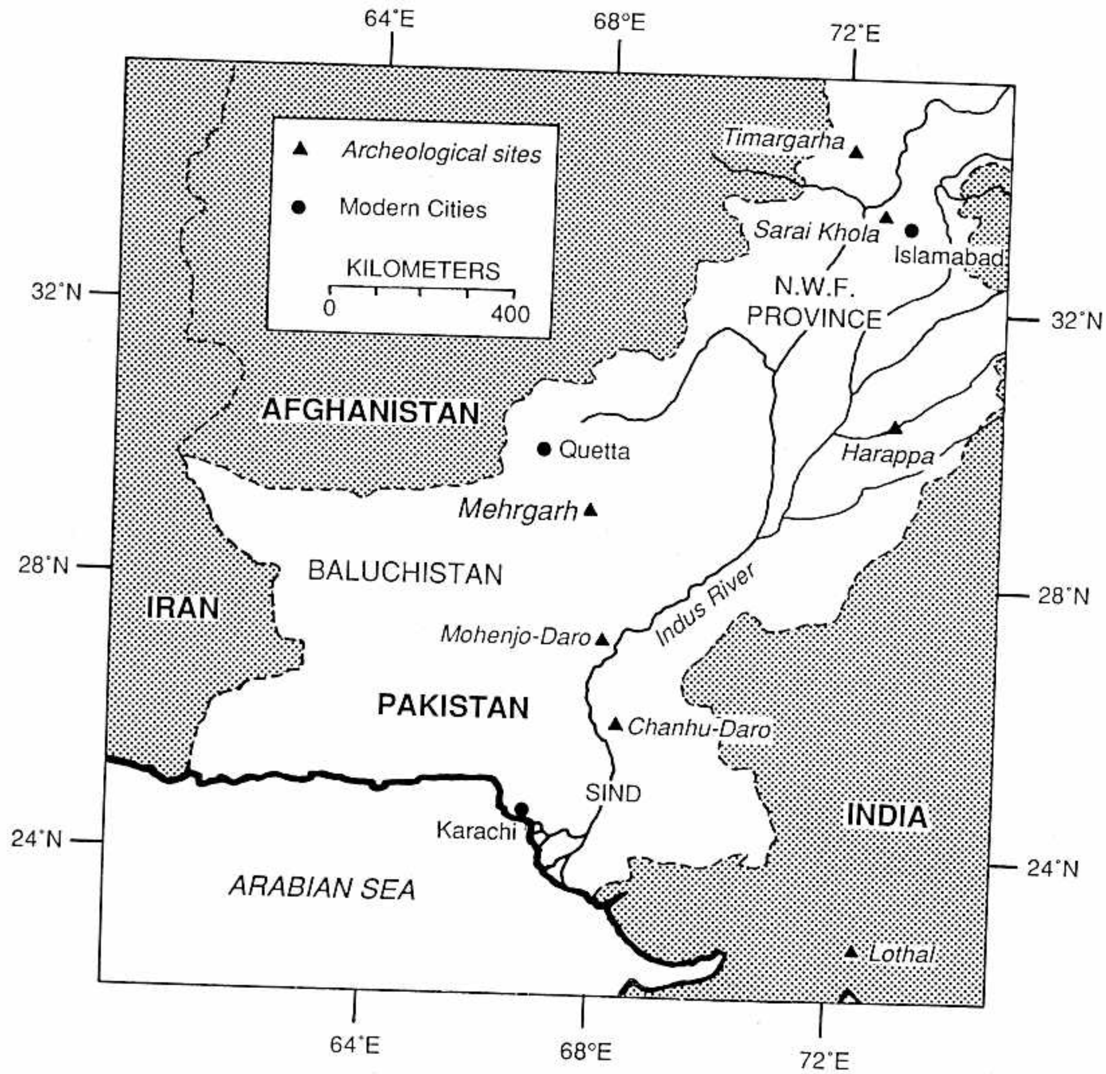

Fig. 1. Location map for Harappa site.

arms alongside the body, and the body was often placed in a wooden coffin, the outlines of which are discernable. Funerary goods include personal jewelry (beads of steatite, semi-precious stones, and gold) and pottery vessels placed around the head or below the body (Dales and Kenoyer, 1991). Analysis of the human skeletal remains was subdivided according to the expertise of four physical anthropologists involved in the project. Dr. K.A.R. Kennedy (Cornell University) documented morphological and metrical features of the cranial and post-cranial skeleton, Dr. Nancy Lovell (University of Alberta) observed pathological conditions of the skeleton, and Dr. Brian E. Hemphill (University of Oregon) recorded discrete variations in both cranial and post-cranial bones. Analysis of the dental remains, including pathology, odontometrics, and morphology, was completed by Lukacs. A preliminary report of the Harappa excavation campaign, including initial results of the physical anthropology staff, is now in press (Dales and Kenoyer, 1991).

The dental sample on which this study is

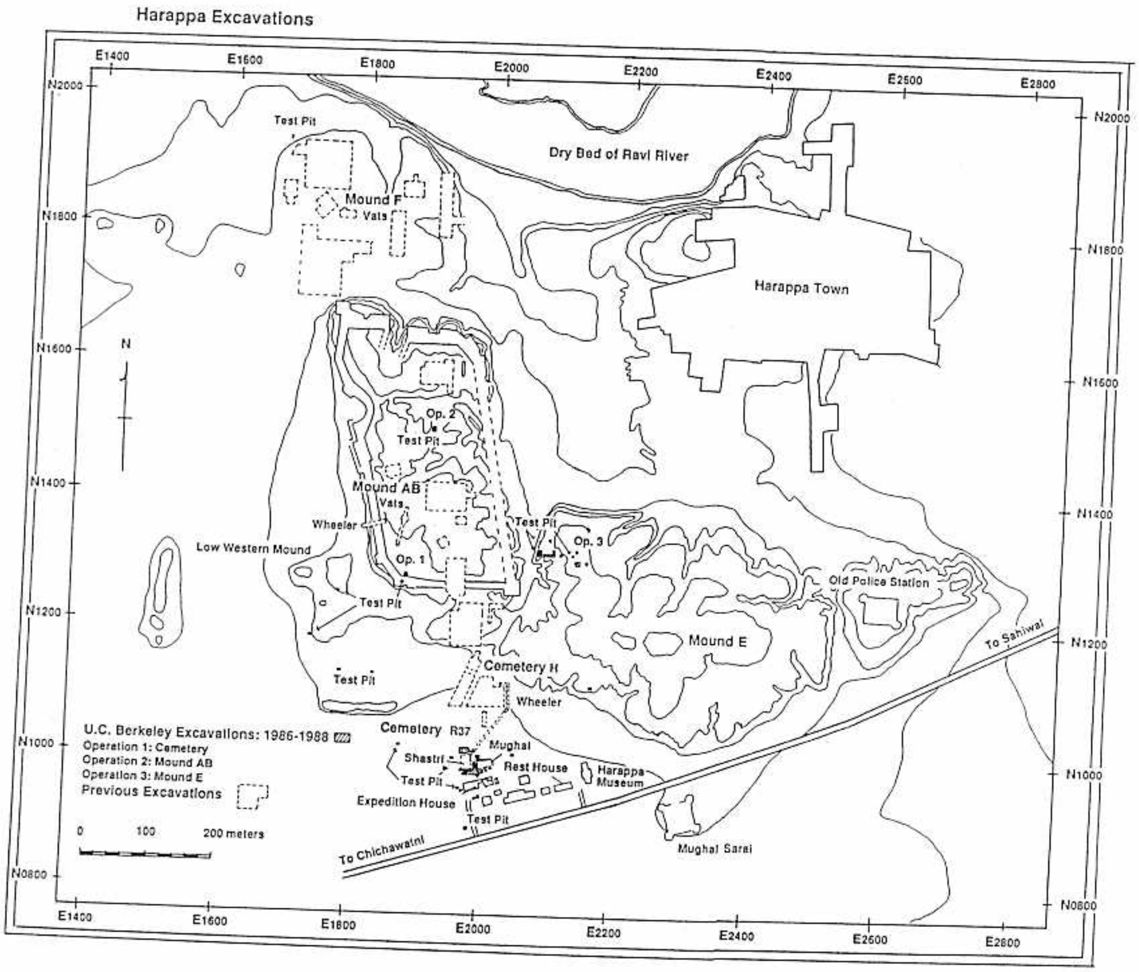

Fig. 2. Harappa site map with Cemetery R-37.

based was recovered from two different burial contexts—primary and secondary. Primary contexts include undisturbed burials which contain a complete skeleton in its original burial position. Sixteen primary burials provided dental evidence for inclusion in this investigation. In this report dental remains from primary burial contexts are referred to as the primary dental sample. Secondary burials consist of incomplete skeletal remains that have been displaced from their original context by erosion or by later intrusive burials. Dental remains derived from secondary burial contexts that retained teeth in jaw fragments or associations of teeth from one individual are referred to as secondary. Loose teeth from secondary contexts not found in association with other skeletal parts are referred to as isolated dental remains.

Table 1 presents a summary of the Harappan dental sample by burial context (top half) and by sex (bottom half). Dental remains from primary burials comprise 48.1% of the dental sample, secondary dental remains constitute 36.9% of the sample, and isolated dental elements make up only 15.0%. Across all burial contexts maxillary teeth (47% of the sample) are slightly underrepresented in comparison with mandibular dental remains (53%). When the dental sample is broken down by sex, males (37.4%) and females (38.3%) are equally well represented, but nearly one-quarter (24.2%) of the sample comes from skeletal elements of unknown sex.

TABLE 1. Harappa dental sample—tooth count[1]

By burial context

	Primary			Secondary			Isolated			Total		
	Mx	Md	T	Mx	Md	T	Mx	Md	T	Mx	Md	T
I1	25	24	49	12	11	23	12	6	18	49	41	90
I2	21	24	45	11	13	24	10	6	16	42	43	85
C	23	28	51	13	13	26	9	4	13	45	45	90
P3	23	26	49	18	19	37	8	5	13	49	50	99
P4	27	25	52	16	20	36	4	10	14	47	55	102
M1	20	20	40	23	28	51	5	9	14	48	57	105
M2	22	21	43	18	30	48	6	12	18	46	63	109
M3	13	19	32	11	21	32	3	4	7	27	44	71
Sum	174	187	361	122	155	277	57	56	113	353	398	751

By sex

	Male			Female			Unknown			Total		
	Mx	Md	T	Mx	Md	T	Mx	Md	T	Mx	Md	T
I1	17	16	33	16	16	32	16	9	25	49	41	90
I2	14	16	30	17	18	35	11	9	20	42	43	85
C	16	17	33	18	21	39	11	7	18	45	45	90
P3	16	18	34	18	25	43	15	7	22	49	50	99
P4	18	20	38	19	23	42	10	12	22	47	55	102
M1	18	22	40	16	19	35	14	16	30	48	57	105
M2	17	23	40	15	22	37	14	18	32	46	63	109
M3	13	20	33	6	19	25	8	5	13	27	44	71
Sum	129	152	281	125	163	288	99	83	182	353	398	751

[1]Mx, maxilla; Md, mandible.

Pathological conditions observed in each specimen include abscesses, ante-mortem tooth loss (AMTL), calculus, caries, hypoplasia, hypercementosis, pulp exposure, and alveolar resorption. Standardized methods for quantifying the degree of expression of each condition are thoroughly documented elsewhere (Lukacs, 1989; Lukacs et al., 1989). This analysis of the dental pathology profile at Harappa employs two primary reporting methods: prevalence of dental disease on the basis of the number of individuals affected by each disorder (individual count method), and prevalence and distribution of specific dental lesions by tooth type and class (tooth count method). Advantages and limitations are associated with each method of reporting prevalence of dental lesions. The individual count method is justifiable on the basis that individuals are the primary unit upon which natural selection acts. However, when a prehistoric sample is subdivided by age and sex the number of individuals often becomes quite small, precluding reliable statistical analysis. When the effects of dental disease on specific tooth classes or jaws is a concern, the tooth count method is more appropriate, and enlarges sample size. In addition, by reporting the results of this study in both ways comparability with other dental paleopathology studies is greatly enhanced.

RESULTS

Individual count

The prevalence of dental diseases at Harappa is presented by sex and for the total skeletal series in Table 2 and Figure 3 (individual count). The sample on which these frequencies are calculated includes all primary context burials (n = 16) and most of the more complete secondary context burials (n = 26). Of the dental disorders documented in this study gross linear enamel hypoplasia was the most frequent, affecting 72.2% of 36 individuals for whom observations were possible. The least frequent condition in the series was hypercementosis (4.9%). Dental afflictions of low prevalence in the total sample include abscesses (18.4%) and exposure of the pulp chamber (17.1%). Antemortem tooth loss (31.7%), calculus (42.5%), dental caries (43.6%), and alveolar resorption (52.6%) exhibit intermediate frequencies at Harappa.

Prevalence of dental disease by sex is also presented in Table 2. Sex differences in dental health at Harappa were investigated using the chi-square test of independence

TABLE 2. Prevalence of dental diseases at Harappa

	Male			x^2	Female			Unknown			Total		
	Pres	n	%	*P*	Pres	n	%	Pres	n	%	Pres	n	%
Abscesses	3	17	17.7	0.67	4	17	23.5	0	4	0.0	7	38	18.4
AMTL	3	17	17.7	0.06	9	19	47.4	1	5	20.0	13	41	31.7
Calculus	8	17	47.1	0.73	7	17	41.2	2	6	33.3	17	40	42.5
Caries	6	17	35.3	0.12	10	16	62.5	1	6	16.7	17	39	43.6
Hypoplasia	9	16	56.3	0.02	13	14	92.9	4	6	66.7	26	36	72.2
Hypercement	1	17	5.9	0.93	1	19	5.3	0	5	0.0	2	41	4.9
Pulp exposure	2	16	12.5	0.31	5	19	26.3	0	6	0.0	7	41	17.1
Resorption	9	16	56.3	0.72	9	18	50.0	2	4	50.0	20	38	52.6

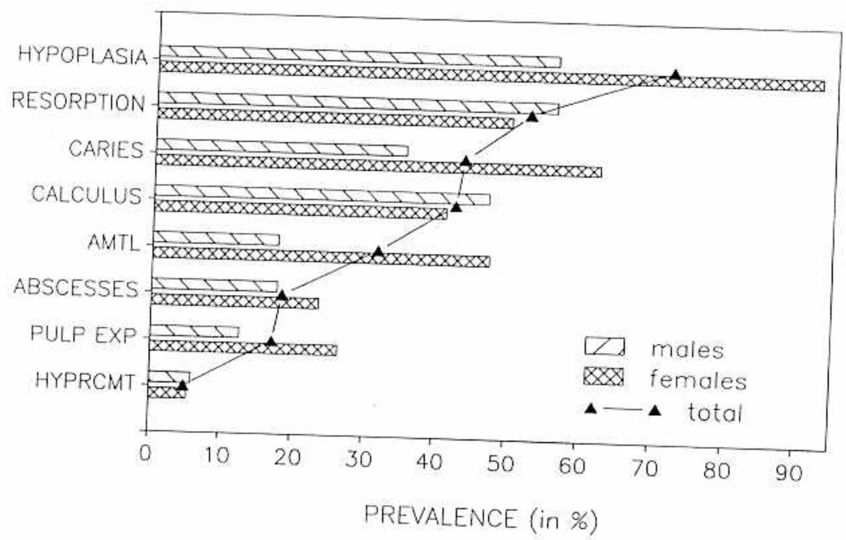

Fig. 3. Prevalence of dental lesions by individual count.

($\alpha = 0.05$). Enamel hypoplasia was the only dental disorder for which a statistically significant difference exists between the sexes. The greater prevalence of AMTL, caries, and pulp exposure among females, while not statistically significant ($P \geqslant 0.05$), may have been of biological significance for the Harappans.

Tooth count

The analysis of dental afflictions by the tooth count method permits evaluation of a lesion's distribution by jaw, tooth class, or size and location on the tooth crown. This more detailed evaluation of dental lesions at Harappa is employed in the analysis of abscesses, ante-mortem tooth loss, caries, gross enamel hypoplasia, and exposure of the pulp chamber. Results of the tooth count assessment of dental afflictions at Harappa are presented in Table 3. Periapical dental abscesses were most prevalent in premolar teeth and least prevalent in molars. One individual (H87/137/148a) was afflicted by an exceptionally high incidence of dental abscesses, six in the maxilla and five in the mandible; this specimen accounts for nearly 50% (47.8%; 11/23) of the abscesses observed in this skeletal series (Fig. 4).

The Harappan skeletal series provided unambiguous evidence for ante-mortem loss of 70 teeth. The prevalence of ante-mortem tooth loss (AMTL) is best calculated as the number of teeth determined to have been lost in life (70), divided by the total number of teeth present in the skeletal series prior to any tooth loss (teeth observed (751) plus the number lost ante-mortem (70) = 821). This calculation yields an 8.53% prevalence of AMTL at Harappa (70/821; Table 3). The

TABLE 3. *Prevalence of dental lesions at Harappa by tooth count*

	Abscesses		Ante-mortem tooth loss		Caries		Pulp exposure	
	n	%	n	%	n	%	n	%
Tooth class								
I	4	2.29	9	4.89	4	2.29	6	3.43
C	4	4.44	1	1.10	6	6.67	6	6.67
P	13	6.47	14	6.51	11	5.47	17	8.46
M	2	0.70	46	13.90	30	10.53	8	2.81
Total	23	3.06	70	8.53	51	6.79	37	4.93
Sex								
M	5	21.7*	13	20.3*	18	38.3	28	75.7*
F	18	78.3	51	79.7	29	61.7	9	24.3
Jaw								
Mx	14	60.9	24	34.3*	32	62.7	28	75.7*
Md	9	39.1	46	65.7	19	37.3	9	24.3

*$P \leq 0.05$.

molar tooth class exhibits the highest rate of AMTL, while the least affected tooth class is the canine. Fewer teeth were lost during life from the maxilla than from the mandible, and from the dental arcade of males than from females. These differences in the prevalence of AMTL by jaw and by gender are statistically significant (see Table 3).

Table 4 provides a tabulation of dental caries prevalence by sex, jaw, and tooth. The overall caries prevalence at Harappa is 6.8% (51/751), but notable differences exist in caries rate between the upper (9.1%) and the lower (4.8%) jaw, and between the anterior teeth (incisor and canine; 3.8%) and posterior teeth (premolar and molar; 8.4%). These percentages are based on the total number of teeth in each category. It is important to note that if teeth lost prior to death (AMTL) were ultimately lost because of carious decay, then the true caries rate at Harappa would be higher than the 6.8% prevalence rate reported here (see caries correction factor below). The teeth of males and females exhibit similar caries rates throughout the dentition, with one conspicuous exception. The high frequency of caries in the maxillary anterior teeth (incisors and canines) of females is an anomalous deviation from the norm, in which caries are typically uncommon in, or absent from, anterior teeth. This caries pattern suggests important sex based differences in dietary or occupational usage of anterior teeth among Harappan females.

If the sample of carious teeth is the focus of analysis, more affected teeth are derived from females (61.7%; 29/47) than from males (38.3%; 18/47), and from maxillae (62.7%; 32/51) than from mandibulae (37.3%; 19/51), though neither of these proportions differs significantly from a 50:50 distribution. In addition to recording mere presence/absence of caries, the size of the lesion and its position on the tooth were recorded. Caries size was classified into four categories: 1) small pit or fissure caries, 2) less than 1/2 the tooth crown destroyed, 3) greater than 1/2 the tooth crown destroyed, and 4) the entire tooth crown obliterated by caries (Metress and Conway, 1975). The data on caries size is presented in Table 5, and indicates that maxillary caries were more severe than mandibular caries. In the maxilla, 56.3% (18/32) of caries lesions were graded size 3 or 4, while only 21.1% (4/19) of mandibular caries fall in these categories. Conversely, 78.9% (15/19) of mandibular caries were small, destroying less than half of the tooth crown (size grades 1 and 2), but in the maxilla only 43.7% of carious lesions fell in size grades 1 and 2. A χ^2 test of independence revealed no association between jaw and caries size ($P = 0.21$).

Caries location was assessed by noting which surface of the tooth crown was primarily affected. In this analysis the categories utilized included mesial, distal, buccal, lingual, occlusal and unknown. In instances where the carious lesion destroyed the bulk of the dental crown mass, the initial location of the lesion remains indeterminate and is recorded as unknown. Results of the caries location analysis are presented in the lower half of Table 5. The lingual category is omitted from this table because in no instance was a caries lesion found on this surface of

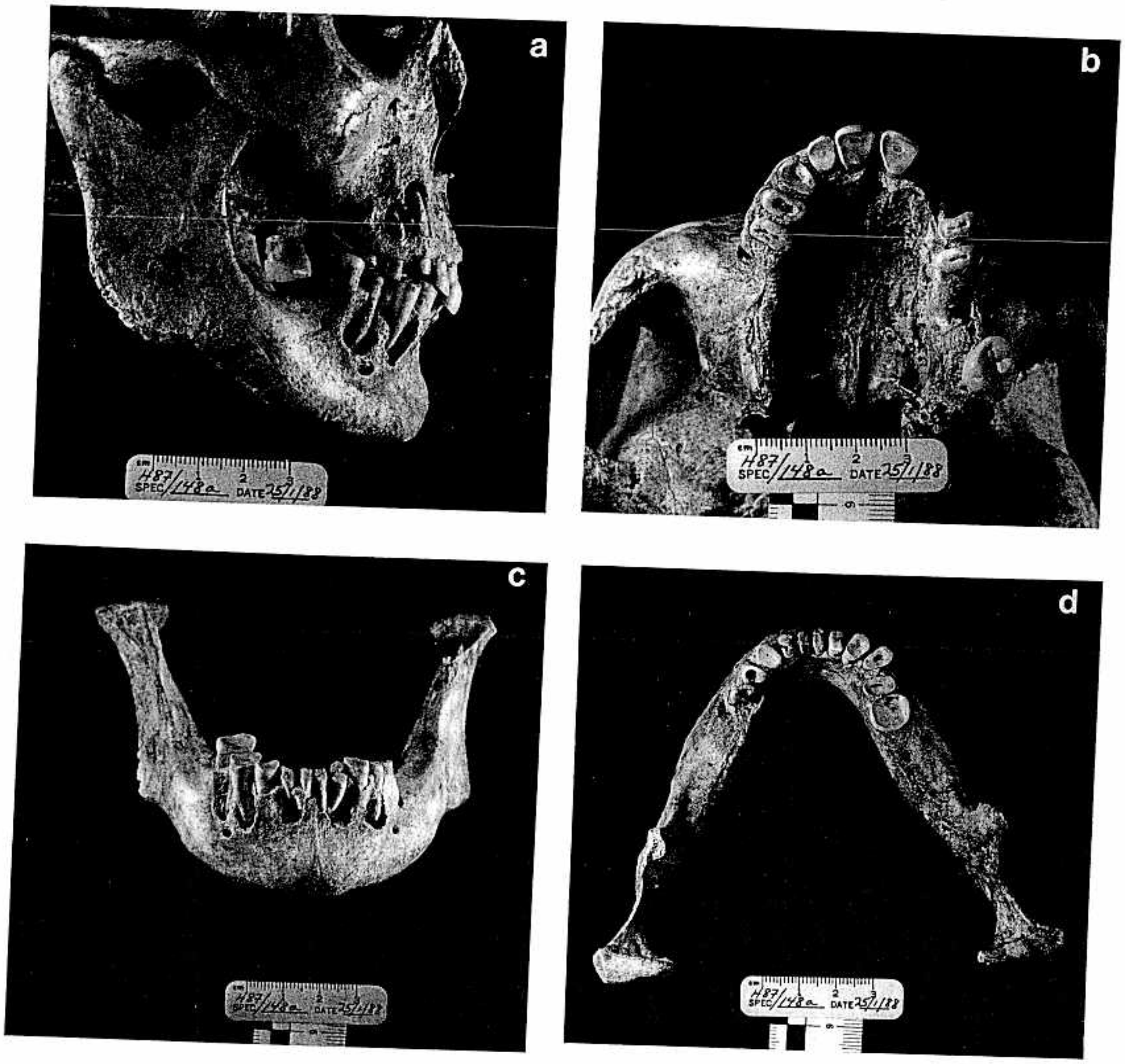

Fig. 4. Extensive dental abscesses in the maxilla and mandible of H87/137/148a. a: Right lateral view of lower face. Note large abscesses in maxilla and mandible, and ante-mortem tooth loss (neg/no R158F9). b: Palatal view showing pulp exposure and alveolar healing in progress (neg/no R158F8). c: Anterior view of mandible. Note extensive abscessing (neg/no R158F6). d: Superior view of mandible showing pulp exposure though dental attrition and ante-mortem tooth loss. (neg/no R158F5).

the crown in either maxillary or mandibular teeth. Three patterns are evident in the caries location data: mesial and distal surfaces are predisposed to caries decay in the maxilla, the buccal surface of mandibular teeth are primary decay sites due to the buccal groove and pit in mandibular molar teeth, and the high number of unknown caries locations for the maxilla is due to the high percentage of size grade 4 caries documented above for maxillary teeth.

Two additional observations on caries that provide valuable information for dietary reconstruction include whether the lesion exposed the pulp chamber of the tooth, and if the caries was located at the dental cervix (neck caries). In this dental sample 49.0% (n = 51) of caries lesions penetrated the crown deeply enough to expose the pulp chamber, an event that frequently results in infection of the pulp tissue, abscessing, and subsequent tooth loss. In the carious dental

TABLE 4. Dental caries prevalence by sex

	Male		Female		Unknown		Total	
	n	%	n	%	n	%	n	%
I1	0	0.0	1	6.3	0	0.0	1	2.0
I2	0	0.0	3	17.6	0	0.0	3	7.1
C	0	0.0	6	33.3	0	0.0	6	13.3
P3	2	12.5	2	11.1	0	0.0	4	8.2
P4	2	11.1	1	5.3	0	0.0	3	6.4
M1	4	22.2	2	12.5	0	0.0	6	12.5
M2	4	23.5	2	13.3	0	0.0	6	13.0
M3	2	15.4	1	16.7	0	0.0	3	11.1
Sum	14	10.9	18	14.4	0	0.0	32	9.1
Mandible								
I1	0	0.0	0	0.0	0	0.0	0	0.0
I2	0	0.0	0	0.0	0	0.0	0	0.0
C	0	0.0	0	0.0	0	0.0	0	0.0
P3	1	5.6	1	4.0	0	0.0	2	4.0
P4	1	5.0	1	4.3	0	0.0	2	3.6
M1	0	0.0	1	5.3	3	18.8	4	7.0
M2	0	0.0	4	18.2	1	5.6	5	7.9
M3	2	10.0	4	21.1	0	0.0	6	13.6
Sum	4	2.6	11	6.7	4	4.8	19	4.8
Total	18	6.4	29	10.1	4	2.3	51	6.8

TABLE 5. Size and location of caries lesions

Caries size	Caries size categories								
	1		2		3		4		Total
Jaw	n	%	n	%	n	%	n	%	n
Maxilla	1	3.1	13	40.6	5	15.7	13	40.6	32
Mandible	5	26.3	10	52.6	0	0.0	4	21.1	19
Total	6	11.8	23	45.1	5	9.8	17	33.3	51

Caries location	Tooth surface										
	Mesial		Distal		Buccal		Occlusal		Unknown		Total
	n	%	n	%	n	%	n	%	n	%	n
Maxilla	7	21.9	5	15.6	1	3.1	3	9.4	16	50.0	32
Mandible	2	10.5	1	5.3	7	36.8	5	26.3	4	21.1	19
Total	9	17.6	6	11.8	8	15.7	8	15.7	20	39.2	51

sample, 17.6% (n = 51) of the caries are located at the cervix of the tooth, while the majority (80.4%) of caries lesions were confined to the tooth crown. Root caries were rare; only one case (2.0%) was evident in the 51 carious lesions detected in this study.

One carious lesion that is especially interesting occurs in the RM^2 of specimen H87/136/147a (Fig. 5). This caries lesion (size grade 2) exposed the pulp chamber of the tooth, and resulted in the formation of a small periapical abscess at the distobuccal root. This lesion undoubtedly caused discomfort in life to the extent that the individual probed and picked at the decaying cavity, probably with a bone needle. This activity practiced habitually over time resulted in the formation of a shallow interproximal groove adjacent to the caries lesion. Pressure on the bone needle from the distally adjacent tooth (RM^3) would have been sufficient to create the wear groove. This is the first such association of an interproximal groove with dental caries from the South Asian prehistoric skeletal record (Lukacs and Pastor, 1988).

Exposure of the pulp chamber was observed in 37 Harappan teeth, yielding a prevalence of 4.93% (37/751) for this painful affliction. The premolar tooth class is most

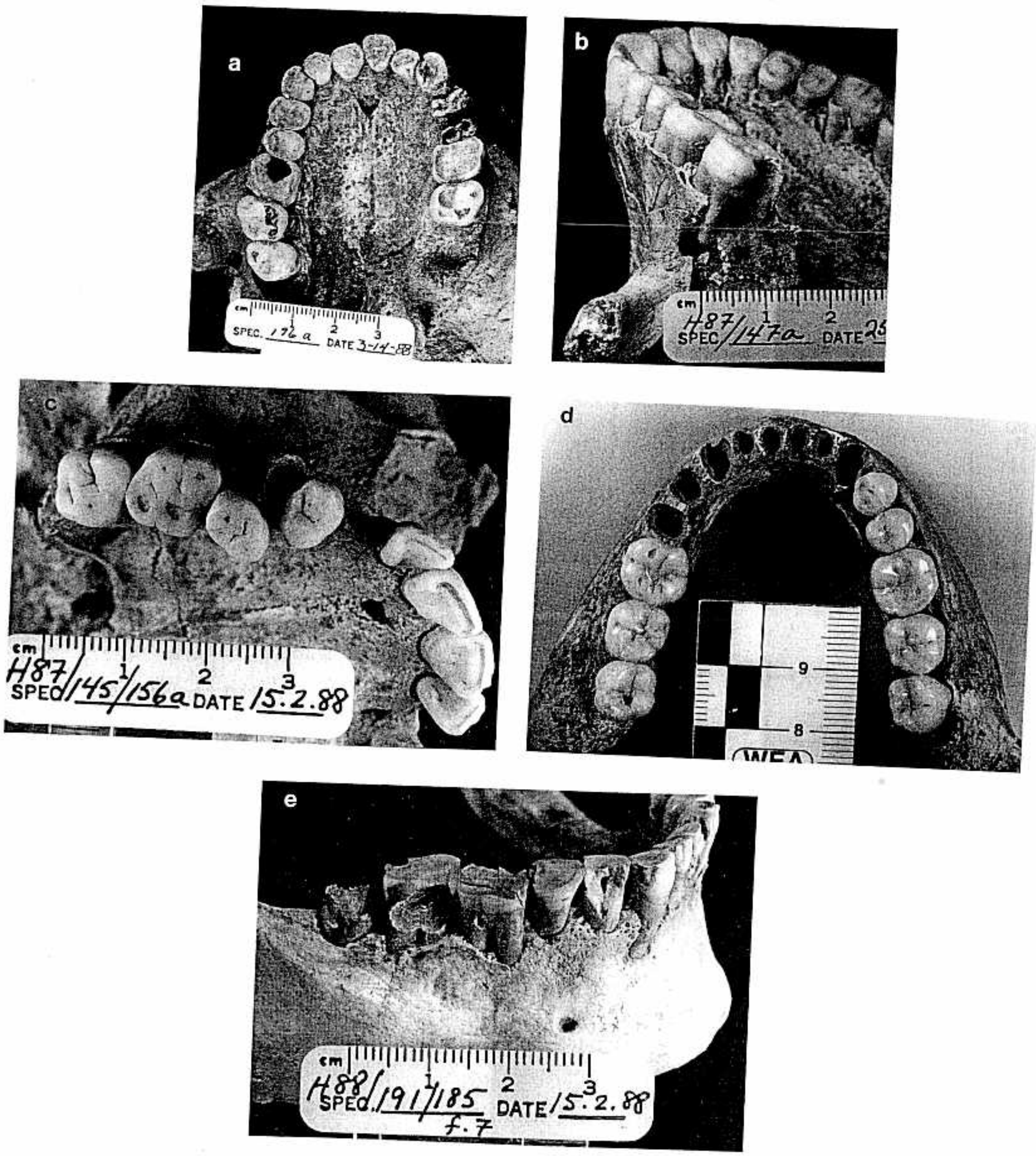

Fig. 5. Dental caries expression at Harappa. a: Carious destruction of the LP^4 crown leaving only roots remaining and grade 2 caries on occlusal surface of RM^1 (H88/194/196a; neg.no R14F17). b: Grade 2 caries with associated interproximal groove in the RM^2 of H87/136/147a (neg/no R157F10). c: Transposed RC exhibits a grade 4 caries lesion. Note also diastema and malpositioned RP^3 and RP^4 (H87/145/156a; neg/no H88-2-32). d: Pit/fissure caries (grade 1) on occlusal surface of LM_3 (H87/85/49b.1; neg/no 87H3-11). e: Grade 2, buccal, neck (cervical) caries in RM_2 and grade 4 caries in RM_3 of H88/191/185f.7 (neg/no H88-6-29).

frequently affected by pulp exposure (8.46%; 17/201) followed by the canine, incisor and molar tooth classes (Table 3). Teeth exhibiting exposed pulp chambers are more common in the maxilla (75.7%; 28/37) than in the mandible (24.3%; 9/37), and females possess teeth with exposed pulps (75.5%; 28/37) much more often than males (24.3%; 9/37). Teeth presenting exposed pulp chambers were categorized by etiology into two groups:

attrition and caries. Caries induced pulp exposure (67.6%; 25/37) is more prevalent at Harappa than attrition induced pulp exposure (32.4%; 12/37).

The relative contribution of attrition and caries to pulp exposure, in conjunction with AMTL rates presented above, permits a more accurate estimation of caries prevalence at Harappa through the use of the caries correction factor. The objective of the caries correction factor is to estimate the proportion of teeth lost ante-mortem because of severe caries exposing the pulp chamber of the tooth. This figure can then be used, in conjunction with the number of observed caries, to produce a more accurate estimate of the true caries prevalence. This procedure requires that we assume all AMTL (n = 70) was caused by the combined effects of attrition and caries through the exposure of pulp. If this assumption is valid, then the proportion of teeth exhibiting exposed pulps due to attrition (32.4%) vs. caries (67.6%) can be used to partition the number of teeth lost antemortem due to each causal factor. This would then permit an estimate of the number of teeth lost ante-mortem due to caries ($0.68 \times 70 = 48$), a figure that can then be added to the number of observed teeth with caries lesions (observed carious teeth, [51] plus estimated AMTL due to caries [48] equals estimate of true number of carious teeth [99]). If the corrected number of carious teeth (99) is then divided by the total tooth count prior to any AMTL (821), the new, corrected caries prevalence rate for Harappa is 12.1%. This corrected caries rate is nearly twice the uncorrected (6.8%) caries rate reported above since it takes into account the high AMTL rate due to caries. While there are other factors in addition to attrition and caries induced pulp exposure that may result in AMTL (such as alveolar resorption, traumatic injury, cultural ablation), evidence for these phenomena at Harappa is rare or absent. In view of these considerations, the corrected caries prevalence estimate for Harappa (12.1%; 99/821) is regarded as a more accurate indicator of the true caries incidence for this skeletal sample.

None of the linear enamel hypoplasias (LEH)[1] observed in the Harappa sample are severe; most defects are linear and mild to medium in degree of severity. A total of 44 lineations were recorded on maxillary and mandibular canine teeth. Multiple LEH were found in 52% of the individuals affected (n = 25), and some exhibited as many as four clearly discernable, distinct lineations. The position of linear enamel hypoplasia on the labial surface of canine teeth was recorded in millimeters above the cementoenamel junction (Goodman and Rose, 1990). These measurements were converted to developmental age at the time of growth disruption using the regression formulae provided by Walker in the "hypoager" database program (Walker, 1991; Phil Walker, pers. comm.). The mean developmental age at which LEH occurs in the Harappa series is presented in Table 6. While more hypoplastic events are present on the teeth of females than males, there is no difference in the mean age of occurrence of hypoplastic lines by gender. The variances, however, are unequal, suggesting that females exhibit a significantly wider age range in the occurrence of hypoplastic markers of growth disruption.

TABLE 6. Developmental age of enamel hypoplasia

Sex	$\bar{x}$	n	sd	Min	Max
Female	4.32	25	0.90	2.3	5.6
Male	4.27	17	0.66	3.3	5.5
Total[1]	4.29	44	0.79	2.3	5.6

[1]Total n includes 2 LEH from individuals of indeterminate sex.

COMPARATIVE ANALYSIS

The dental pathology profile for Harappa will be compared with recent data for living foragers and farmers, and with other prehistoric samples at the regional and the worldwide level. An important finding of this Harappan study is the difference in dental health between the genders. The prevalence of dental caries, enamel hypoplasia, antemortem tooth loss and pulp exposure is greater among females than males, based on both individual and tooth count reporting methods. Recent studies of activity patterns among hunter-gatherers and farmers reveal that gender based division of labor is often accompanied by significant differences in diet between the sexes (Hill and Hurtado, 1989; Walker and Hewlett, 1990). These gender based differences in diet correlate with differential prevalence of dental caries among the Aka and Mbuti pygmies and their Bantu horticulturalist neighbors (Walker

[1]Although only LEH is discussed here two other types of hypoplastic defects were observed in the Harappa skeletal series: foramen caecum hypoplasia (Pedersen, 1949) and localized hypoplasia of deciduous canine teeth (Lukacs, 1991a).

and Hewlett, 1990). Female foragers eat more frequently throughout the day, and in addition, may have regular access to more cariogenic foodstuffs than men. Conversely, men eat less often and habitually consume meat during the course of hunting expeditions, as among the Ngarulurutja of Australia (Hayden, 1979) for example. In a synergistic manner these factors combine to lower the cariogenic potential of male foragers' diets relative to females'. Similar findings were reported for prehistoric inhabitants of the Georgia coast by Larsen (1983, 1984), where the transition to agriculture involved a greater increase in caries rates among women than among men. Females exhibit higher caries rates than males among Upper Paleolithic and Mesolithic samples from Europe (Frayer, 1989), Santa Rosa Islanders from Cape Verde cemetery, California (Walker and Erlandson, 1986), and predynastic and Christian Egyptians and Nubians (Hillson, 1979), for example. While this gender difference in dental disease prevalence is not universal (Powell, 1988), cases in which females suffer an increased incidence of affliction are not directly related to mode of subsistence or to antiquity of the skeletal sample. The prime factor of import appears to be sexual division of labor which entails divergent activity and dietary patterns. Faunal evidence suggests that Harappans may have regularly hunted wild game (see below). Since hunting is primarily a male activity, Harappan men may have preferentially consumed a higher protein diet than women.

At Harappa, however, the anterior teeth are involved and in addition to caries, antemortem tooth loss, pulp exposure, and enamel hypoplasia show differences between the sexes. The difference in enamel hypoplasia is significant because it suggests that more females were subject to stress-induced growth disruptions than males. In addition female canine teeth exhibit more hypoplastic lines than male canines, suggesting that growth disruptions occurred more frequently among females than males. A survey of gender differences in the frequency of enamel hypoplasia fails to follow a consistent pattern, though Goodman et al. (1987) found a slightly higher incidence in female Mexican children. His proposed explanation, that differential access to essential resources is gender based, may apply to the Harappan hypoplasia data. In Hindu society male offspring are more highly valued than female infants (Beals, 1974; Tyler, 1973). A recent review by Hrdy (1990) employs remarkable South Asian examples in a sociobiological approach to understanding differential parental investment in sons and daughters. Female newborn are received without celebration and have higher mortality rates than males, and their illnesses are not regarded to be as serious or in need of immediate treatment as those of males (Tyler, 1973). The disparity in prevalence of enamel hypoplasia between the sexes at Harappa may directly signify the positive differential value this society placed on male offspring. The higher variance in age at which growth disruptions occur among females (see Table 6) may be interpreted to indicate that females were less well buffered against stress from birth, or that the low value this culture assigned female children placed them at risk earlier and later in development than males. Finally, the possibility of a causal link between the high carbohydrate, low protein diet of Harappan mothers and the common occurrence of enamel hypoplasia among female children should be mentioned. Diets inadequate in protein and calories during pregnancy may jeopardize the health and welfare of the fetus, damping their immune response system, thereby decreasing their ability to resist post-natal infectious diseases. These observations necessitate reconsideration of the egalitarian nature of the Harappan Civilization so frequently encountered in archaeological reports (Miller, 1985). However egalitarian the Harappans may have been in respect to social classes or occupational guilds, differences in dental disease patterning between the genders strongly suggest that sex based inequities existed in the diet of adults and in the health status of infants.

The regional level comparison of Harappa with other prehistoric skeletal series from the Indian subcontinent seeks to discern a relationship between increasing agriculturalism and changing patterns of dental pathology. This analysis utilizes dental pathology data collected personally by Lukacs, thereby precluding inter-observer error (Frayer, 1987). Data come from archaeological sites that span the spectrum of subsistence strategies from mesolithic hunter-gatherers of the Ganga Plains (Mahadaha (MDH), ca. 8000 B.C.; Lukacs and Hemphill, 1991a) to Iron Age inhabitants of the Deccan Plateau that had a mixed economy (Mahurjhari (MHJ), 600 B.C.; Lukacs, 1981, 1991c). One of the most important dental pathology data points for the subcontinent is the site of Mehrgarh, in Baluchistan Province, Pakistan. An analysis of the changing prevalence of dental disease from Neolithic (MR3) (ca 6000 B.C.) to Chalcolithic (MR2) (4500 B.C.) periods at Mehrgarh was recently conducted by Lukacs (et al., 1985; Lukacs, 1985a; Lukacs and Minderman, 1991). Other South Asian dental pathology data are taken from Sarai Khola [SKH] and Timargarha (TMG), Iron Age sites in northern Pakistan (Lukacs et al., 1989), and Pomparippu (PPP), an Iron Age site in Sri Lanka (Lukacs, 1976). The only data not collected by Lukacs are derived from a report by Kennedy (1965) on the mesolithic occupants of Bellan Bandi Palassa (BBP), Sri Lanka.

The first comparison focuses on dental pathology and agricultural intensification in the greater Indus Valley, and utilizes sites that have adequate sample sizes and approximately equivalent age structures. Archaeological evidence of agricultural intensification is well documented from three Indus Valley sites: Neolithic Mehrgarh, Chalcolithic Mehrgarh, and Harappa (Allchin and Allchin, 1982; Meadow, 1989). The earliest evidence for settled agriculture in the Indian subcontinent comes from aceramic and later Neolithic levels at Mehrgarh (ca. 6000 B.C., Periods Ia, Ib), where the mud-brick impressions (n = 5,956) of six-row barley (91%), einkorn-emmer (4%), wild (two-row) barley (2.5%), hulled six-row barley (1.8%), and durum-bread wheat (0.7%) were recognized (Costantini, 1984). In Chalcolithic times (4500 B.C., Period III) barley persists but a dramatic increase in wheat, including a shift to *Triticum sphaerococcum*, is clearly evident. In addition, evidence of the date palm (*Phoenix dactylifera*) and the Indian jujube (Zizyphus) is present from Neolithic through Chalcolithic levels. Meadow (1987) envisions an early (Neolithic) period of barley/wheat agriculture during the mid-sixth millenium B.C., supplemented early in the second millenium by the introduction of rice, millet, and sorghum. Important technological developments relating to food storage and preparation are also evident from aceramic to ceramic Neolithic to Chalcolithic levels. These include the development of utilitarian pottery from Neolithic bitumen-lined basketry, grinding stones, composite microlithic sickles, and architectural features that have been interpreted as grain storage structures (Jarrige, 1981, 1985; Jarrige and Meadow, 1980; Jarrige and Lechevallier, 1979; Lechevallier and Quivron, 1981, 1985; Lechevallier et al., 1982; Samzun, 1991). Faunal remains have been interpreted by Meadow (Jarrige and Meadow, 1980; Meadow, 1982, 1984, 1989) to show a gradual shift from wild to domestic varieties beginning in early Neolithic levels. Cattle, sheep, and goat were part of the early (Neolithic) domestication process, and were supplemented by camel, horse, and donkey early in the second millenium B.C. (Meadow, 1987).

For sites of the Indus Valley Civilization, evidence of greater dependence on agriculture is abundant and comes from Harappa, Kalibangan, and Mohenjo-daro (Allchin and Allchin, 1982). Two varieties of wheat, barley, field peas, sessamum, and mustard were cultivated, and evidence of dates is present. Plowed Harappan fields in pre-Harappan levels at Kalibangan (Thapar, 1973) suggest considerable antiquity for the contemporary practice of plowing furrows at right angles to one another to accommodate two crops simultaneously. And, if the large architectural structures at many Harappa sites, controversially interpreted as granaries, actually served the purpose of grain storage, the only reasonable conclusion is that grain was an important dietary staple (however, see Fentress, 1984). Harappan sites also present a well-developed copper/bronze technology, which includes a variety of vessels and tools that may have been used in the treatment and preparation of food (Allchin and Allchin, 1982; Wheeler, 1968). An important aspect of the Harappan subsistence strategy includes reliance upon the hunting of wild animals, an exploitation pattern attested to by the wide range of wild species' bones recovered from urban Harappan sites, and most recently confirmed by Meadow in his analysis of newly recovered faunal evidence from Harappa (Dales and Kenoyer, 1991).

The prevalences of seven dental afflictions among selected South Asian prehistoric skeletal series are presented in Fig. 6, which is based on the percentage of individuals affected. The dental lesions are arranged, from left to right, in order of decreasing frequency of occurrence in the Harappa sample. In all three samples enamel hypoplasia is the most prevalent dental affliction. This finding contrasts dramatically with an earlier report of low incidences of enamel hy-

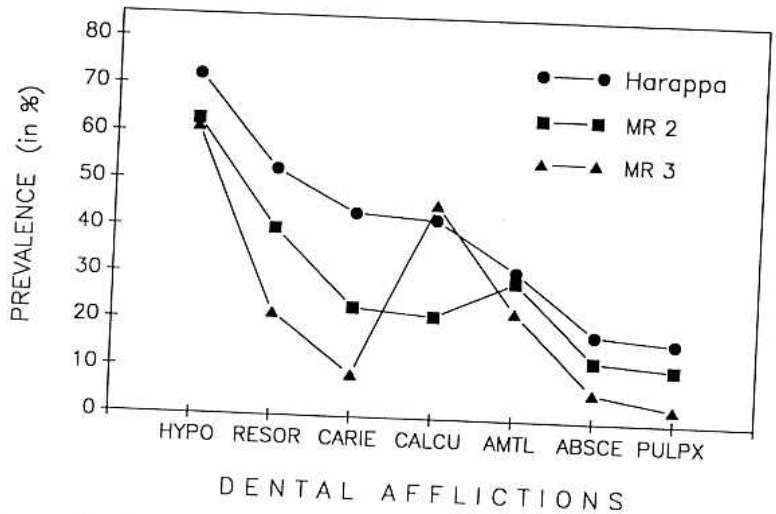

Fig. 6. Comparative view (individual count) of dental disease at Harappa. HYPO, enamel hypoplasia; RESOR, alveolar resorption; CARIE, dental caries; CALCU, calculus; AMTL, ante-mortem tooth loss; ABSCE, abscesses; PULPX, pulp exposure.

poplasia among skeletal series from Harappan sites (Lovell and Kennedy, 1989)[2]. The prevalence of all dental lesions, except calculus, increases through time in association with increasing degree of dependence upon an agricultural subsistence base. The progressive increase in enamel hypoplasia with increasing dependence on agricultural subsistence has been reported for prehistoric skeletal series from North and South America, Africa, Europe, and the Middle East (Cohen and Armelagos, 1984; Goodman and Rose, 1990). The decline in dental health with increasing dependence on agriculture is exacerbated by continued development of food producing and storage technology from Neolithic to Harappan times. The combination of dependence upon an economic system that relied heavily on agriculture, but also included a significant contribution from hunted wild game, may account for the lack of a more rapid increase in caries rates. The gradual increase in dental pathology with agriculture in the Indus Valley is not as dramatic or as debilitating as specialized dependence upon maize agriculture was to Native American populations (Cohen and Armelagos, 1984).

The second approach to comparative interpretation of the Harappa dental pathology profile employs the tooth count reporting method in conjunction with data reported by Anadi Pal (1981) and previous studies of dental paleopathology in South Asia by Lukacs. Pal's (1981) analysis of dental health in ancient India utilizes the tooth count method only, does not address sex differences, and presents prevalence data in summary form—data from all sites with a similar "culture" are lumped together. While his methodology precludes a direct comparison of Pal's data for the site of Harappa with the results reported in this paper, Pal's pooled "Harappan" sample (which includes data from the sites of Harappa, Mohenjo-daro, Kalibangan, Lothal and Rupar) can be used for general comparative purposes.

The results of this comparison are intriguing. Despite Pal's larger dental sample (n = 1,501 teeth), he reports substantially lower prevalences for virtually all dental lesions and afflictions than are documented in this paper—for example, abscesses (Pal, 0.1%; Lukacs, 3.1%), AMTL (Pal, 2.1%; Lukacs, 8.5%), caries (Pal, 1.8%; Lukacs, 6.8% direct count, 12.1 corrected), and attrition induced pulp exposure (Pal, 0.5%; Lukacs, 1.6%). The disparity of these results is great in some instances, and could be due to several factors: inter-observer variance (different criteria used in the recognition and scoring of dental lesions), demographic

[2]This is a qualitative assessment based on Kennedy's analysis of human skeletons from earlier excavations at Harappa, Lothal, and Mohenjo-daro, curated at the Anthropological Survey of India, Calcutta.

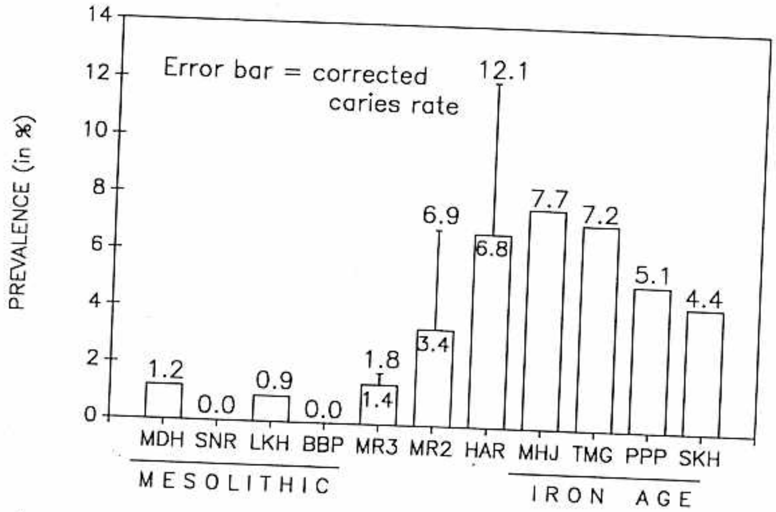

Fig. 7. Caries prevalence and cultural association in the Indian subcontinent. Bar height represents caries rate uncorrected for ante-mortem tooth loss; error bar represents caries rate adjusted for ante-mortem tooth loss.

TABLE 7. Dental caries prevalence in South Asia

Study sample	Culture level	Caries rate (%)	n	Source
Sarai Khola	Iron Age	4.4	815	Lukacs et al., 1989
Timargarha	Iron Age	7.2	615	Lukacs et al., 1989
Mahurjhari	Iron Age	7.7	196	Lukacs, 1981
Pomparippu	Iron Age	5.1	79	Lukacs, 1976
Megalithic (3)[1]	Iron Age	2.5	1013	Pal, 1981
Kumhar Tekri (1)	Early Historic	2.1	431	Pal, 1981
Neo-Chalcolithic (4)	—	0.3	567	Pal, 1981
"Harappan" (5)	Bronze Age	1.8	1501	Pal, 1981
Harappa (observed)	Bronze Age	6.8	751	This study
Harappa (corrected)	Bronze Age	12.1	821	This study
Mehrgarh—MR2	Chalcolithic	3.4	685	Lukacs and Minderman, 1991
Mehrgarh—MR3	Neolithic	1.4	1272	Lukacs and Minderman, 1991
Sarai Nahar Rai	Mesolithic	0.0	114	Lukacs and Hemphill, 1991a
Lekhahia	Mesolithic	0.9	112	Lukacs and Hemphill, 1991a
Bellan Bandi Palassa	Mesolithic	0.0	120	Kennedy, 1965
Mahadaha	Mesolithic	1.2	261	Lukacs and Hemphill, 1991a

[1]Number of sites included in study sample shown in parentheses.

differences between study samples, and study samples derived from different socio-economic strata of Harappan society. Despite the purported lack of social differentiation in Harappan society (Miller, 1985), procedural, demographic, and socioeconomic factors, probably acting in concert, account for these disparate results.

In the final comparison, dental caries prevalence at Harappa is compared, using the tooth count method, with mesolithic hunter-gatherers and Iron Age skeletal series from South Asia in Figure 7. This chart is based on data presented in Table 7, and yields several valuable insights: mesolithic caries rates are consistently low, Iron Age rates vary from 7.7 to 4.4, the uncorrected caries rate for Harappa fall within the Iron Age values, and the corrected caries rate for Harappa is double the mean Iron Age caries rate (6.1%; sd = 1.6; n = 4). The progressive decline in dental health, reflected in the increasing caries rates from Neolithic Mehrgarh (MR3), to Chalcolithic Mehrgarh (MR2), to Harappa, reflects the combined influence of increasing reliance upon agriculture as the principal subsistence strategy and gradual but significant improvements in food processing technology.

CONCLUSION

This analysis provides the first comprehensive report on dental paleopathology for prehistoric members of the Indus Valley Civilization, and thereby permits a preliminary investigation of changing patterns of dental pathology among early inhabitants of the greater Indus Valley. These new data and insights derived through comparative analyses lead to the following conclusions:

1. The Harappa dental pathology profile exhibits characteristics commonly associated with agricultural subsistence systems in other regions of the world.
2. A significant difference in dental pathology, especially dental caries, is discernable between the genders and probably reflects different activities and diets. Adult males, who may be involved in hunting, display lower caries rate than females, who may have devoted more time to processing the fruits of agriculture.
3. Hypoplastic markers of childhood growth disruption affect more females than males, and may reflect differential access to essential resources and care, and/or inadequacy of the pregnant mother's diet, thus predisposing the child to post-natal stress. Preferential treatment of male infants, a behavioral characteristic of modern South Asian society, may have great antiquity. While archaeological data indicate that urban Harappans may have been egalitarian in respect to social classes, inequities clearly existed between the genders in adult diets and health of infants.
4. Individual and tooth count data reveal a pattern of increasing dental affliction which parallels intensification of agriculture and significant improvements in food processing technologies among prehistoric populations of the greater Indus Valley.
5. Future research should be devoted to the investigation of possible regional variations in prevalence of dental disease within the Harappan sphere of influence, confirmation of the gender differences in dental pathology utilizing larger samples, and linking dental pathology profiles of individuals with other indicators of health and welfare (stature, macroscopic and histologic skeletal pathology, bone chemistry, and dental microwear).

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