International Journal of Osteoarchaeology
Int. J. Osteoarchaeol. **19**: 375–385 (2009)
Published online 22 July 2008 in Wiley InterScience
(www.interscience.wiley.com) DOI: 10.1002/oa.986

Spondylolysis in a Pre-Contact San Francisco Bay Population: Behavioural and Anatomical Sex Differences

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ABSTRACT Spondylolysis refers to a separation of the spinal body from the arch. Researchers have documented that these fractures occur due to stresses related to activities involving the lower limb and back. Spondylolysis in sacral and lumbar vertebrae of 146 (66 males, 66 females, 14 indeterminates) California Amerinds were examined to determine whether sex differences were present. Sacral anatomy (i.e. sacralisation and lumbarisation, sacral base angles, and superior facet morphology) was analysed in relation to spondylolysis and sex, to explore whether sex differences could be better explained through activity patterns or anatomical variation. Spondylolysis afflicted 24 individuals (16.4%). Males had more than twice the rate of spondylolysis than did females (26% and 11%, respectively). Activity patterns, such as thrusting and throwing shafted obsidian points, could explain the sex differences. Males were most frequently buried with obsidian point artefacts, whereas females were buried with mortar and pestles. For sacral anatomy, only males had lumbarisation, and all other anatomical variation had no significant sex differences. Lumbarisation related to spondylolysis in males. In this study, sacral anatomical variation could not fully account for sex differences in spondylolysis; activity patterns provided a better explanation. Nonetheless, anatomical variation may predispose males to spondylolysis, or spondylolysis may affect sacral anatomy.

Key words: spondylolysis; sex; activity patterns; sacral anatomy

Introduction

Spondylolysis is a condition of the spine that refers to a separation of the vertebral arch from the vertebral body, and excludes the lack of fusion of the spinous process (Merbs, 1996a). Merbs (1996a) discussed the role that bipedality plays in spondylolysis; typical spondylolysis (limited to the lumbosacral region) is absent in non-human primates and in children too young to walk. Spondylolysis, however, must have supplementary causes since the percentage of individuals with spondylolysis ranges from less than 5% in some populations, such as Native American remains from the Columbia River region (Congdon, 1932) to over 50% in Eskimo populations (Merbs, 1983, 1995, 1996a,b).

Anthropologists have frequently used the presence of spondylolysis to reconstruct activity patterns (e.g. Stewart, 1953; Reinhard *et al.*, 1994; Arriaza, 1997). However, recently other indicators of activity (such as muscle markers and osteoarthritis) have been shown to correlate with non-activity related factors (such as body size, genetics and anatomical variation) (Weiss, 2003,

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Received 20 June 2007
Revised 21 December 2007
Accepted 23 January 2008

2005; Weiss & Jurmain, 2007). Thus, this study attempts to determine whether spondylolysis in a bioarchaeological sample can be best explained by anatomical variation or activity patterns.

Clinicians and anthropologists link the appearance of spondylolysis to activity patterns. For over a century, researchers conducted studies linking spondylolysis to specific activity patterns and general heavy labour. In 1887, Lane associated heavy labour with spondylolysis. In the sports literature, clinicians find higher spondylolysis rates than population norms in gymnasts (Commandre *et al.*, 1988), football players (McCarroll *et al.*, 1986), rowers (Stallard, 1980; Rumball *et al.*, 2005), wrestlers (Rossi & Dragoni, 1990), weightlifters (Risser, 1991), rugby players (Iwamoto *et al.*, 2005), soccer players (Rassi *et al.*, 2005) and other athletes (see Shrier, 2001, for a summary). Recent studies also link spondylolysis to sports that require extensive use of one upper limb side, such as cricket, baseball and tennis (Ruiz-Cotorro *et al.*, 2006). Many of these activities involve hyperextension of the hip and torsion of the back, such as in swinging a bat and throwing a ball. Clinicians have had a difficult time diagnosing spondylolysis; it is not always evident on X-rays. Furthermore, only individuals with back pain are likely to be examined for spondylolysis and, thus, spondylolysis rates may be underreported.

Anthropologists too have documented spondylolysis and, as mentioned above, correlated it with various activities. Stewart (1953) associated spondylolysis with bending at the waist, as documented in Eskimo populations. Additionally, Arriaza (1997) connected the lifting or moving of heavy objects with spondylolysis, such as moving large stone pillars in Guam. Bridges (1989) tied spondylolysis to non-specific activities related to hunting and gathering. Merbs (1983, 1996b, 2002) noted that the high percentage of spondylolysis in Arctic populations is related to heavy labour required to live in those cold climates, such as lifting heavy items, kayaking, paddling and wrestling. Yet, one must note that many anthropologists agree it is difficult to tie specific activities to spondylolysis, and even in sports the predictive rate of spondylolysis with an activity is very low (Bridges, 1989; Merbs, 1996a; Jurmain, 1999).

Some patterns of spondylolysis occur regardless of activities and cultures. In the vertebral column, for instance, the fifth lumbar is most frequently affected with spondylolysis, followed by the fourth lumbar (e.g. Stewart, 1931; Bridges, 1989; Merbs, 1996a,b, 2002; Arriaza, 1997; Fibiger & Knüsel, 2005). Further patterns include a predominance of complete bilateral separation, with about half of all spondylolysis cases being of this classic type (Merbs, 1996a). Merbs (1996a) attributed these patterns to hyperextension at the hip coupled with bipedal locomotion. Spondylolysis of this type increases flexibility and thus creates an advantage for those with the fracture. Merbs (1996a) supported his conclusions through the lack of spondylolysis in individuals too young to walk or non-human primates, along with ethnographic data on sports and Arctic population activities. He added information about gymnasts and other individuals to support the possibility of spondylolysis being an advantage for some people.

Age patterns, too, have emerged in spondylolysis studies. Spondylolysis does not afflict individuals too young to walk (e.g. Rowe & Roche, 1953; Merbs, 1996a,b; Fibiger & Knüsel, 2005), which relates to the necessity of stresses plus bipedal behaviour (as mentioned above). In skeletal populations, stresses associated with spondylolysis (such as hip hyperextension, back torsion, heavy lifting) increase throughout adulthood, especially if they are related to food attainment and processing or other necessities that adults tend to perform (e.g. Merbs, 1983, 1996a,b, 2002; Arriaza, 1997; Fibiger & Knüsel, 2005). Clinical studies of modern populations, conversely, record younger individuals afflicted by spondylolysis, which one may attribute to adults reducing their sports activities compared with juveniles and young adults (e.g. McCarroll *et al.*, 1986; Commandre *et al.*, 1988; Shrier, 2001). Another interesting twist is that as individuals grow very old, spondylolysis seems to decrease. Merbs (2002) noted that the decrease in spondylolysis rates in older adults could relate to the healing of fractures, and thus prior spondylolysis escapes detection. However, this must be coupled with older individuals ceasing their strenuous activities, since Reiter *et al.* (2006) and Bridges (1989) have both found

DOI: 10.1002/oa

spondylolysis in elderly individuals. Reiter *et al.* (2006) discovered spondylolysis in a clinical group of elderly individuals (the mean age of the individuals with spondylolysis was 72) with no history of back pain or athletic endeavours as children and adolescents, which suggests that spondylolysis can occur at any age after walking has begun. Furthermore, Bridges (1989) found an increase in spondylolysis frequency in older females in southeastern Archaic Amerinds, which she suggested related to osteoporosis and degenerative joint disease.

Another nearly consistent pattern occurs in the distribution between the sexes. Most studies on spondylolysis find higher frequencies in males (e.g. Stewart, 1931; Roche & Rowe, 1951; Gunness-Hey, 1982; Merbs, 1983, 1996a,b, 2002; Virta *et al.*, 1992; Arriaza, 1997; Fibiger & Knüsel, 2005), although this difference is often not signficant. Sex differences have most often been related to activity pattern differences between males and females. An example comes from Arriaza (1997) who looked at a population in Guam and found higher rates of spondylolysis in males than in females, which he related to males moving large stone pillars. There are exceptions to the higher male spondylolysis frequency trend. Bridges (1989), in her study of western Alabama Archaic Indians, found that the females had slightly greater frequencies of spondylolysis than did their male counterparts (17% in males and 20% in females), but these differences were not statistically significant. In addition, in Lester & Shapiro's (1968) study of Point Hope Alaskan Eskimos females had slightly higher (less than 5%) frequencies than males. Another exception with well-documented ethnohistorical evidence comes from studies on the northeastern Nebraska Amerinds; females were responsible for hide scraping, house construction, and gathering firewood (Reinhard *et al.*, 1994). In this population of Nebraskan Amerinds, females had greater spondylolysis frequencies than did their male counterparts (Reinhard *et al.*, 1994). As mentioned above, sex differences are often attributed to activity patterns, but biological sex differences associated with anatomical differences may also be present which predispose males to spondylolysis at a greater frequency than females.

In the anthropological and clinical literature, discussions surrounding the genetic contributions to spondylolysis have occurred (e.g. Bridges, 1989; Merbs, 1996a; Jurmain, 1999). Many researchers have documented familial occurrences of spondylolysis, but what one inherits remains an enigma (Wiltse, 1957, 1962; Haukipuro *et al.*, 1978; Shahriaree *et al.*, 1979; Merbs, 1996a,b; Whiteside *et al.*, 2005). The specific genetics are in question, with even dominance versus recessiveness not yet determined. Activity intensity of relatives interconnected to family lifestyle is also difficult to control and can be a confounding factor.

Normal anatomical variation is easier to document than genetic differences, but also difficult to interpret. Issues of cause and effect are never simple to answer using skeletal samples, and clinical measures cannot always be performed on skeletons. Moreover, complete skeletal remains are rare in the bioarchaeological record, so skeletal measures may differ between autopsy collections and bioarchaeological collections. Thus, the variation examined differs from that of clinical and osteological studies, but the main purpose (i.e. to find anatomical causations of spondylolysis) remains the same. One such study comes from Peterson *et al.* (1990) who looked at radiographs of 30 individuals in the neutral upright lateral position to determine whether sacral base, sacrovertebral, and lumbosacral disc angles relate to spondylolysis. They noticed a correlation with sacral base angle and spondylolysis in males, but could not find any other correlations (which they attribute to small sample sizes). Mays (2006) found suggestive evidence that sacral angle has a link with spondylolysis presence. He studied medieval and modern British populations and discovered they varied significantly in their spondylolysis frequencies; the medieval sample had a frequency of 11.9% and the modern sample frequency was 5.8%. Also, the two populations differed significantly in sacral base angles, but within a population, the correlations with sacral base angles and spondylolysis were not present. Earlier, Stewart (1956) examined variation in the length of the lower presacral spine, inclined sacral bases, acute lumbar curvature, and facet concavity in a clinical study to determine whether anatomical variations led to increased spondylolysis risk. Although Stewart noted that

DOI: 10.1002/oa

patterns occurred, they were not significant. Another recent study looked at facet distance in relation to spondylolysis. Ward and Latimer (2005) examined 30 individuals who they matched for sex and age from the Hamann-Todd osteological collection to determine whether transverse distances between the fourth lumbar inferior facets and first sacral superior facets affected frequency of spondylolysis. They detected that individuals with less distance between the facets had greater risk of spondylolysis (with a vertebral size control), which they attributed to the pressure of the two vertebrae on the fifth lumbar. Merbs' (1983) study on the Canadian Inuit discovered a correlation between transitional vertebrae (e.g. lumbarisation) and spondylolysis. Anthropologists have yet to research these sacral anatomies fully, especially with regard to sex differences. Finally, one must be careful to separate causation from correlation in any anatomical study that focuses on skeletal remains.

The purpose of this study is three-fold. Firstly, I examine spondylolysis patterns in the study population to determine what patterns exist and whether they corroborate previously published patterns, especially those mentioned by Merbs (1996a). Secondly, this study explores whether there are sex differences in spondylolysis in this central Californian hunter-gatherer population. Thirdly, this study looks at whether anatomical variation may play a role in spondylolysis predisposition with regard to sex differences, as noted in some other studies.

Materials and methods

Sample

The skeletal sample consists of 146 individuals (66 males, 66 females, 14 indeterminates) ranging from infancy to 40+ years of age from the Ryan Mound site (CA-Ala-329), located on the southeastern side of the San Francisco Bay, dating from 2180 to 250 yrs BP (which is pre-European contact) and housed at the San José State University Anthropological Collection. Although the time span is great, there seems to have been cultural continuity as indicated by similarities in mortuary practices and artefacts (Leventhal, 1993). Additionally, claims of genetic cohesion have been made based on cranial morphology (Jurmain, 1993). For examination of spondylolysis patterns, all individuals had all of their lumbar vertebrae. For the sacral anatomy analyses, individuals had at least 2/3 complete sacral bases, one superior facet intact, and lumbar vertebrae 3 to 5.

Jurmain (1990) aged and sexed individuals according to standard osteological procedures. Males and females have an even age distribution as tested by cross-tabulations, and a chi-square test revealed no significant differences (0.551; $P = 0.908$).

The Ryan Mound Site (CA-Ala-329) contained numerous indicators of rich environmental resources. The site had large quantities of shellfish, waterfowl, and mammal bones (Leventhal, 1993). The Amerinds also utilised acorns, berries and seeds, as inferred from the large number of mortars, pestles, and related refuse found around the site (Leventhal, 1993). Obsidian points, along with shafts and other types of hooks and harpoons, were in abundance at CA-Ala-329; most of these artefacts (especially the obsidian points) were associated with male burials (Leventhal, 1993). This possibly indicates an emphasis on hunting as a male activity; females were more likely to be buried with pestles and cobblestone (Leventhal, 1993). The Amerinds from CA-Ala-329 were hunter-gatherers with a heavy reliance on acorns and supplemented by hunted foods (Jurmain, 1990, 1993; Leventhal, 1993).

The remains at CA-Ala-329 represent high lineage or wealthy individuals from various villages. Villagers were not isolated from other villagers, as indicated by lack of artefactual and mortuary differences (Leventhal, 1993). Population density was high, which inevitably led to escalated levels of interpersonal aggression (Jurmain, 1988; Jurmain & Bellefemine, 1997). From the skeletal remains and archaeological material, anthropologists know these Amerinds used shafted obsidian points in hunting and aggressive acts (Jurmain, 1988, 1990, 1993; Jurmain & Bellefemine, 1997; Leventhal, 1993).

Methods

The lumbosacral regions of the vertebral columns were sorted and examined for spondylolysis.

DOI: 10.1002/oa

Following Merbs (2002), the author noted the presence or absence of the condition, when it occurred, whether the separation was partial or complete, which vertebrae were affected, whether the condition was unilateral (along with the side it occurred on) or bilateral, and whether there was evidence of healing.

Along with the spondylolysis, the author took scores of sacral base angles (sacral base is straight or flat = 1; anterior sacral base angled superiorly = 2; anterior sacral base angled inferiorly = 3) (Figure 1). Sacral base angle was estimated because Stewart (1956), Mays (2006), and Peterson *et al*. (1990) all examined a variety of different sacral angle measurements in relation to spondylolysis and reported mixed results. The theoretical background to sacral base angle causing spondylolysis rests on the biomechanics of the spine; in short, it appears that sacral bases that are either flat or inclined increase shearing forces (Peterson *et al*., 1990; Merbs, 1996b; Mays, 2006). Shearing forces are the forces most likely to break bone and could cause anterior vertebral slippage and spondylolysis. The method of data collection used in this study is a simple method ideal for the study of skeletal remains that lack a pelvis. Nevertheless, it is not without problems. Stewart (1956) pointed out the difficulty in positioning the sacrum in anatomical position with only the skeletal elements. Also, complications arose; in order to eliminate problem cases, sacra that were difficult to assign an angle to and those with fused vertebrae were excluded.

Sacral superior articular facets were also scored on a 1 to 3 scale for orientation (medial = 1, angled outward = 2, posterior = 3) and curvature (concave = 1, straight = 2). Sacral facet orientation was based on whether the facets were facing to the posterior side (3), facing one another (1), or in between (2) (Figure 2). Sacral superior facet curvature and orientations were taken because less curved sacral facets and outward-angled facets have been suggested to increase stresses on the vertebral arches (Merbs, 1996). Stewart (1956) found a non-significant pattern of sacral facet curvature and spondylolysis frequency. One of the aims of the current study is to investigate whether there is a significant link between the two in the study sample. Furthermore, this could possibly help in the understanding of spondylolysis aetiology.

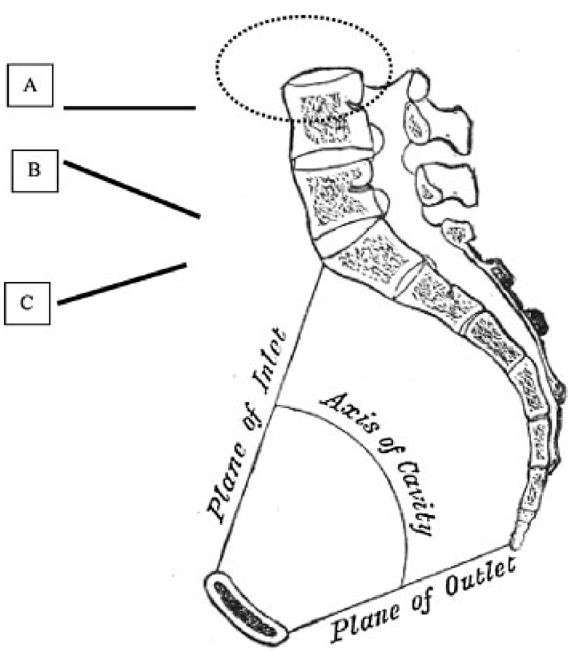

Figure 1. Left lateral view of sacra (modified from Gray, 1918). Sacral base angle variation is illustrated with lines, left side is anterior: (a) straight or flat = 1; (b) anterior sacral base angled superiorly = 2; (c) anterior sacral base angled inferiorly = 3.

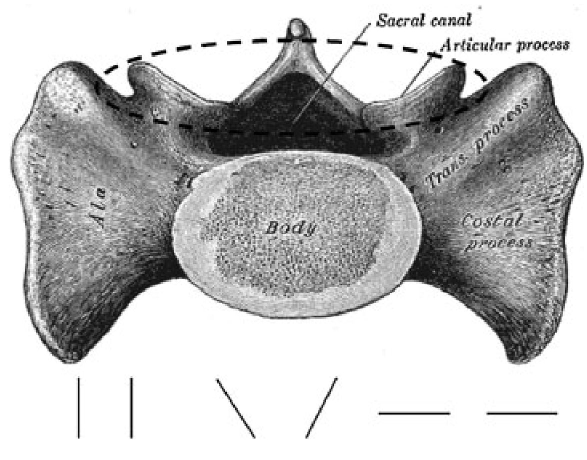

Figure 2. Superior view of sacra (modified from Gray, 1918). Facet orientation is illustrated with lines representing superior articular sacral facets: (a) medial = 1; (b) angled outward = 2; (c) posterior = 3.

DOI: 10.1002/oa

The absence or presence of lumbarisation of the first sacral vertebra or sacralisation of the last lumbar vertebra was noted, following Barnes (1994). Lumbarisation refers to a caudal shift where the first sacral segment has morphological characteristics of lumbar vertebrae; on the other hand, sacralisation refers to a cranial shift where the last lumbar vertebra is morphologically similar to a sacral segment and often is fused to the sacrum. Lumbarisation and sacralisation were examined because they are readily visible on skeletal remains. These defects can be complete, incomplete, unilateral, bilateral or asymmetrical; although I took down specific variation, I tested spondylolysis only against absence or presence of these defects. Breaking down into other categories would reduce the sample size unacceptably. Merbs (1983) also found a correlation between lumbarisation and sacralisation and spondylolysis. He hypothesised that these anatomical variations increase spondylolysis frequency by increasing pre-sacral length, and thus causing an increased amount of force on the lower lumbar vertebrae. Other researchers (e.g. Stewart, 1931; Elster, 1989) have not found similar correlations. The issue of transitional vertebrae and aetiology of spondylolysis remains unanswered, and thus will be addressed in the current study.

Scores were taken three times each, and no changes or averaging of scores were needed. Later, I re-examined the individuals a fourth time and found again no changes were needed.

Statistical analysis

The data were analysed using the statistical software program SPSS (version 14.0).

For spondylolysis patterns, sex differences were tested for statistical significance using non-parametric chi-square tests. Additionally, patterns of vertebral distribution, spondylolysis type, and age were tested using non-parametric Wilcoxon signed rank and chi-square tests.

Sacral anatomical differences were examined to determine whether normal (i.e. non-pathological) variation could predispose individuals to spondylolysis. The independent variables were spondylolysis presence and sex; dependent variables were sacral base angle, lumbarisation, sacralisation, facet orientation, and facet curvature (all of which were tested using a non-parametric chi-square test). All alpha levels were set at 0.05.

Due to the varying degrees of completeness of skeletal material, some cases were excluded in some of the statistical analyses, which led to variation in sample size for any particular test.

Results

Spondylolysis is present in 24 (16.4%) individuals in this sample (Table 1). Twenty (83%) individuals have only one affected vertebra, whereas three individuals have two affected vertebrae and one individual has three affected vertebrae. Over half of the affected individuals (14/24) have classical spondylolysis, defined as complete bilateral separation at the pars interarticularis in lumbar vertebrae (Figure 3). Other individuals have sacral spondylolysis, incomplete separation, or asymmetrical spondylolysis (Figure 4). The distribution within the vertebral column are as follows: L1 = 4; L2 = 1; L3 = 1; L4 = 5; L5 = 18; S1 = 1. The highest frequency in L5 is significantly higher than all other affected vertebrae (Wilcoxon signed rank test; Z values range from 3.237 to 4.032; $Ps < 0.001$).

Spondylolysis is absent in the individuals under the age of 18 years. In young adults (18–24 years), spondylolysis occurs in 2 out of 15 individuals (13%). In adults (25–39 years), spondylolysis occurs in 17 out of 70 individuals (24%); and, in older adults (40+ years), spondylolysis affects 5 out of 37 individuals (14%). These differences are not significant (possibly due to sample size constraints). Sex differences, however, are significant: 17 of the affected individuals are male, which is 26% of the males in the sample; seven are female, which is 11% of the females in the sample (chi-square value is 8.56, $P < 0.05$).

Relationship to sacral anatomy

Sex differences are marginally present in lumbarisation (chi-square = 3.43, $P < 0.06$) (Table 2). In the current population, only males have lumbarised sacral vertebrae. Individuals with lumbar-

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Table 1. Individuals with spondylolysis

Specimen	Sex	Age (group)*	Comments
5	Male	Adult	L4, L5; complete and bilateral
21	Male	Adult	L5; complete and bilateral
23	Male	Adult	L3; partial and right
26	Female	Adult	L5; partial and right
30	Female	Adult	L2; partial and bilateral
39	Male	Adult	L5; complete and bilateral
71	Male	Adult	L4, L5; complete and bilateral
78	Male	Older adult	L1; partial and bilateral
94	Male	Adult	L1; partial and left
110	Male	Adult	L4; complete and right
167	Female	Adult	L4; L5; partial and left; S1; partial and bilateral
168	Male	Adult	L5; complete and left
180	Male	Older adult	L5; complete and left
188	Female	Older adult	L5; complete and bilateral
201	Male	Older adult	L5; complete and bilateral
202	Male	Young adult	L5; complete and bilateral
206	Male	Adult	L4, L5; complete and bilateral
212	Male	Adult	L5; complete and bilateral
239	Male	Young adult	L5; complete and bilateral
242	Male	Older adult	L5; complete and left
252	Male	Adult	L5; complete and bilateral
257	Female	Adult	L5; complete and bilateral
280	Female	Adult	L1; complete and bilateral
284	Female	Adult	L5; complete and bilateral

*Juvenile = 11–17 years of age; young adult = 18–24 years of age; adult = 25–39 years of age; older adult = 40+ years of age.

isation (all male) are more likely to have spondylolysis (Table 3). In order to determine whether the lumbarisation connection with spondylolysis is confounded by sex, sacral anatomy and spondylolysis presence are examined separately for each sex. Within males, lumbarisation significantly relates to frequency of spondylolysis (chi-square $= 7.12$, $P < 0.01$) (Table 4). Males with lumbarisation are more likely to have spondylolysis than other males. Within females, no significant relationships between sacral anatomy and spondylolysis occur (Table 5).

Figure 3. Specimen number 5. Posterior view of fifth lumbar from an adult male showing complete bilateral separation.

Figure 4. Specimen number 26. Posterior view of fifth lumbar from an adult female showing incomplete separation through the right interarticularis.

DOI: 10.1002/oa

Table 2. Chi-square and Student's *t*-test results for sex and sacral anatomy

Chi-square	*n*	Value	d.f.	Sig. (2-sided)
Sacral base angle	95	1.89	2	0.39
Facet orientation	94	1.75	2	0.42
Facet curvature	94	1.21	2	0.55
Sacralisation	91	1.25	1	0.26
Lumbarisation[a]	91	3.43	1	0.06

[a] Lumbarisation occurred in four males (4/50) and in no females (0/41).

Table 4. Chi-square and Student's *t*-test results for spondylolysis and sacral anatomy in males

Chi-square	*n*	Value	d.f.	Sig. (2-sided)
Sacral base angle	52	2.45	1	0.12
Facet orientation	51	0.329	2	0.85
Facet curvature	51	0.17	1	0.68
Sacralisation	50	0.00	1	0.99
Lumbarisation[a]	50	7.12	1	0.01

[a] Males with lumbarisation had spondylolysis more frequently.

Discussion

This study found that spondylolysis occurred in 16.4% of this prehistoric California Amerind population. Spondylolysis is high in this population in relation to many other prehistoric and modern populations, which start at around 5%. Arctic samples who are considered to have large amounts of spondylolysis include populations with rates of 15% to over 50%. This relatively high rate in the study sample may be related to a strenuous lifestyle, genetics (which has not been tested), or anatomy. Furthermore, males had over twice the rate of spondylolysis than females. Males and females also differed in lumbarisation. This study found that lumbarisation was coupled with spondylolysis in males, but not in females.

This study further corroborates some universal patterns in spondylolysis appearance (e.g. Stewart, 1931; Bridges, 1989; Merbs, 1996a,b, 2002; Arriaza, 1997; Fibiger & Knüsel, 2005). For most individuals affected with spondylolysis, only one vertebra had spondylolysis (83%). Over half of the affected individuals had classical spondylolysis (i.e. complete bilateral separation at the pars interarticularis in lumbar vertebrae). Finally, the highest frequency of spondylolysis was in the fifth lumbar. This distribution pattern may be reflective of bipedality as an underlying causative factor, as initially suggested by Merbs (1996a). It appears that classic spondylolysis in the lower lumbar vertebrae also increases flexibility, and thus may be advantageous (Merbs, 1996a). Nevertheless, since the frequency of spondylolysis ranges from about 5% in some populations to over 50% in other populations, there must be additional causes beyond bipedality, such as specific and varying activities related to cultural practices or anatomical variation.

In the current study, age differences were not significant (which is probably due to sample size constraints), but patterns were consistent with previously published bioarchaeological data (e.g. Rowe & Roche, 1953; Merbs, 1996a,b; Fibiger & Knüsel, 2005). Among the California Amerinds examined, spondylolysis was absent in individuals under the age of 18. Spondylolysis frequency increased in young adults (13%) and adults (24%). Spondylolysis does not afflict individuals too young to walk, which relates to the correlation of spondylolysis to bipedality (Merbs, 1996a); in this study, no young individuals had

Table 3. Chi-square and Student's *t*-test results for spondylolysis and sacral anatomy

Chi-square	*n*	Value	d.f.	Sig. (2-sided)
Sacral base angle	95	1.14	2	0.57
Facet orientation	94	0.29	2	0.87
Facet curvature	94	0.47	2	0.79
Sacralisation	91	0.00	1	1.00
Lumbarisation[a]	91	11.42	1	0.01

[a] Individuals with lumbarisation had spondylolysis more frequently.

Table 5. Chi-square and Student's *t*-test results for spondylolysis and sacral anatomy in females

Chi-square	*n*	Value	d.f.	Sig. (2-sided)
Sacral base angle	43	0.20	2	0.91
Facet orientation	44	0.05	2	0.97
Facet curvature	43	3.38	2	0.19
Sacralisation	41	0.35	1	0.55
Lumbarisation[a]	41	—	—	—

[a] No cases of lumbarisation were present in females.

spondylolysis. In older adults, spondylolysis affected 14% of the individuals compared to a slightly higher 24% in adults. The decrease in older adults is minor in the current Amerind population examined, which may be due to the lack of very old individuals in the population or a continuation of the activities that cause stresses related to spondylolysis in the older group. Merbs (1996a) noted that a decrease in spondylolysis may be due to the fractures healing and escaping detection; however, this must be coupled with a decrease in activities since new fractures could occur (Bridges, 1989; Reiter *et al.*, 2006). Age distribution of spondylolysis is complex and needs further examination.

Another common pattern in most populations is higher rates (but not necessarily significant) of spondylolysis in males than in females, which is most often attributed to differences in activity patterns (e.g. Stewart, 1931; Roche & Rowe, 1951; Gunness-Hey, 1982; Merbs, 1983, 1996a,b, 2002; Virta *et al.*, 1992; Arriaza, 1997; Fibiger & Knüsel, 2005). The currently studied hunter-gatherer population was not an exception. Males had over twice the spondylolysis frequency of females (26% and 11%, respectively). In the current study, the higher male frequencies could relate to throwing spears and carrying hunted remains back to a home base. Leventhal (1993) pointed out that males were often buried with obsidian points, whereas females were buried with mortars and pestle, thus confirming the link of hunting and warfare in males. Although, the current population practised hunting and gathering subsistence, female activities were similar to agricultural populations; instead of maize processing, females processed acorns. Thus, female activities may have relied more on upper limb actions rather than lower limb actions. Male activities (of hunting and warfare) are similar in nature to sports behaviour that have been linked to spondylolysis. For instance, throwing and swinging activities in sports (such as baseball and cricket) have been linked to an increase in spondylolysis (Ruiz-Cotorro *et al.*, 2006). Conversely, biological sex differences associated with anatomical differences may also be present that predispose males to spondylolysis at a greater frequency than females.

Sacral anatomical sex differences occurred in lumbarisation rates (only males had lumbarised sacral vertebrae). With this information, I also needed to determine the relationship between sacral anatomy and spondylolysis. Lumbarisation was linked to spondylolysis with the sexes combined. None of the other variables (sacral base angle, facet orientation, curvature or sacralisation) related to spondylolysis with sexes combined. Since lumbarisation occurred only in males, it obliged me to examine how sacral anatomy variation related to spondylolysis presence within each sex. Within males, lumbarisation significantly related to spondylolysis; males with lumbarisation were more likely to have spondylolysis than other males. The results on lumbarisation corroborate Merbs (1983), who stated that lumbarisation could increase spondylolysis frequency by increasing pre-sacral length and, thereby, cause an increased amount of force on the lower lumbar vertebrae.

Other studies have had similar results. Peterson *et al.* (1990) and Merbs (1983) found spondylolysis and sacral anatomical variation only correlated in males. They suggested that the lack of correlation in females might be due to sample size. Males might have additional activity-related causes that would make lumbarisation of importance to the aetiology of spondylolysis. In the present sample, the activity mentioned above (spear-throwing) and others, coupled with anatomical differences that increase shearing forces, may exacerbate bone stress and cause spondylolysis. As an aside, one should be cautious and avoid mistaking association with effect; it could be that spondylolysis causes lumbarisation, rather than lumbarisation causes spondylolysis, and the same reasoning can be used for sacral base angle. That is, certain activity patterns and spondylolysis could change the anatomy of the sacrum, especially when started young in life and done repeatedly. Further research on cause and effect of spondylolysis and anatomical variation is needed.

Conclusions

Spondylolysis in this prehistoric California Amerind population displayed the usual pattern of distribution (highest frequency in L5; most common type was complete bilateral separation). Furthermore, the population differences also corroborated previous studies; the youngest

DOI: 10.1002/oa

individuals were least likely to be afflicted and adults had the highest rates of affliction. Sex differences also occurred in the typical pattern: males had twice the rate of spondylolysis than did females. This study extends previous research that suggests activity patterns and possibly anatomical variation may relate to spondylolysis in individuals. Lumbarisation had a link with spondylolysis presence in males, but not in females. Thus, it appears sex differences in the current study sample cannot be explained via anatomical variation, and that activity patterns seem to better fit the pattern of sex difference. Future research needs to examine anatomical variation, especially with regard to the confounds of sex, age and activity, in more detail.

Acknowledgements

I would like to thank Leslie Corona and Gisela Weiss for assisting with data collection.

References

Arriaza BT. 1997. Spondylolysis in prehistoric human remains from Guam and its possible etiology. *American Journal of Physical Anthropology* **104**: 393–397.

Barnes E. 1994. *Developmental Defects of the Axial Skeleton in Paleopathology*. University Press of Colorado: Boulder.

Bridges PS. 1989. Spondylolysis and its relationship to degenerative joint disease in the prehistoric southeastern United States. *American Journal of Physical Anthropology* **79**: 321–329.

Commandre FA, Taillan B, Gagenerie F, Zakarian H, Lescourgues M, Fourre JM. 1988. Spondylolysis and sponydlolithesis in young athletes: 28 cases. *Journal of Sports Medicine and Physical Fitness* **28**: 104–107.

Congdon RT. 1932. Spondylolithesis and vertebral anomalies in skeletons of American Aborigines With clinical notes on spondylolisthesis. *Journal of Bone and Joint Surgery* **14**: 511–524.

Elster AD. 1989. Bertolotti's syndrome revisited: transitional vertebrae of the lumbar spine. *Spine* **14**: 1373–1377.

Fibiger L, Knüsel CJ. 2005. Prevalence rates of spondylolysis in British skeletal populations. *International Journal of Osteoarchaeolology* **15**: 164–174.

Gray H. 1918. *Anatomy of the Human Body*. Lea and Fibiger: Philadelphia.

Gunness-Hey M. 1982. The Koniag Eskimo presacral vertebral column: variations, anomalies and pathologies. *Ossa* **7**: 99–118.

Haukipuro K, Keranan N, Koivisto E, Lindholm R, Norio R, Punto L. 1978. Familial occurrence of lumbar spondylolysis and spondylolisthesis. *Clinical Genetics* **13**: 471–476.

Iwamoto J, Abe H, Tsukimura Y, Wakano K. 2005. Relationship between radiographic abnormalities of lumbar spine and incidence of low back pain in high school rugby players: a prospective study. *Scandinavian Journal of Medicine and Science in Sports* **15**: 163–168.

Jurmain R. 1988. Paleoepidemiology of trauma in a prehistoric central California population. *Zagreb Paleopathology Symposium*; 241–248.

Jurmain R. 1990. Paleoepidemiology of a central California prehistoric population from CA-ALA-329: II degenerative disease. *American Journal of Physical Anthropology* **83**: 83–94.

Jurmain R. 1993. Paleodemography and paleopathology. In *The Archaeology of the Guadalupe Corridor*, Cartier R, Bass Ortman, Jurmain (eds). Santa Clara County Archaeological Society: Santa Clara, California; 79–88.

Jurmain R. 1999. *Stories from the Skeleton: Behavioral Reconstruction in Human Osteology*. Taylor and Francis: London.

Jurmain R, Bellefemine VI. 1997. Patterns of cranial trauma in a prehistoric population from Central California. *International Journal of Osteoarchaeology* **7**: 43–50.

Lane WA. 1887. A. remarkable example of the manner in which pressure-changes in the skeleton may reveal the labour history of the individual. *Journal of Anatomical Physiology* **21**: 385–406.

Lester CW, Shapiro HL. 1968. Vertebral arch defects in the lumbar vertebrae of pre-historic American Eskimos. *American Journal of Physical Anthropology* **28**: 43–48.

Leventhal A. 1993. *A reinterpretation of some Bay Area shellmound sites: A view from the mortuary complex from CA-Ala-329, The Ryan Mound*. MA thesis, San Jose State University, San Jose, CA.

Mays SA. 2006. Spondylolysis, spondylolisthesis, and lumbo-sacral anatomy in a Medieval English population. *American Journal of Physical Anthropology* **131**: 352–362.

McCarroll JR, Miller JM, Ritter MA. 1986. Lumbar spondylolysis and spondylolisthesis in college football players. *American Journal of Sports Medicine* **14**: 404–406.

DOI: 10.1002/oa

Merbs CF. 1983. *Patterns of Activity-induced Pathology in a Canadian Inuit Population*. National Museum of Man Mercury Series, Archaeological Survey of Canada Paper No. 119: Ottawa.

Merbs CF. 1995. Incomplete spondylolysis and healing: a study of ancient Canadian Eskimo skeletons. *Spine* **20**: 2328–2334.

Merbs CF. 1996a. Spondylolysis and spondylolisthesis: a cost of being an erect biped or a clever adaptation. *Yearbook of Physical Anthropology* **39**: 201–228.

Merbs CF. 1996b. Spondylolysis of the sacrum in Alaskan and Canadian Inuit skeletons. *American Journal of Physical Anthropology* **101**: 357–376.

Merbs CF. 2002. Spondylolysis in Inuit skeletons from Arctic Canada. *International Journal of Osteoarchaeology* **12**: 279–290.

Peterson CK, Haas M, Harger BL. 1990. A radiographic study of sacral base, sacrovertebral, and lumbosacral disc angles in persons with and without defects in the pars interarticularis. *Journal of Manipulative Physiological Therapy* **13**: 491–497.

Rassi GE, Takemitsu M, Woratanarat P, Shah SA. 2005. Lumbar spondylolysis in pediatric and adolescent soccer players. *American Journal of Sports Medicine* **33**: 1688–1693.

Reinhard KJ, Tieszen L, Sandness KL, Beiningen LM, Miller E, Ghazi A, Miewalk CD, Barnum SV. 1994. Trade, contact, and female health in northeast Nebraska. In *In the Wake of Contact: Biological Responses to Conquest*, Larsen CS, Milner GJ (eds). Wiley-Liss: New York; 63–74.

Reiter L, Frater CJ, Qurashi S, Loneragan R. 2006. Degenerative spondylolysis: a concise report of scintigraphic observations. *Rheumatology* **45**: 209–211.

Risser WL. 1991. Weigh-training injuries in children and adolescents. *American Family Physician* **44**: 2104–2108.

Roche MB, Rowe GG. 1951. The incidence of separate neural arch and coincident bone variations. A. survey of 4,200 skeletons. *Anatomical Record* **109**: 233–252.

Rossi F, Dragoni S. 1990. Lumbar spondylolysis: occurrence in competitive athletes. Updated achievements in a series of 390 cases. *Journal of Sports Medicine and Physical Fitness* **30**: 450–452.

Rowe GG, Roche MB. 1953. The etiology of separate neural arch. *Journal of Bone and Joint Surgery* **35A**: 102–110.

Ruiz-Cotorro A, Balius-Matas R, Estruch-Massana A, Vilarã AJ. 2006. Spondylolysis in young tennis players. *British Journal of Sports Medicine* **40**: 441–446.

Rumball JS, Lebrun CM, Di Ciacca SR, Orlando K. 2005. Rowing injuries. *Sports Medicine* **35**: 537–555.

Shahriaree H, Sajadi K, Rooholamini SA. 1979. A family with spondylolisthesis. *Journal of Bone and Joint Surgery* **61A**: 1256–1258.

Shrier I. 2001. Spondylolysis incidence in various sports. *Physical Sports Medicine* **29**: 5.

Stallard MC. 1980. Backache in oarsman. *British Journal of Sports Medicine* **14**: 105–108.

Stewart TD. 1931. Incidence of separate neural arch in the lumbar vertebrae of Eskimos. *American Journal of Physical Anthropology* **16**: 51–62.

Stewart TD. 1953. The age incidence of neural-arch defects in Alaskan natives, considered from the standpoint of etiology. *Journal of Bone and Joint Surgery* **35A**: 937–950.

Stewart TD. 1956. Examination of the possibility that certain skeletal characters predispose to defects in the lumbar neural arches. *Clinical Orthopaedics and Related Research* **8**: 44–60.

Virta L, Rönnemaa T, Österman K, Aalto T, Laakso M. 1992. Prevalence of isthmic lumbar spondylolisthesis in middle-aged subjects from eastern and western Finland. *Journal of Clinical Epidemiology* **45**: 917–922.

Ward C, Latimer B. 2005. Human evolution and the development of spondylolysis. *Spine* **30**: 1808–1814.

Weiss E. 2003. Understanding muscle markers: aggregation and construct validity. *American Journal of Physical Anthropology* **121**: 230–240.

Weiss E. 2005. Humeral cross-sectional morphology from 18th-century Quebec prisoners of war: limits to activity reconstruction. *American Journal of Physical Anthropology* **126**: 311–317.

Weiss E, Jurmain RD. 2007. In and out of joint: osteoarthritis revisited. *International Journal of Ostearchaeology* **17**: 437–450.

Whiteside TE, Horton WC, Hodges L. 2005. Spondylolytic spondylolisthesis: a study of pelvic and lumbosacral parameters of possible etiologic effect in two genetically and geographically distinct groups with high occurrence. *Spine* **30**: S12–S21.

Wiltse LL. 1957. Etiology of spondylolisthesis. *Clinical Orthopaedics and Related Research* **10**: 48–58.

Wiltse LL. 1962. The etiology of spondylolisthesis. *Journal of Bone and Joint Surgery* **44A**: 539–560.

DOI: 10.1002/oa