Preservation of Human Bone in Prehistoric and Historic Sites of Western Japan

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THE DEGREE OF preservation of skeletal remains is influenced by many factors such as acidity of soil, content of calcium (Ca) or other chemical substances, grain-size of soil, stratum composition, exposure of sites, decomposing action of soil microorganisms, geographic location and climate, and style of burials. Human skeletons buried in the earth are eroded or protected according to the actions and interactions of these factors.

Soils that are alkaline or have a high calcium content are favorable to human bone preservation (Cornwall 1960, 1964; Brothwell 1981; Watanabe 1949, 1950; Miwa 1958). Because of the chemical composition of human bone (hydroxyapatite, see Bale 1940) and the general chemical reaction of calcium compounds in acid or alkaline solutions, it seems quite reasonable to expect a high correlation between them. To date, however, few studies have actually dealt quantitatively with the problem of bone preservation related to environmental conditions such as pH and Ca content, so the presumed correlation between bone preservation and pH value of soil, for example, is still ambiguous. Their practical relation (that is, the degree of correlation) in sites in which the conditions vary considerably has not been sufficiently studied. The present paper is a preliminary attempt to pursue such a course of study using material available in western Japan.

In general, the soils of Japan are acidic, reflecting their origin from volcanic ash and the relatively high amount of rainfall (1500–2000 mm/year at least). Consequently almost the whole territory is unfavorable to the preservation of bony substances. At several sites, however, a high degree of bone preservation has been observed, although, as will be described later, there are great differences in preservation among these sites in relation to differences in their conditions.

As Cornwall (1960) has noted, before work is begun it is important for excavators to be able to infer the presence of presumed burials and the probable degree of preservation of skeletal remains. Hence, it will be beneficial to clarify the correlation between bone preservation and those environmental conditions that are assumed to influence it.

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MATERIALS AND METHODS

Degree of Preservation of Skeletal Remains

The degree of preservation of human bones collected from sites in western Japan is shown by the ratio of weight of the excavated bones to that of the dry, fat-free bones of modern human skeletons. The age and numbers of sites and skeletons that were used in this study are shown in Table 1. From the collection in our laboratory excavated over the last 20 years or more, 343 human skeletons from 32 sites were chosen for this study. Specimens from the Yayoi period (300 B.C.–A.D. 300) account for 75 percent of the total. Since there was a significant sex difference in skeletal weight, accurate determination of sex was an important first step; several methods were used (Washburn 1949; Keen 1950; Hanna and Washburn 1953; Phenice 1969; Krogman 1973; Steele 1976; Black 1978; Ferembach et al. 1979; Brothwell 1981). Occasionally, it was impossible to determine sex because of the poor degree of preservation and fragmentary nature of the skeleton. In such cases the remains were treated as male in the calculation of weight ratios.

The dry and fat-free skeletons from which data were taken for the calculation of weight ratios consist of 20 male and 20 female adult individuals. All came from western Japan and belong to the Department of Anatomy at Kyushu University. Table 2 presents their mean weight. The male bones (3779 g) are significantly heavier than the female (2819 g), and skeletal weight decreases slightly with increasing age throughout the period examined in this study. This is consistent with the findings of Trotter and Hixon (1974), although there was great variation between individuals.

The degree of skeletal preservation was calculated for each site, and the relationships between bone preservation and the several environmental factors described above were examined.

pH Value and Content of Exchangeable Ca

Soil samples were taken from the strata in which skeletal remains were discovered. For detailed analysis, in some sites, samples were also taken at several points around the skeleton, for example, upper and lower strata, outside and inside of grave pit, closely adjacent and relatively distant parts.

Following the general methods of pedology, 10 g of fresh soil were dissolved in 25 cc distilled water and 25 cc 1N–KCl respectively, and sufficiently mixed by stirring for 30 minutes. The suspension pH values were then determined by pH meter (Hitachi–Horiba M–7).

TABLE 1. NUMBER OF SITES AND SKELETONS FROM WESTERN JAPAN STUDIED IN THIS PAPER

AGE	NUMBER OF SITES	NUMBER OF SKELETONS
Jomon (B.C. 1500–B.C. 300)	3	12
Yayoi (B.C. 300–A.D. 300)	22	259
Kofun (4 C–7 C)	3	15
Middle (15 C–16 C)	3	57
Modern (18 C)	1	—
Total	32	343

TABLE 2. MEAN WEIGHT (gm)[a] OF EACH BONE, SKELETAL COMPONENT, AND TOTAL SKELETON (20 INDIVIDUALS OF EACH SEX) OF WESTERN JAPANESE

	MALE		FEMALE	
	MEAN	RANGE	MEAN	RANGE
Age (years)	42.1	22–65	41.5	20–68
Cranium	642.6	505–802	578.9	362–835
Mandible	88.9	76–109	72.1	40–113
Humerus	241.3	157–330	162.2	102–228
Radius	79.6	52–107	51.3	35–73
Ulna	97.5	68–128	64.7	43–89
Hand bones	97.1	65–151	72.1	48–102
Clavicle	41.9	27–55	31.2	22–45
Scapula	112.1	68–156	75.6	46–105
Femur	661.0	476–900	468.4	324–662
Patella	23.8	15–36	15.5	10–22
Tibia	379.2	257–511	272.9	163–422
Fibula	89.2	52–113	64.7	41–92
Foot bones	214.8	142–330	163.4	95–228
Vertebrae	331.2	215–436	214.5	128–351
Ribs	252.1	164–374	175.4	100–255
Sternum	18.1	12–29	10.5	6–16
Hip	294.6	181–440	248.0	154–367
Sacrum	71.3	41–109	61.9	40–92
Total	3779.9	2780–4803	2819.0	1991–4065

[a] These weights are of dry, fat-free bones from the collection at Kyushu University.

For measurement of exchangeable Ca content, 10 g of fresh soil were dissolved in 40 ml 1M–CH_3COONH_4. After being mixed, the sample was left overnight and then filtered in a solution of 1M–CH_3COONH_4 to 100 ml final volume. After dilution with distilled water, 10 ml of 10,000 ppm strontium solution was added, then absorption at 442.7 nm was measured by Atomic Absorption Spectroscopy (Perkin–ELMER 703).

Grain-size Distribution

For the soil specimens sampled in coastal sandy sites, which form most of the sites studied here, grain size was determined by the methods of Bouyoucos (1929, 1935) using a 9- and 70-mesh screen.

RESULTS

pH and Bone Preservation

The degree of preservation of human skeletons varies considerably from site to site and shows a strong correlation with the pH values of the soil (see Fig. 1), even though, in the same site, some differences in bone preservation were observed between individuals through probable minor environmental differences.

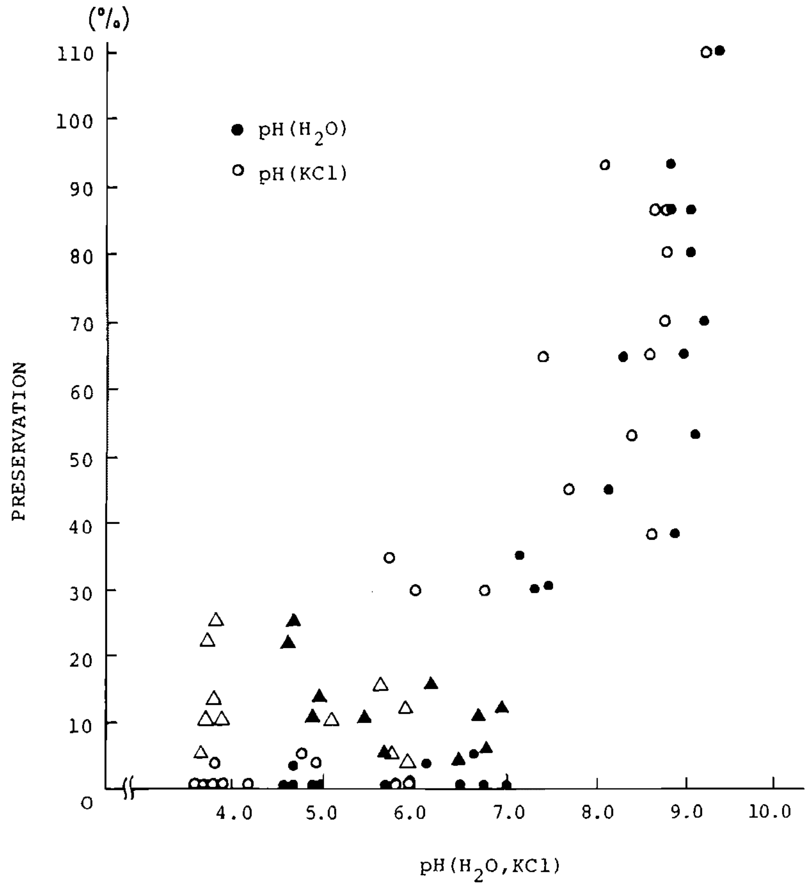

Fig. 1 Correlations between bone preservation and pH values. Jar burials were presented by ▲(H_2O) and △(KCl).

The correlation coefficients between calculated bone preservation and suspension pH values are 0.8927 (KCl) and 0.8703 (H_2O), significant at the 0.01 level. The pH values measured in 1N–KCl solution show a higher correlation than those for H_2O. In the sites with basic soil above pH 7.5 (KCl) and pH 8.0 (H_2O), human bones show a higher degree of preservation with increasing pH value. On the other hand, no skeletal remains at all, except for some small fragments, were discovered in acid soil under pH 6.0 (KCl) and pH 7.0 (H_2O) as shown in Fig. 1. Even in the modern age site studied here (18C), the bones were badly eroded and fragmented by the acidity of the soil (pH 6.31 [H_2O], 5.19 [KCl]).

During the Yayoi period (300 B.C.–A.D. 300) of western Japan, which is represented by the greater part of the sites studied here, bodies were frequently buried in large jars. In such cases, the quality of the skeletal remains is probably attributable to the degree of preservation of the jars themselves, even in acid soil (this is indicated by ▲–H_2O and △–KCl in Fig. 1). For this reason, a lower correlation coefficient between preservation and soil pH was obtained for jar burial sites.

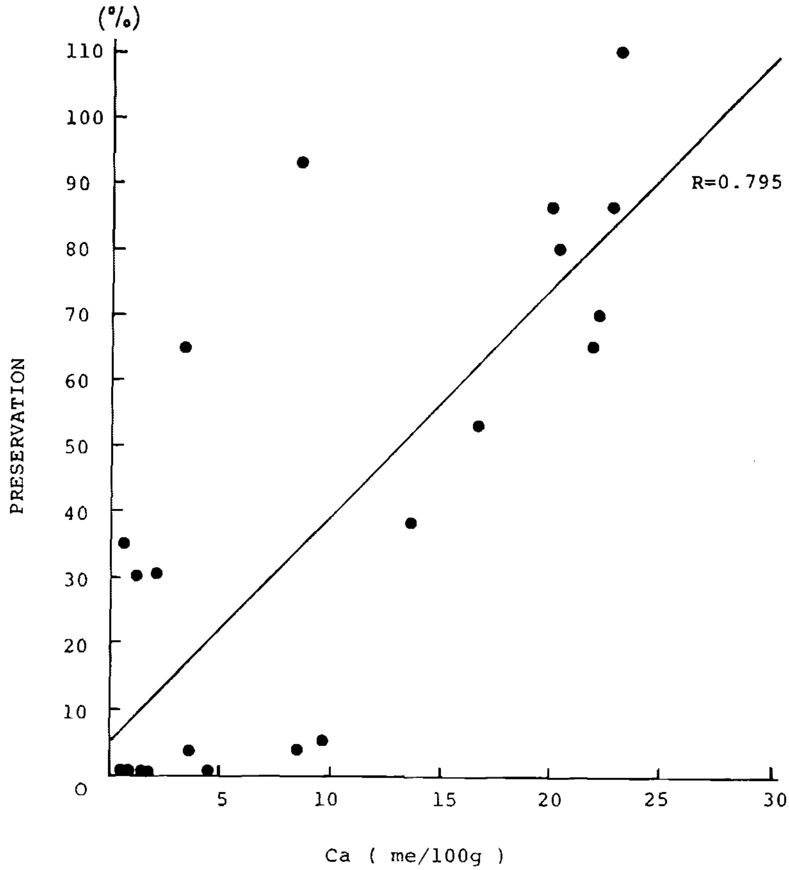

Fig. 2 Correlations between bone preservation and exchangeable Ca content. The calcareous cave sites containing exceptionally large amounts of exchangeable Ca were excluded.

Exchangeable Ca Content and Bone Preservation

In the sites studied here, excepting the calcareous cave sites (with soil containing over 40 me/100 g Ca), the exchangeable Ca content varies from nearly 0 to 25 me/100 g and shows a significant correlation with pH value ($r = 0.6594$ [H_2O], 0.6991 [KCl]). The correlation coefficient between exchangeable Ca content and bone preservation is 0.6429, statistically significant at the 0.01 level, but ranking lower than that of pH. If the calcareous cave sites are excluded where the soil contains an exceptionally large amount of exchangeable Ca (>40 me/100 g), the correlation coefficient increases from 0.6429 to 0.7950 (see Fig. 2, Table 3).

On the whole, sites containing over 10 me/100 g Ca generally provide well-preserved skeletons, although the possibility of a high degree of preservation cannot be rejected even for areas with low Ca content.

Grave Depth and Bone Preservation

At the Yoshimo site in Yamaguchi prefecture, western Japan, the relation between depth of grave pit and bone preservation was examined. Yoshimo is a coastal

TABLE 3. Correlation Coefficients between Bone Preservation and pH (H_2O), pH (KCl), Exchangeable Ca, Grave Depth, and Grain Size

		Preservation		
		N	Correlation coefficient	t(R)
pH (KCl)	A	25	0.8927	9.50**
	B	30	0.8272	7.79**
pH (H_2O)	A	25	0.8703	8.47**
	B	30	0.7872	6.57**
Ca (me/100 g)	A	25	0.6429 (0.7950)[a]	4.02**
	B	29	0.5084 (0.7832)	3.06**
Grave depth		41	0.5968	4.64**
Grain size		16	−0.4344	−1.80+

Note. A = Sites excluding jar burials and cists; B = Sites including all kinds of burial.
[a]( ) = Correlation coefficients excluding calcareous cave sites.
** Significance at 99% level.
+ Non significance.

sandy site and chronologically belongs to the Middle Ages (15C–16C). Over 100 medieval Japanese were discovered in a fine, homogeneous sand stratum one or two meters below the surface. Owing to the high pH (8.71 [H_2O], 8.62 [KCl]) and Ca content (20 me/100 g), bone preservation is relatively good and shows a statistically significant increase as the depth of the grave pit ranged from 10 to 70 cm. The difference in degree of preservation between shallow and deep grave pits is recorded in Fig. 3.

Grain-size Ratio and Bone Preservation

For the sand specimens sampled in dune sites, separation of large from small grains was made at 0.21 mm and then correlations were calculated among the weight ratios of large grains ($\phi > 0.21$ mm), pH(H_2O, KCl), exchangeable Ca content and bone preservation. As illustrated in Fig. 4, good skeletal preservation was observed in sites with fine-grain sand; in several sites with large-grain sand, bone preservation falls to nearly zero.

From the sites on the southeast islands of Japan that contain abundant fragments of shell and coral, a high degree of bone preservation, owing to high pH value and plentiful Ca, was observed in spite of the high weight ratio of large grains.

On the whole, there was a recognizable tendency for decrease of pH value, exchangeable Ca content, and also bone preservation with increasing weight ratio of large grains ($\phi > 0.21$ mm), although the correlations among these factors did not reach the 0.05 level of significance.

Skeletal Component and Geographical Differences in Bone Preservation

The skeletons were divided into six components: (1) skull (cranium and mandible), (2) thorax (ribs and sternum), (3) vertebral column, (4) pelvis, (5) superior limbs (clavicles, scapulae, humeri, radii, ulnae, and bones of the hands), and (6)

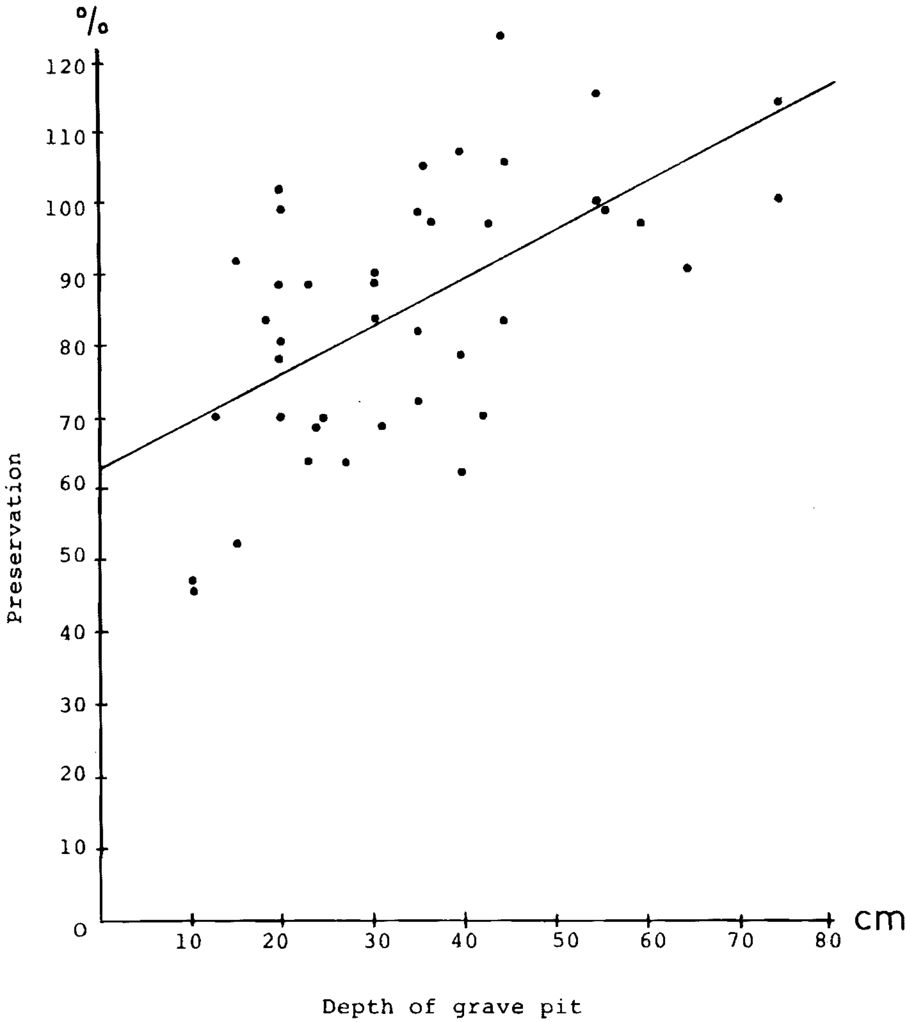

Fig. 3 Correlations between bone preservation and depth of grave pit at the Yoshimo Middle Ages site in Yamaguchi prefecture.

inferior limbs (femora, tibiae, fibulae, and bones of the feet). The preservation of each of these components was assessed separately; differences in the preservation of each component were then studied in comparison with total preservation, pH value, Ca content, and location of site.

As presented in Table 4 and Fig. 5, the skulls were found to show the highest degree of preservation for all sites, while thorax, vertebrae, and pelves were the opposite.

In sites with a high degree of preservation (generally high pH value and Ca content), the difference in the degree of preservation between the six components is not evident. With decreasing total preservation, pH value, and Ca content, the differences between these components, especially between skull and thorax or vertebrae,

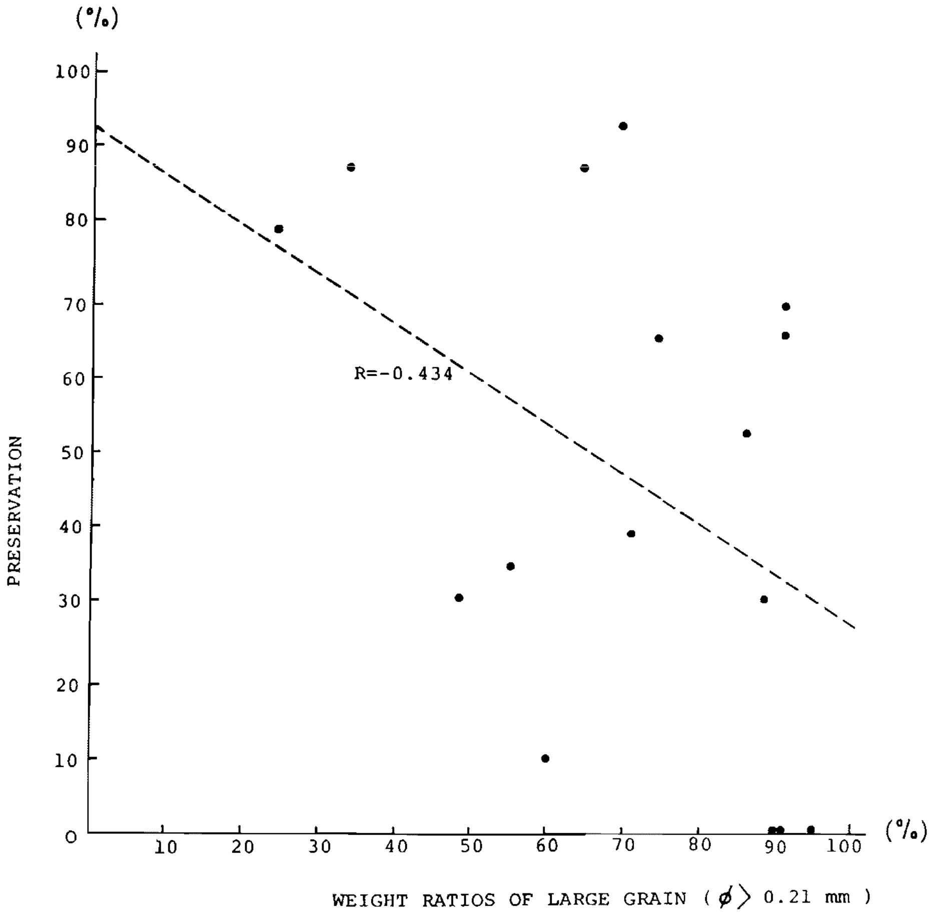

Fig. 4 Correlation between bone preservation and weight ratio of large grains ($\phi > 0.21$ mm).

became obvious (see Fig. 5). The low figure for preservation of the upper limb is largely due to poor preservation of scapulae and clavicles.

The sites studied here can be divided generally into two types: coastal sandy sites and inland earthy sites. Between these divisions, clear differences in bone preservation are associated with differences in pH value and Ca content (Table 5). Excepting calcareous cave sites and shell-mound and coastal sandy sites that contain a large amount of shell or coral fragments, the soil of almost the whole territory (95 percent according to Watanabe 1949) of inland Japan is characterized by acidic conditions under which human bone does not last long without deterioration.

No significant difference in bone preservation between the sexes was observed.

DISCUSSION

The human skeleton undergoes chemical changes in the earth, differing in nature and degree with the chemistry of the surrounding matrix. Although the conditions studied here represent a limited number of the factors that influence bone preserva-

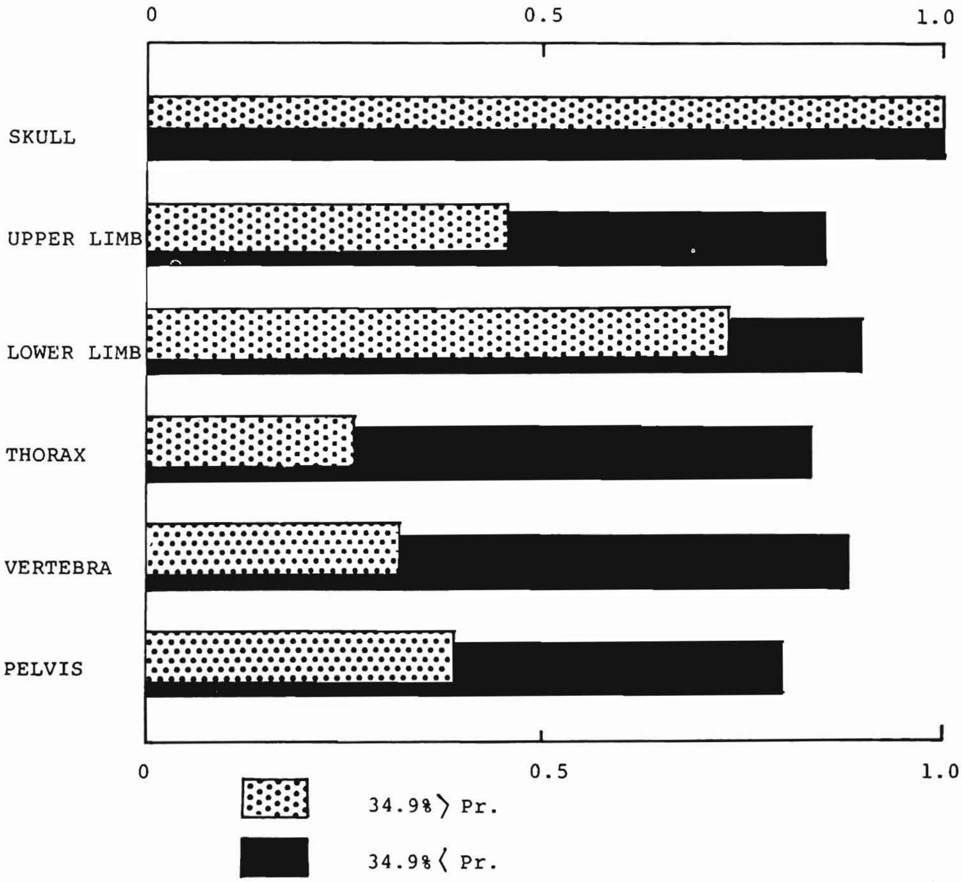

Fig. 5 Differences of bone preservation among six components. The sites were separated at the 34.9 percent mean value of bone preservation and then compared. The preservation of the skull was treated as 1.0 and each other component was calculated in proportion.

tion, they are shown to have an important role (Table 3). There are statistically significant correlations ($p = 0.01$) between bone preservation and these factors. In particular, pH(H_2O, KCl) provides the highest coefficient of correlation.

Since bony substance consists of apatite microcrystals, ossein, and other organic substances, it is chemically resistant to alkaline reactions generally. In a well-aerated and wet acid soil, not only is the organic matter in the bone quickly decomposed, but even the mineral part is soon attacked, and the specimen may disappear without a trace in a comparatively short time (Cornwall 1964). For example, in the Kashihara modern age site (18C), the skeletal remains are severely damaged by soil acidity (pH [KCl] 5.19) in the manner noted above.

To explain the higher coefficient of correlation of pH(KCl) compared to pH(H_2O), we can say that due to substituted acidity, as is generally known in pedology, the pH value in 1N–KCl solution presents a concentration of H^+ more steadily than in H_2O. Although the conditions studied here do not act independently but jointly on the skeletal remains, one of the purposes of this study was to find a useful

TABLE 4. Differences in Bone Preservation among Six Components of Total Skeletons[a]

	all sites (n = 27) mean	Pr.>34.9% (n = 9) mean	Pr.<34.9% (n = 18) mean
Skull	44.2 (%)	74.7	29.0
Upper limb	30.1	63.8	13.2
Lower limb	36.7	67.8	21.1
Thorax (ribs and sternum)	25.8	62.5	7.5
Vertebra	28.1	66.0	9.2
Pelvis	27.4	59.8	11.2
Total	34.9	68.5	17.9

[a]The sites were divided into well- and poorly-preserved sites, choosing 34.9 percent as the dividing point.

index for inferring the degree of bone preservation. In this regard, pH value, especially the measurement in 1N–KCl solution, seems to be most useful index among the factors considered here.

The results of multiple regression analysis also seem to confirm this conclusion. For example, in 16 dune sites, the following formula was obtained (see Table 6):

Bone preservation = 28.352(X1) + 0.299(X2) − 0.632(X3) − 160.32, where X1 = pH(KCl), X2 = Ca(me/100 g), and X3 = grain size.

In this calculation, pH(H_2O) value was excluded by reason of the high correlation between pH(KCl) and pH(H_2O). As shown in Table 6, the standard regression coefficient of pH(KCl) is 0.9871, the multiple correlation coefficient is 0.8915, and the coefficient of determination is 0.7947. These values show the utility of this formula and especially the importance of the pH(KCl) value for the purpose intended here.

Calcium is one of the most important substances correlated with bone preservation, because of both its abundance and its relative ease of measurement. The results, however, show a lower correlation coefficient than that for pH, although, if the calcareous cave sites containing exceptionally large amounts of exchangeable Ca are excluded, r values increase nearly to the pH(H_2O) level. This may be due to the

TABLE 5. Differences between Coastal Sandy Sites and Inland Earthy Sites in Bone Preservation, pH (H_2O, KCl) and Exchangeable Ca Content (me/100 g)

	coastal, sandy site (n = 16)		inland, earthy site (n = 13)	
	mean	s.d.	mean	s.d.
Preservation (%)	52.64	34.98	9.07 (14.88)	13.15 (11.81)
pH (KCl)	8.14	0.92	6.04	1.26
pH (H_2O)	7.50	1.24	4.92	1.39
Ca (me/100 g)	11.25	9.60	9.51	15.01

TABLE 6. MULTIPLE REGRESSION ANALYSIS

VARIABLE	STANDARD REGRESSION COEFFICIENT
X_1: pH (KCl)	0.9871
X_2: Ca (me/100 g)	−0.1637
X_3: grain size	0.1829

presence of calcium carbonate (shell, coral, and limestone), which is a main supplier of exchangeable Ca and not precisely detectable by this method. Moreover, exchangeable Ca is easily washed away and hence relatively subject to environmental change. Hence we cannot exclude the possibility that the results obtained here do not reflect the whole story of the role of calcium in skeletal remains in the earth. In any case, the chemical condition of soil that is determined by several chemical substances containing calcium must be reflected, to a certain extent, in the value of pH (H_2O, KCl), as indicated by the high correlation between Ca content and pH (H_2O, KCl) ($r = 0.6594$ [H_2O], 0.6691 [KCl]).

The Yoshimo Middle Ages site is well suited to demonstrate the effects of depth of grave pit, since this is one of the coastal sandy sites of homogeneous, fine grains and relatively simple stratigraphy. In this site, over 100 individuals were discovered from grave pits differing in depth and degree of bone preservation. Although sand specimens were sampled at various points, there was no detectable difference in pH value and exchangeable Ca content between them. Two elements must be considered in evaluating depth of grave pit: (1) depth increase caused by alluvial action, and (2) depth reduction caused by erosive action or other disturbance during the course of time. Although this change in depth may reduce the apparent correlation between bone preservation and grave depth, a significant correlation between them nevertheless remains. In sandy sites like Yoshimo and possibly also in inland earthy sites, the chemical and physical conditions of the soil are more stable for the deeper burials generally, unless a peculiar stratum—for example, a stratum containing plentiful underground water—exists near the burials, as at the Hirota Yayoi age site. This stability would be favorable for bone preservation, especially in cases of high pH or Ca content. For example, at the Yoshimo site, we found that skeletons of Yayoi age from 2 m or more depth had a higher degree of preservation than skeletons of the Middle Ages from about 1 m, although there were no detectable differences in the chemical and physical nature of the sand.

Grain size distribution is of great importance for the determination of the chemical and physical nature of soil. The results show a recognizable tendency towards a decrease in bone preservation with an increase in sand grain size. In a site with large-grain sand, the chemical and physical characteristics of the contents are easily altered by rainwater (pH 5.7 in general). Also, if there is the possibility of exposure to atmospheric oxygen, organic substances are gradually broken down into simple compounds, as described by Cornwall (1964). Since access for oxygen and water is easy in soils of shallow depth and large grain size, even the mineral part of bone is more readily dissolved. In the sites on the southern island of Japan, which contain large amounts of shell and coral, however, H_2CO_3 produced from CO_2 and rainwater is neutralized immediately by abundant $CaCO_3$ (Foth 1978). Hence bone preservation is remarkably good in spite of large grain size. The great difference in bone preservation between coastal sandy sites and inland earthy sites seems to be due mainly to this function of $CaCO_3$. In inland earthy sites (generally low pH value and Ca content, see Table 5), the bones are considerably decayed by permeation with acidic water and the decomposing action of soil microorganisms. Only in calcareous caves, shellmounds, and special burials, for example jar burials or cists, are skeletons discovered with a high degree of preservation.

The skull shows the highest degree of preservation. Though the high degree of preservation of the skull and the low degree of preservation of the thorax and vertebrae could be mainly due to the differences in their histology and structure, it seems to be associated with an artificial factor too, that is, the difference in difficulty of digging up the various parts and of their different importance in anthropological study.

Many problems remain. The effect of time on these conditions is an especially important subject for future study. As yet, however, we lack a sufficient number of sites to allow us to finally resolve the problems raised.

CONCLUSIONS

1. The acidity of the soil in sites has a great effect on bone preservation, and the measurement of pH in 1N–KCl soultion is the most simple and useful index for inferences concerning bone preservation.

2. Exchangeable Ca content is also significantly correlated with bone preservation, but in comparison with pH value, a greater discordance in correlation was observed.

As a whole, for sites from late Jomon to the Middle Ages (1500 B.C.–A.D. 1600) in Japan, human bones generally show a high degree of preservation in soil above pH 7.5 (KCl), pH 8.0 (H_2O) and 10 me/100 g Ca content. On the other hand, they cannot be preserved without damage in soil under pH 6.0 (KCl) and pH 7.0 (H_2O) except in special cases such as jar and cist burials.

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