Title
Evidence of osteoarthritis in the Tiwanaku Colony, Moquegua, Peru (AD 500–1100)

Journal
International Journal of Osteoarchaeology, 28(1)

ISSN
1047-482X

Authors
Becker, SK
Goldstein, PS

Publication Date
2018

DOI
10.1002/oa.2634

Peer reviewed

Received: 17 May 2017 | Revised: 9 September 2017 | Accepted: 9 November 2017
DOI: 10.1002/oa.2634

WILEY

RESEARCH ARTICLE

Evidence of osteoarthritis in the Tiwanaku Colony, Moquegua, Peru (AD 500–1100)

S.K. Becker[1] | P.S. Goldstein[2]

[1] Department of Anthropology, University of California, Riverside, Riverside, CA, USA
[2] Department of Anthropology, University of California, San Diego, San Diego, CA, USA

Correspondence
Sara K. Becker, Department of Anthropology, University of California, Riverside, 1334 Watkins Hall, Riverside, CA 92521, USA.
Email: sara.becker@ucr.edu

Abstract

The Tiwanaku (AD 500–1100) colonized ecologically diverse, lower elevation areas to produce goods not easily grown in the high altitude heartland (3,800 m a.s.l.). One colony near present-day Moquegua, Peru (900–1,500 m a.s.l.) was composed of multiple Tiwanaku settlements. Colonists farmed products like maize and coca and transported goods via llama caravan between the colony and heartland. Two subsistence groups emerged in terms of settlement, those of "Chen Chen-style" affiliation associated with an agrarian lifestyle and those of "Omo-style" representing more of a pastoralist lifeway. Considering Tiwanaku people likely began light chores around 5 years of age (e.g., babysitting siblings), with heavier labour beginning at approximately 8 years of age, we questioned if these social and occupational differences translated into skeletal changes associated with osteoarthritis (i.e., porosity, lipping, osteophyte formation, and/or eburnation). Individuals from 5 sites, 2 that represent the Omo-style (M16 and M70) and 3 that are in the Chen Chen-style (M1, M10, and M43), were evaluated for osteoarthritis while controlling for age-at-death and sex using 25 total joint surfaces in the shoulder, elbow, wrist, hip, knee, ankle, and sacroiliac. Overall, our comparisons show no combined significant differences between the Omo-style and Chen Chen-style groups. Instead, distinctions in osteoarthritis evidence by age-at-death and sex emerged, reflecting the likelihood of specific age- or sex-related tasks. Arthropathy evidence among children in elbow and ankle joints also supported the cultural legacy in the Andes that work begins at a relatively young age and would show up in patterns of adult osteoarthritis.

KEYWORDS

activity, age-related changes, agriculture, childhood, gendered labour, labour, pastoralism

1 | INTRODUCTION

Dating from AD 500–1100, the Tiwanaku culture developed in the high elevation, altiplano (high flat plain) of the Lake Titicaca Basin, Bolivia (3,800 m a.s.l.), and expanded into lower elevation regions on the slopes of the Andes through direct, colonial settlement. One of these secondary settlement areas was in the mid-Moquegua Valley, Peru (900–1,500 m a.s.l.). Tiwanaku peoples moved into this valley after AD 600 likely because of available farmland along the Moquegua River suitable for temperate crops. Archaeologists (Goldstein, 2005; Goldstein, 2015; Williams, 2006) note that the Moquegua region became a major agricultural production hub during the Tiwanaku state, with maize as the most prominent export crop. Moquegua settlement also brought goods to and from the altiplano via Tiwanaku-controlled llama caravans, under a conjoined agricultural-pastoralist economy (Becker, 2017; Browman, 1984; Goldstein, 2005; Goldstein, 2012; Janusek, 2008; Lynch, 1983; Stanish et al., 2010; Vallières, 2016). Recent research on five Tiwanaku colonial settlements in Moquegua spatially reflected this agro-pastoral duality with "Chen Chen-style" sites and their cemeteries (i.e., M1, M10, and M43) associated with locations of sedentary agriculture, whereas "Omo-style" sites and burial areas (i.e., M16 and M70) were linked with pastoralist peoples (Figure 1; Gaggio & Goldstein, 2015; Gaggio & Goldstein, 2016; Goldstein, 2015).

Chen Chen-style Tiwanaku sites were located closest to prime Moquegua River agricultural areas and canal irrigation systems (Goldstein & Magilligan, 2011; Williams, 2006). These sites contained dense, planned, domestic architectural settlements with numerous belowground storage cists, lithic evidence of stone hoes, and large grinding stones (Goldstein, 2005). Dietary evidence also showed

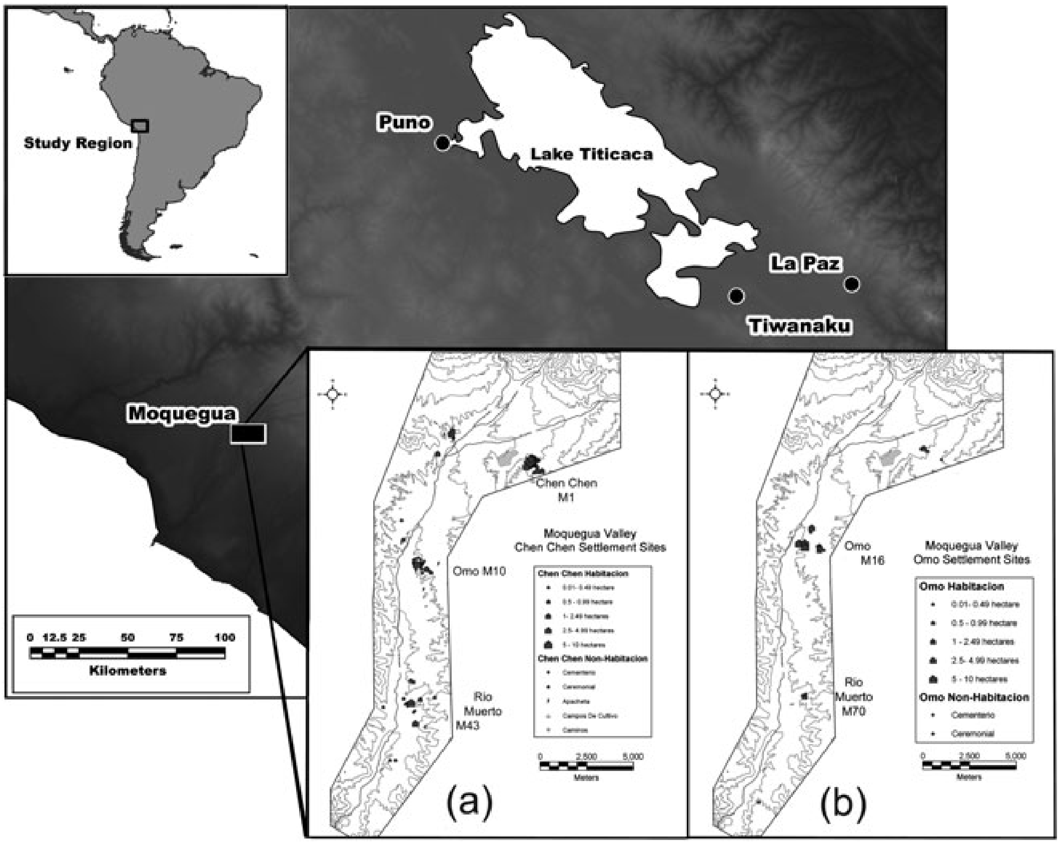

FIGURE 1 Map of the larger study area, with insert of the (a) Chen Chen-style agriculturalist settlements and (b) Omo-style pastoralist settlements in the Moquegua River basin

intense agricultural production and consumption of lowland crops (Gaggio & Goldstein, 2015; Gaggio & Goldstein, 2016; Somerville et al., 2015). Chen Chen-style cemetery areas contained Tiwanaku-style underground, seated flexed burials (Figure 2). Most individuals showed local strontium isotope paleomigration signatures (Knudson & Blom, 2011; Knudson, Goldstein, Dahlstedt, Somerville, & Schoeninger, 2014; Knudson, Price, Buikstra, & Blom, 2004), as would be expected with sedentary people.

Omo-style Tiwanaku settlements were located farther away from agrarian areas and appear to be less permanent due to their ephemeral, tent-like architecture. They contained relatively little infrastructure or tools for agricultural processing and were situated close to long-used and well-marked trade routes for llama caravans that avoided farmland and the local Moquegua River floodplain (Goldstein, 2005; Goldstein, 2015). Omo-style cemeteries were also distinct in that they had significant aboveground structures, suggesting easily visible marked burial grounds (Figure 3). Strontium isotope paleomigration analyses showed many Omo-style burials with intermediate values from between the altiplano and the Moquegua Valley, suggesting lifelong movement between these two regions (Knudson et al., 2014).

FIGURE 2 Chen Chen-style tombs, (a) Rio Muerto site M43A unit J and (b) below-ground seated flexed burial M43A-58 (Photos by Paul S. Goldstein)

FIGURE 3 Omo-style cemetery, M70B aboveground cairn (photo by Paul S. Goldstein)

In this paper, we tested if there were skeletal distinctions between Chen Chen-style and Omo-style burials using evidence of bony changes (i.e., lipping, porosity, osteophyte formation, and/or eburnation) associated with osteoarthritis (OA). OA is a degenerative joint disease with a multifactorial aetiology that could include obesity, genetics, an individual's sex, repeated mechanical stress to a joint, advanced age, and trauma (Felson, 2004; Hunter, March, & Sambrook, 2002; Jurmain, 1999; Jurmain, Alves Cardoso, Henderson, & Villotte, 2012; Rogers & Waldron, 1995; Rogers, Waldron, Dieppe, & Watt, 1987; Rytter, Egund, Jensen, & Bonde, 2009; Spector & MacGregor, 2004; Waldron, 1995; Waldron, 1997; Weiss & Jurmain, 2007). Whichever the cause or causes, the bone changes linked to OA generally indicate damage to a joint surface and the body's attempt to repair the area (Brandt, Dieppe, & Radin, 2009). In this study, 25 total surfaces in six synovial joints (shoulder, elbow, wrist, hip, knee, and ankle) and one synovial and fibrous joint (sacroiliac) were scored for OA (Table 1). Using these data, we evaluated if there were any significant variations between the two stylistic groups, as these may translate into evidence of subsistence strategy-based repetitive motion differences (Becker, 2016; Becker, 2017; Bridges, 1991; Bridges, 1992; Bridges, 1995; Cheverko & Bartelink, 2017; Cope, Berryman, Martin, & Potts, 2005; Domett, Evans, Chang, Tayles, & Newton, 2017; Jurmain, 1999; Walker-Bone & Palmer, 2002; Weiss & Jurmain, 2007).

In addition, we performed age-at-death and sex comparisons between the two groups, which could provide more nuanced understandings of Tiwanaku lifestyle. This is because historic and recent accounts of tasks in the Andes show labour division first by age and then by gender (Bolin, 2006; Ebert & Patterson, 2006; Guaman Poma de Ayala, 2006: 1613; Harris, 1980; Lucy, 2005; Mitchell, 2003; Silverblatt, 1987; Somerville et al., 2015; Widmark, 2000). For example, modern Andean children rarely have specific activities for girls or boys. Rather, upwards from age 5 years, they are given tasks that they can handle (e.g., babysitting younger siblings) and are often seen by age 7 or 8 years as capable of heavier work (Graham, 1997: 1703; Hardman, 1976: 2). Pre-teen children regularly contribute to the pastoralist or farming economy by pasturing animals, spinning wool into yarn, obtaining water and firewood, helping prepare fields for planting, finding forgotten yields (e.g., potatoes), and preparing food (e.g., walking on potatoes to help freeze-dry them into chuño) (Abercrombie, 1986: 115; Bolin, 2006: 72; Carter, 1967; Hardman, 1976: 2; Lucy, 2005: 43; Mitchell, 2003: 276). In addition to age, as Andean children grow older, gendered division of labour is also often related to partnership in marriage. These relationships still have relative gender equality, but Andean women tend more to household activities, whereas men work more collective tasks like reciprocal work parties (Abercrombie, 1986; Carter, 1967; Dean, 2001; Hardman, 1976; Harris, 1978; Harris, 1980; Silverblatt, 1987).

TABLE 1 List of joints and joint surfaces observed for OA

Joint	Joint surfaces
Shoulder (2 surfaces)	• Glenoid fossa of scapula • Head of humerus
Elbow (7 surfaces)	• Capitulum of humerus • Trochlea of humerus • Head of radius • Trochlear notch of ulna • Olecranon process of ulna • Coronoid process of ulna • Radial notch of ulna
Wrist (3 surfaces)	• Distal articular surface of the radius • Distal articular surface of the ulna • Ulnar surface of radius
Hip (2 surfaces)	• Acetabulum of the os coxa • Head of femur
Knee (6 surfaces)	• Medial condyle of femur • Lateral condyle of femur • Medial facet of patella • Lateral facet of patella • Medial condyle of tibia • Lateral condyle of tibia
Ankle (3 surfaces)	• Distal articular surface of tibia • Superior articular surface of talus • Medial malleolar surface of talus
Sacroiliac (2 surfaces)	• Auricular surface of os coxa • Auricular surface of sacrum

Our research was also able to address prior scholarship (e.g., Benjamin et al., 2006; Halcrow & Tayles, 2011; Jurmain et al., 2012; Pearson & Buikstra, 2006; Villotte & Knüsel, 2013) that noted that skeletal changes associated with occupation and repeated mechanical stress likely began earlier in life. Comparisons of all ages of Andean Tiwanaku people in this study provide an opportunity to study OA evidence from a group that likely laboured from a young age. Thus, by evaluating Tiwanaku's Moquegua colony by comparing the two major social-stylistic groups and considering both age-at-death and sex, we see observable patterns in evidence of OA connected to occupation and division of labour in the colonial settlements of this state-level society.

2 | MATERIALS AND METHODS

The sample for this study consisted of 1,389 Tiwanaku individuals housed at the Museo Contisuyo, Moquegua, Peru. These burials were excavated from the Atacama Desert, and the majority of remains have near-perfect bone preservation due to this area's lack of rainfall and low humidity. Although the Moquegua Valley has mummified burials, data were only collected from partially mummified or skeletonized people if joint surfaces were visible. Sex estimates used traditional macroscopic methods of scoring the pelvic bones (Bass, 1981; Buikstra & Ubelaker, 1994; Ubelaker, 1999). To estimate age, multiple methods were used wherever possible: dental eruption, dental wear, closure of the epiphyseal sutures, pubic symphysis, auricular surface, and sternal rib end changes (Buikstra & Ubelaker, 1994; Iscan, Loth, & Wright, 1984; Key, Aiello, & Molleson, 1994; Lovejoy, 1985; Scheuer & Black, 2000; Suchey & Katz, 1998; Ubelaker, 1999). Table 2 shows demography of the sample divided by Chen Chen-style and Omo-style into subadults and adults. We grouped subadults into categories with preservation often permitting very narrow age-at-death groupings (i.e., fetal–1 year, 2–4 years, 5–9 years, 10–12 years, and 13–15 years). However, as it is more difficult to estimate adult age from skeletal remains (Hoppa, 2002), wider ranges were required, and adults were grouped as young (16–29 years), middle (30–49 year), or older (+50 years) adult. We also separated adults for sex and a combined category of sex with age-at-death (noted in Table 2). Overall, there is a disparity in the sample size comparison between the two subsistence-groups, especially as the sex and age-at-death categories narrow. The statistical analysis, explained below, has helped account for these differences.

In terms of OA, Rogers and Waldron (1995) noted evidence of this condition when there was pitting or porosity, new bone growth in the form of osteophytes or lipping, changes in joint contour, or in severe cases, bone polishing with eburnation on a joint's surface. This research used this definition and also followed standards (Buikstra & Ubelaker, 1994: 121–123). Data were recorded bilaterally for each surface if at least 90% of the joint was visible and intact. Each joint surface was scored as present for evidence of OA if lipping, porosity, osteophytes, and/or eburnation were noted over at least one third of the joint surface or margin, and in general, at least two criteria were required for a count of present. In addition, if any overt evidence of trauma was noted (e.g., broken and healed bone), the individual was not included. All comparisons were made while controlling for age-at-death and sex in order to address concerns about age- or sex-based skeletal changes (Jurmain, 1999; Jurmain et al., 2012; Weiss & Jurmain, 2007). Finally, the cemetery collections in this study represent people who were genetically similar (Baitzel & Goldstein, 2016; Blom, 2005; Blom, Hallgrímsson, Keng, Lozada, & Buikstra, 1998; Blom & Knudson, 2007; Knudson, 2004) but not from an isolated or closed population causing accelerated rates of OA (Domett et al., 2017). Thus, although we cannot say that any OA changes when observed were solely from activity, we have tried to limit many of the aetiological factors.

Although data were recorded for each individual, this research focused on a population-based perspective to evaluate general patterns in skeletal changes associated between groups. However, due to the multiple joint surfaces in each joint and multiple joints within each individual, information could be lost if results are limited to individual or skewed by one person if there are multiple affected surfaces. The generalized estimating equation (GEE) statistical method, an extension of generalized linear models, was chosen to help with these issues. GEE is a population-averaged method accounting for correlation among measures within subjects, which can assess the simultaneous impact of multiple factors and their effects (Agresti, 2007; Ghislatta & Spini, 2004; Liang & Scott, 1986). GEE works well for this type of data because it models estimates of population parameters that are calculated using each recorded data point within each individual's joint, allowing for the largest possible sample size while still remaining linked to an individual. Thus, it preserves individual-level information but does not permit one heavily effected individual to

TABLE 2 Demographic information for individuals in this study

	Age-at-death	Chen Chen-style (# of individuals)	Omo-style (# of individuals)
Subadults = 697 individuals	Foetus-1 year	217	34
	2–4 years	158	17
	5–9 years	84	10
	10–12 years	50	4
	13–15 years	77	3
	Subadult, age indeterminate	40	3
Adults = 692 individuals	Young adult (15–29 years)	142	18
	Middle adult (30–49 years)	247	11
	Older adult (50+ years)	42	2
	Adult, age indeterminate	216	14
	Sex	**Chen Chen-style (# of individuals)**	**Omo-style (# of individuals)**
Adults by sex = 692 individuals	Female	195	12
	Possible female	36	0
	Male	138	14
	Possible male	43	3
	Sex indeterminate	237	14
	Sex + age-at-death	**Chen Chen-style (# of individuals)**	**Omo-style (# of individuals)**
Females by age = 207 individuals	Female, young adult (16–29 years)	62	7
	Female, middle adult (30–49 years)	107	4
	Female, older adult (50+ years)	24	1
	Female, age indeterminate	2	0
Males by age = 152 individuals	Male, young adult (15–29 years)	39	9
	Male, middle adult (30–49 years)	89	4
	Male, older adult (50+ years)	8	1
	Male, age indeterminate	2	0

skew the data. Although this style of data modelling may have some smoothing effects due to the population-averaged methodology, GEE does have many beneficial elements (see Gagnon & Wiesen, 2013; Nikita, 2014 for further bioarchaeological discussion). In sum, it accommodates variables that are not normally distributed, small sample sizes, and randomly missing or unobservable variables, which are especially useful in this study and bioarchaeological research in general (Becker, 2012; Becker, 2013; Gagnon & Wiesen, 2013; Ghislatta & Spini, 2004; Nikita, 2014). GEE can also evaluate any number of nominal or quantitative predictor variables that cannot be assessed using bivariate analysis, such as controlling for age-at-death and sex, as was used in this study. All data were evaluated at the 0.05 level using the chi-square statistic, and comparisons were made between individuals from sites at the population level with Chen Chen-style and Omo-style, and by age-at-death, sex, and combined age-at-death and sex in SAS 9.4.

3 | RESULTS

Subadults in this study were evaluated for evidence of arthropathic changes using evidence of lipping, porosity, osteophyte formation, and/or eburnation (Table 3). GEE could not be modelled for the majority of subadult joint surfaces likely because articular surfaces were observable, but there were few-to-no reported present scores to address the population-averaged response. However, children showed results on surfaces in the elbow and ankle joints for both the Chen Chen-style and Omo-style burials. In the combined under 15-years group, as well as 5–9, 10–12, and 13–15 years-at-death categories, children had modelled results in the elbow. In the ankle, results were noted in the under 15-years group in the left, right, and combined sides and in the 5–9 years-at-death group in the right and combined side comparisons.

All adults and adults divided by sex (only males and females were used) are noted in Table 4 with no significant results in the overall sample. GEE could be performed for the majority of the sample by sex. The only significant difference by sex is the right hip of the female sample, which showed higher modelled rates from the Omo-style burial sample. When divided by age (Table 5), there were more significant modelled results. Young adults showed a significant difference in the combined wrist joint, with higher modelled rates from Chen Chen-style burials, 12% versus 3% from Omo. Middle adults had three significant differences, in the shoulder, the right sacroiliac, and combined left and right sacroiliac and Omo-style burials had the higher rates. Older adults also had three significant comparisons, in the wrist, the left hip, and left knee with higher Omo-style modelled percentages. However, as noted in the population demography, these significant differences were more likely due to the small Omo-style sample size.

Finally, data were compared by sex combined with age-at-death, and these results are noted in Tables 6 and 7. Overall, there were no significant differences for males (Table 7). Females (Table 6) had two significant results for the middle year group and 12 significant results for the older year group; however, the latter was likely due to small sample size. Among female middle-age adults, the Chen Chen-style burials showed significantly higher modelled rates in the wrist, akin to younger adults not divided by sex (Table 5). In contrast, the sacroiliac results showed higher modelled rates from Omo-style cemeteries than Chen Chen ones, with 80% and 56%, respectively.

4 | DISCUSSION

In this research, the first noteworthy result was the evidence of subadult arthropathy in the elbow joint throughout all age groups and in the ankle joint in the combined and 5–9 years-at-death groups. It is somewhat surprising to find any subadult with evidence of lipping, porosity, osteophyte formation, and/or eburnation, as rates of bone remodelling are more rapid than in adults. Clinical literature has reported a few cases of secondary OA associated with ongoing medical conditions like lupus, hip dislocation, systemic infection, or sickle-cell disease in children age 15 years and younger (Coulibaly et al., 2009; Klippel, Stone, Crofford, & White, 2008; Lehman, 2004; Ramos Amador et al., 1998). Other clinical research (Chammas, 2014; Lohmander, Englund, Dahl, & Roos, 2007; Lovell, 2008; Nandi, Maschke, Evans, & Lawton, 2009; Nicholson, Dickman, & Maradiegue, 2009; Von Porat, Roos, & Roos, 2004) has linked OA in the joints of subadults with overuse and repeated trauma from stress fractures, although obesity and family history may also have played a role. Focusing on the affected joints, repeated impact use (i.e., osteochondritis dissecans) has caused OA-type changes in the elbow and ankle joints of modern children and in the elbow where subluxation occurred (Chammas, 2014; Nandi et al., 2009). In addition, ankle OA in younger individuals is especially prevalent when associated with joint instability trauma (e.g., sprain causing permanent proprioception problems) (Harrington, 1979; Taga, Shino, Inoue, Nakata, & Maeda, 1993; Valderrabano, Horisberger, Russell, Dougall, & Hintermann, 2008).

Although we cannot rule out that these affected children had other ongoing conditions (e.g., systemic infections), were obese, or familially prone, our results could be evidence of high-impact repeated tasks required of Andean children as young as 5 years (Bolin, 2006; Carter, 1967; Graham, 1997: 1703; Hardman, 1976). Other research on subadults by Becker (in Blom, Knudson, Janusek, Becker, & Bowen, 2016) from highland Tiwanaku skeletal collections has shown evidence of OA in three individuals (two with temporomandibular joint OA and one with OA in the joints of the foot), as well as unusually robust upper body musculature that may indicate labour began very young among Andean Tiwanaku children. This pattern of hard work likely continued as we saw younger adults in Tiwanaku's Moquegua colony with evidence of OA (Tables 4, 5, and 6) and throughout the state in people younger than 20 years-at-death (Becker, 2013; Becker, 2017).

A second major finding from these results was that were no significant differences in OA in the comparisons between the Chen Chen-affiliated and Omo-affiliated burials overall. The lack of significant results in the combined sample may mean that each culturally affiliated group had few overarching subsistence group-specific tasks. Instead, akin to our historic and ethnographic

TABLE 3 Subadult arthropathy comparison by stylistic groups (values in bold text have a *p* value at .05 or less using the chi-square statistic, generalized estimating equation modelling was not possible for changes in the shoulder, wrist, hip, knee, and sacroiliac, and for any areas left blank)

	Combined Subadults (age 15 and under) in % of Modeled Frequency						Subadults Age 5-9 years in % of Modeled Frequency						Subadults Age 10-12 years in % of Modeled Frequency						Subadults Age 13-15 years in % of Modeled Frequency					
	L		R		Combined		L		R		Combined		L		R		Combined		L		R		Combined	
	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style
Elbow	17% (n=27)	33% (*p*=.14)	15% (n=37)	21% (*p*=.2)	22% (n=64)	22% (*p*=.08)	23% (n=87)	26% (*p*=.6)	21% (n=79)	22% (*p*=.9)	22% (n=166)	24% (*p*=.7)	22% (n=27)	22% (*p*=.14)	24% (n=37)	17% (*p*=.2)	33% (n=64)	15% (*p*=.08)	23% (n=87)	26% (*p*=.6)	21% (n=79)	22% (*p*=.9)	22% (n=166)	24% (*p*=.7)
Ankle	2% (n=79)	4% (*p*=.6)	4% (n=83)	4% (*p*=.93)	3% (n=162)	4% (*p*=.8)															10% (n=83)	20% (*p*=.93)	6% (n=162)	18% (*p*=.8)

TABLE 4 Osteoarthritis stylistic comparison for adults, females, and males (values in bold text have a *p* value at .05 or less using the chi-square statistic, any blank box notates that generalized estimating equation modelling was not possible)

	All adults combined in % of modeled frequency						Females in % of modelled frequency						Males in % of modelled frequency					
	L		R		Combined		L		R		Combined		L		R		Combined	
	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo–style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style
Shoulder	18% (*n* = 297)	29% (*p* = .2)	20% (*n* = 306)	23% (*p* = .8)	19% (*n* = 604)	26% (*p* = .4)	20% (*n* = 157)	36% (*p* = .2)	21% (*n* = 158)	27% (*p* = .6)	20% (*n* = 315)	32% (*p* = .2)	18% (*n* = 109)	20% (*p* = .8)	22% (*n* = 115)	19% (*p* = .8)	20% (*n* = 224)	19% (*p* = .9)
Elbow	28% (*n* = 1,448)	28% (*p* = .96)	30% (*n* = 1,484)	35% (*p* = .4)	29% (*n* = 2,932)	31% (*p* = .6)	27% (*n* = 768)	28% (*p* = .8)	28% (*n* = 780)	39% (*p* = .2)	27% (*n* = 1,584)	34% (*p* = .4)	31% (*n* = 511)	25% (p=.4)	37% (*n* = 538)	26% (*p* = .09)	34% (*n* = 1,049)	25% (*p* = .1)
Wrist	21% (*n* = 493)	14% (*p* = .3)	21% (*n* = 482)	15% (*p* = .5)	21% (*n* = 975)	15% (*p* = .4)	22% (*n* = 261)	12% (*p* = .4)	20% (*n* = 262)	10% (*p* = .4)	21% (*n* = 523)	11% (*p* = .4)	27% (*n* = 170)	15% (*p* = .1)	23% (*n* = 171)	14% (*p* = .5)	25% (*n* = 341)	15% (*p* = .2)
Hip	18% (*n* = 382)	17% (*p* = .9)	14% (*n* = 379)	19% (*p* = .5)	16% (*n* = 761)	18% (*p* = .8)	19% (*n* = 209)	18% (*p* = .9)	**14%** **(n = 214)**	**35%** **(p = .048)**	17% (*n* = 423)	27% (*p* = .2)	17% (*n* = 148)	16% (*p* = .9)			15% (*n* = 291)	9% (*p* = .4)
Knee	20% (*n* = 737)	20% (*p* = .96)	22% (*n* = 780)	18% (*p* = .5)	21% (*n* = 1,517)	19% (*p* = .7)	18% (*n* = 351)	16% (*p* = .8)	24% (*n* = 384)	21% (*p* = .7)	21% (*n* = 735)	18% (*p* = .7)	18% (*n* = 295)	23% (*p* = .6)	22% (*n* = 312)	13% (*p* = .3)	20% (*n* = 607)	19%% (*p* = .9)
Ankle	19% (*n* = 381)	9% (*p* = .07)	20% (*n* = 389)	16% (*p* = .5)	20% (*n* = 770)	12% (*p* = .1)	16% (*n* = 196)	10% (*p* = .4)	17% (*n* = 198)	19% (*p* = .8)	16% (*n* = 394)	14% (*p* = .7)	22% (*n* = 141)	9% (*p* = .2)	22% (*n* = 143)	14% (*p* = .5)	22% (*n* = 284)	11% (*p* = .2)
Sacroiliac	42% (*n* = 341)	44% (*p* = .8)	42% (*n* = 322)	49% (*p* = .5)	42% (*n* = 664)	47% (*p* = .5)	48% (*n* = 199)	52% (*p* = .7)	49% (*n* = 190)	54% (*p* = .7)	48% (*n* = 289)	53% (*p* = .6)	34% (*n* = 129)	38% (*p* = .8)	30% (*n* = 120)	40% (*p* = .5)	32% (*n* = 249)	39% (*p* = .6)

TABLE 5 Osteoarthritis stylistic comparison by age-at-death (values in bold text have a *p* value at .05 or less using the chi-square statistic, any blank box notates that generalized estimating equation modelling was not possible)

	Young adults in % of modelled frequency						Middle adults in % of modelled frequency						Older adults in % of modelled frequency					
	L		R		Combined		L		R		Combined		L		R		Combined	
	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo–style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style
Shoulder	13% (*n* = 109) (*p* = .8)	16%	14% (*n* = 113) (*p* = .95)	14%	14% (*n* = 222) (*p* = .9)	15%	21% (*n* = 161) (*p* = .1)	46%	23% (*n* = 167) (*p* = .09)	43%	**22%** **(*n* = 328) (*p* = .049)**	**44%**	24% (*n* = 25) (*p* = .5)	50%			27% (*n* = 49) (*p* = .9)	25%
Elbow	17% (*n* = 528) (*p* = .4)	23$	17% (*n* = 568) (*p* = .2)	23%	17% (*n* = 1,096) (*p* = .2)	23%	33% (*n* = 792) (*p* = .2)	35%	15% (*n* = 792) (*p* = .2)	37%	35% (*n* = 2,497) (*p* = .3)	42%	41% (*n* = 100) (*p* = .9)	43%	47% (*n* = 101) (*p* = .4)	64%	44% (*n* = 201) (*p*=.6)	54%
Wrist	12% (*n* = 172) (*p* = .2)	5%			**12%** **(*n* = 336) (*p* = .03)**	**3%**	24% (*n* = 275) (*p* = .5)	20%	23% (*n* = 276) (*p* = .5)	17%	24% (*n* = 51) (*p* = .4)	18%	34% (*n* = 38) (*p* = .2)	67%			**34%** **(*n* = 73) (*p* = .01)**	**83%**
Hip	10% (*n* = 146) (*p* = .3)	3%	8% (*n* = 143) (*p* = .6)	12%	9% (*n* = 289) (*p* = .8)	7%	24% (*n* = 210) (*p* = .2)	42%	18% (*n* = 202) (*p* = .4)	31%	21% (*n* = 412) (*p* = .1)	36%	**10%** **(*n* = 23) (*p* = .004)**	**50%**	19% (*n* = 30) (*p*=.8)	25%	16% (*n* = 53) (*p* = .09)	38%
Knee	13% (*n* = 306) (*p* = .6)	18%	15% (*n* = 309) (*p*=.5)	10%	14% (*n* = 615) (*p* = .98)	14%	26% (*n* = 366) (*p* = .4)	16%	26% (*n* = 396) (*p* = .5)	20%	26% (*n* = 762) (*p* = .3)	18%	**13%** **(*n* = 50) (*p* = .008)**	**42%**	33% (*n* = 60) (*p* = .6)	42%	24% (*n* = 110) (p = .08)	42%
Ankle	24% (*n* = 216) (*p* = .3)	13%	11% (*n* = 142) (*p* = .6)	16%	12% (*n* = 274) (*p* = .7)	10%	24% (*n* = 216) (*p* =. 3)	13%	23% (*n* = 207) (*p* = .4)	13%	23% (*n* = 423) (*p* = .2)	13%	19% (*n* = 25) (*p* = .7)	25%	38% (*n* = 28) (*p* = .6)	25%	29% (*n* = 53) (*p* = .8)	25%
Sacroiliac	27% (*n* = 120) (*p* = .2)	43%	26% (*n* = 121) (*p* = .6)	32%	27% (*n* = 241) (*p* = .3)	38%	48% (*n* = 195) (*p* = .8)	46%	**49%** **(*n* = 179) (*p* = .03)**	**92%**	**48%** **(*n*=374) (*p*=.04)**	**68%**	55% (*n* = 26) (*p* = .6)	50%	58% (*n* = 23) (*p* = .2)	25%	56% (*n* = 49) (*p* = .1)	38%

TABLE 6 Osteoarthritis stylistic comparison for females by age-at-death (values in bold text have a *p* value at .05 or less using the chi-square statistic, any blank box notates that generalized estimating equation modelling was not possible)

	Female young adults in % of modeled frequency						Female middle adults in % of modeled frequency						Female older adults in % of modeled frequency					
	L		R		Combined		L		R		Combined		L		R		Combined	
	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo–style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style
Shoulder	13% (*n* = 57) (*p* = .8)	17%	11% (*n* = 56) (*p* = .7)	17%	12% (*n* = 113) (*p* = .8)	17%	24% (*n* = 83) (*p* = .3)	50%	24% (*n* = 86) (*p* = .1)	50%	24% (*n* = 169) (*p* = .2)	50%					**24%** **(*n* = 33) (*p* = .049)**	**50%**
Elbow	17% (*n* = 276) (*p* = .8)	19%	20% (*n* = 303) (*p* = .4)	27%	18% (*n* = 579) (*p* = .6)	23%	31% (*n* = 422) (*p* = .8)	33%	31% (*n* = 408) (*p* = .1)	48%	31% (*n* = 830) (*p* = .2)	41%	**38%** **(*n* = 70) (*p* < .0001)**	**71%**	**40%** **(*n* = 69) (*p* < .0001)**	**86%**	**39%** **(*n* = 139) (*p* < .0001)**	**79%**
Wrist							26% (*n* = 145) (*p* = .2)	10%			**24%** **(*n* = 292) (*p* = .04)**	**5%**						
Hip	11% (*n* = 78) (*p* = .7)	7%	7% (*n* = 83) (*p* = .1)	23%	9% (*n* = 161) (*p* = .5)	15%	25% (*n* = 113) (*p* = .45	33%	18% (*n* = 110) (*p* = .1)	50%	22% (*n* = 233) (*p* = .2)	43%	**13%** **(*n* = 18) (*p* = .01)**	**50%**	**21%** **(*n* = 21) (*p* = .04)**	**50%**	**17%** **(*n* = 39) (*p* = .02)**	**50%**
Knee	11% (*n* = 141) (*p* = .99)	11%	14% (*n* = 149) (*p* = .8)	16%	12% (*n* = 290) (*p* = .9)	13%	25% (*n* = 182) (*p* = .3)	13%	30% (*n* = 197) (*p* = .6)	23%	28% (*n* = 379) (*p* = .4)	18%	**9%** **(*n* = 28) (*p* < .0001)**	**50%**	25% (*n* = 38) (*p* = .46	33%	19% (*n* = 66) (*p* = .6)	42%
Ankle			8% (*n* = 73) (*p* = .9)	9%	9% (*n* = 137) (*p* = .5)	5%	19% (*n* = 115) (*p* = .6)	13%	21% (*n*=107) (*p*=.8)	25%	20% (*n* = 222) (*p* = .9)	19%	**20%** **(*n* = 17) (*p* = .02)**	**50%**	**25%** **(*n* = 18) (*p* = .03)**	**50%**	**23%** **(*n* = 35) (*p* = .006)**	**50%**
Sacroiliac	33% (*n* = 72) (*p* = .3)	50%	32% (*n* = 76) (*p* = .8)	29%	33% (*n* = 148) (*p* = .6)	39%	53% (*n* = 108) (*p* = .7)	57%			**56%** **(*n* = 206) (*p* = .001)**	**80%**	65% (*n* = 19) (*p* = .1)	50%	64% (*n* = 16) (*p* = .08)	50%	**64%** **(*n* = 35) (*p* = .03)**	**50%**

TABLE 7 Osteoarthritis stylistic comparison for malces by age-at-death (values in bold text have a *p* value at .05 or less using the chi-square statistic, any blank box notates that generalized estimating equation modelling was not possible)

	Male young adults in % of modelled frequency						Male middle adults in % of modelled frequency						Male older adults in % of modelled frequency					
	L		R		Combined		L		R		Combined		L		R		Combined	
	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style	Chen Chen-style	Omo-style
Shoulder	13% (*n* = 44) (*p* = .8)	15%	15% (*n* = 42) (*p* = .9)	13%	14% (*n* = 86) (*p* = .97)	14%	19% (*n* = 59) (*p* = .2)	40%	25% (*n* = 67) (*p* = .5)	33%	22% (*n* = 126) (*p* = .08)	36%						
Elbow	19% (*n* = 201) (*p* = .5)	25%	15% (*n* = 204) (*p* = .6)	18%	17% (*n* = 405) (*p* = .4)	22%	36% (*n* = 291) (*p* = .5)	29%	47% (*n* = 313) (*p* = .4)	38%	42% (*n* = 604) (*p* = .4)	34%	42% (*n* = 19) (*p* = .3)	14%	57% (*n* = 21) (*p* = .6)	43%	50% (*n* = 40) (*p* = .5)	29%
Wrist	19% (*n* = 60) (*p* = .3)	9%			19% (*n* = 121) (*p* = .1)	5%	30% (*n* = 101) (*p* = .9)	29%	23% (*n* = 103) (*p* = .3)	11%	27% (*n* = 204) (*p* = .5)	19%	17% (*n* = 9) (*p* = .3)	33%			40% (*n* = 16) (*p* = .2)	67%
Hip							23% (*n* = 86) (*p* = .2)	50%			19% (*n* = 171) (*p* = .4)	27%						
Knee	16% (*n* = 133) (*p* = .6)	23%	14% (*n* = 128) (*p* = .3)	6%	15% (*n* = 261) (*p* = .99)	15%	20% (*n* = 147) (*p* = .95)	21%	24% (*n* = 167) (*p* = .5)	17%	22% (*n* = 314) (*p* = .7)	19%			55% (*n* = 17) (*p* = .9)	50%	30% (*n* = 32) (*p* = .5)	42%
Ankle	10% (*n* = 56) (*p* = .7)	7%	12% (*n* = 55) (*p* = .5)	21%	11% (*n*=111) (*p*=.7)	14%	28% (*n* = 81) (*p* = .7)	20%			26% (*n* = 163) (*p* = .1)	9%						
Sacroiliac	19% (*n* = 45) (*p* = .4)	36%	13% (*n* = 42) (*p* = .1)	36%	16% (*n* = 87) (*p* = .2)	36%	41% (*n* = 79) (*p* = .98)	40%			39% (*n* = 152) (*p* = .4)	57%	33% (*n* = 5) (*p* = .3)	50%			33% (*n* = 10) (*p* = .6)	25%

accounts (Abercrombie, 1986: 115; Bolin, 2006: 72; Carter, 1967; Hardman, 1976: 2; Lucy, 2005: 43; Mitchell, 2003: 276), the salient differences noted may be more about age and gendered labour divisions in Andean subsistence. There were significant differences between the Omo- and Chen Chen-style groups in age-related comparisons (Table 5). Younger adults in Chen Chen-style burials had significantly more wrist OA and could indicate some kind of repetitive agricultural task that injured the wrist. Middle-aged adults in the Omo-style burial sample had significantly higher rates of OA in the shoulder and sacroiliac joints, likely indicating age-related tasks that Omo people performed more than Chen Chen groups did. Significant differences among older adults were likely a product of a small sample size and not necessarily true distinctions.

When OA was evaluated by sex and sex with age-at-death, males and males by age-at-death do not show any significant results (Tables 4 and 7). However, females and females by age-at-death had significant results (Tables 4 and 6). Comparable to other research on complex societies and labour (e.g., Arnold, 2006; Brumfiel, 1991; Brumfiel, 1992; Ebert & Patterson, 2006; Hastorf, 1991; Silverblatt, 1987), these results may represent gendered activity distinctions in the way females among the stylistic groups lived their lives. There were significantly higher Omo-style rates in the right hip in the female sample and both sides of the sacroiliac among middle-aged females. These results could indicate distinctions in the way Chen Chen and Omo females lived and moved. This trend could also correlate with clinical accounts of lower back, hip, and sacroiliac OA among modern people who run or walk while wearing heavy backpacks (Chosa, Totoribe, & Tajima, 2004; Whiting & Zernicke, 2008: 281) and Andean pastoralists who porter loads on their backs (Tripcevich, 2008; Tripcevich & Capriles, 2016).

Akin to younger adults, middle-age females also had higher OA rates from Chen Chen-affiliated burials in the wrist joint. Wrist arthritis could be indicative of a repetitive task related to agriculture that young people and middle-aged females did. Unfortunately, modelling could not be performed on younger females, so we currently cannot tell if this was a gendered plus age-at-death trend. In addition, significant results for females in the older age category were likely a product of a small sample size.

5 | CONCLUSIONS

Our main goal in this research was to look for OA differences between the Chen Chen-style and Omo-style burials to determine if there were any overarching OA skeletal differences. We did not find any statistically significant differences in the overall population and both groups showed similar modelled rates of OA in the combined adult population. However, when sorted by sex, age-at-death, and sex with age-at-death, we did find patterning by cultural affiliation in younger and middle-aged people and in females coinciding with modern and ethnohistoric accounts of Andean age and gender divisions (Abercrombie, 1986: 115; Bolin, 2006: 72; Carter, 1967; Hardman, 1976: 2; Lucy, 2005: 43; Mitchell, 2003: 276). Although other factors may have been involved (e.g., obesity and genetics), this research likely represents evidence of significant repetitive tasks performed using the wrist joint by Chen Chen-style young adults and middle-aged females, perhaps in food preparation and weaving. Conversely, among Omo style peoples, the middle-aged, females, and middle-aged females, there is possible evidence of portering loads on the joints in the shoulder, hip, and sacroiliac. These age and sex distinctions are consistent with our archaeological hypothesis of occupationally specialized corporate agricultural and pastoral groups within Tiwanaku.

This research also supports clinical and bioarchaeological studies that note intense and repetitive work from a younger age may positively influence skeletal evidence of activity indicators (Benjamin et al., 2006; Halcrow & Tayles, 2011; Jurmain et al., 2012; Pearson & Buikstra, 2006; Villotte & Knüsel, 2013). The subadults with evidence of lipping, porosity, osteophyte formation, and/or eburnation in the elbow and ankle joints may reflect modern examples of Andean children beginning work at a young age (approximately 5 years), with damage gaining in intensity as individuals aged. In addition, we have tried in this research to address some of the concerns with using OA as an indicator of activity by evaluating OA in subadults, controlling for age-at-death and sex in our statistical comparisons and narrowing possible OA aetiology. By contextualizing our research to this specific population and using extremely well-preserved individuals, we have hoped to address concerns raised by various scholars about OA's association with activity (e.g., Cardoso & Henderson, 2013; Jurmain, 1999; Jurmain et al., 2012; Pearson & Buikstra, 2006; Perréard Lopreno, Alves Cardoso, Assis, Milella, & Speith, 2013; Weiss & Jurmain, 2007). By using a reliable archaeological record for comparison in light of modern, historic, and ethnohistoric data from Andean populations, this research has synthesized multiple lines of evidence to understand evidence of OA lifeways in this Tiwanaku colony.

ORCID

S.K. Becker http://orcid.org/0000-0002-3395-309X

REFERENCES

Abercrombie, T. (1986). The politics of sacrifice: An Aymara cosmology in action. PhD Dissertation, Department of Anthropology, University of Chicago, Chicago.

Agresti, A. (2007). *An introduction to categorical data analysis*. Hoboken, NJ: John Wiley & Sons, Inc.

Arnold, B. (2006). Gender and archaeological mortuary analysis. In S. Nelson (Ed.), *Handbook of gender in archaeology* (pp. 137–170). Lanham, MD: AltaMira Press.

Baitzel, S. I., & Goldstein, P. S. (2016). No country for old people: A paleodemographic analysis of migration dynamics in early Andean states. *International Journal of Osteoarchaeology*, *26*, 1001–1013.

Bass, W. M. (1981). *Human osteology: A laboratory and field manual of the human skeleton*. Columbia, MO: Missouri Archaeological Society.

Becker, S. K. (2012). Using generalized estimating equations to evaluate activity in human skeletal remains. International Conference on Advances in Interdisciplinary Statistics and Combinatorics, AISC, Greensboro, NC.

Becker, S. K. (2013). Labor and the rise of the Tiwanaku state (AD 500–1100): A bioarchaeological study of activity patterns. PhD Dissertation, Department of Anthropology, University of North Carolina, Chapel Hill, NC.

Becker, S. K. (2016). Skeletal evidence of craft production from the Ch'iji Jawira site in Tiwanaku, Bolivia. *Journal of Archaeological Science: Reports*, *9*, 405–415.

Becker, S. K. (2017). Community labor and laboring communities within the Tiwanaku state (CE 500–1100). *Archaeological Papers of the American Anthropological Association*, *28*, 38–53.

Benjamin, M., Toumi, H., Ralphs, J., Bydder, G., Best, T., & Milz, S. (2006). Where tendons and ligaments meet bone: Attachment sites ("Entheses") in relation to exercise and/or mechanical load. *Journal of Anatomy*, *208*, 471–490.

Blom, D. E. (2005). Embodying borders: Human body modification and diversity in Tiwanaku society. *Journal of Anthropological Archaeology*, *24*, 1–24.

Blom, D. E., Hallgrímsson, B., Keng, L., Lozada, M. C., & Buikstra, J. E. (1998). Tiwanaku 'colonization': Bioarchaeological implications for migration in the Moquegua Valley, Peru. *World Archaeology*, *30*, 238–261.

Blom, D. E., & Knudson, K. J. (2007). The relationship between Tiwanaku mortuary behavior and geographic origins at Chen Chen (Moquegua, Peru). The 72nd Annual Meeting of the Society for American Archaeology, Austin, TX.

Blom, D. E., Knudson, K. J., Janusek, J. W., Becker, S. K., & Bowen, C. M. (2016). Formation and transformation of identities in the Andes. Society for American Archaeology Meeting, Orlando, FL.

Bolin, I. (2006). *Growing up in a culture of respect: Child rearing in highland Peru*. Austin: University of Texas Press.

Brandt, K. D., Dieppe, P., & Radin, E. L. (2009). Commentary: Is it useful to subset "primary" osteoarthritis? A critique based on evidence regarding the etiopathogenesis of osteoarthritis. *Seminars in Arthritis and Rheumatism*, *39*, 81–95.

Bridges, P. S. (1991). Degenerative joint disease in hunter–gatherers and agriculturalists from the southeastern United States. *American Journal of Physical Anthroplogy*, *85*, 379–391.

Bridges, P. S. (1992). Prehistoric arthritis in the Americas. *Annual Review of Anthropology*, *21*, 67–91.

Bridges, P. S. (1995). Skeletal biology and behavior in ancient humans. *Evolutionary Anthropology: Issues, News, and Reviews*, *4*, 112–120.

Browman, D. L. (1984). Tiwanaku: Development of interzonal trade and economic expansion in the altiplano. In D. Browman, R. Burger, & M. Rivera (Eds.), *Social and economic organization in the prehispanic Andes, Bar International Series 194* (pp. 117–142). Oxford: British Archaeological Reports.

Brumfiel, E. M. (1991). Weaving and cooking: Women's production in Aztec Mexico. In J. Gero, & M. Conkey (Eds.), *Engendering archaeology: Women and prehistory* (pp. 224–251). Oxford: Basil Blackwell, Ltd.

Brumfiel, E. M. (1992). Distinguished lecture in archaeology: Breaking and entering the ecosystem—Gender, class, and faction steal the show. *American Anthropology*, *94*, 551–567.

Buikstra, J. E., & Ubelaker, D. H. (1994). *Standards for data collection from human skeletal remains*. Fayetteville, AR: Arkansas Archaeological Survey.

Cardoso, F. A., & Henderson, C. (2013). The categorisation of occupation in identified skeletal collections: A source of bias? *International Journal of Osteoarchaeology*, *23*, 186–196.

Carter, W. E. (1967). *Aymara communities and the Bolivian agrarian reform*. Gainesville: University Press of Florida.

Chammas, M. (2014). Post-traumatic osteoarthritis of the elbow. *Orthopaedics & Traumatology, Surgery & Research*, *100*, S15–S24.

Cheverko, C. M., & Bartelink, E. J. (2017). Resource intensification and osteoarthritis patterns: Changes in activity in the prehistoric Sacramento-San Joaquin Delta Region. *American Journal of Physical Anthroplogy*. https://doi.org/10.1002/ajpa.23272.

Chosa, E., Totoribe, K., & Tajima, N. (2004). A biomechanical study of lumbar Spondylolysis based on a three-dimensional finite element method. *Journal of Orthopedic Research*, *22*, 158–163.

Cope, J. M., Berryman, A. C., Martin, D. L., & Potts, D. D. (2005). Robusticity and osteoarthritis at the trapezoimetacarpal joint in a Bronze Age population from Tell Abraq, United Arab Emirates. *American Journal of Physical Anthroplogy*, *126*, 391–400.

Coulibaly, Y., Diakite, A. A., Keita, M., Diakite, I., Dembele, M., & Diallo, G. (2009). Aspects epidemiocliniques et therapeutiques des osteoarthites de l'enfant. *Mali Médical*, *24*, 7–10.

Dean, C. (2001). Andean androgyny and the making of men. In C. Klein (Ed.), *Gender in pre-hispanic America* (pp. 143–182). Washington, DC: Dumbarton Oaks Research Library and Collection.

Domett, K., Evans, C., Chang, N., Tayles, N., & Newton, J. (2017). Interpreting osteoarthritis in bioarchaeology: Highlighting the importance of a clinical approach through case studies from prehistoric Thailand. *Journal of Archaeological Science: Reports*, *11*, 762–773.

Ebert, V., & Patterson, T. (2006). Gender in South American archaeology. In S. Nelson (Ed.), *Handbook of gender in archaeology* (pp. 853–874). Latham, MD: AltaMira Press.

Felson, D. (2004). Risk factors for osteoarthritis. *Clinical Orthopaedics and Related Research*, *427S*, S16–S21.

Gaggio, G., & Goldstein, P. S. (2015). Plants of the Tiwanaku gods: Results of a paleoethnobotanical analysis of the temple of Omo M10a, Moquegua, Peru. Annual Meeting of Society for American Archaeology, San Francisco, CA.

Gaggio, G., & Goldstein, P. S. (2016). Food and identity in the Tiwanaku state: A view from the lowland site of Rio Muerto, Moquegua, Peru. Annual Meeting of Society for American Archaeology, Vancouver, BC, Canada.

Gagnon, C. M., & Wiesen, C. (2013). Using general estimating equations to analyze oral health in the Moche Valley of Perú. *International Journal of Osteoarchaeology*, *23*, 557–572.

Ghislatta, P., & Spini, D. (2004). An introduction to generalized estimating equations and an application to assess selectivity effects in a longitudinal study on very old individuals. *Journal of Educational and Behavioral Statistics*, *29*, 421–437.

Goldstein, P. S. (2005). *Andean diaspora: The Tiwanaku colonies and the origins of the South American empire*. Gainesville: University of Florida Press.

Goldstein, P. S. (2012). Embedded Andean economic systems and the expansive Tiwanaku state: A case for a state without market exchange. In K. G. Hirth, & J. Pillsbury (Eds.), *Merchants, markets, and exchange in the pre-Columbian world*. Washington, DC: Dumbarton Oaks.

Goldstein, P. S. (2015). Multiethnicity, pluralism, and migration in the south central Andes: An alternate path to state expansion. *Proceedings of the National Academy of Sciences*, *112*, 9202–9209.

Goldstein, P. S., & Magilligan, F. J. (2011). Hazard, risk and agrarian adaptations in a hyperarid watershed: El Niño floods, streambank erosion, and the cultural bounds of vulnerability in the Andean middle horizon. *Catena*, *85*, 155–167.

Graham, M. A. (1997). Food allocation in rural Peruvian households: Concepts and behavior regarding children. *Social Science & Medicine*, *44*, 1697–1709.

Guaman Poma de Ayala, F. (2006). *El primer nueva corónica y buen gobierno*. (pp. 1613). Mexico City: Editorial Siglo Veintiuno.

Halcrow, S. E., & Tayles, N. (2011). The bioarchaeological investigation of children and childhood. In S. C. Agarwal, & B. A. Glencross (Eds.), *Social bioarchaeology* (pp. 333–360). Malden, MA: Wiley-Blackwell.

Hardman, M. J. (1976). Andean women. Film essay, AUFS documentary film program, wheelock educational resources.

Harrington, K. (1979). Degenerative arthritis of the ankle secondary to long-standing lateral ligament instability. *Journal of Bone and Joint Surgery*, *61*, 354–361.

Harris, O. (1978). Complementarity and conflict: And Andean view of women and men. In J. Fontaine (Ed.), *Sex and age as principles of social differentiation*. London: Academic Press.

Harris, O. (1980). The power of signs: Gender, culture and the wild in the Bolivian Andes. In M. Carol, & S. Marilyn (Eds.), *Nature, Culture, and Gender* (pp. 70–94). Cambridge: Cambridge University Press.

Hastorf, C. A. (1991). Gender, space, and food in prehistory. In J. Gero, & M. Conkey (Eds.), *Engendering archaeology: Women and prehistory* (pp. 132–159). Oxford: Basil Blackwell, Ltd.

Hoppa, R. D. (2002). Paleodemography: Looking back and thinking ahead. In R. D. Hoppa, & J. W. Vaupel (Eds.), *Paleodemography* (pp. 9–28). Cambridge: Cambridge University Press.

Hunter, D., March, L., & Sambrook, P. (2002). Knee osteoarthritis. *Clinical and Experimental Rhuematology*, *20*, 93–100.

Iscan, M. Y., Loth, S. R., & Wright, R. K. (1984). Metamorphosis at the sternal rib end: A new method to estimate age at death in white males. *American Journal of Physical Anthropology*, *65*, 147–156.

Janusek, J. W. (2008). *Ancient Tiwanaku*. New York: Cambridge University Press.

Jurmain, R. (1999). *Stories from the skeleton: Behavioral reconstruction in human osteology*. Amsterdam: Gordon and Breach.

Jurmain, R., Alves Cardoso, F., Henderson, C., & Villotte, S. (2012). Bioarchaeology's Holy Grail: The reconstruction of activity. In A. L. Grauer (Ed.), *A companion to paleopathology* (pp. 531–552). Malden, MA: Wiley-Blackwell.

Key, C. A., Aiello, L. C., & Molleson, T. (1994). Cranial suture closure and its implications for age estimation. *International Journal of Osteoarchaeology*, *4*, 193–207.

Klippel, J. H., Stone, J. H., Crofford, L. J., & White, P. H. (2008). *Primer on the rheumatic diseases*. New York: Springer.

Knudson, K. J. (2004). Tiwanaku residential mobility in the south central Andes: Identifying archaeological human migration through strontium isotope analysis. PhD Dissertation, Department of Anthropology, University of Wisconsin, Madison.

Knudson, K. J., & Blom, D. E. (2011). The complex relationship between Tiwanaku mortuary identity and geographic origin in the south central Andes. In K. J. Knudson, & C. M. Stojanowski (Eds.), *Bioarchaeology and identity in the Americas* (pp. 194–211). Gainesville, FL: University Press of Florida.

Knudson, K. J., Goldstein, P. S., Dahlstedt, A. C., Somerville, A. D., & Schoeninger, M. J. (2014). Paleomobility in the Tiwanaku diaspora: Biogeochemical analyses at Rio Muerto, Moquegua, Peru. *American Journal of Physical Anthroplogy*, *155*, 405–421.

Knudson, K. J., Price, T., Buikstra, J. E., & Blom, D. E. (2004). Uses of strontium isotope analysis to investigate Tiwanaku migration and mortuary ritual in Bolivia and Peru. *Archaeometry*, *46*, 5–18.

Lehman, T. J. (2004). *It's not just growing pains*. New York: Oxford University Press.

Liang, K.-Y., & Scott, S. L. (1986). Longitudinal data analysis using generalized linear models. *Biometrika*, *73*, 13–22.

Lohmander, L., Englund, P., Dahl, L., & Roos, E. (2007). The long-term consequence of anterior cruciate ligament and meniscus injuries: Osteoarthritis. *American Journal of Sports Medicine*, *35*, 1756–1769.

Lovejoy, C. O. (1985). Dental wear in the Libben population: Its functional pattern and role in the determination of adult skeletal age at death. *American Journal of Physical Anthropology*, *68*, 47–56.

Lovell, D. J. (2008). A. juvenile idiopathic arthritis. In J. H. Klippel, J. H. Stone, L. J. Crofford, & P. H. White (Eds.), *Primer on the rheumatic diseases* (pp. 142–148). New York: Springer.

Lucy, S. (2005). The Archaeology of Age. In M. Diaz-Andreu, S. Lucy, S. Babic, & D. N. Edwards (Eds.), *The archaeology of identity: Approaches to gender, age, statues, ethnicity and religion* (pp. 43–66). New York: Routledge.

Lynch, T. F. (1983). Camelid pastoralism and the emergence of Tiwanaku civilization in the south-central Andes. *World Archaeology*, *15*, 1–14.

Mitchell, W. (2003). Aymara. In C. R. Ember, & M. Ember (Eds.), *Encyclopedia of sex and gender*. New York: Springer.

Nandi, S., Maschke, S., Evans, P. J., & Lawton, J. N. (2009). The stiff elbow. *The Hand*, *4*, 368–379.

Nicholson, S., Dickman, K., & Maradiegue, A. (2009). Reducing premature osteoarthritis in the adolescent through appropriate screening. *Journal of Pediatric Nursing*, *24*, 69–74.

Nikita, E. (2014). The use of generalized linear models and generalized estimating equations in bioarchaeological studies. *American Journal of Physical Anthropology*, *153*, 473–483.

Pearson, O. M., & Buikstra, J. E. (2006). Behavior and the Bones. In J. E. Buikstra, & L. A. Beck (Eds.), *Bioarchaeology: The contextual analysis of human remains* (pp. 207–225). Amsterdam: Elsevier.

Perréard Lopreno, G., Alves Cardoso, F., Assis, S., Milella, M., & Speith, N. (2013). Categorization of occupation in documented skeletal collections: Its relevance for the interpretation of activity-related osseous changes. *International Journal of Osteoarchaeology*, *23*, 175–185.

Ramos Amador, J. T., López Laso, E., Romero Blanco, I., Alba Romero, C., Curto de la Mano, A., González del Orbe, G., & Scarpellini Vera, A. (1998). Osteoartritis séptica en niños. *Anales de Pediatría*, *49*, 481–486.

Rogers, J., & Waldron, T. (1995). *A field guide to joint disease in archaeology*. New York: J. Wiley & Sons.

Rogers, J., Waldron, T., Dieppe, P., & Watt, I. (1987). Arthropathies in palaeopathology: The basis of classification according to most probable cause. *Journal of Archaeological Science*, *14*, 179–193.

Rytter, S., Egund, N., Jensen, L. K., & Bonde, J. P. (2009). Occupational kneeling and radiographic tibiofemoral and patellofemoral osteoarthritis. *Journal of Occupational Medicine and Toxicology*, *4*, 19.

Scheuer, L., & Black, S. (2000). *Developmental juvenile osteology*. San Diego: Academic Press.

Silverblatt, I. (1987). *Moon, sun, and witches: Gender ideologies and class in Inca and colonial Peru*. Princeton, NJ: Princeton University Press.

Somerville, A. D., Goldstein, P. S., Baitzel, S. I., Bruwelheide, K. L., Dahlstedt, A. C., Yzurdiaga, L., … Schoeninger, M. J. (2015). Diet and gender in the Tiwanaku colonies: Stable isotope analysis of human bone collagen and apatite from Moquegua, Peru. *American Journal of Physical Anthropology*, *158*, 408–422.

Spector, T. D., & MacGregor, A. J. (2004). Risk factors for osteoarthritis: Genetics. *Osteoarthritis and Cartilage*, 12 Supplement A.

Stanish, C., de la Vega, E., Moseley, M. E., Williams, R. P., Chavez, C., Vining, B., & LaFavre, K. (2010). Tiwanaku trade patterns in southern Peru. *Journal of Anthropological Archaeology*, *29*, 524–532.

Suchey, J. M., & Katz, D. (1998). Applications of pubic age determination in a forensic setting. In K. Reichs (Ed.), *Forensic osteology* (2nd ed.). Springfield: Charles C. Thomas.

Taga, I., Shino, K., Inoue, M., Nakata, K., & Maeda, A. (1993). Articular cartilage lesions in ankles with lateral ligament injury. *The American Journal of Sports Medicine*, *21*, 120–127.

Tripcevich, N. (2008). Llama caravan transport: A study of mobility with a contemporary Andean salt caravan. Annual Meeting of the Society for American Archaeology, Vancouver, B.C., Canada.

Tripcevich, N., & Capriles, J. M. (2016). Advances in the archaeology of Andean pastoralism. In N. Tripcevich, & J. M. Capriles (Eds.), *The archaeology of Andean pastoralism* (pp. 1–10). Albuquerque: University of New Mexico Press.

Ubelaker, D. H. (1999). *Human skeletal remains: Excavation, analysis, interpretation*. Washington, D.C: Taraxacum.

Valderrabano, V., Horisberger, M., Russell, I., Dougall, H., & Hintermann, B. (2008). Etiology of ankle osteoarthritis. *Clinical Orthopaedics and Related Research*, *467*, 1800.

Vallières, C. (2016). Camelid pastoralism at Ancient Tiwanaku: Urban provisioning in the highlands of Bolivia. In J. Capriles, & N. Tripcevich (Eds.), *The archaeology of Andean pastoralism*. Albuquerque: University of New Mexico Press.

Villotte, S., & Knüsel, C. J. (2013). Understanding entheseal changes: Definition and life course changes. *International Journal of Osteoarchaeology*, *23*, 135–146.

Von Porat, V., Roos, E., & Roos, H. (2004). High prevalence of osteoarthritis 14 years after an anterior cruciate ligament tear in male soccer players: A study of radiographic and patient relevant outcomes. *Annals of the Rheumatic Diseases*, *63*, 269–273.

Waldron, T. (1995). Changes in the distribution of osteoarthritis over historical time. *International Journal of Osteoarchaeology*, *5*, 385–389.

Waldron, T. (1997). Osteoarthritis of the hip in past populations. *International Journal of Osteoarchaeology*, *7*, 186–189.

Walker-Bone, K., & Palmer, K. T. (2002). Musculoskeletal disorders in farmers and farm workers. *Occupational Medicine*, *52*, 441–450.

Weiss, E., & Jurmain, R. (2007). Osteoarthritis revisited: A contemporary review of Aetiology. *International Journal of Osteoarchaeology*, *17*, 437–450.

Whiting, W. C., & Zernicke, R. F. (2008). *Biomechanics of musculoskeletal injury*. Champaigne, IL: Human Kinetics.

Widmark, C. (2000). *Contesting Models for Gender Equality in a Bolivian Context*. Conference on power, resources, and culture in a gender perspective, Uppsala University, Sweden.

Williams, P. R. (2006). Agricultural innovation, intensification, and sociopolitical development. In C. Stanish, & J. Marcus (Eds.), *Andean watersheds* (pp. 309–333). Los Angeles: Cotsen Institute of Archaeology, UCLA.

How to cite this article: Becker SK, Goldstein PS. Evidence of osteoarthritis in the Tiwanaku Colony, Moquegua, Peru (AD 500–1100). *Int J Osteoarchaeol*. 2017;1–13. https://doi.org/10.1002/oa.2634