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Paleopathological and Paleoepidemiological Investigation of Human Skeletal Remains of Early Hawaiians from Mokapu Site, Oahu Island, Hawaii

Takao Suzuki

Department of Epidemiology, Tokyo Metropolitan Institute of Gerontology

(Abstract)

Paleopathological changes appearing in human bones were investigated on 349 early Hawaiian skeletal remains from the Mokapu site, Oahu Island, Hawaii. At the same time, a gross observation of abnormal changes was carried out on well-preserved adult individuals in order to obtain data for epidemiological analyses.

Among various pathological evidence including trauma, infections and tumors, relatively high frequencies of skeletal tuberculosis and, in contrast, the lack of certain evidence of skeletal treponematosis attract our special attention. This finding may suggest some paleoepidemiological relationships between human migration and the spread of a specific infectious disease as represented by tuberculosis during long voyage through the Pacific in the ancient times.

Epidemiological analysis through stress indicators in bones such as cribra orbitalia, spondylosis deformans, osteoarthritis in the cervical spines and degenerative joint disease in the elbow and knee joints suggests a peculiar feature of the early Hawaiian subsistence.

Keywords: Paleopathology, Paleoepidemiology, Mokapu, Early Hawaiian

INTRODUCTION

The purpose of this research is to reveal the lifeways, including health and disease conditions, of the prehistoric inhabitants of the Hawaiian Islands. Much of our knowledge concerning the lifeways of the early Hawaiians is derived primarily from skeletal remains recovered from various archeological sites in the islands which are now housed in the B.P. Bishop Museum in Honolulu, Hawaii.

As previously mentioned by the editor of this report, an extensive anthropological examination was conducted on the prehistoric Hawaiian skeletal materials from 1984 through 1989 in the Bishop Museum. The author participated fully in this research project, and took charge of paleopathological examination of the Mokapu skeletal remains.

Many anthropological contributions have been made on prehistoric Polynesian skeletal materials. Most of these, however, concern osteometric study, especially, craniology. Very little is known about the health status and epidemiological aspects of prehistoric Polynesians. Together with osteometric study, pathological examination can also provide useful information on the biological properties of the skeletal population.

There are two specific goals of this study focusing on the Mokapu skeletal remains, which is the larget skeletal collection of early Hawaiians. The first is to describe pathological changes appearing on bones in order to recognize individual health problems of prehistoric peoples. The second is to compare the epidemiological data with that from other skeletal populations in order to clarify the status of the Mokapu people within the ancient bio-ecosystem in the Pacific region.

MOKAPU SKELETAL SERIES

The Mokapu Peninsula extends into the north Pacific beyond the general windward coastline of Oahu Island. There are many sand dunes, including the Heeia sand dune which contains most Mokapu burials. The first important archeological observation of the Mokapu site was done by Otto Finsch in 1879. He found human skeletons in the burials without any association of European artifacts. However, he gave no information of orientation, sex or age of those skeletal remains.

Two important archeological excavations at the Mokapu site were carried out in 1938. Kenneth P. Emory, Bishop Museum ethnologist, began an exploratory excavation at the site in the Heeia dunes on March 6, 1938. Gordon T. Bowles, University of Hawaii, physical anthropologist, successively excavated the Heeia dune sites from October of that year. Excavation continued for nearly 15 months and ended in January 1940. After World War II, major excavation was conducted by Robert N. Bowen, University of Hawaii anthropologist, at the two Heleloa sites in 1957. The total number of skeletal remains discovered by these excavations amounts to over a thousand individuals, most of which are now housed in the Bishop Museum.

With regard to the archeological dating of the Mokapu burials, unsolved problems still remains. In general, these burials are said to be of pre-European contact, based on both the existence of bony fishhooks and the lack of metallic artifacts. Bowen, who conducted the major excavation in 1957, described the archeological date of the site as follows:

"One important feature of the man-made evidence at Mokapu is the complete absence of European materials. While over 1000 individuals have been recovered, no glass beads, buttons, nails, metal smoking pipe fittings, or pieces of European pottery have been found. All artifacts have been of native materials, fashioned in typically Hawaiian style. This complete lack of European influence perhaps justified the conclusion that the burial ground was founded, used and abandoned prior to the time when European material culture spread to windward Oahu from leeward anchorages" (Bowen; 1971)

A detailed anthropological and osteological study of the Mokapu skeletal collection was conducted by Charles E. Snow. His monograph, published in 1974, contains the skeletal demography, a large number of measurements and indices of both cranium and post cranial skeletons, and morphology, including abnormal and pathological features of the Mokapu people.

The first pathological description of a large number of Mokapu skeletons was carried out by Bowers (1966). He reported many interesting pathological cases consisting of fracture, infection, arthritis, and tumor found in 864 skeletal individuals. Snow (1974) also reported many pathological specimens based on the previous work of Bowers. Johnson and Kerley (1974) described in detail several pathological specimens, and made diagnoses for some cases, including two probable spinal tuberculosis and four talipes equinovarus.

However, in spite of the large number of specimens which Bowers and Snow examined, they overlooked the general tendency and pattern of the pathologies of the Mokapu people in relation to the age and sex of individuals, i.e., a lack of accurate epidemiological analysis based on individual variables which rendered the reconstruction of the total health condition of the Mokapu people insufficient. Furthermore, some tentative diagnoses, made by them at that time, must be reconsidered in the light of today's knowledge of paleopathology. For example, what was thought to be an example of neuroarthropathy (Bowers, ibid) has been recently re-diagnosed by the author (Suzuki; 1987) as a case of osteosarcoma, one of the primary malignant bone tumors.

In the present study, various pathological conditions in individual skeletons are recorded in detail by gross observation in the light of modern concepts of paleopathology. Using some stress indicators appearing on the bone, epidemiological analysis has been carried out in order to reconstruct the health status of the Mokapu population in relation to age and sex. Finally, whenever possible, data obtained here have been compared with those of other ancient Pacific islanders in order to discuss the bioecological, sociocultural and habitual properties of the early Hawaiians.

MATERIALS

The skeletal materials used in the present study were obtained from sand dune burial sites in the Mokapu Peninsula. Over a thousand individuals have been unearthed from Mokapu sites, since the first major excavation in 1938. These individuals were originally registered according to the field area (H,C,N, ··· Fig. 1). They are now rearranged in the order of the museum-registration (BPBM) number which has been adopted for this study (cf., Pietrusewsky; 1971).

The osteological materials are, in general, in good condition for observation. In the process of examination, minimum reconstruction was attempted on bones with clean breaks. In this study, in order to obtain reliable data for epidemiological analysis, only adult individuals having enough well-preserved skeletal parts to be used for sexing and age-estimation were observed in detail. As a result, the final number of individuals examined in this study was 349 adult skeletons after exclu-

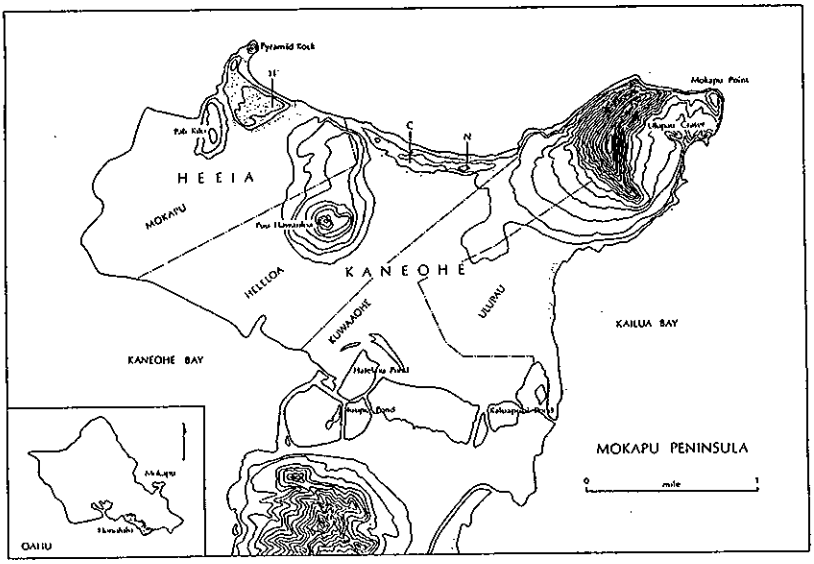


Fig. 1. The map of Mokapu site, Mokapu Peninsula, Oahu (quoted from C.E. Snow (1974)).

sion of doubtful materials. For whole individual pathologies and exact epidemiological analysis, such materials as infant/subadult bones (more than 300) and mixed/broken fragmental bones were omitted. In spite of mixed and fragmental bones, not a few specimens showing certain pathological changes, were subject to be treated as just reference materials. On the isolated skulls without postcranial skeleton, because the skulls provide information as good stress indicators and on specific diseases such as cribra orbitalia, osteoarthritis in the temporomandibular joint, sinuitis and periodontal diseases, complete skulls were taken into account in this gross pathological examination.

SEX AND AGE DETERMINATION

Sexing and age-estimation of the 349 skeletal individuals were carried out according to the standard morphological criteria (Krogmann; 1973, Bass; 1979, Brothwell; 1981). In addition, the original data recoded by Snow and housed in the BPBM provided much information for determination of sex and age of the Mokapu skeletal materials.

In regard to sex determination, the morphology of the skull and pelvis were carefully examined, as well as general size and robustness of the whole skeleton. In particular, because the pelvic bone is the key to diagnostic criteria of sexing, whenever possible, such structures as the greater sciatic notch, preauricular sulcus and infrapubic angle were primarily examined. In the isolated skulls, reliability of sex determination decreased by a certain degree. Nevertheless, some cranial features such as glabella, mastoid process and external occipital protuberance were observed in sexing the materials.

In regard to age-estimation, individual skeletons should be assigned to a fine age group (e.g., five-year scale) in order to provide reliable information for census or paleodemographical study. Subadults are suitable for such fine age grouping based on the condition of tooth eruption (Ubelaker; 1978). However, such fine-age discrimination was not always possible among adult skeletons dealt with in this paleopathological study.

In the present study, the following general age indicators were used as criteria: 1) Morphology of pubic symphysis (Hanihara; 1952, Hanihara & Suzuki; 1978) offers the most reliable age-estimation in the adult skeleton between 18 to about 45 years. 2) Three main suture closures (Koizumi; 1982) and intraorbital sutures (Kamijo; 1979) sometimes give good evidence for age-estimation of mature and senile skull. 3) Assessing teeth condition, such as attrition, periodontal diseases and tooth loss, may offer a rough age-estimation, as well as degenerative changes in the vertebral column and in the major joint areas in the post cranial skeleton. After the age-estimation in this study, each individual was classified into one of the following three age-group categories, "Young"(-ca 20), "Adult" (ca 20-45) and "Mature-Senile" (ca 45 +).

The results of sex and age-estimation of the 349 skeletal individuals used in this paleopathological study are given in Table 1. Furthermore, the numbers of the individual bone examined are shown in Table 2.

Table 1. Material used; sex, age and total number of individuals

Sex	Tatal number of individuals	Age-group		Major Parts of the skeleton		
				Skull only	Skull + PCS	PCS only
Male	168	Young	7	63	96	9
		Adult	109			
		Mature/Senile	52			
Female	181	Young	27	75	92	14
		Adult	123			
		Mature/Senile	31			

Table 2. Material used; number of individual bones

Sex	Total number	Skull (Skull only)	Vert.	Pelvis		Clav.		Scap.		Humer.		Ulna		Radius		Femur		Tibia		Fibula	
				r	l	r	l	r	l	r	l	r	l	r	l	r	l	r	l	r	l
Male	168	159 (63)	81	84	80	76	73	63	65	90	88	83	85	79	80	82	78	79	74	65	60
Female	181	167 (75)	82	92	94	70	76	60	64	95	90	93	90	94	88	97	98	93	92	81	83
Total	349	326 (138)	163	176	174	146	149	123	129	185	178	176	175	173	168	179	176	172	166	146	143

PATHOLOGICAL OBSERVATIONS

Gross observation of abnormal changes appearing in ancient skeletons principally provides the basic derection for paleopathological diagnosis. In the present study, bearing in mind the various diseases as listed in Table 3, pathological changes were completely described and given tentative diagnosis based on macroscopic observation. In a few pathological specimens, X-ray examination was available. Dr. R. Bender, staff radiologist in the U.S. Army Medical Section had already taken many X-ray films of the Mokapu skeletons and gave me permission to re-examine them. Furthermore, through the courtesy of Dr. N. Furue and Dr.

Table 3. Items of the palaeopathological observation
(*; the items of stress-marker on the bone for paleoepidemiological analysis)

Ⅰ) Trauma
- 1) injury
- 2) fracture
- 3) traumatic dislocation

Ⅱ) Inflammation
- 1) non-specific inflammation
  - i) periostitis
  - ii) osteomyelitis
- 2) specific inflammation
  - i) tuberculosis (Pott's disease)
  - ii) syphilis
  - iii) leprosy

Ⅲ) Endocrinary disease
- 1) hyperpituitarisum (acromegary)
- 2) hypopituitarisum (dwarfisum)

Ⅳ) Metabolic bone disease
- 1) rickets
- 2) osteomalacia
- 3) scurvy
- 4) gout

Ⅴ) Anemic bone change
- 1) iron defeciency anemia (cribra orbitalia*)
- 2) osteoporosis symmetriea (spongy hyperostosis)

Ⅵ) Tumor
- 1) benign bone tumor
  - i) osteoma
  - ii) osteochondroma
  - iii) exostosis multiplex
  - iv) others
- 2) benign/malignant
  - i) giant cell tumor
  - ii) fibrous dysplasia
  - iii) others
- 3) malignant bone tumor
  - i) osteosarcoma
  - ii) multiple myeloma
  - iii) metastatic carcinoma
  - iv) histiocytosis X
  - v) others

Ⅶ) Joint disease
- 1) osteoarthrosis (degenerative joint disease)*
- 2) traumatic arthritis
- 3) rheumatoid arthritis

Ⅷ) Deformation
- 1) skull deformity (craniosynostosis)
- 2) shoulder joint dislocation
- 3) hip joint dislocation (LCC, Perthes' disease)
- 4) disused atrophy of the long bones
  - i) polyomyelitis (spinal paralysis in childhood)
  - ii) infantile paralysis
- 5) congenital radio-ulnar synostosis
- 6) others

Ⅸ) Vertebral disease
- 1) intervertebral apophyseal joint disease*
- 2) spondylosis deformans*
- 3) lumbosacral transitional spine
- 4) spina bifida occluta*
- 5) Schmol's cartilagenous nodule
- 6) spondylolysis*
- 7) ankylopoetica spondylitis
- 8) osteoporosis

Ⅹ) Others
- 1) Paget's disease
- 2) achondroplasia
- 3) cleft palate and cleft lip
- 4) congenital abnormalities of the bone
- 5) others

S. Collins, Central Identification Center, U.S. Army in Honolulu, the author had the opportunity to take X-ray films using their facilities. No microscopic analysis using thin-sliced sections of the bones was carried out because of the value of the specimens and the lack of proper equipment and allocated time for in this overseas research.

The indicators of epidemiological analyses adopted in this study were cribra orbitalia, degenerative joint disease (osteoarthrotic changes) in the major joints of the extremities, osteophytosis (spondylosis deformans) in the vertebral column, and spondylolygis in the lumbar spine.

Among 349 individual skeletal remains in the Mokapu series, there were more than seventy individual skeletons showing recognizable pathological bone changes, which are now described in the order of the following categories; 1) trauma, 2) infectious diseases, 3) bone tumors, 4) metabolic disorders, 5) congenital abnormalities, and 6) hyperostotic conditions in the vertebrae.

Additionally, epidemiological analyses comparing data with that from other archeological populations were carried out using the stress indicators for evaluating the health status of the prehistoric pupulations.

1) Trauma

This category generally includes 1) bone wounds caused by sharp instruments, 2) dislocation, 3) fracture, and 4) amputation or artificial injuries to the bone. Table 4 shows the individual numbers of each category observed in the Mokapu population. Table 5 is the list of individuals showing these traumatic bone changes, and Table 6 refers to the location in the skeleton of traumatic lesion.

As shown in the tables, thirty six cases (36/349; 10.3%) had evidence of trauma. Among them, males are predominant (22 males and 14 females). As to age, adult males had the highest frequency of 16.5% (18/109). In the nineteen cases of healed fracture of the long bones, 18 showed complete union and only one case (No. 1880; mature female) was diagnosed as non-union fracture of the left humerus. Among thirty-six cases showing traumatic lesion, 15 cases were in the skull and 21 cases were in the post-cranial skeleton.

There was no evidence showing bone injuries caused by a sharp instrument such as an arrow head or other projectile point. In addition, cut marks made by a

Table 4. Classification and number of traumatic changes

	Male (168)	Female (181)
Bone wounds by sharp instrument	0	0
Traumatic dislocation	0	0
Fracture	20	14
Amputation	1	0
Inflammatory change by trauma	1	1
Total	22 (13.1%)	15 (8.3%)

Table 5. List of the cases showing traumatic changes

No.(BPBM)	Sex[1)]	Age[2)]	Location	Remarks[3)]
1258	M	Ad	Skull	nasal and malar bone fx.
1273	F	Ad	Pelvis(r)	fx. with hip joint OA.
1337	M	Ad	Skull	orbital and nasal bone fx.
1351	F	Ad	Skull	temporal and zygomatic bone fx.
1358	F	Ad	Tibia(r)	fx. of proximal tibia.
1521	F	MS	Ulna(l)	fx. of shaft.
1551	F	Ad	Ulna(r)	Monteggia fx.
1583	M	Ad	Radius(l)	Colles' fx.
1622	M	Ad	Fibula(l)	fx. of shaft.
1652	F	MS	Ulna(l)	fx. of shaft.
1668	M	Ad	Skull	zygomatic and nasal bone fx.
1673	F	Ad	Skull	blow hole.
1679	F	MS	Vertebrae	compression fx.
1723	M	Ad	Vertebrae	compression fx.
1733	M	MS	Skull	depressive fx. of parietal.
1746	M	Ad	Clavicula(l)	fx. of shaft.
1783	F	Ad	Tibia(l)	bumper fx. of proximal tibia.
1806	M	MS	Fibula(l)	fx. of shaft.
1824	F	MS	Radius(r)	Colles' fx.
1825	F	Ad	Ulna(l)	fx. of shaft.
1838	M	Ad	Ulna(r) & Radius(l)	multiple fx. of forearm.
1858	M	Ad	Skull	nasal bone fx.
1875	F	Ad	Skull	nasal bone fx.
1880	F	MS	Humerus(l)	fx. of lat. candyle.
2014	M	MS	Skull	zygomatic bone fx.
2015	M	Ad	Skull	nasal bone fx.
2026	M	Ad	Skull	nasal bone fx.
2029	M	Ad	Ulna(l)	fx. of shaft.
2057	M	Ad	Femur(r)	fx. of shaft.
2062	M	Ad	Humerus(l)	amputation at mid-shalf.
2138	M	Ad	Ulna(l)	fx. of shaft.
2152	M	MS	Skull	depressive fx. in both parietal bones.
2671	F	Ad	Fibula(l)	runner's fx. (susp.)
2683	F	Ad	Skull	scalp wound (susp.) in the right parietal.
2690	M	Ad	Skull	depressive fx. of r-parietal.
2732	M	Ad	Humerus(l)	posttraumatic myositis ossificans.
2736	M	Ad	Skull	depressive fx. of l-frontal.

1) Sex : M ; male, F; female
2) Age : Yg; young, Ad; adult, MS; mature/senile
3) Remarks: Fx ; Fracture, OA; Osteoarthritis

Table 6. Location in the Skeleton of Traumatic Change

Location	Number/Total Number (%)
Skull	15 / 326 (4.6)
Vertebrae	2 / 163 (1.2)
Pelvis	1 / 350 (0.3)
Clavicula	1 / 295 (0.3)
Humerus	3 / 363 (0.8)
Ulna	7 / 351 (2.0)
Radius	3 / 341 (0.9)
Femur	1 / 355 (0.3)
Tibia	2 / 338 (0.6)
Fibula	3 / 289 (1.0)

wedge-shaped instrument such as a sword could not be found either in the skull or in the post-cranial skeletons of the Mokapu people.

A possible case of traumatic blow hole on the left frontal bone could be seen in a mature female skull (No. 1673) (Fig. 2). The shape of the blow hole along the sagittal axis was oval with a diameter of 28 × 16 mm. There were two cracks from the hole going in different directions. The inner (endocranial) table was much more widely detached than the outer (ectocranial) table.

There were eight cases showing remarkable nasal bone fracture (7 male and one female; Fig 3). In regard to nasal bone fracture, Bowers reported 70 cases showing fracture in the nasal bone, and Snow observed that "broken nose (healed fracture) were more common than broken long bones. They were found in 33 percent of the men and 29 percent of the women, some seventy individuals in all. This high rate of fracture of the nose is ascribed to fighting and perhaps marital difficulties, as

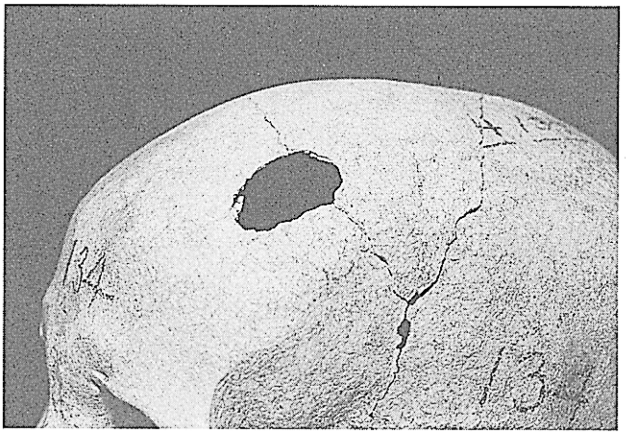


Fig. 2. A possible case of traumatic blow hole in the skull (No. 1673).

Fig. 3. A case of healed fracture in the nasal bones (No. 2014).

well as accidents". In my observation, however, even though there were some other suspicious cases of nasal fracture, only eight cases in 326 skulls (2.5%) could be diagnosed as nasal fracture. One of the major reasons for this difference in the incidence may be in the number of skulls observed. However, another reason may exist in over-diagnosis by the previous investigators on the nasal bone which often shows very wide variation from lack of nasal bone to marked (congenital) deformation (c.f. Brothwell; 1981). Actually, for example, there were certain cases showing excess furrow in the midportion of bilateral nasal bones which, Snow presented as fracture in his monograph, seemed to be a kind of congenital anomaly rather than a healed fracture. Furthermore, if the nasal fracture could be seen in more than thirty percent of the whole specimens in the Mokapu series as Snow stated, neighboring fractures associated with nasal bone fracture should be recognized much more frequently than they were. In fact, in spite of the high frequency of nasal bone fracture, there were only a few cases of neighboring fracture, e.g., fractures in the frontal process of the maxilla, or in the orbital and zygomatic bones.

Only one adult male skull showed a remarkable healed fracture in the orbit (No. 1337, Fig 4). The major fracture lines still remained through the lower margin of the right orbit and the frontal process of the right maxilla. There was also marked deformity with asymmetry of the upper part of the nasal cavity.

Fig. 4. A case of healed fracture in the orbit (No. 1337).

There were five cases (four males and one female) showing healed depressive fracture in the carvarium. The largest fracture in the skull could be seen in an adult male (No. 2736, Fig 5), with marked elliptical defects in the center of the fracture which was probably caused by intentional injury with a strong blow. The clear evidence of new bone growth could be seen in both ecto- and endo- cranial bones. The skull of a mature male (No. 1733, Fig 6) also showed a large and shallow depressive fracture on the parietal bone.

The malar bone was also conspicuous among fractures of the facial skeleton.

Fig. 5. The large elliptical defect with healed depressive fracture in the frontal bone probably caused by intentional injury with a strong blow (No. 2736).

Fig. 6. The linear fracture with shallow depression in the perietal bone (No. 1733).

There were a total of four cases showing healed fracture in the zygomatic arch in the Mokapu skeletal series. For example, the skull of a mature male (No. 2014, Fig 7) showed clear evidence of such a healed zygomatic fracture with deformation.

There were several cases showing fracture or fracture-like deformity in vertebrae. An adult female (No. 1679) had a compression fracture in the first lumbar spine which ankylosed with the second lumbar spine at the anterior margin. Another compression fracture with wedgewise deformity in the lumbar spine was found in an adult male (No. 1723).

As Snow had already mentioned, there were many cases showing healed fracture in the post-cranial skeleton in the Mokapu skeletal remains. In my observation of 349 sexed and age-estimated skeletal individuals of the Mokapu series, as shown in Table 5, twenty-one (11 males and 10 females) cases had evidence of fracture in the post-cranial skeleton. The most common part of fracture was in the forearms (7 ulnae; Fig. 8, and 3 radii) followed by crural bones (3 fibulae and 2 tibiae;

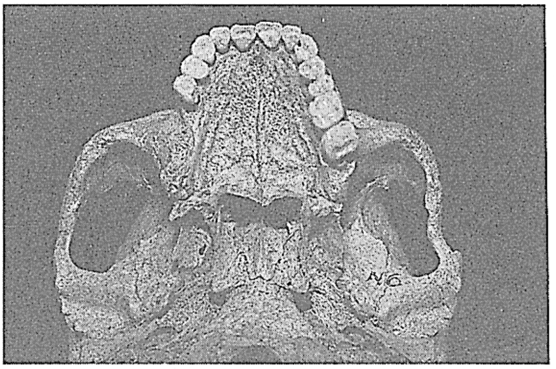


Fig. 7. A case of healed zygomatic fracture (No. 2014).

Fig. 8. A case of healed fracture with marked deformity in the ulna (No. 1551)

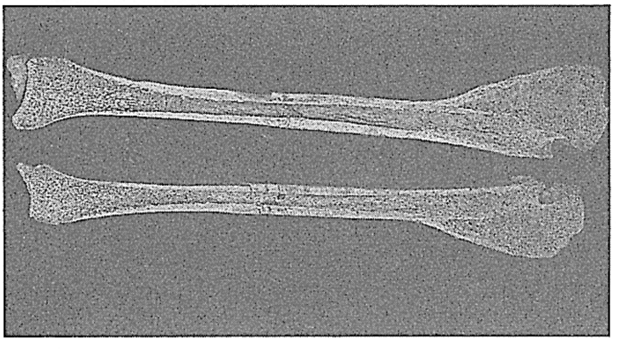


Fig. 9. Longitudinal section of a fractured tibia showing the sliding of the proximal head by oblique fracture (No. 1783).

Fig.9). Healing with good union in the fracture could be seen in all cases but one of a mature female (No. 1880, Fig 10) which revealed non-union at the lateral condyle of the left humerus. In addition, there was clear evidence of one other non-union fracture with formation of pseudoarthrosis, which had already been illustrated by Snow. However, this case could not be counted as an examined subject

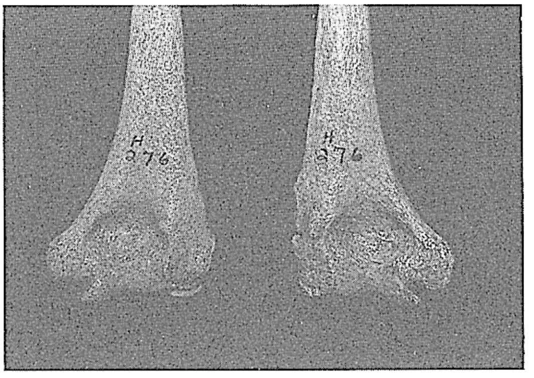


Fig. 10. A case of non-union fracture at the lateral condyle of the humerus (No. 1880).

for this study because of its isolation without any other important part of the skeleton. The high incidence of fractures of the shaft of ulnae among the Mokapu people seems to be associated with parrying a blow with the forearm.

Regarding the high incidence of good union in fractures, Snow ascribe the reason as follows: "It seems reasonable to believe that Mokapuans had the care of skilled bone setters (kahunas), whose knowledge of anatomy and the physiological process of bone repair was extensive and time-proven. In addition to the development of technique in setting broken bones they must also have had remedies which were effective in reducing swelling and bringing the separated bone ends into line so that they would heal properly."

There were two other interesting traumatic changes in the Mokapu series. One was a possible case of amputation, which had already been reported by Snow, at the midshaft of the left humerus of an adult male (No. 2062. Fig 11). No other left arm bones remained in the box holding the skeleton. The end of the proximal fragment of the left humerus was well-healed with smooth surface at the lesion. There were neither infectious changes of osteomyelitis nor evidence of excess calci-

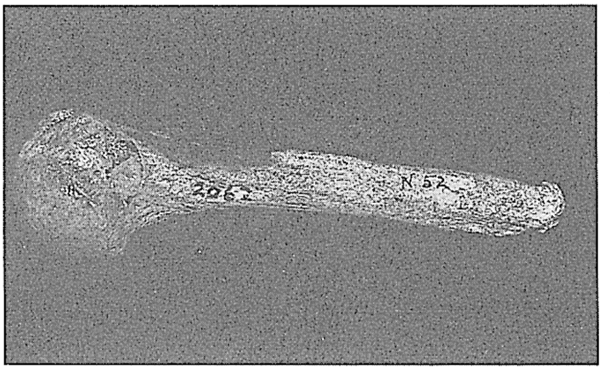


Fig. 11. A possible case of amputation at the midshaft of the humerus (No. 2062).

fication which was often seen in the case of non-union fracture of the long bones. Another possible traumatic change was in the left humerus of an adult male (No. 2732, Fig 12). A large bone mass with very smooth surface could be recognized at the proximal area of the shaft from the anatomical neck to the deltoid tuberosity. This large new bone proliferation corresponded with the location of the muscle belly of the deltoid. It showed no signs of malignant changes such as rough, irregular and spongy (unorganized) structure in the new bone mass. The left humerus was definitely shorter than the healthy right side. There were some shallow and curved grooves probably caused by vascular impression on the surface of the bone mass. In this case, posttraumatic myositis ossificans was the most favorite diagnosis of this morphology of limited lesion, rather than fibrous dysplasia, osteochondroma, osteoid osteoma, or osteosarcoma.

Fig. 12. A possible case of posttraumatic myositit ossificans with a large bone mass at the proximal shaft of the left humerus (No. 2732).

2) Infectious diseases

Cases in this category are principally classified into two major groups: 1) non-specific inflammatory bone changes, and 2) specific inflammatory bone changes. These classifications of inflammatory lesion originated in the modern concept of pathology and are also useful in paleopathology. In general, according to a textbook of modern pathology (e.g., Robbins Pathologic Basis of Disease, 1989), acute inflammation may have one of four outcomes: 1) complete resolution, 2) healing by scarring, 3) abscess formation, and 4) progression to chronic inflammation. The last one, chronic form of infection, may often begin insidiously as a low-grade smoldering response which is referred to as granulomatous inflammation and includes some of the most common and disabling diseases of humans, such as tuberculosis, leprosy, treponematosis, and schistosomiasis. The term of specific inflammation used here is almost equivalent to the term granulomatous inflammation.

Non-specific inflammatory changes on the bones are commonly characterized by periosteal reactive new bone formation limited on the surface to the normal cortex. These limited new bone proliferations are often called "plaque-like" bone lesions (Stothers and Metres; 1975), which may show various degrees of severity from small pitting with striations to irregular thickening deposits on the surface of bone. Periostitis is so frequently encountered in archeological skeletal materials that anthropologists could easily recognize this characteristic condition. However, this does not necessarily mean that it is easy to make an exact diagnosis on the etiology of the lesion. Periostitis, which may be derived not only from non-specific inflammatory changes but also from very early stage of specific inflammatory changes such as syphilis and tuberculosis, has often been treated as an independent entity because of its difficulty in determination of the etiology in borderline cases (Suzuki; 1991, Fig. 13).

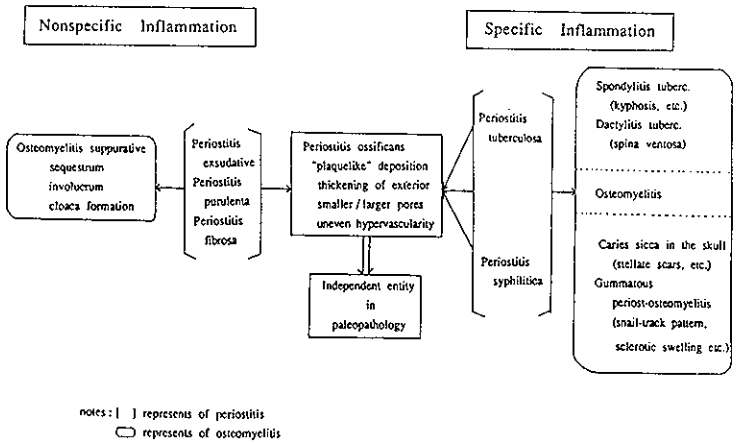


Fig. 13. Schematic representation of the inflammatory process of the bone in paleopathology (quoted and modified from Suzuki (1991)).

Though much less common than periostitis, another important type of non-specific bone lesion can be recognized in archeological skeletal remains. This is so-called osteomyelitis, which is characterized macroscopically by conspicuously drastic bone changes such as involucrum formation with sequestrum, cloaca for pus drainage and irregular sclerotic bone formation in the marrow space and neighboring cortex of the bone in typical and advanced cases.

Because of the close anatomical relationship of periosteum and bone marrow, clear distinction between periostitis, ostitis, and osteomyelitis in dry bone specimen cannot always be made. However, periostitis lacks pathological changes in and around the marrow cavity.

Both suppurative periostitis and osteomyelitis occur not only by hematogenous dissemination from other focal infections, but also by direct invasion of pyogenic bacillen from (chronic) skin ulceration or from serious (acute) traumatic wounds such as open fracture. Though *staphylococcus aureus* is the most common bacteria attributed to these suppurative non-specific bone infection, it is often impossible to detect the causative microorganism in paleopathology.

Specific inflammatory bone changes can be defined by certain characteristic features in the dry bone specimen. Originally, as stated above, specific (mesenchymal) inflammation in the living tissue tends to produce more or less granulomatous nodules or tubercula with peculiar proliferation of cells and/or connective tissue. These specific changes often occur in the skeleton, too, which can be easily recognized by their characteristic morphology in the dry bone specimen. The following three infectious diseases are representative of this category: tuberculosis, leprosy and treponematosis including venereal syphilis and yaws. Furthermore, these three specific inflammatory diseases tend to make their own distribution of the bone lesion which may often lead to a definitely correct diagnosis in paleopathology. Namely, tuberculosis can be detected frequently by bone lesions in the vertebral column; leprosy may leave severe atrophic changes in hand and foot bones as well as in facial bones around the nose; treponematosis usually produces serious destructive bone lesion in the skull vault and lower extremities.

In the examination of the Mokapu skeletal remains, as shown in Tables 7 and 8, there were eighteen (5.16%) cases showing inflammatory bone changes of 349 individuals. Among those eighteen, nine cases were diagnosed as non-specific infectious bone lesions, and only four cases (4/18; 22.2%) could be categorized as specific inflammatory changes. The remaining five cases, as shown in Table 8, were categorized as undetermined cases which could not be distinguished into either non-specific or specific inflammatory disease because of the borderline morphology of the lesions in vertebra and tibiae.

Regarding non-specific inflammatory lesions, there were two cases of periostitis in the long bones (No. 1656; Fig. 14, No. 1961) with typical features of bark-like or plaque-like new bone formation on the surface of the cortex of the metaphysis. Two cases (No.1707, No.1961) showed evidence of abscess and cloaca formation in the mastoid process (mastoiditis) of the skull.

There were four tibiae of two males (No. 1835; Fig. 15, No. 2281) and two females (No. 1742, No. 1824) which showed the same long-standing inflammatory features in the metaphysis consisting of sclerotic hypertrophy with the vascular impression like snail-tracking. These were tentatively diagnosed as chronic sclerotic osteomyelitis (Garre's sclerosing osteomyelitis), together with a slight possibility of osteomyelitis caused by treponematosis (probably yaws). In spite of the resemblance of pathological morphology to the treponemal osteomyelitis in tibiae, the laterality of the lesion, which was very inconsistent with typical cases of advanced treponematosis, could not allow for a diagnosis of treponematosis. Additionally, no characteristic changes of treponematosis could be found in the skull of those cases.

Only one case could be diagnosed as a clear-cut case of non-specific osteomyelitis. The right femur of an adult female (No. 2051) had the features of long-standing and drastic infection along the entire shaft of the femur, namely, the large involucrum with marginal sclerosis and many cloaca formations in the irregular

Table 7. List of the cases showing inflammatory bone changes

No.(BPBM)	Sex	Age	Location	Remarks [teutative diagnosis]
1329	F	Ad	Sacrum	osteolytic destruction in the ventral surface. [non-specific inflammatory change or metastatic carcinoma]
1490	M	Ad	Lumbar/Sacrum	destructive osteolytic changes with minimal bone proliferation. [tuberculosis]
1592	M	MS	Lumbar	inflammatory changes in the neighbouring lumbar spines. [suppurative spondylitis]
1656	M	Ad	r-Tibia & Fibula	periostitis with bark-like new lone formation. [non-specific periostitis]
1707	M	MS	Skull	many abscess and cloaca formation in the right mastoid process. [puruleut mastoiditis]
1742	F	Ad	r-Tibia	widely sclerotic change in the mid-shaft of the tibia with irregular surface. [Garre's osteomyelitis]
1801	M	MS	Thoracic/Lumbar	inflammatory changes in the neighbouring 12th thoracic and 1st lumbar spine. [suppurative spondylitis]
1824	F	MS	l-Tibia	widely hypertrophic and sclerotic bone changes with relatively smooth surface of the shaft of the tibia. [Garre's osteomyelitis or treponemal osteomyelitis]
1835	M	Ad	r-Tibia	hypertrophic and sclerotic bone change with bark-like bone formation and snail tracking pattern in the surface. [non-specific periost-osteomyelitis or treponemal osteomyelitis]
1864	F	MS	Skull	limited inflammatory erosion in the frontal bone probably caused by scalp ulceration. [non-specific infection]
1880	F	MS	r-Sacroiliac joint	destructive osteolytic changes in the right sacroiliac joint with exposured inner spongy trabeculae in the auricular surface. abscess formations with cloaca. [tuberculosis]
1961	F	Yg	Skull r-Humerus l-Tibia	cloaca formation with inflammatory change in the left mastoid process and external auditory meatus. periostitis with bark-like surface in the mid-shaft of the right humerus and left tibia. [external otitis with mastoiditis/non-specific periostitis]
2051	F	Ad	r-Femur	typical pathological changes of non-specific osteomyelitis showing irregular swelling of the shaft with cloaca and involucrum formation. [non-specific osteomyelitis]
2147	M	MS	Skull	two destructive inflammatory changes in the frontal process of right maxilla and below the nasion. no pathological changes in the maxilla-alveolar region. [non-specific inflammatory change (susp.)]
2281	M	Ad	r-Tibia	hypertrophic and sclerotic bone change with plaque-like irregularity in the mid-shaft of the tibia. [Garre's osteomyelitis or treponemal osteomyelitis]
2674	F	Ad	Lumbar	destructive osteolytic change in the 5th lumbar spine with minimal healing process. exposure of sclerotic spongy substances in the lesion. [tuberculosis]
2688	M	Ad	Thoracic	remarkable destructive changes in the neighbouring two lower thoracic spines with reactive new bone formation making bony bridge. [suppurative spondylitis]
2694	F	Ad	Thoracic	block-vertebrae formation with 6th-9th thoracic spines with chronic bone inflammatory changes. [tuberculosis]

Table 8. Inflammatory bone changes in the Mokapu series

Category	Sex		Location			
	Male	Female	Skull	Vertebrae	Upper Extr.	Lower Extr.
Non-specific inflammation periostitis / osteomyelitis	6	3	4	3	1	4
Undetermined	2	3	0	1 1)	0	4 2)
Specific inflammation						
tuberculosis	1	3	0	4	0	0
treponematosis	0	0	0	0	0	0
leprosy	0	0	0	0	0	0

Note: 1) osteolytic destruction probably caused by either inflammatory change or metastatic carcinoma in the ventral surface of sacrum (No. 1329).
2) sclerotic hyperostotic swelling in the tibial shaft probably caused by either non-specific inflammatory changes (Garre's osteomyelitis) or treponematosis (yaws) (No. 1742, 1824, 1835, 2281).

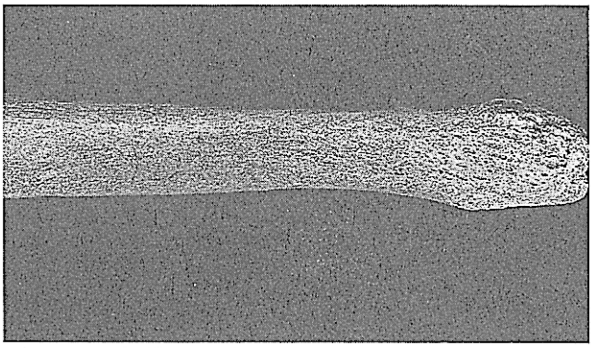


Fig. 14. A case showing non-specific inflammation in the tibia with bark-like new bone deposition on the surface of the shaft (No. 1961).

Fig. 15. A case with long-standing inflammatory process in the shaft with sclerotic hypertrophy and vascular impression (No. 1835).

swelling shaft of the femur (Fig. 16).

The most interesting finding among the inflammatory problems of the Mokapu skeletal series was the comparatively high frequency (7/18; 38.9%) of infectious changes in the vertebral column. Three cases (No.1592, No. 1801, No. 2688) were diagnosed as suppurative (non-specific) spondylitis rather than spinal tuberculosis, because they showed much reactive new bone growth and a lack of abscess formation surrounded by sclerotic trabeculae in the lesions.

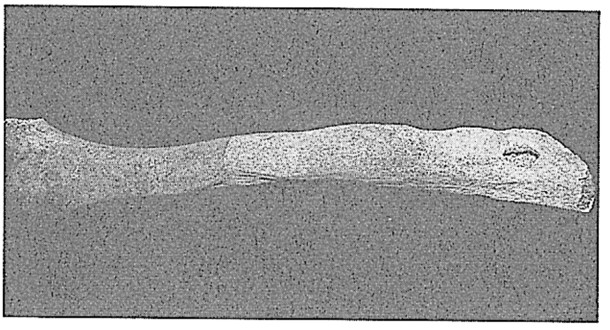


Fig. 16. A case of (non-specific) osteomyelitis with large involucrum and cloaca formation in the entire diaphysis of the femur (No. 2051).

Regarding specific inflammatory bone changes in the Mokapu series, there were four cases diagnosed as spinal tuberculosis (No. 1490; Fig. 17, No. 1880; Fig. 18, No. 2674, No. 2694; Fig. 19) with certainty (Table 9). Among them, two showed destructive and osteolytic changes with minimum reactive new bone formation in the lumbar spine. One revealed pathological destruction in the sacro-iliac joint, which is one of the most commonly involved areas in skeletal tuberculosis. Another had block-vertebral formation in the middle of the thoracic spines, which must have produced a humpback feature while the individual was alive.

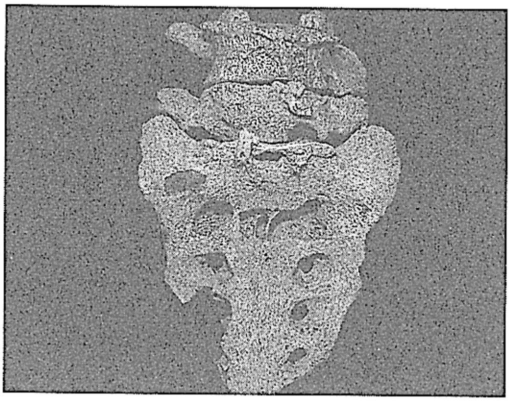


Fig. 17. Spinal tuberculosis (No. 1490).

Fig. 18. Spinal tuberculosis (No. 1880).

Fig. 19. Spinal tuberculosis (No. 2694).

Table 9. Four cases diagnosed as tuberculosis in the vertebral column

No. (BPBM)	Sex	Age	Location	Remarks
1490	M	Ad	Lumbar/Sacrum	Destructive osteolytic changes with minimal healing process in the lumbar bodies and ventral surface of sacrum.
1880	F	MS	Sacroiliac joint	Destruction in the right sacroiliac joint producing many abscess cavities with cloaca and exposured inner spongy trabeculae in the auricular surface.
2674	F	Ad	Lumbar	Osteolytic change with evident sclerosis in the spongy substance of the 5th lumbar spine.
2694	F	Ad	Thoracic	Block-vertebrae formation from 6th to 9th thoracic spines with chronic inflammatory changes.

The inner aspect of the underlying trabecular bone of these destructive lesions probably caused by tuberculosis was distinctive with sclerotic and hypertrophic trabeculae, which may be one of the representative features of skeletal tuberculosis (Suzuki; 1985).

There was neither a case of treponematosis nor of facial leprosy among the 326 Mokapu skulls. As stated before, these two specific infections tend to produce characteristic pathological changes on the skull. In the calvariae and crania affected by treponematosis, as Hackett (1975) described pathological changes based on the description by Virchow in 1896; "caries sicca, the scar remaining after the healing of superficial gummatous osteitis of the calvaria was the only pathognomonic bone change of syphilis". Gross pathology of the cranial syphilis, which may be similar to other cranial treponematosis, is usually characterized by: 1) diffuse and multi-focal lesions, 2) various morphological features such as osteolytic destruction, sclerotic clumps of bone and stellate scars, and 3) healed process with reactive and irregular new bone formation (Suzuki; 1984). These characteristic gross pathologies, once seen, could never be confused with any other diseases. In this context, concerning yaws, one of the treponematosis which can be found commonly among the ancient tropical Pacific islanders, there might have been no prevalence among the ancient Hawaiians. If treponematosis with the exception of pinta had been present among them, many characteristic gummatous lesions mentioned above should have been recognized much more frequently in the skull vault, and typical subperiosteal new bone formation should have been widespread in both tibiae and femora bilaterally.

Though not being counted in this study and stated here only as reference, there were some other interesting specimens showing inflammatory lesions. An isolated scapula which, therefore, could not be sexed and estimated age at death, had the marked feature of suppurative osteomyelitis, probably caused by serious injury (Bower; ibd). Johnson and Kelley (1974) described three vertebrae of an adult of middle age showing a very large area of massive destruction with excessive vascular pitting, and pocking in the lesion of all vertebrae which most probably was caused by tuberculosis. They also described irregular punched-out lesions appearing in four vertebrae of an adult of the middle age range with the conclusion "granulomatous inflammation is more likely than a suppurative inflammation because of the extensive destruction and the absence of sclerosis in the underlying cancellous bone".

Regarding the other prehistoric Hawaiian skeletal population from Keopu site (Collins; 1986), 26 cases of 269 (9.67%) adult skeletons showed evidence of infectious diseases, which was a significantly higher frequency than that of the Mokapu series (5.16%, $\chi^2 = 4.67$, $P < 0.05$). However, in almost all cases of the Keopu series, the identified pathology was periostitis, and there was no clear-cut case of osteomyelitis with the formation of cloaca and involucrum. In contrast with the Keopu series, as stated above, there were several cases showing typical osteomyelitis in both non-specific and specific inflammatory processes in the Mokapu skeletal series.

3) Bone Tumors

On the basis of original cell line of the tumor matrix, detail classifications of bone tumor (and tumor-like condition of bone) have been made in the modern clinicopathological field (e.g., Liechtenstein; 1977).

In paleopathology, however, because of the difficulty of detailed classification, gross obsevation on dry bone specimen can allow classification into the following three major categories: 1) benign bone tumor, 2) malignant bone tumor, 3) tumor-like condition and/or soft tissue tumors affecting the bone, which is also used in this study.

a) Benign bone tumor

In this category, osteoma usually called ivory osteoma or button osteoma, is by far the most common form in the archeological skeletal materials. Among the Mokapu skeletal series, this benign osteoma could be found most frequently in the frontal and parietal areas of the skull. As is well known, the shape of osteoma is considerably variable, ranging from obscure without definite margin to unequivocal structure of bony protrusion. It is somewhat difficult, therefore, not only to diagnose this bone tumor with certainty, particularly in obscure cases, but also to take an exact incidence among skeletal populations.

Osteochondroma (osteocartilaginous exostosis) is the most common tumor of bone among the benign bone tumors in the clinical aspect (Jaffe; 1968; Dahlin, 1978). However, only a few examples have been identified and reported from archeological materials. Osteochondroma is usually classified into two categories based on the etiology, distribution and shape of the lesion, i.e., "solitary osteochondroma" representing only a single lesion in the skeleton, and "multiple osteochondroma" showing lesions widely distributed over the skeleton. There is a certain difference in shape between "solitary" and "multiple" osteochondroma. The former tends to show a single cartilage-capped bony projection with peduncle, and the latter, being much less common than the former, is usually characterized by multiple exostosis with sessile shape, particularly in the long bones. In the present study, focusing on the proximal part of the tibia, gross obsevations of these osteochondroma were made in the Mokapu skeletal series.

Seven tibiae of six individuals of the 177 adult skeletons showed osteochondroma. All but one had a solitary type of osteochondroma, as shown in the table and figures (Table 7, Fig. 20, 21). The rate of occurrence of osteochondroma was 3.39 percent (6/177) and the incidence of affected tibiae was seven (2.07%) in the Mokapu series. Among six individuals showing this benign tumor, three were males and three were females. The incidence of osteochondroma in each sex (3.7 percent in male and 3.1 percent in female) represented no significant sex difference. Regarding the morphology of osteochondroma, as described in Table 10, four were of the peduncle type and only one was sessile type (No. 2142) which was diagnosed as "multiple osteochondroma".

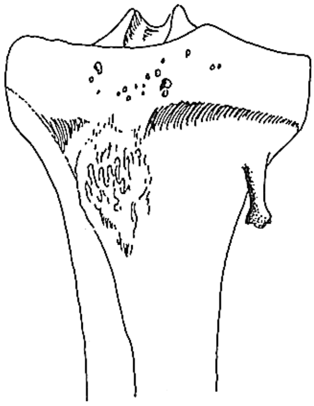


Fig. 20. Schematic representation of small osteochondroma projecting from proximal metaphysis of tibia.

Fig. 21. A case of multiple osteochondroma (hereditary multiple exostosis or diaphyseal aclasis) (No. 2142).

Table 10. The cases showing osteochondroma in the tibiae from the Mokapu site

Registered No.	Sex	Age	Side	Location	Type / description
1577	M	MS	left	prox., med.	peduncle type with enlarged distal component as shown in Fig. 2-a.
1864	F	MS	right	prox., med.	hook-like appearance with tapering down to a point as shown in Fig. 2-b.
2142	M	Ad	both	prox. both (multiple)	sessile type with flat distal component in particular in the left side as shown in Fig. 2-c.
2692	F	Ad	left	prox., med.	peduncle type
2719	F	Ad	left	prox., med.	peduncle type with long stem.
2731	M	Ad	right	prox., med.	peduncle type

b) Malignant bone tumor

This category consists of the following two groups: 1) primary malignant tumor of bone, and 2) secondary malignant tumor (metastatic carcinoma to the bone). There were three cases diagnosed as malignant bone tumor among the Mokapu skeletal remains as shown in Table 11.

Table 11. List of cases showing the lesion of malignant bone tumor

No. (BPBM)	Sex	Age	Location	Remarks
1359	M	MS	Skull	isolated skull with many osteolytic holes scattered in the entire skull. "punched out" lesion probably caused by multiple myeloma.
1506	F	Ad (ca.20 yrs)	l-Femur	extremely irregular bone proliferation in the distal end (metaphysis ~ diaphysis) of the left femoral shaft. "coral-like" appearance with "sun-burst" in X-ray films confirmed the diagnosis of osteosarcoma (Suzuki; 1987).
1617	F	MS	Vertebrae r-Innominate	"moss-eaten" destructive lesions widely scattered in the vertebral column and pelvic bone. favorite diagnosis was metastatic cancer (breast, lung, kidney etc.) to the bone.

One case was diagnosed as osteosarcoma, one of the primary malignant bone tumors. The distal portion of the left femoral shaft of a young-adult female (No. 1506; Fig. 22) consisted of an extensive amount of tumorous tissue showing a coarse, coral-like appearance expanding not only outwardly, but also into the marrow cavity (Suzuki; 1987). The marrow space was completely filled with massive tumorous bone tissue so that the normal spongy structures of the metaphyseal area disappeared. There were many bone fragments separated from the original locations of the lesion due to postmortem change. These bony fragments also showed

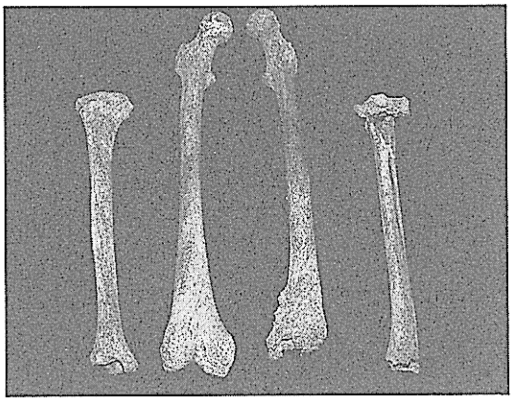


Fig. 22. A case of osteosarcoma found in a distal metaphyseal area of the left femur of a young-adult female (No. 1506; already reported by the author in 1988).

an irregular massive growth of bone tissue as well as tumorous tissue associated with the original lesion of the femur. X-ray films of this specimen showed a divergent speculated pattern, and the so-called "sunburst appearance" could be recognized. On the basis of the morphological findings obtained from both gross observation and X-ray examination, osteosarcoma is the most likely diagnosis in this young-adult Mokapuan female.

The other two cases were diagnosed as secondary metastatic tumor of bone. The skull of a mature male (No. 1359) showed many osteolytic destructive lesions without any healing process (Fig. 23). The age of this individual, from the isolated skull, was estimated at more than fifty years old at death, based on both the almost complete suture closures in the crania and the remarkable attrition of the teeth. The whole appearance of the lesion consisted of many osteolytic holes with diameters ranging from 5 to 9 mm looking just like a "punched out" lesion usually found in certain malignant bone tumors such as multiple myeloma, metastatic tumors to the skull from breast, thyroid and stomach cancers. X-ray film also revealed "punched out" lesion spread in the entire skull where neither hyperostotic nor sclerotic changes around destructive holes could be found. In this case, inflammatory changes by bacterial infection seemes most unlikely because of the lack of healing processes. Multiple myeloma is the most suitable to sex and age of this individual.

Fig. 23. A case of secondary metastatic tumor in the skull showing many osteolytic destructions without any healing process (No. 1359).

Another case of this category could be found in an almost whole skeleton with good preservation (No. 1617, Fig. 24). This individual, estimated as a mature female, had several osteolytic lesions in the vertebral column and in the right pelvic bone. There were no pathological changes in either skull or long bones of the extremities. Diffuse osteolytic destruction with moth-eaten appearance could be

Fig. 24. A possible case of secondary metastatic tumor in the vertebral column (No. 1617).

recognized in the bodies and neural arches of the 7th, 8th, 12th thoracic and 2nd lumbar vertebra, and in the center of ventral surface of the sacrum. Those pathological destructions without any healing processes invaded more or less into the inner spongy bones of the vertebral body. The same type lesion of moth-eaten appearance also existed in the right iliac crest of the innominate bone where the inner spongy structure was exposed, as well as in the vertebral bodies. Considering the age and sex of this individual, those destructive "moth-eaten" lesions without healing status lead without doubt to a diagnosis of metastatic carcinoma to the bone. As to the primary region of the cancer, while several types of cancer may produce such osteolytic changes, breast cancer is one of the most frequent carcinoma in the mature female. Other metastatic cancers from thyroid, lung, kidney and stomach could not necessarily be ruled out (Suzuki; 1989).

Recently, Strouhal (1991) took into account the problems in differential diagnosis between lesions caused by the primary osseous tumor "multiple myeloma" (MM) and the "lytic form of metastatic carcinoma" (LMC), and demonstrated several critical features that might be of use in the separation of both disorders including the 1) density of the lesions, 2) the form of the outline of the lesions, 3) the size of the lesions, 4) the sharpness of the edges of the lesions, 5) X-ray film findings, 6) topographic predilection, and 7) sexual predilection. His discussion based on these features is helpful in the consideration of differential diagnosis among the cases showing malignant osteolytic changes found in the Mokapu skeletal series.

4) Metabolic disorders of bone

There are many metabolic diseases affecting the skeleton, such as rickets, osteomalacia, scurvy and gout. Rickets results from a lack of vitamin D and of a utilization of calcium during the bone formation, which, therefore, usually occurs during early childhood. Sometimes it causes bone softening and deformation, particularly in the weight-bearing long bones in advanced cases. The etiology of osteomalacia, a bone disease of adulthood, is identical with that of rickets-vitamin D deficiency (Ortner and Putcher; 1981). Scurvy arises from a lack of vitamin C, and sometimes shows consequent subperiosteal hemorrhage which can be seldom recognized in the archeological materials, particularly in the ancient Pacific Islanders. Regarding evidence of vitamin C deficiency or scurvy, Saul (1976) found that seventeen (27%) among 63 adult individuals showed ossified subperiosteal hemorrhages in various locations on various bones from ancient Maya remains in Guatemala. He stated that "in seeking an explanation for the high and frequently associated occurrence of ossified subperiosteal hemorrhages and periodontal degeneration, it has become apparent that a good circumstantial case can be made for vitamin C insufficiency resulting in various degrees of deficiency through to scurvy". In the Mokapu skeletal remains, neither evidence of rickets nor of scurvy could be found.

Fig. 25. A possible case of gout with well-defined lytic lesion in the first metatarso-phalangeal joint in the foot (No. 2662).

Gout results from failure to excrete uric acid, with consequent accumulations of sodium biurate in the form of joint tophi. Particularly, typical punched out lesion by tophi (masses) is found around the first metatarso-phalangeal joint in the foot. A possible case of gout was found in an almost complete adult male skeleton (No. 2662 Fig. 25). The age at death of this individual could be estimated to be mid-thirty's, using major skeletal morphology for age-estimation. In the skull, cribra orbitalia with porous type existed in both orbital roofs. The right tempolo mandibular joint showed osteoarthrotic changes. In the foot bones, there were also remarkable osteoarthrotic changes with pitting, eburnation and osteophytes in and around the articulation at the talo-navicular, talo-calcaneal and other intratarsal joint areas. Furthermore, conspicuous bone ankylosis probably caused by advanced osteoarthrotic changes existed between the first and second cuneiforms and second metatarsal bone. Besides these extensive osteoarthrotic changes, well-demarcated and round-shaped osteolytic destruction could be recognized in the first metatarsal-phalangeal joint. The bone defect with a diameter of about 1 cm was located in the dorsal side of the joint. Although there was no evidence of chalky substance which might have been packed in the defects as seen in the case mummies (Wells; 1965), the characteristic location and figure of sharply circumscribed defects suggested that gouty tophi was the most likely diagnosis in this middle aged man.

5) Congenital abnormalities

There were several cases of this category in the Mokapu skeletal series. An adult isolated skull with associated mandibula (No. 2721) showed a tendency of craniosynostosis by premature suture closure of the sagittal suture in the skull. Regarding age-estimation, dentition with complete eruption of the third molars meant that the age at death of this women should be more than twenty (cf., Brothwell; 1981). On the other hand, complete dental condition with minimum attrition suggested that this individual should be younger than middle-aged and might be around the mid-twenty's. In spite of her age, the sagittal suture revealed complete obliteration of almost the entire part. Additionally, other cranial sutures such as coronal and lumbdoidal also showed complete fusion and partial obliteration. The upper view of the skull with the cranial index of 71.8 belonged to the dolicocrania, and did not reveal typical scaphocephalic appearance. Despite its shape and the cranial index, the skull showed clear evidence of premature suture closure in the three major sutures which could be diagnosed as craniosynostosis.

Congenital anomaly in the upper cervical vertebrae could be found in two cases. An adult female (No. 1758) showed congenital fusion between C_2 and C_3 in the bodies, pedicles, arches and a root of spinous processes, which was one of the most common anomalies in the cervical spine (Gunnes-Hay; 1984). Another anomaly with incomplete fusion at the posterior tubercule (spina bifida) in the atlas was recognized in an adult female (No. 2678). A mature male (No. 1519) had spina bifida at the tip of the spinous process of the sixth cervical vertebra.

Unidentified two middle ribs fused together at the area between tubercle and angle without any traumatic or inflammatory evidence in an adult male (No. 2048; Fig. 26).

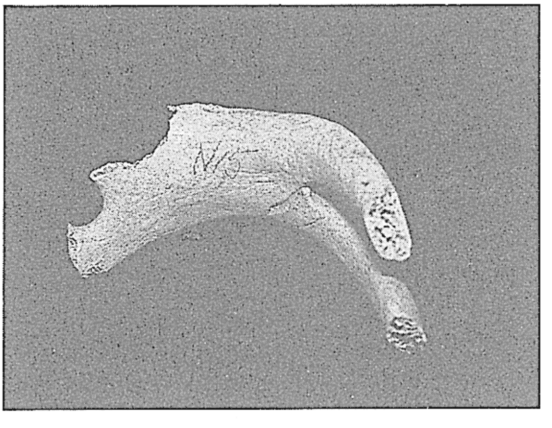


Fig. 26. Congenital fusion of the ribs (No. 2048).

Congenital anomaly concerning unilateral spondylolysis could be detected in an adult male (No. 1858; Fig. 27), i.e., a small fragment caused by unilateral spondylolysis at the left pars interarticulasis (inferior) of the third lumbar spine completely ankylosed with the corresponding area of the left parts interarticularis (superior) of the fourth lumbar spine.

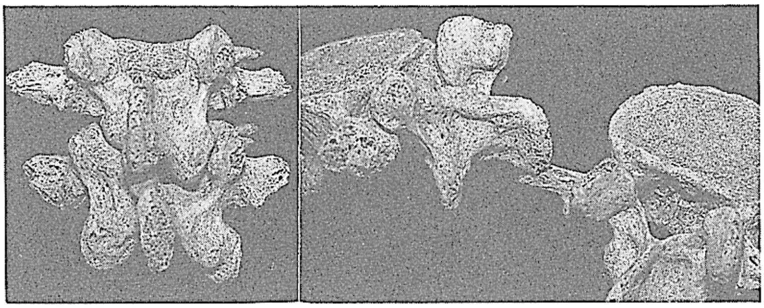


Fig. 27. Unilateral spondylolysis with congenital anomaly (No. 1858).

6) Hyperostotic conditions in the vertebrae (SD, ASH, DISH)

In the paleoepidemiological analysis, the author deals with the frequency and degree of osteophytosis in the lumbar spine through the diagnosis of spondylosis deformans (SD). Though SD has been traditionally considered as a degenerative process of aging, appearing along the margin of the vertebral body, other pathological entities resembling the morphology of SD in each isolated vertebra have been recently proposed as a hyperostotic condition occurring not only in each vertebra, but also in the whole vertebral column and/or general skeletal system. These are ASH (ankylosing spinal hyperostosis by Forestier and Rotes-Querol; 1950) and DISH (diffuse idiopathic skeletal hyperostosis by Resnick *et al.*; 1975), respectively.

From the paleopathological point of view, Waldron (1991) recently reported the prevalence of osteoarthritis of the facet joints, osteophytosis, intervertebral disc disease and DISH on 968 skeletal individuals from a crypt in London used between 1729 and 1859. He concluded that osteophytes were common in the thoracic and lumbar spines. Concerning DISH in this skeletal group, he reported that 47 skeletons matched the criteria for DISH, and the prevalence in the 65 + age group in females was 16.4 per 1000. He also pointed out that the difference in the frequency of DISH between males and females was highly significant in this skeletal sample. Another result of his study showed that there was no significant correlation between DISH and age, which correlated significantly with other conditions such as osteoarthritis, osteophytosis and intervertebral disc disease.

Snow (1974) described these hyperostotic conditions on the vertebrae under the name of "arthritis deformans (osteoarthritis)" as follows: "The most dramatic evidence of arthritis was found along the backbone. The lumbar vertebrae show bony spurs (osteophytes) first. In the most extreme cases the arthritic outgrowths join each other, literally fusing one vertebra to the next, above and below —that is, ankylosis. ···, as if by candle wax which in melting has flowed down over the candle and candlestick". He also reported the frequency of such osteoarthritis in the vertebrae of the Mokapu series. That is, among 164 (66 males and 98 females) spinal columns, 127 (or 77 percent) showed evidence of some degree of arthritis ranging from "beginning" (73 cases), "moderate" (39 cases) and "advanced or extreme" (15 cases). Thirty-five (or 21 percent) of 164 cases had arthritis in all areas of the spine, usually in varying degree, with an advanced stage in the lumbar region.

In the present study, hyperostotic conditions are described and classified under the definition of ASH as ankylosing hyperostosis along the vertebral culumn, and DISH as systemic hyperostosis not only in the vertebral column, but also in the other skeletal parts of the whole body. However, during the actual observation of these hyperostotic conditions, there were many borderline cases with subtle and overlapping differences in the dry bone materials. The Table 12 lists the cases showing such hyperostotic condition found in the Mokapu skeletal population (Fig. 28, 29).

Table 12. The list of the cases showing hyperostotic condition in the whole vertebral column (ASH) and/or in the systemic skeleton (DISH).

Designation	Sex	Age	diagnosis	description
1538	F	Ad	ASH	: very sever SD (almost kissing between $L_1/_2$) along the vertebral column.
1557	F	MS	DISH	: kissing spines along the vertebral column with appearance of candlewax dripping and bamboo spine. complete fusion at the left sacro-iliac joint. severe OA changes in the major joints of the long bones.
1632	M	Ad	ASH (DISH?)	: kissing spine between L_5 and S_1. severe OA change in both apophyseal joints in the cervical spines and major joints of the long bones.
1656	M	Ad	ASH	: very sever SD (almost kissing) along the vertebral column.
1693	M	MS	ASH	: very sever SD (almost kissing) along the vertebral column.
2659	M	Ad	ASH	: very sever SD (almost kissing) along the vertebral column.
2684	F	Ad	ASH (DISH?)	: complete kissing in the lower thoracic and in the lumbar spines with appearance of bamboo spine. incomplete fusion in the left sacro-iliac joint. mild OA changes in the major joints of the long bone.
2706	M	MS	DISH	: very severe osteophytes partly kissing the adjecent vertebrae in the lower thoracic and lumbar spines. marginal lipping formation in the sacro-iliac joint. remarkable and advanced OA changes in major joint areas and excess ossification in some muscle attachment areas in the long bones.
2725	M	Ad	ASH	: very severe SD (almost kissing) along the vertebral column.

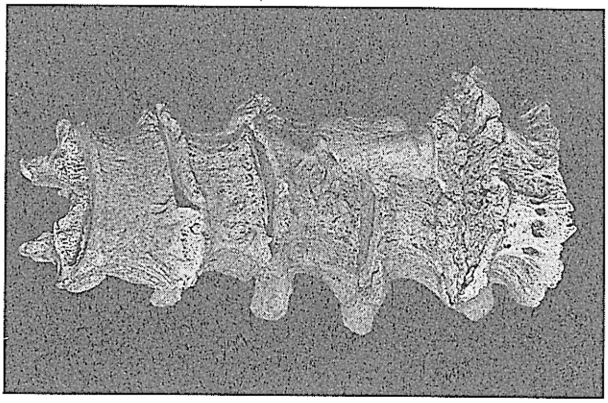


Fig. 28. A case of hyperostotic conditions in the vertebral column (ASH; No. 2659).

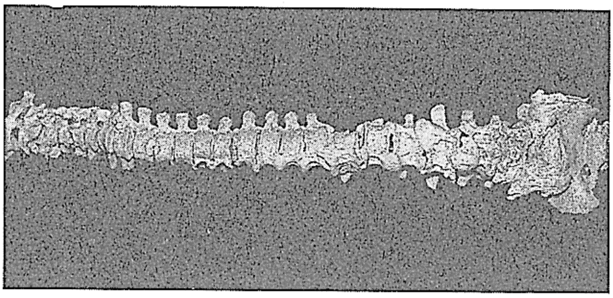


Fig. 29. A case of hyperostotic conditions in the vertebral column (ASH or DISH?; No. 2684).

PALEOEPIDEMIOLOGICAL ANALYSIS

—using some stress markers appearing on bones—

Various bone changes caused by "stress", not only in individual bones but also in skeletal populations, have recently been considered as paleoepidemiological indicators, which are powerful and indispensable in analyzing the health condition and disease pattern among prehistoric skeletal populations. This is largely due to the accumulation of archeological information concerning the subsistence of prehistoric people and osteological materials showing such common changes in bone.

According to Goodman et al. (1984), physiological disruption ("stress") causing bone pathology is a product of three sets of factors, i.e., environmental constraints, cultural systems, and host resistance (Fig. 30). They attempted to construct three groups of indicators of stress with the following headings: (1) indicators of general, cumulative stress including mortality, growth assessment, etc., (2) indicators of general, episodic stress including Harris lines, enamel hypoplasia, etc., (3) indicators of stress associates with specific diseases including porotic hyperostosis (cribra orbitalia), degenerative conditions of joints, etc. as listed in Table 13.

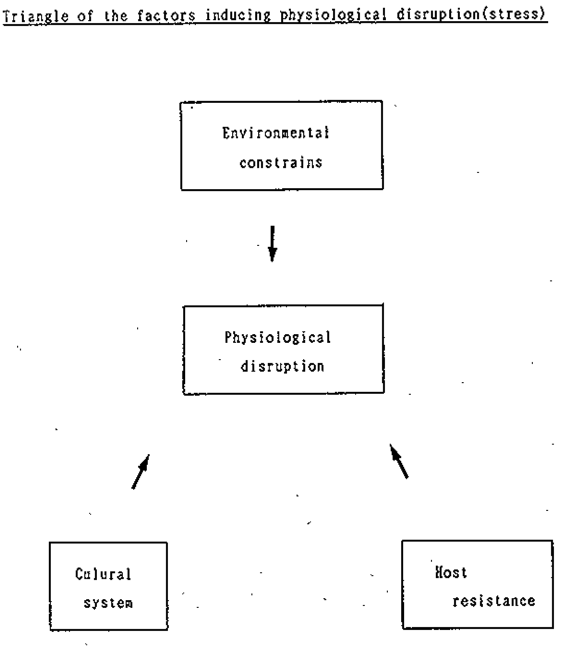


Fig. 30. Three main factors inducing physiological disruption (stress) (quoted from Goodman *et al.*; (1984)).

Table 13. Indicators of stress in the archeological skeletal population (quoted and modified from Goodman *et al*, 1984)

Ⅰ) General and Cumulative indicators
  1) Mortality
    i) life expectancy at birth
    ii) construction of life tables
  2) Growth assessment
    i) measurments of long bones for each category (in subadults and adults)
    ii) estimation of stature
    iii) sexual dimorphism

Ⅱ) Episodic indicators
  1) Harris lines (dense transverse lines of long bones)
  2) Enamel hypoplasias (enamel aplasia from a cessation in amelogenesis)
  3) Wilson bands (microdefect in amelogenesis)

Ⅲ) Specific disease indicators
  1) Porotic hyperostosis and cribra orbitalia
  2) Trauma
    i) fractures
    ii) dislocations and displacement
    iii) deformity induced artificially
  3) Infections diseases
    i) non-specific infections
    ii) specific infections

4) Degenerative conditions
   i) osteoarthritis in the major joints
   ii) degenerative changes in the vertebral column
5) Congenital abnormality
   i) synostotic changes (ex. craniosynostosis)
   ii) defective changes (ex. spina bifida occuluta)
6) Dental pathologies
   i) attrition
   ii) caries
   iii) abscessing/periodontal alveolar resorption

Ⅳ) Trace Element Studies

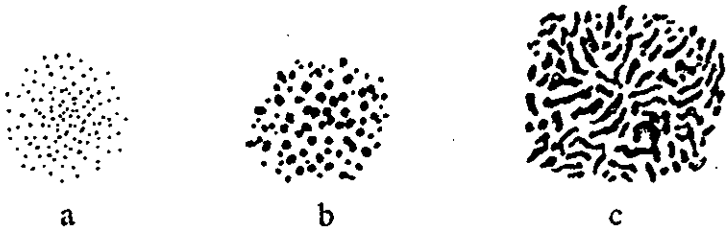
In this study, only indicators of stress associated with specific diseases were observed and analyzed. Some other indicators including mortality and growth assessment by long bone measurements had already been studied by Snow (1974). The following indicators are particularly focused in this study: (1) porotic hyperostosis (cribra orbitalia (CO)), (2) spondylosis deformans (SD) in the lumbar spine, (3) osteoarthrosis in the apophyseal joints (OA) in the cervical spine, (4) spondylolysis (SL) in the fifth lumbar, and (5) degenerative joint disease (DJD) with osteoarthrotic changes in the elbow and knee joints.

1) Cribra orbitalia

Cribra orbitalia is characterized by a sieve-like osteoporosis in the anterior portion of orbital roofs, usually appearing bilaterally. Since Welcker described this condition in 1888, many anthropologists have reported racial incidences, and discussed the etiology of cribra orbitalia linked with both malnutritional status and iron-deficiency anemia during childhood in particular. Recently, based on its etiological factor, cribra orbitalia has been used as a good epidemiological indicator on the health condition of ancient human populations (e.g., El-Najjar *et al.*, 1976; Cybulski, 1977; Lallo *et al.*, 1977).

In the present study, the frequency and severity of cribra orbitalia appearing in the adult skulls from the Mokapu site were examined. The total number of materials used in this study was 303 (154 males and 149 females) adult skulls, which were in well-preserved condition for observing the anterior orbital roof. Regarding the classification of cribra orbitalia, one of the most popular classifications proposed by Nathan and Haas (1966) was adopted. As shown in Fig. 31, three types of cribra orbitalia were examined. Namely, 1) the porotic type (characterized by scattered fine and small foramina), 2) the cribrotic type (characterized by larger and more numerous pits and holes), and 3) the trabecular type (characterized by larger coalescing holes with deep furrows).

As a result, 38 of 303 skulls (12.5%) showed cribra orbitalia ranging from porotic to cribrotic type as shown in Table 14. The incidence was 13.0% (20/154) in males and 12.1% (18/149) in females. Among these 38 cases, the greatest degree of severity was found in an adult female skull labeled No. 1980, which was classified as cribrotic type. Twenty-nine of 301 were involved in the right side orbit, and



Schematic representation of the three main types (degrees of development) of the cribra orbitalia.
a) Porotic type: scattered, isolated fine apertures.
b) Cribrotic type: conglomerate of larger but still isolated apertures.
c) Trabecular type: apertures confluent resulting in the formation of bone trabeculac.

Fig. 31. Classification of cribra orbitalia (quoted from Nathan and Hass; (1966)).

Table 14. List of individuals showing cribra orbitalia

No. (BPBM)	Age[1)]	Sex[2)]	Cribra orbitalia[3)]	
			r	l
1296	Ad	M	+	+
1333	MS	F	/	+
1338	Ad	M	+	+
1539	Ad	F	++	++
1582	Yg	F	−	+
1610	Ad	M	+	+
1632	Ad	M	−	+
1705	Yg	F	+	+
1719	Ad	M	−	+
1724	MS	F	+	−
1750	Ad	F	++	+
1760	MS	M	+	+
1780	Ad	F	+	+
1798	Yg	F	++	++
1858	Ad	M	+	+
1933	Yg	F	++	++
1939	Ad	M	++	++
1947	Ad	F	−	+
1970	Yg	M	++	++
1980	Yg	F	++	++
2044	Ad	M	++	++
2056	MS	M	+	−
2067	Yg	M	++	++
2075	Ad	M	−	+
2076	Ad	M	−	+
2118	MS	F	−	+

2140	MS	M	+	+
2153	Yg	M	+	+
2219	Ad	M	+	+
2221	MS	F	+	+
2651	Ad	F	++	++
2662	Ad	M	+	+
2669	Ad	M	+	+
2675	Ad	F	+	+
2694	Ad	F	+	+
2706	MS	M	+	+
2749	Ad	F	+	+
2759	MS	F	−	+

Note; 1) Yg; young, Ad; adult, MS; mature/senile
2) M; male, F; female
3) ╱; unobserved, −; absent, +; porotic type, ++; cribrotic type

thirty-six of 302 were in the left side. There was no significant difference in frequency either between males and females, or between right and left side (Table 15).

These frequencies of cribra orbitalia obtained from the Mokapu skulls seem to be almost average and within normal range among ancient Pacific skeletal populations (Table 16), which means that the living and nutritional condition of the Mokapu people may have been a relatively good one, at last concerning iron-supply in the food in the pre-Cook period (Suzuki; 1986).

Table 15. Frequency of cribra orbitalia

Total number of C.O. / Skull ;	38 / 303 (12.5%)
Sex differencies ; n.s.	[20 / 154 (13.0%) in male, 18 / 149 (12.1%) in female]
Side differencies ; n.s.	[29 / 301 (9.6%) in right, 36 / 302 (11.9%) in left]
Age differencies ; sig.	[8 / 34 (23.6%) in young, 21 / 232 (9.1%) in adult, 9 / 83 (10.8%) in mature and senile]

Table 16. Frequencies of cribra orbitalia in adult skulls among the Pacific skeletal populations

Hawaiin (Mokapu)	12.5% (38/303)
Micronesian (Guam)	9.9% (16/161)
Ainu	14.3% (20/140)
Australians	14.3% (57/400)

2) Spondylosis deformans (SD)

Spondylosis deformans characterized by excess bony development (osteophytosis) at the superior and/or inferior margin of the vertebral body is the most common pathological feature encountered in ancient skeletal remains. The etiology of this bony outgrowth with spur formation is attributed to, besides the aging process, continuous mechanical (and microscopic) stress caused by hard physical activities. That is the reason why SD has been also used as a good indicator of health status in skeletal populations (Swedborg; 1974, Suzuki; 1978, Gunness-Hey; 1980, Waldron; 1991).

The degree of osteophytosis involved in each vertebra was classified according to morphology as follows: 1) slight but recognizable osteophytes as isolated points along the inferior and/or superior margins of the vertebral body; 2) lipping curling away from the margins of bony projectiles without a break horizontally; 3) extensive and marked lipping assuming the characteristic bird's beak shape with curving upwards or downwards, and 4) ankylosing or union of the osteophytes on the adjacent vertebra in advanced cases (Fig. 32). In the present study, the frequency and degree of osteophytes (severity) were examined in the lumbar vertebrae, one of the most common sites for this pathology in the vertebral column (Nathan; 1966, Wada; 1975, Suzuki: 1978).

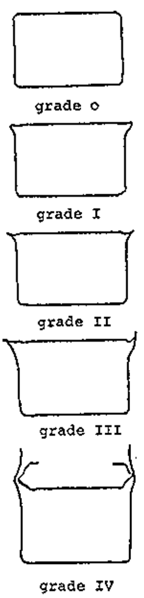


Fig. 32. Schematic representation of degree of osteophytes in the lumbar vertebra (quoted from Suzuki; (1978)).

Table 17 shows the result of examination of SD on 149 (74 males and 75 females) individuals. There was a significant sex difference in the frequency of non-SD (grade-0). As to the degree of SD by aging, there was a positive (direct) association between age and grade, i.e., the older the age-group, the more the advanced grade of SD. Table 18 shows the comparative data of the frequencies of the lumbar SD in males from other Pacific skeletal pupulations.

Table 17. The frequency of SD in the lumbar vertebrae of the Mokapu skeletal population

Sex	Age-group	No. of individual	No. of lumb. vert	No. of involved vert.			
				grade-0	grade-1	grade-2	grade-3 +
male	Young	2	10	10	–	–	–
	Adult	56	268	112	33	45	78
	Mat./Sen.	16	76	9	15	20	32
	Total(%)	74	354(100)	131(37.0)	48(13.6)	65(18.4)	110(31.1)
female	Young	10	44	44	–	–	–
	Adult	49	237	156	30	30	21
	Mat./Sen.	16	72	16	13	21	22
	Total(%)	75	353(100)	216(61.2)	43(12.2)	51(14.4)	43(12.2)

Table 18. Comparison of frequency of S.D. in lumbar spine (male only)

Population	No. of individual	Total No. of lumbar	No. of lumbar with S.D. (%)			
			grade-0	grade-1	grade-2	grade-3 +
Mokapu (Present study)	74	354	131 (37.0%)	48 (13.6%)	65 (18.4%)	110 (31.1%)
Mariana (Suzuki; 1986)	8	33	20 (60.6%)	5 (15.2%)	2 (6.1%)	6 (18.2%)
Jomon (Suzuki; 1978)	54	210	35 (16.7%)	55 (26.2%)	54 (25.7%)	66 (31.4%)
Edo-Japanese (Suzuki; 1978)	24	84	22 (26.2%)	27 (32.1%)	17 (20.2%)	18 (21.4%)
Ainu (unpublished)	42	194	83 (42.8%)	36 (18.6%)	32 (16.5%)	43 (22.2%)
Marquesas (Pietrusewsky; 1976)	–	103	86 (83.5%)	6 (5.8%)	11 (10.7%)	0

3) Osteoarthrotic (OA) change in the apophyseal joints of the cervical vertebrae

Osteoarthrotic changes are one of the most frequent pathological changes appearing in the skeletal population. By far the most common area to be involved is the weight bearing long-bones joints, such as hip and knee joints. Cervical apophyseal joints are also one of the most affected areas because they bear the heavy weight and complex movement of the skull in human beings.

These OA changes in the cervical apophyseal joints, as well as those in SD and DJD, may also result from degenerative processes accelerated by aging and continuous mechanical stress on the relatively small joints. OA changes in this area, therefore, may serve as a health indicator of the skeletal population. OA changes in the cervical apophyseal joints are characterized by increasing porosity (pitting) in the articular facet, and by excess bone formation (osteophytes/lipping) around the articular margin. Fig. 33 shows the classification of these apophyseal OA changes originally proposed by Higuchi (1983) and adopted for the present study. Fig. 34 is an example of OA in the apophyseal joint of the cervical spine found in an adult male (No. 1524).

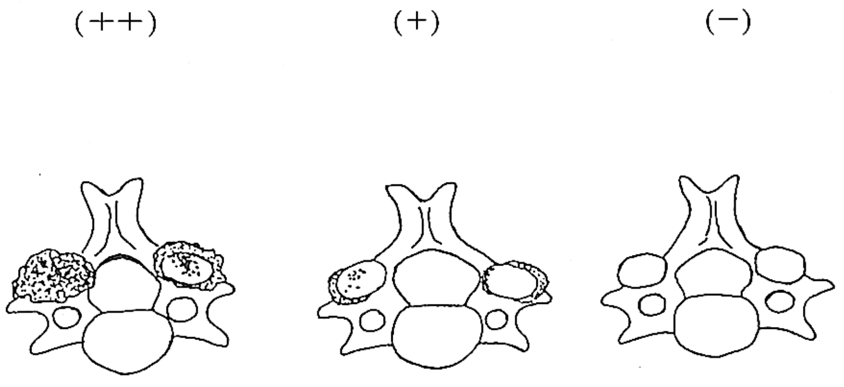


Fig. 33. Schematic representation of the degree of osteoarthritic changes in the apophyseal joint in the cervical spine (quoted from Higuchi; (1983)).

Fig. 34. An example of the apophyseal joint OA in the cervical spines (No. 1524).

Table 19 shows the results for the frequency of each grade, which can be compared with other prehistoric and modern skeletal populations in the Pacific area. There was a significant sex difference in the frequency of the affected individual between males (26/70) and females (10/70). It should be noticed that a considerably high frequency of OA changes in the cervical apophyseal joint could be seen in the Mokapu male from the comparative data.

4) Spondylolysis (SL) in the fifth lumbar vertebra

Spondylolysis refers to the discontinuity between anterior and posterior parts of the vertebra and is usually seen at the fourth or fifth lumbar spine. When such a discontinuity or defect occurs bilaterally through the pars interarticularis, the vertebra is segmented into two pieces; i.e., anterior segment including body, trans-

Table 19. Comparison of frequency of osteoarthrotic change in the apophyseal joint area of cervical spine

Population	Sex	Total No.	Individual No. with OA	Total No. of cervical spine	No. of affected cervical spine (+)	(++)	Percentage (OA/N)
Mokapu	Male	70	26	450	39	37	16.9% (76/450) **
	Female	70	10	460	16	11	5.9% (27/460)
Micronesia (Guam)	Male	4	0	23	0	0	(0/ 23)
	Female	7	1	38	2	0	5.3% (2/ 38)
Japan (modern-Kanto)	Male	85	12	580	24	11	6.0% (35/580) **
	Female	27	5	185	8	7	8.1% (15/185)
Japan (modern-Kinki)	Male	78	6	537	11	6	3.2% (17/537)
	Female	38	0	258	0	0	(0/258)

(**; $p < 0.01$)

verse processes and pedicles, and posterior segment including laminate and spinous process. In this study, only SL with bilateral defect was dealt with as one of the paleoepidemiological indicators. The etiology of SL is believed due to a stress fracture by continuous axial loading with congenital and fundamental weakness on the pars interarticularis.

Table 20 shows the list of individual specimens having this anomaly in the lumbar vertebrae. SL was observed in 12 of 148 (8.1%) individuals in the Mokapu sample. The frequency in males (10.0%; 7/70) was higher than that in females

Table 20. list of individuals affected by SL

No.	Sex	Age-group	Site
1482	F	Ad	L_5
1484	M	Ad	L_5
1522	M	Ad	L_4,L_5
1524	M	Ad	L_5
1535	F	Ad	L_5
1721	M	Yg	L_5
1788	M	Ad	L_5
1814	F	Ad	L_5
1832	F	Ad	L_5
1838	M	Ad	L_5
1867	F	Ad	L_5
2044	M	Ad	L_5

Frequency: Male ; 7/70 (10.0%)
Female ; 5/78 (6.4%)

(6.4%; 5/78). All cases were those of bilateral separation. Only one case (No. 1522, adult male) showed SL in both L_4 and L_5. Unilateral separation at the left pars interarticularis could be found in an adult male (No. 2190). Another unilateral separation with complete spina bifida at the spinous process found in an adult male (No. 1858) has already been mentioned in terms of congenital anomaly.

5) Degenerative conditions of the joints

Osteoarthrotic changes with irregular hyperostosis in the articular regions are, as mentioned above, one of the most common phenomena found in ancient human skeletal remains. These changes are usually classified into two categories, i.e., primary and secondary osteoarthrosis. Primary osteoarthritis is basically due to aging with degeneration of articular cartilage. In particular, long-standing biomechanical stress is most apparent at the articular surface of joints, and is referred to as "degenerative joint disease" (DJD). Another osteoarthritis, secondary osteoarthritis, on the contrary, results from trauma, infection and/or metabolic disease. These DJD may occur not only in the major joints of the long bones such as hip, knee and shoulder, but in small joints of everywhere in the body (Fig. 35).

Fig. 35. Degenerative joint disease (DJD) found in the temporo-mandibular joint (a) and in the metatarso-phalangeal joint of the foot (b).

DJD is usually characterized by such morphological features as porotic destruction (pitting) with increase of bone density in the articular surface, and irregular new bone formation at the articular margin (lipping or osteophytes). Among the major joints of the body, the knee is the most common site of osteoarthrotic changes because of its vigorous movement and for being a major weight-bearing joint, followed by the hip, elbow and shoulder joints.

In the present study, the frequency and grade of DJD in either the distal joint of humerus or the proximal joint of ulna in the elbow joint (Fig. 36), and either

Fig. 36. An example of DJD in the elbow joint.

the distal joint of femur or the proximal joint of tibia in the knee joint were examined.

A diagnostic criterion on the presence of DJD is shown in Fig. 37 based on the following pathological findings:

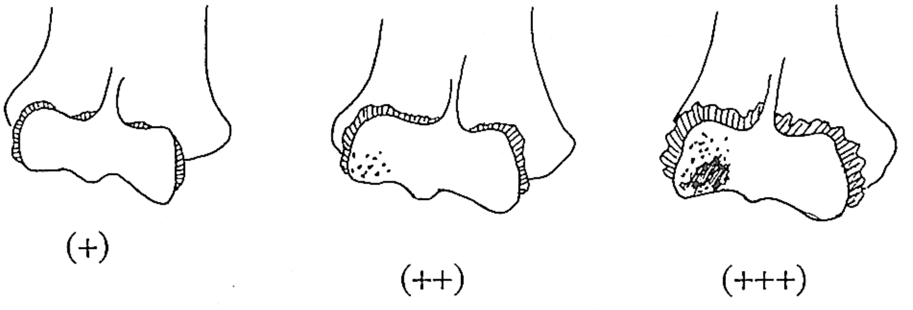


Fig. 37. Schematic representation of the degree of degenerative joint disease (DJD) or osteoarthritic changes in the distal joint of humerus.

(+) moderate with slight lipping
(++) medium with lipping and pitting
(+++) advanced with lipping, pitting and eburnation

Table 21 and 22 list the frequencies of DJD in the elbow of 175 individuals and in the knee of 171 individuals with a comparison with other prehistoric/historic

Table 21. Frequency of DJD in elbow and knee joint

joint / sex	Elbow r	Elbow l	Knee r	Knee l
Male	27/85	22/80	21/80	18/78
(%)	(31.8%)	(27.5%)	(26.3%)	(23.1%)
Female	9/87	9/84	19/87	18/89
(%)	(10.3%)	(10.7%)	(21.8%)	(20.2%)

Table 22. Comparison of Frequency of DJD in elbow and knee joint (right side)

Population	Sex	Elbow (Total N)	%	Knee (Total N)	%
Mokapu	male	(85)	31.8%	(80)	26.3%
(present study)	female	(87)	10.3%	(87)	21.8%
Mariana	male	(41)	19.5%	(38)	18.4%
(Suzuki; 1986)	female	(35)	17.1%	(26)	7.7%
Pecos Pueblo	male	(111)	15.2%	(111)	31.0%
(Jurmain; 1980)	female	(97)	13.4%	(97)	16.0%
Jomon	male	(23)	26.1%	(14)	21.4%
(Yamaguchi; 1984)	female	(25)	16.0%	(10)	20.0%

populations.

In the elbow joint, the frequency of DJD in males was significantly higher than in females ($P < 0.01$). The severity of DJD was also prominent in males. In the knee joint, there was no significant sex differences in the frequency between males and females. As to the severity in the knee joint, males showed more advanced DJD than females.

According to Collins (1986), the knee joint was the most common site of DJD and females showed markedly higher frequency (50 percent) than males (38 percent). Comparing the female frequencies of DJD in the knee joint between the Keopu and the Mokapu studies, there might have been a discrepancy of the prevalence of DJD between them, which remains to be confirmed in other paleoepidemiological studies.

CONCLUSION AND SUMMARY

Based on the various pathological findings, some characteristic patterns of disease and health condition have been elucidated from the 349 well-preserved adult skeletal population recovered from Mokapu site, Oahu Island, Hawaii.

As Snow (1974) described many interesting cases of healing fracture found in both crania and post-cranial skeleton, fractures and injuries seemed to be common among the Mokapu people, and the relative high rate of fracture may be ascribed to fighting rather than accident.

There were many cases showing inflammatory changes in the Mokapu skeletal series. The majority of cases (about 78%) with these changes was diagnosed as non-specific inflammatory process with localized periostitis, especially on the long bones. Regarding specific inflammatory process, two specific infections should be noticed, i.e., tuberculosis, and treponematosis, which showed a quite contrary pattern of prevalence among the Mokapu skeletal pupulation. As previously mentioned, there were at least four cases diagnosed with certainty as spinal tuberculosis, which were represented by destructive bone changes with minimum reactive (periosteal) new bone formation in the lesion. The frequency of such skeletal tuberculosis meant that there must have been a serious prevalence of tuberculosis among Mokapu society. On the contrary, though there were four cases showing sclerotic hyperostotic swelling in the tibia unilaterally which may occur occasionally in treponematosis, no clear-cut case of treponematosis could found in the Mokapu series. In this context, the distribution and prevalence of these specific diseases in the Pacific Islands should be reconsidered carefully in the future.

Regarding bone tumor, the first archeological case of osteogenic osteosarcoma in a very well preserved whole individual skeleton was detected. This rare case of primary malignant bone tumor will contribute to the understanding of differential diagnosis and the history of those bone tumors in archeological populations.

Paleoepidemiological analysis revealed that 1) the frequency of cribra orbitalia was within the normal range among ancient Pacific skeletal population, concluding a healthy condition concerning iron-supply in the food, 2) the distribution pattern of grade in spondylosis deformans in the fifth lumbar spine showed relatively high frequency of advanced and marked osteophytes and 3) the highest frequency of degenerative joint desease or osteoarthritis in both elbow and knee joints existed in the over-use of the right side arm among the Mokapu people.

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モカプ出土の先史ハワイアン古人骨の古病理学的・古疫学的研究

鈴木　隆雄

要旨：ハワイ、オアフ島モカプ遺跡出土の先史ハワイアン古人骨349体についての古病理学的および古疫学的研究を行なった。対象とした骨格はいずれも比較的保存が良好で、性および年齢推定の可能な成人骨格である。

古病理学的には外傷や感染症、腫瘍など実にさまざまな病変が認められた。それらの中で特に、比較的高頻度に出現する骨結核と、(対照的に) 骨トレポネーマ症の欠如という現象は、太古の昔に長い航海を経てなされたヒトの移住とこれらの感染症の伝播との関係において興味のもたれることが示唆された。

骨に出現したストレス指標を用いて疫学的解析もなされたが、それらは先史ハワイ人達の生活や生態に結びつく特有の結果を示していた。