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Case study

Two cases of smallpox from 1540 CE circum-contact (early colonial) Northern Coastal Peru

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ABSTRACT

Objective: This project seeks to create a differential diagnosis for lesions found on the skeletal remains of two children as a means to explore the presence of viral disease in 16th- century Peru.
Materials: Extremely well-preserved human remains of two children who died between the ages of 1–2 years old, recovered from the circum-contact (~1540 CE) cemetery in Huanchaco, Peru.
Methods: Macroscopic and radiographic analysis.
Results: Both individuals present with cortical thickening, symmetrical destructive lesions, metaphyseal expansion, perforations, exposure of the medullary cavity, resorption of metaphyseal ends and necrosis of the long bones, and deposited reactive new bone. These features are consistent with osteomyelitis variolosa and bacterial osteomyelitis.
Conclusions: Three features of Individuals IG-124 and IG-493 suggest a highly consistent diagnosis of osteomyelitis variolosa: multiple skeletal lesions, the historical context of the area, and the high mortality rate of non-adults in the circum-contact cemetery.
Significance: Although viral infections are ubiquitous and well documented historically, their etiologies are often difficult to determine in archaeological populations. *Orthopoxvirus variola* (smallpox) is one of the many viruses whose archaeological impact is still under explored in skeletal remains.
Limitations: The absence of smallpox in other children from the Huanchaco cemetery creates difficulty in ascertaining true prevalence rates or information on potential outbreaks.
Suggestions for further research: Further research analyzing aDNA from calculus and/or residues using a *DIP*-GC-MS method might create a better understanding of how smallpox spread through the region.

1. Introduction

In this paper, two circum-contact (~1540 CE) non-adult burials from Huanchaco, Peru, Individuals IG-124 and IG-493, reveal disseminated hematogenously spread pathological changes. Both present the possibility of a viral infectious agent and outbreak. The aim of this paper is to provide differential diagnoses for the individuals using macroscopic pathological changes and radiographs and to explore the presence of viral disease in 16th-century Peru.

2. Background

2.1. Immune response adaptations and European contact with North and South America

The conquistador Francisco Pizarro and his soldiers were in the Huanchaco area by early 1533 and founded the Spanish of city Trujillo by late 1534 (Zevallos Quiñones, 1992). While physical contact between Indigenous groups and Europeans was gradual, the introduction of deadly pathogens (smallpox, measles, mumps, and yellow fever) was more immediate (Barnes, 2005). The novel suite of infectious disease resulted in high morbidity and mortality in Indigenous populations for the following reasons: a lack of genetic resistance; no allele similar to the European *CCR5-Δ32* allele; the Inka conquest of the Chimu empire; the

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recent Inka civil war; and no cultural experience with these new diseases (Cook, 1992; Crosby, 2003; Larsen, 1994; Larsen et al., 2001; Reff, 1991; Rostworowski 1981; Schliekelman et al., 2001).

Although scattered descriptions of outbreaks exist, there is limited data on the health of Early Colonial populations (Crosby, 2003; Dobyns, 1963; Hemming, 2012). In Arequipa, historical sources recorded that post-contact epidemics claimed the lives of 60% of children 0–4 years and 40% of adults over 40 years (Dixon, 1962, p. 326). Cook's data (1981, p. 118) suggests that the north coast lost 71% of its total population between 1570 and 1620; this was the highest depopulation in Peru. However, historical records and demographic information from 1534 to 1600, before the *reducciónes*, are lacking for the Moche Valley and Trujillo (Cook, 1981).

2.1.1. Previous bioarchaeological work in Colonial Peru

Work in the Lambayeque and Chicama Valleys represents other major bioarchaeological studies done on the health patterns in colonial period burials from northern Peru. In the Lambayeque Valley, the chapel of San Pedro de Mórrope has early colonial burials (Klaus, 2016b; Klaus, 2008; Klaus and Tam, 2010, 2009), and the church of Capilla del Niño Serranto de Eten has early contact (1530–1540) burials (Klaus and Alvarez-Calderón, 2017). In the Chicama Valley, 28 individuals were recovered from a reducción site near the church at Magdalena de Cao Viejo (Gaither and Murphy, 2020). Together these studies represent work completed on over 1500 individuals, but none have been definitively identified as a case of osteomyelitis variolosa. Only one possible case has been identified (Groth et al., 2018).

2.2. Smallpox

Smallpox is caused by the virus *Orthopoxvirus variola* (Babkin and Babkina, 2015; Henderson, 1999; Moore et al., 2006). *Orthopoxvirus variola* has two strains, major and minor, and is referred to as the variola virus (VARV). Variola major is more virulent with a fatality rate of ~30%; variola minor is less virulent, and has a fatality rate of < 1% (Henderson, 1999; Moore et al., 2006). In variola major, the disease has several expression types; the most common (in ~90% of cases) is ordinary smallpox (Moore et al., 2006). Variola minor is not a focus of this study, as it was identified in the late 20th century and has not been documented in South America (Fenner, 1996).

2.2.1. Identifying smallpox in bone

When the smallpox virus expressed as variola major impacts bone, it is called osteomyelitis variolosa (Resnick, 2002). Three types of bone disease related to smallpox have been described by Cockshott and MacGregor (1958):

1) Necrotic nonsuppurative (absence of pus) osteomyelitis (possibly caused by the smallpox virus itself). Commonly seen in the epiphyses and diaphysis of the long bones and destroying epiphyseal lines with destruction, deformity, and premature fusion of the epiphyses.
2) Nonsuppurative arthritis appearing one to four weeks after initial infection. Polyarticular and symmetrical abnormalities are common and can follow secondary infection of the joint.
3) Suppurative (formation and discharge of pus) arthritis one to four weeks after initial infection (probably caused by secondary infection of the pustule). This type was seen especially in under-nourished, anemic children.

How osteomyelitis variolosa manifests in the skeleton can be age dependent. Clinically there are two presentations in the skeleton: 1) bone disease (type two and three) with arthritis; and 2) bone disease alone (type one). The latter is less frequent, as it is more likely to appear in children and seems to be the result of a localized infection in the bone shaft rather than metaphyseal joint disease (Cockshott and MacGregor, 1959). The former is more common in adults and characterized as an inflammatory joint disease. Skeletal lesions can start as early as one to six weeks after the onset of infection (Cockshott and MacGregor, 1959, 1958). Osteomyelitis variolosa results from the variola virus invading bone cells at the initial phase of viremia (Bertcher, 1956).

In infants and children, osteomyelitis variolosa can initiate weeks after the onset of infection (Cockshott and MacGregor, 1959). However, bony changes related to osteomyelitis variolosa have been observed to be active in children up to a year after the infection (Cockshott and MacGregor, 1959). In children, there can be the separation of the epiphysis at the epiphyseal junction and possibly bone destruction resulting in reduction of longitudinal growth and bending deformities in weight-bearing areas (Cockshott and MacGregor, 1958; Davidson and Palmer, 1963; Eeckels et al., 1964; Grauer and Roberts, 2019; Jackes, 1983; Thomas, 2017). In adults, sequelae of osteomyelitis variolosa includes ankylosis, hypoplastic femoral condyles, and advanced osteoarthritis; in radiographic images transverse bands of juxta-metaphyseal osteoporosis can be seen (Balaji, 2011; Cockshott and MacGregor, 1958; Darton et al., 2013; Davidson and Palmer, 1963; Eeckels et al., 1964; Jackes, 1983; Resnick, 2002; Thomas, 2017).

2.2.2. Previously documented archaeological cases of osteomyelitis variolosa

There are four archaeological individuals diagnosed with osteomyelitis variolosa, and none are from South America (Darton et al., 2013; Jackes, 1983; Ortner, 2007, 2003; Powers and Walker, 2008). A possible fifth case is the aforementioned individual from the north coast of Peru (Groth et al., 2018). The prevalence of osteomyelitis variolosa in individuals with smallpox can be as high as 20%; this rate suggests far more archaeological cases are going unidentified (Davidson and Palmer, 1963). There are a variety of reasons osteomyelitis variolosa goes undiagnosed: a lack of awareness of the influence of viral interactions on bone; lack of Early Colonial burials from the Americas; and the problematic nature of preservation of non-adult remains (Manifold, 2012). Additional work on smallpox in bone includes the relationship of cribra orbitalia and porotic hyperostosis in historic populations with known smallpox outbreaks (Peckmann, 2003).

3. Material and methods

3.1. Materials

Excavations in Huanchaco, Peru (La Libertad) encountered a multicomponent cemetery with graves dating to the initial period of contact ~1540 CE (Fig. 1). The date is based on grave goods, burial contexts, and radiocarbon dating (Ascencio, 2019; Ascencio et al., 2016; Prieto, 2020). The cemetery around the Iglesia de Huanchaco has late Chimu-Inka and Early Colonial burials. We define the Huanchaco cemetery as circum-contact, and this is an important distinction because it reflects the dynamic fluctuations of change during the first few decades of colonization. The term circum-contact describes contact in terms of physical contact with European individuals and the spread of novel diseases, which often occurred first. This time period is before systematic establishments such as *reducciónes* or *encomienda* (VanValkenburgh, 2021).

In the circum-contact section of the cemetery, there are 118 intact burials and two disarticulated looted burials. Non-adults (< 20 years) compromise 75% (90/120) of the population and adults (> 20 years) compromise 25% (30/120). There is a high number of infants and children (<12 years; 67.5% [81/120]). The majority (66.7%, 60/90) of the non-adults were 5 years old or under. The individuals were buried in

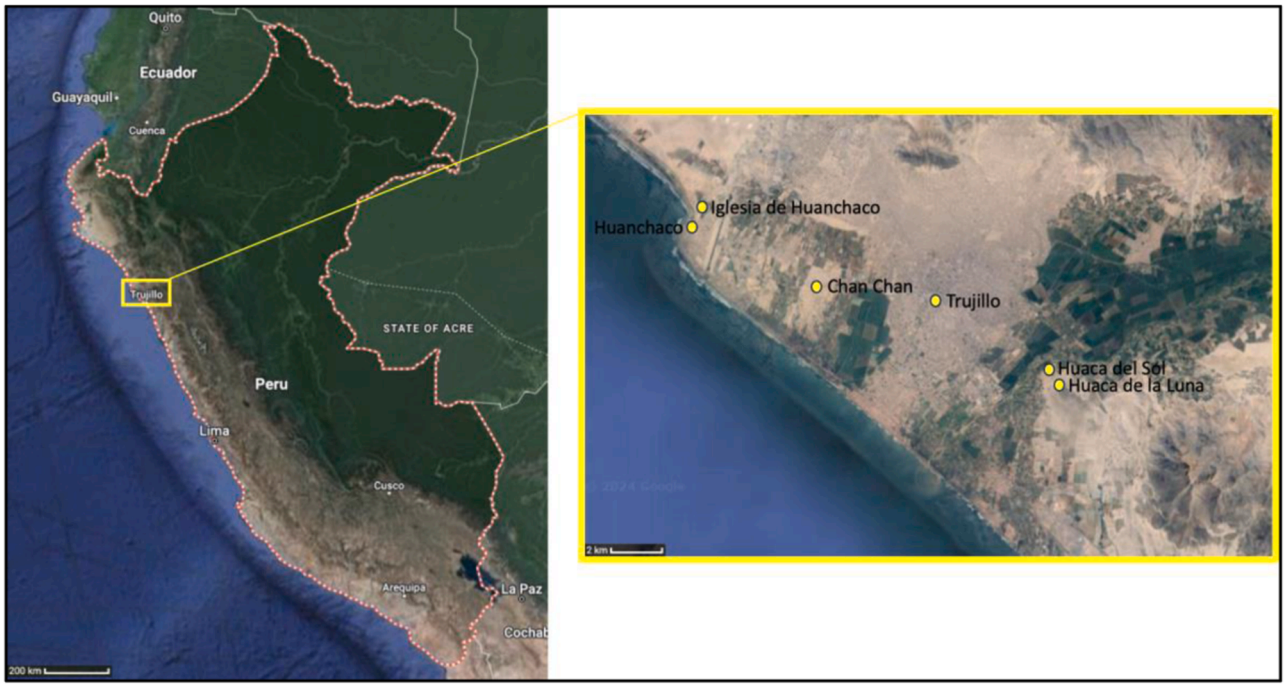

Fig. 1. Map showing the location of Huanchaco and the church of Huanchaco in relation to Chan Chan, Trujillo, and Huacas de Moche (Google maps).

an extended position with the feet toward the west (Individual IG-124) or east (Individual IG-493). Individuals IG-124 and IG-493 are two of the intact circum-contact children, and both present with pathological changes potentially related to their death.

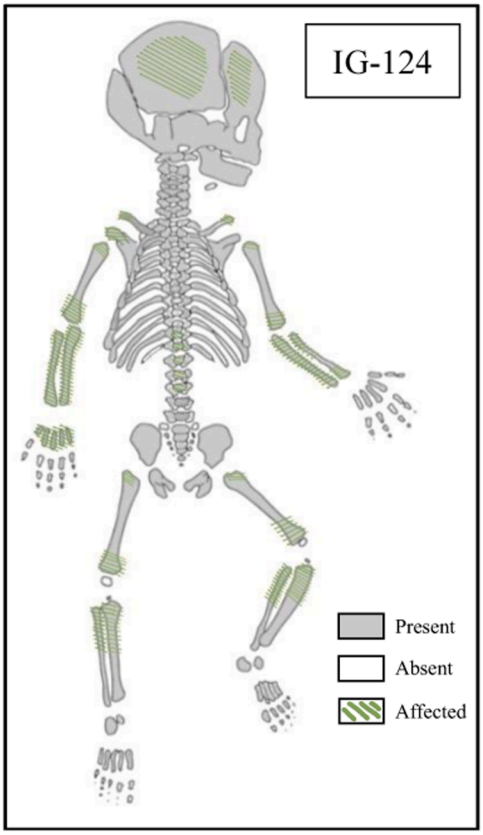

Fig. 2. Skeletal completeness and pathological distribution of Individual IG-124.

Both individuals are represented by all skeletal elements except the right 12th rib (Individual IG-124) and some hand and foot bones (Individuals IG-124 and IG-493) (Figs. 2 and 3). Likely a result of preservation, possibly related to the disease process, no epiphyses from either child were recovered. Both skeletons shows minimal to no fragmentation with excellent (grade 0) cortical preservation (McKinley, 2004). Individual IG-124 was wrapped in textiles and buried with one reed cross and multiple strands of beaded jewelry; the beads were a mix of shell, green mineral, and one of metal. Individual IG-493 was wrapped in textiles and buried with two reed crosses(Table 1)

4. Methods

4.1. Age estimation

The ages of Individuals IG-124 and IG-493 were estimated using dental development, tooth and crown development (Van Beek, 1983), and epiphyseal fusion (Brothwell, 1981; Cunningham et al., 2016, p. 200; Scheuer and Black, 2000, p. 107; Ubelaker, 1978; Van Beek, 1983; WEA, 1980).

4.1.1. Pathological conditions

The individuals were macroscopically examined systematically for lesion location, expression, and stage; the abnormal lesions observed were described and anatomically mapped (Roberts and Connell, 2004). Radiographs were taken at Tomonorte in Trujillo, Peru (Table 2)

5. Results

Both Individuals IG-124 and IG-493 are estimated to be 1.5 years (+/- 6 months) old. Individuals IG-124 and IG-493 show similar distributions of pathological lesions (Figs. 2 and 3). Considering the propensity of the changes, the pathological lesions are organized by joint, when possible (see Supplementary Information for further description and photos) (Figs. 3 and 4).

Fig. 3. Right ulna, antero-medial (A) and posterior-lateral (B) view of Individual IG-124. The black arrows indicate destructive lesions. The ulna is entirely covered with reactive new periosteal bone formation. The black circle highlights the destruction, perforation, and expansion of the ulnar proximal epiphyseal end. The black oval highlights the destructive perforation of the mid to distal shaft.

5.1. Individual IG-124

6. Discussion

6.1. Differential diagnosis

Macroscopic analysis of Individuals IG-124 and IG-493 revealed symmetrical destructive lesions (Fig. 6), expansion into the adjacent joints, deposited reactive bone, bone perforations with exposure of the medullary cavity, resorption of metaphyseal ends, expansion/ necrosis at the metaphyseal ends, dactylitis, and joint impairment. Symmetrical lesions appear in joint areas of the shoulders, elbows, wrists, hips, knees, and ankles. Other areas with lesions include the cranium, vertebral column, hands, and pelvis. The distribution of pathological changes (particularly vertebral involvement) in Individuals IG-124 and IG-493 corresponds with a hematogenous spread of the pathogen. Radiographically, osteolysis, marked periosteal new bone formation (Fig. 7) and endosteal scalloping can be noted (Figs. 8 and 9).

Some of these skeletal alterations are consistent congenital syphilis and leukemia (Table 3). However, the diagnoses of congenital syphilis and leukemia are less probable. Congenital syphilis is consistent with Hutchinson's incisors, Moon's molars, or snail track periosteal reaction (Hillson et al., 1998), while leukemia is consistent with pitting/ porosity without marginal involvement or an inflammatory response (Klaus, 2016a). Individuals IG-124 and IG-493 do not exhibit these changes. Additionally, congenital syphilis and leukemia are not consistent with destructive lesions in the elbows and perforating destructive lesions (Grauer and Roberts, 2019), such as those found in Individual IG-124 (Fig. 10).

Most skeletal alterations are consistent with the suppurative form of osteomyelitis variolosa and bacterial osteomyelitis (in Individual IG-124 possibly resulting from a fracture in the right ulna and an unknown source for Individual IG-493). The pathogenesis of osteomyelitis variolosa and bacterial osteomyelitis are both related to the vascular supply of the metaphysis and the spread of the pathogen hematogenously. Therefore, there is an overlap in pathological changes caused by these infections.

Based on the age of the individuals, and if the infection was bacterial, this would mean that the individuals were afflicted with infantile or childhood bacterial osteomyelitis (Resnick, 2002). In the infantile or childhood form of bacterial osteomyelitis, the lower extremities account for 75% of the infections, with the femur (23–29%), tibia (19–26%), pelvis (3–14%) and fibula (4–10%) being the most common locations (Peltola and Pääkkönen, 2014). The upper extremities are affected less commonly (< 21%), with the humerus (5–13%), radius (1–4%), and ulna (1–2%) being uncommon locations (Peltola and Pääkkönen, 2014). However, the risks of multifocality involvement in children < 5 years of age is more than children > 5 years of age (Jaramillo et al., 2017). Individuals IG-124 and IG-493 are < 5 years of age and have multifocal involvement. However, in both cases, the cranium, clavicle, scapula, spine, humerus, ulna, radius, hands, pelvis, femur, tibia, fibula, and feet are affected. This diffuse spread over the body is not common in bacterial osteomyelitis, even in the infantile or childhood form (Jaramillo et al., 2017; Peltola and Pääkkönen, 2014).

The presence of cloacae and bone necrosis can also be found in suppurative cases of osteomyelitis variolosa. There can be numerous sequestra and disappearance of intra-articular portions of the bone, especially in young children (Cockshott and MacGregor, 1958).

Both individuals have diffuse symmetric lesions. Destructive lesions consistent with osteomyelitis variolosa are often symmetric and consist of a diffuse swelling around affected joints with the spread to and thickening of adjacent bones (Cockshott and MacGregor, 1958; Grauer and Roberts, 2019). Bacterial osteomyelitis (infantile, childhood, and adult) is not consistent with symmetric lesions. Only chronic nonbacterial osteomyelitis (CNO) and its more severe form, chronic recurrent multifocal osteomyelitis (CRMO), both of which more frequently affect children and adolescents, are consistent with symmetric lesions (Jaramillo et al., 2017; Zhao et al., 2021). However, these diseases are very rare with an incidence rate of 1,000,000 (Karunaratne et al., 2021). In CNO and CRMO, the lower extremities are still affected at a higher rate than the upper extremities (Jaramillo et al., 2017).

Both elbows, including the radii, of Individuals IG-124 and IG-493 are severely affected. For unknown reasons, smallpox has a predilection for the elbow joint, seen in about 80% of cases (Cockshott and MacGregor, 1958, 1959; Resnick, 2002). Often, all three bones of the elbow (humerus, ulna, and radius) are involved, as opposed to most other infections where the radius is usually spared (Cockshott and MacGregor, 1958; Grauer and Roberts, 2019). In addition to the elbow (noted in Individuals IG-124 and IG-493), other joints commonly affected in osteomyelitis variolosa are the shoulder (noted in Individuals IG-124 and IG-493), wrist (noted in Individuals IG-124 and IG-493), knee (noted in Individuals IG-124 and IG-493), and ankle (noted in Individual IG-493). While pathological changes to the ribs (absent in Individuals IG-124 and IG-493), spine (present in Individuals IG-124 and IG-493), pelvis (present in Individuals IG-124 and IG-493), and cranium (present in Individuals IG-124 and IG-493) are less common, any joint may be affected in osteomyelitis variolosa (Cockshott and MacGregor, 1958; Grauer and Roberts, 2019; Resnick, 2002).

Individuals IG-124 and IG-493 present with lesions in some atypical

Table 1
Pathological Changes Observed in Individual IG-124.

Location	Macroscopic Symmetrical Lesions	Transverse / Perforating Lesion(s)	Fusiform Lesion(s)	Circular/ Oval Lesions	Medullary Expansion	Deposited New Reactive Bone	Pinpoint Porosity	Joint Area Resorbed	Cloaca/ Abscess	Unaffected	Radiographic Cortical Thickening	Osteolysis	Endosteal Scalloping
Cranium: Endocranial Surface	✓	-	-	-	-	✓	-	-	-	-	/	/	/
Acromioclavicular Junction	✓	✓	-	✓	-	✓	✓	✓	-	-	/	/	/
Glenohumeral Junction	✓	-	-	✓	-	✓	✓	-	-	-	/	/	/
Humeroulnar, Humeroradial, and Proximal Radioulnar Metaphyses (see Fig.s 3 and 4)	✓	✓	✓	✓	✓	✓	✓	✓	✓	-	✓	✓	-
Distal Radioulnar Metaphyses and the Metacarpals (see Figs. 3 and 4)	✓	✓	-	✓	✓	✓	✓	✓	✓	-	✓	✓	-
Vertebral: Laminae Midline	n/a	✓	-	✓	-	✓	✓	✓	-	-	/	/	/
Vertebral: Neurocentral Junction	n/a	-	-	✓	-	-	-	-	-	✓	/	/	/
Pelvis	✓	-	-	-	-	✓	-	-	-	-	-	✓	-
Tibiofemoral and Proximal Tibiofibular Metaphyses	✓	✓	✓	✓	✓	✓	✓	-	✓	-	✓	✓	✓
Tibiotalar and Distal Tibiofibular Metaphyses	-	-	-	-	-	-	-	-	-	✓	✓	✓	✓

Key: ✓ = present, - = absent, n/a = not applicable, / = not assessed

Table 2
Pathological Changes Observed in Individual IG-493.

Location	Macroscopic										Radiographic		
	Symmetrical Lesions	Transverse /Perforating Lesion(s)	Fusiform Lesion(s)	Circular/ Oval Lesions	Medullary Expansion	Deposited New Reactive Bone	Pinpoint Sized Perforations	Articular Area Completely Resorbed	Cloaca/ Abscess	Unaffected	Cortical Thickening	Osteolysis	Endosteal Scalloping
Cranium: Endocranial Surface	✔	-	-	-	-	✔	-	-	-	-	n/a	n/a	n/a
Acromioclavicular Junction	✔	-	✔	✔	-	✔	✔	-	✔	-	-	✔	-
Glenohumeral Junction	✔	-	-	✔	✔	✔	✔	✔	-	-	-	✔	-
Humeroulnar, Humeroradial, and Proximal Radioulnar Metaphyses	✔	✔	-	✔	✔	✔	✔	✔	✔	-	✔	✔	-
Distal Radioulnar Metaphyses and the Metacarpals (Figs. 8 and 9)	✔	-	✔	✔	✔	✔	✔	✔	✔	-	✔	✔	-
Vertebral: Laminae Midline	n/a	-	-	-	-	-	-	-	-	✔	n/a	n/a	n/a
Vertebral: Neurocentral Junction	n/a	-	✔	✔	-	-	✔	-	-	-	n/a	n/a	n/a
Pelvis	✔	-	✔	✔	-	✔	✔	-	-	-	-	✔	-
Tibiofemoral and Proximal Tibiofibular Metaphyses	✔	-	✔	✔	✔	✔	✔	✔	✔	-	✔	✔	-
Tibiotalar and Distal Tibiofibular Metaphyses	-	-	✔	-	✔	✔	✔	-	-	-	✔	✔	-

Key: ✓ = present, - = absent, n/a = not applicable, / = not assessed

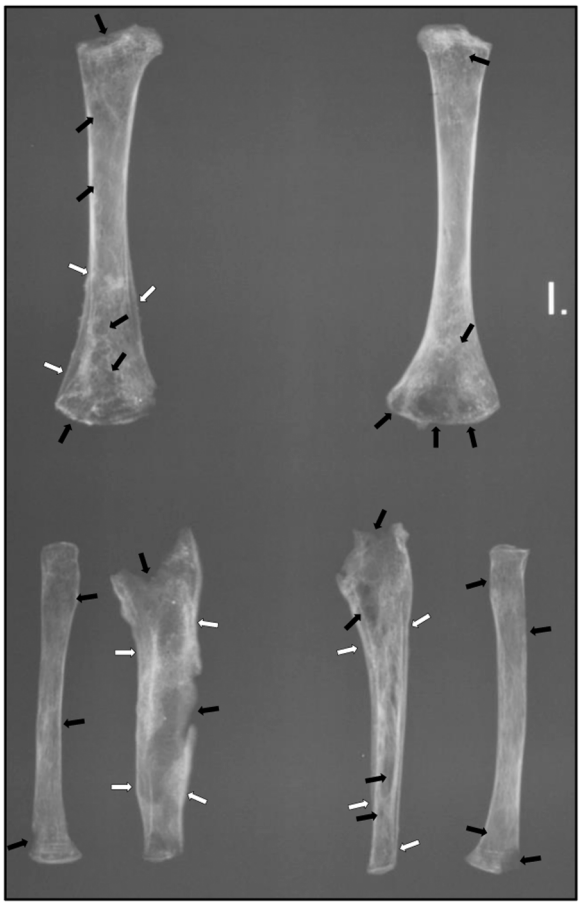

Fig. 4. Radiograph of the right and left arm bones of Individual IG-124. The black arrows indicate osteolysis, the white arrows indicate areas of marked cortical thickening.

Fig. 5. Lumbar vertebra of Individual IG-124 with spinous process destruction. The black arrows indicate a destructive lesion, the white arrows indicate areas of reactive new periosteal bone formation.

anatomical locations for osteomyelitis variolosa and bacterial osteomyelitis, including the cranium and vertebrae. The cranial meningeal reaction could be from a secondary infection unrelated to smallpox infection, or it could be normal growth (Lewis, 2004). However, much of the research done on osteomyelitis variolosa has been clinical and therefore understanding the impact to bone is not fully understood. It is possible that in clinical studies, like those of Cockshott and MacGregor (1958), new bone formation on the cranium was undetectable based on radiographs. Additionally, Individuals IG-124 and IG-493 are at the age where the laminae of the lower thoracic/ lumbar vertebrae and the

Fig. 6. Left inferior distal femur of Individual IG-124. Note the two large destructive lesions on the medial and lateral borders.

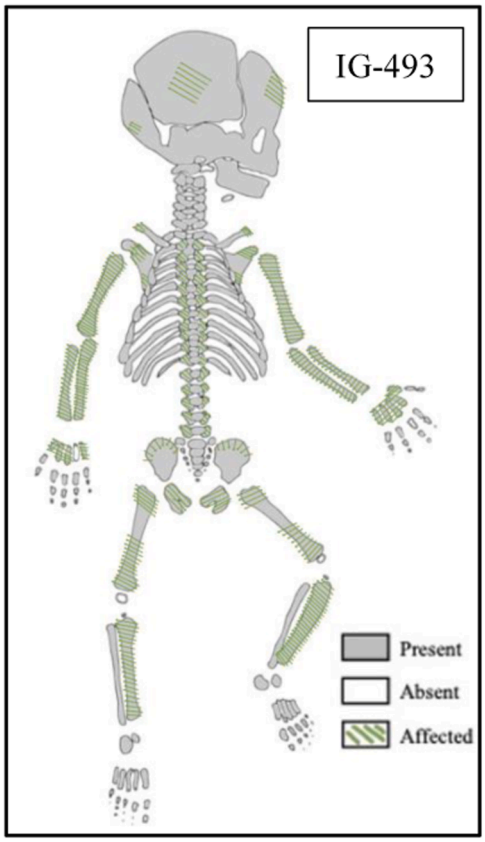

Fig. 7. Skeletal completeness and pathological distribution of Individual IG-493.

neurocentral junction are in the process of fusing (Cunningham et al., 2016). The difference in vertebral involvement between Individual IG-124 (laminae) and Individual IG-493 (neurocentral junction) might be due to different fusion progression. Individual IG-124 has multiple laminae actively fusing (C1-T1, L1-L5) and in Individual IG-493, only two laminae are unfused (C1 and L5). Perhaps the active nature of the

Fig. 8. Individual IG-493 arm bones showing destructive lesions centered around the elbows.

ossification center is why this atypical, but not undocumented, area is affected.

Both individuals fall into the age range when most children are affected by osteomyelitis variolosa (Cockshott and MacGregor, 1959). Between 2% and 5% of young children with smallpox develop osteomyelitis variolosa, the majority under 5 years of age (Cockshott and MacGregor, 1959, 1958; Middlemiss, 1962). However, Davidson and Palmer (1963) found prevalence rates of osteomyelitis variolosa can be as high as 20% (n=82/400) in young children (9 months-14 years). The majority of children with osteomyelitis variolosa, 80% (n= 66/82), were 9 months to 5 years of age. Children within this age range are still growing and developing. Osteomyelitis variolosa is known to disrupt normal bone growth, resulting in and bending deformities in weight-bearing areas (Cockshott and MacGregor, 1958; Davidson and Palmer, 1963; Eeckels et al., 1964; Grauer and Roberts, 2019; Jackes, 1983; Thomas, 2017). The left radius of Individual IG-493 has slight bending deformity indicating possible bone weakness and alteration during crawling.

In conclusion, the skeletal alterations observed in Individuals IG-124 and IG-493 are consistent with a bacterial spread of osteomyelitis. However, the skeletal alterations in Individuals IG-124 and IG-493 are more *highly* consistent with the suppurative form of osteomyelitis variolosa; a response to the early stages of smallpox is likely (Cockshott and MacGregor, 1959, 1958). Therefore, a diagnosis of osteomyelitis variolosa for both individuals is the most probable diagnostic option.

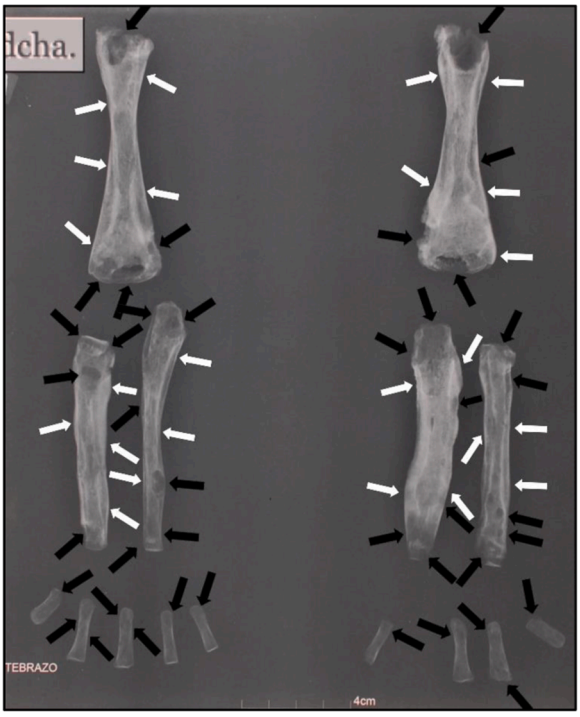

Fig. 9. Radiograph of the right and left arm bones of Individual IG-493, anterior view. The black arrows indicate osteolysis, the white arrows indicate areas of marked cortical thickening.

6.2. *Supported context in osteomyelitis variolosa diagnosis*

Based on the historical nature of the circum-contact Huanchaco cemetery (~1540 CE) there is a great likelihood of smallpox in this region and time period (Cook, 1998, 1992, 1981; Cook and Lovell, 1991; Covey, 2020; Crosby, 2003; Garcia-Putnam et al., 2021; Hemming, 2012). There is a high mortality rate of non-adults who were 5 years old or under (50% [60/120]) in the circum-contact cemetery in Huanchaco. Infants and young children (<5 years) have developing immune systems and therefore may have an increased susceptibility to infectious diseases (Ahmed et al., 2007; Learmonth, 1988; Roberts and Buikstra, 2003; Roberts et al., 1992). Diseases that do not typically manifest in the skeleton, like smallpox, may be inferred by identifying an increase in the child mortality rate through time (Cook, 1992; Dixon, 1962; Wood et al., 1992). Population declines can serve as a proxy for disease or nutritional stress (Steckel et al., 2002) and would reveal the detrimental biological impacts of contact and colonialism on Indigenous populations' health. The high mortality rate at the circum-contact cemetery likely indicates a novel disease presence, possibly smallpox.

For circum-contact Huanchaco, 3.33% (2/60) of the children 5 years or under were diagnosed with osteomyelitis variolosa. If we include older children (< 12 years), the rate decreases to 2.5% (2/81), and if we include all of the non-adults (< 20 years) the rate decreases slightly to 2.22% (2/90). The actual rates are probably higher, as not all the non-adults likely contracted smallpox. However, these rates are still comparable to clinical findings (Cockshott and MacGregor, 1959, 1958; Middlemiss, 1962).

Table 3
Differential Diagnosis of Individuals IG-124 and IG-493.

Differential Diagnosis	Macroscopic										Area				Radiographic		
	Transverse / Perforating Lesion(s)	Fusiform Circular/ Oval Lesion(s)	Medullary Expansion	Deposited New Reactive Bone	Pinpoint Porosity	Joint Area Resorbed	Cloaca/ Abscess	Flaring of Metaphases	Dactylitis	Systemic	Symmetrical	Elbow Joint	Humerus / Ulna / Radius	Knee Joint	Femur/ Tibia/ Fibula	Cortical Thickening	Osteolysis	Endosteal Scalloping
Normal Variation	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-
Osteomyelitis variolosa (smallpox)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Bacterial Osteomyelitis	+	+	+	+	+	+	+	-	-	+	-	+/-	+/-	+	+	+	+	+
Congenital syphilis	-	+	+	+	+	+	-	+	+	+	-	-	+	-	+	+	-	-
Leukemia	-	+	-	-	+	-	-	-	-	+	-	-	+	-	+	-	-	-

Key: s, consistent with condition; +/-, consistent with the pathophysiology of the disease condition, but reported as rare (<10%); -, inconsistent with condition.

Fig. 10. Left inferior distal femur of Individual IG-124. Note the two large destructive lesions on the medial and lateral borders. The black arrows indicate a destructive lesion or possible cloaca, the white arrows indicate areas of reactive new deposited bone formation.

7. Conclusion

The two individuals presented here have pathological lesions highly consistent with the suppurative form of osteomyelitis variolosa, which appears to confirm that during the Early Colonial period (1532–1600 CE) there was a smallpox outbreak in Huanchaco. Smallpox and other novel infectious diseases affected the most vulnerable segments of the Andean north coast population. Both children in this study were buried with Christian reed crosses, indicating that they were voluntarily or perhaps forcefully baptized and converted to the new religion brought by the Spanish in the 16th century to South America. The demographic prevalence rates (nonadults, 75%; < 5 years old 66.7%) indicates there was a significant decrease in the local population. The archaeological data presented here is consistent with the scattered Early Colonial documentation, which describes the abandonment of towns along the coast between the Chicama and Moche valleys before 1580. This includes the Huanchaco area and the surrounding region as well (Lizarraga, 1941).

Diseases physically and culturally alter populations for years following initial outbreak. Understanding how viruses and humans have interacted across time can contribute to how current and future societies evaluate new and emerging diseases. For future archaeological research, we urge researchers to: deeply consider viral etiological agents for destructive and inflammatory responses in bone; further investigate the viral persistence in bone; consider the possibility that DNA might be preserved in human skeletal remains. As we demonstrated in this study with Individuals IG-124 and IG-493, understanding the context of the archaeological population under study will aid in viral etiological interpretations. By highlighting the probability of a viral etiology for Individuals IG-124 and IG-493, we hope future papers will consider viral agents in their differential diagnoses to fully understand the impact on human evolution and cultural change.

CRediT authorship contribution statement

Gabriel Prieto: Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition. **John W. Verano:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition. **Khrystyne Tschinkel:** Writing – review & editing, Writing – original draft,

Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ijpp.2024.04.002.

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