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Spondylolysis in the past: A case study of hunter-gatherers from Southern Patagonia

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ABSTRACT

Spondylolysis is a fracture of the *pars interarticularis*, the portion of the neural arch that lies between the superior articular facets and the inferior articular facets. Clinical evidence has suggested repetitive trauma to be the most probable cause, even though morphological weakness of the vertebra is probably also involved. Prevalence is between 3% and 8% in modern populations, while in archaeological samples it varies from 0% to 71.4%. Considering that very little data about this condition is available in past populations from the southern extreme of South America, the aim of this paper is to analyze the spondylolysis in a human skeletal sample from Southern Patagonia and, at the same time, to explore the prevalence of spondylolysis in archaeological contexts around the world to gain a better understanding of the results presented here. The Southern Patagonian skeletal series analyzed here showed a prevalence of 20%, with lower prevalence in the pre contact sample (11.1%) than in the contact period (23.1%). Skeletons from the Salesian Mission "*Nuestra Señora de La Candelaria*" showed a higher prevalence (25%) than the sample of skeletal remains recovered from outside the mission (20%), suggesting that changes in lifestyle of hunter-gatherers during contact could be implicated in the development of spondylolysis in this sample. A worldwide survey displays a wide range of prevalence figures in American and Asian samples and low diversity between African and European populations. Hunter-gatherers from Southern Patagonia showed similar values to those observed in other American samples.

1. Introduction

Spondylolysis is a unilateral or bilateral bony defect of the spine in which a fracture of the *pars interarticularis* separates the dorsal aspect of the neural arch from the remainder of the vertebra. The anterosuperior part usually consists of the vertebral body with pedicles and transverse and superior articular processes, while the postero-inferior part consists of the inferior articular processes, laminae, and spinous process (Peng, 2016). The defect is usually bridged by fibrous, cartilaginous, or osseous material tissue, and it may produce chronic non-union of the pars, which over time may lead to bony union (Leone et al., 2011). Repetitive trauma has been suggested by clinical evidence as one of the most probable causes (Troup, 1976; Duerson et al., 2016). However, hereditary factors influencing vertebral structure (Wynne-Davies and Scott, 1979; Yamada et al., 2013) and *spina bifida occulta* (Fredrickson et al., 1984) have also been suggested as influential factors in the development of spondylolysis. For that reason, the most accepted etiology is multifactorial, involving a stress fracture linked to congenital weakness of the *pars interarticularis*. Continued stress may produce an incomplete fracture that can progress to complete fracture (Krenz and Troup, 1973; Saraste, 1986; Ward et al., 2010; Peng, 2016).

Spondylolysis affects the fourth and fifth lumbar vertebrae in 95% of cases, even though it can also occur in dorsal, cervical and sacral vertebra (Grogan et al., 1982). It is observed in both children and adults, increasing with age during the two first decades of life (Garet et al., 2013). Both sexes are affected, generally twice as frequent in

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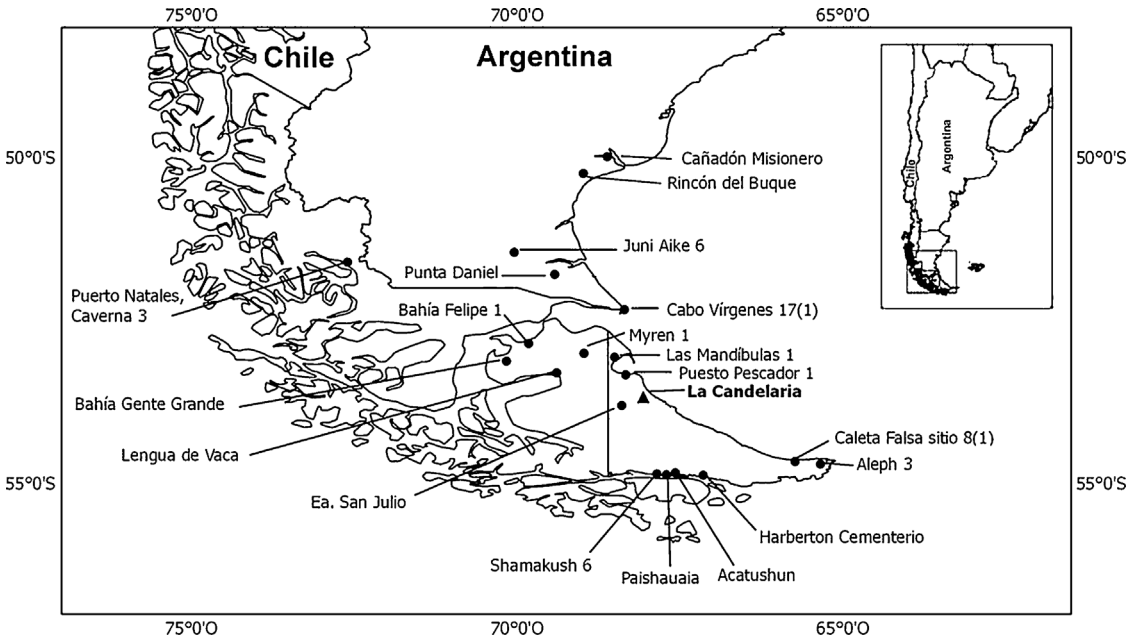

Fig. 1. Location of archaeological sites analyzed in Southern Patagonia.

males than in females (Fredrickson et al., 1984; Merbs, 2002), and it is also suggested that anatomical stress during pregnancy could be involved (Saraste, 1986). Spondylolysis is asymptomatic in most of the cases, but back pain may be present, particularly when displacement of the vertebrae occurs, which is termed spondylolisthesis (Haun and Kettner, 2005), even though the etiopathogenesis of these conditions are different (Merbs, 1996).

Because it is commonly reported, considerable attention has been paid to spondylolysis, and clinical (Leone et al., 2011) and archaeological data (Ward et al., 2010; Ponce, 2010) have been reviewed. Most results suggest that the prevalence of spondylolysis in modern populations is between 3% and 8% (Leone et al., 2011), while in some athletic groups the prevalence reaches more than 60% (Rossi, 1978; Tezuka et al., 2017). The high prevalence observed in such samples supports the idea that increased stress placed on the lumbar spine as a result of repetitive hyperextension is related to the fractures (Duerson et al., 2016). Thus, the influence of physical activity is considered relevant in the development of spondylolysis (Merbs, 2002; Mays, 2006). The prevalence of spondylolysis is generally higher in archaeological skeletal samples than in modern populations, although variable, ranging from 0% to 71.4% (Stewart, 1931; Bridges, 1989; Arriaza, 1997; Merbs, 2002; Weiss, 2009; Lessa, 2010; Pilloud and Canzonieri, 2012; Lessa and Carvalho, 2015).

In contrast with other regions of America, few data about prevalence in archaeological samples from Southern Patagonia (SP) have been published. Castro and Aspillaga (1991:88) remarked that *"spondylolysis of the lumbar vertebrae is another pathology that shows significant evidence"* in SP. They reported that this condition affected three individuals (1 female -Selk'nam- and 2 males -Alakaluf-) of a sample recovered by Martín Gusinde between the years 1919 and 1920 from different places in the north of Tierra del Fuego. These include a Salesian Mission cemetery on Dawson Island, southern Chile, a site in the north of the Rio Grande Salesian Mission, and a site near to Harberton harbor on the Argentinian side of the Beagle Channel, composed of 6 skeletons and 32 skulls (Castro and Aspillaga, 1991). Moreover, only a few other cases have been described (Aspillaga et al., 1999; Guichón and Suby, 2011; Ocampo et al., 2000). However, systematic studies about spondylolysis in SP have not been carried out. Thus, the aim of this paper is to study the prevalence and temporal-spatial variability of spondylolysis in a sample of skeletons of hunter-gatherers from Southern Patagonia and the possible influence of lifestyle changes on spondylolysis frequencies in native peoples during European contact. The prevalence of spondylolysis in archaeological contexts around world is also explored to contextualize our results.

1.1. Biocultural context

Ethnographical surveys have identified terrestrial hunter-gatherers in the southern extreme of the continent, including the north of Tierra del Fuego and maritime hunter-gatherers in the south and west of Tierra del Fuego, i.e. in the Pacific coast and Beagle Channel (Fig. 1; Gusinde, [1931]1982a, b; Legoupil and Fontugne, 1997; Massone, 2004; Santiago, 2009). Both societies were nomadic with high annual mobility (Gusinde, [1931]1982a, b; Chapman, 1989; Guichón, 1994; Saletta 2015). Division of labor between men and women has been described; men were in charge of hunting and hunting artifacts (e.g. lithic instruments, arcs, astils, canoes) and women took over the harvest, preparation of food and clothing, basketry, childcare and camp relocation (Gusinde, [1931]1982a, b; Chapman, 1989, 1990). Since the 1980's, archaeological and paleodietary studies have defined a continuum between the terrestrial and martime lifestyles according to the distance from the coast (Barberena, 2002; Borrero and Barberena, 2006; Zangrando, 2009; Orquera and Piana, 2009).

The populations from SP have been characterized by relative isolation, since Tierra del Fuego archipelago is a set of islands in the extreme south of the American continent, along with a drastic, rapid lifestyle change produced by the Native-European contact. Related to the first point, analyses of mitochondrial DNA have indicated that continental and Fueguian populations are ancestrally related, as well as northern and southern groups from Tierra del Fuego (Lalueza et al., 1997; García-Bour et al., 2004; de la Fuente et al., 2015). On the other hand, craniofacial morphological studies identified some differences between continental and Fueguian populations (Cocilovo and Guichón, 1986; González-José et al., 2002; Guichón, 1994; Lalueza et al., 1996; Varela et al., 1993–94), attributed to evolutionary divergences due to biogeographical isolation produced by the formation of Magellan Strait ca. 8000 YBP and the development of specialized terrestrial and marine economies (González-José et al., 2002; Pérez et al., 2007).

Several historical studies have described the resettlement of natives to missions and farms, along with a drastic demographic reduction

Table 1
Skeletal remains included in this study. References: MFM: Museo del Fin del Mundo, Ushuaia, Argentina; CADIC: Centro Austral de Investigaciones Científicas, Ushuaia; Argentina; MLC: Museo de La Candelaria, Río Grande, Tierra del Fuego, Argentina; PSC: Puerto Santa Cruz skeletal collection, Puerto Santa Cruz, Santa Cruz, Argentina; LEEH: Laboratorio de Ecología Evolutiva Humana, Quequén, Buenos Aires, Argentina; ME: Museo Etnográfico Juan B. Ambrosetti, Universidad de Buenos Aires, Buenos Aires, Argentina; IP: Instituto de la Patagonia, Punta Arenas, Chile. References: IC: Institution code; V: number of available vertebrae; PV: affected vertebra; F: Female; M: male.

Period	Site/Skeleton		Institution	IC	Age	Sex	V	PV	Lession	Chronology Yrs BP	Reference
Pre-contact	Bahía Felipe 1		IP	50104	35-50	M	24			1608 ± 45	Suby (2014)
	Shamakush 6		MFM		35-39	M	22			1536 ± 46	Suby et al. (2011)
	Paiashauaia		MFM		35-39	F	23			1504 ± 46	Suby et al. (2011)
	Punta Daniel		IP	33949	30–40	M	23			1118 ± 43/1090 ± 30	Suby (2014)
	Cabo Vírgenes 17 (1)		LEEH	QQN007	20–34	M	18			900 ± 40	L'Heureux et al. (2003)
	Caleta Falsa, site 8 (1)		MFM	PSC009	18–23	M	20	L5	Complete-bilateral	820 ± 40	Guichón and Suby (2011)
	Rincón del Buque		LFM		35-40	M	24			830 ± 42	Suby et al. (2009)
	Myren 1		IP	3477a	18-23	M	16			640 ± 20	Guichón et al. (2015)
	Aleph 3		ME		30–39	M	14			450 ± 60	Lanata (1995)
Contact	Estancia San Julio		MLC		40-50	M	24			350 ± 50	Suby and Guichón (2010)
	Puestos Pescador 1		CADIC		21–25	M	24			335 ± 35	Suby et al. (2008)
	Lengua de Vaca		IP	6780	30–40	F	24			251 ± 41	Suby (2014)
	Cañadón Misionero		PSC	PSC003	35–45	M	22			70 ± 30	Suby et al. (2009)
	Las Mandíbulas 1		LEEH	QQN002	24	M	24			1770-1950 AD	Guichón et al. (2000)
	Caverna 3, Puerto Natales		IP	50109	20–25	F	18	L5	Complete-bilateral	Post-contact	Prieto (1993–[Prieto, 1993]94)
	Juni Aike 6		IP	50114	30–40	M	23			Post-contact	Aguilera and Grendi (1996)
	Bahía gente grande		IP	859	30–40	M	10			Post-contact	Constantinescu (1999)
	Acatushún		MFM		30–40	F	21	L5	Complete-bilateral	Post-contact	Piana et al. (2006)
	Cementerio Haberton		MFM		25–30	M	23			Post-contact	Piana et al. (2006)
	Salesian Mission "*Nuestra Señora de La Candelaria*"	D 14	LEEH	QQN0032	18–20	M	24			Post-contact	García Laborde (2016)
		E 10–11 (2)	LEEH	QQN0055	18–25	F	24			Post-contact	García Laborde (2016)
		C 14 (2)	LEEH	QQN0033	19–20	F	24			Post-contact	García Laborde (2016)
		C 11 (1)	LEEH	QQN0058	20–30	M	17	S1	Complete-bilateral	Post-contact	García Laborde (2016)
		D 16 (Bis)	LEEH	QQN0039	21–53	F	24	L4	Complete-bilateral	Post-contact	García Laborde (2016)
		C 7–8	LEEH	QQN0027	24–26	F	24			Post-contact	García Laborde (2016)
		E 10–11 (1)	LEEH	QQN0049	25–30	M	24			Post-contact	García Laborde (2016)
		C-13	LEEH	QQN0026	25–35	M	13	L5	Complete-bilateral	Post-contact	García Laborde (2016)
		C-15	LEEH	QQN0028	25–39	M	14			Post-contact	García Laborde (2016)
		D-C 9–10	LEEH	QQN0053	25–40	M	24			Post-contact	García Laborde (2016)
		E-D 10	LEEH	QQN0048	25–45	M	24			Post-contact	García Laborde (2016)
		E 15–16 (2 Bis)	LEEH	QQN0045	30–40	M	21	L4	Complete-bilateral	Post-contact	García Laborde (2016)
		E 12–13	LEEH	QQN0023	35–45	M	24			Post-contact	García Laborde (2016)
		E 15–16 (3)	LEEH	QQN0047	35–45	M	24			Post-contact	García Laborde (2016)
		D 15–16	LEEH	QQN0030	35–49	F	17			Post-contact	García Laborde (2016)
		C 15–16	LEEH	QQN0031	45–60	F	23			Post-contact	García Laborde (2016)

during XIX Century as many were killed by the Europeans (García-Moro et al., 1997). The Salesian Mission "*Nuestra Señora de La Candelaria*" -SMLC- (lat. −53.72°, long. −67.79°; Fig. 1) was one such mission, located near the present-day city of Río Grande, in the north of Tierra del Fuego (Argentina). It included a cemetery, which was recently excavated, recovering skeletal remains of 33 adult and non-adult individuals (Guichón et al., 2006; García Laborde et al., 2010, 2015). The SMLC was founded in 1893 with the aim of "civilizing" and evangelizing the original populations. Its cemetery was used for missionaries and natives between 1897 and 1948, when the final inhumation occurred (Casali, 2011). A hunter-gatherer lifestyle thus passed from high mobility nomadism to sedentism, with higher population densities and occasional overcrowding (Casali, 2011). Changes also included different physical labor and new Western influences, such as single familial housing, monogamous relationships, clothes, hygiene practices, food, religious rituals (including funerary) and private property (Casali, 2011; Martucci, 2016).

From a bioarchaeological point of view, no cemeteries for the pre-Hispanic period have been discovered in SP. Instead, most burials involved one isolated individual, with few exceptions (Guichón et al., 2001; L'Heureux and Barberena, 2008; L'Heureux and Amorosi, 2009; L'Heureux and Amorosi, 2010; Santiago et al., 2011). For that reason, bioarchaeological and paleopathological research has usually grouped isolated skeletons by ethnographic, geographical or paleodietary criteria. By contrast, cemeteries from the contact period have been discovered, frequently associated with missions, as is the cemetery of Salesian Missions of Rio Grande (Casali, 2011; García Laborde et al., 2010) and Dawson Island (Castro and Aspillaga, 1991) or the Anglican Mission located in Ushuaia.

2. Material and methods

The skeletal remains studied here were recovered from archaeological sites of SP (Fig. 1), consisting of the continental and insular

Table 2
Skeletons with spondylolysis from Southern Patagonia, classified by chronology, period and sex.

	Pre-contact (n/obs/%)	Contact (n/obs/%)			Total (n/obs/%)
		Out of SMLC	SMLC	Total	
Total	9/1/11.1	10/2/20	16/4/25	26/6/23.1	35/7/20
Sex					
Male	8/1/12.5	7/0/0	10/3/30	17/3/17.6	25/4/16
Female	1/0/0	3/2/66.6	6/1/16.6	9/3/33.3	10/3/30
Age (years-old)					
Young adult (20–35)	3/1/33.3	3/1/33.3	6/1/16.6	9/2/22.2	12/3/25
Middle adult (35–50)	6/0/0	7/1/14.3	10/3/30	17/4/23.6	23/4/17.4

territories below 50° South latitude. Included here were all adult individuals (aged 18+ years old at death) who had at least 50% of the spine, including the segment L_1-S_1 observable along with definitive with spatial and chronological information. Age at death was estimated by the analysis of pubic symphyses (Todd, 1921a; Todd, 1921b; Brooks and Suchey, 1990), epiphyseal fusion (Buikstra and Ubelaker, 1994), auricular surface (Lovejoy et al., 1985) and the metamorphosis of the fourth sternal rib end (Isçan et al., 1984). Skeletons were sexed following the methods described by Buikstra and Ubelaker (1994) based on the cranium and hip bones.

A total of 35 individuals from 20 archaeological sites were analyzed (Table 1), dating from *ca.* 1600 years BP to the 20th century. Nine of the skeletons correspond to the pre-contact period, before 400 years BP when the Magellan expedition arrived. These were housed in museums and research institutions in Argentina (Museo del Fin del Mundo, Ushuaia; CADIC, Ushuaia; Museo de La Candelaria, Río Grande; Puerto Santa Cruz skeletal collection, Puerto Santa Cruz; Laboratorio de Ecología Evolutiva Humana, Quequén; Museo Etnográfico Juan B. Ambrosetti, Buenos Aires) and Chile (Instituto de la Patagonia, Punta Arenas). The remaining 26 skeletons date to the contact period. Sixteen of them were exhumed from the cemetery of the Salesian Mission "*Nuestra Señora de La Candelaria*" (SMLC), where we assume they lived for an unknown period of time. Five of the other 10 contact period skeletons were radiocarbon dated, while the other five skeletons were chronologically assigned by the archaeological context or historical documents (Table 1).

All the spines were surveyed for unfused fractures of the *pars interarticularis*, following methods of Bridges (1989), Arriaza (1997) and Mays (2006). Complete vs. incomplete, unilateral vs. bilateral, unhealed vs. healing distinctions were also registered, following Buikstra and Ubelaker (1994). Vertebrae with spondylolysis were inspected for spondylolisthesis, identified by new bone formation on the anterior wall of the vertebrae, marginal osteophytes in the affected body and its inferior neighbor (Ikata et al., 1996; Mays, 2006). Statistical differences in lesion frequencies between presence/absence, male/female and pre-contact/during-contact groups were calculated by Fisher's exact test, with two tails and a statistical significance of $p < 0.05$. For that purpose, R software was used.

To contextualize our results from SP, we surveyed the following journals: American Journal of Physical Anthropology, International Journal of Osteoarchaeology, Spine, and the references cited in those papers, including book chapters and PhD dissertations. Spondylolysis, spondylolisthesis, paleopathology, skeletal remains, and ancient populations were used as keywords. We recorded all studies in English or Spanish for skeletal samples of more than 20 individuals, except for South American, Asian, African or Oceania samples, due to the low numbers of analyses. Data were extracted into a database, including authors, year of publication, origin, chronology, size of the sample, prevalence of spondylolysis, classified by sex when available, the analyzed portion of spine, and large categories of subsistence strategy (i.e. hunter-gatherer, and/or agriculturalist) in those samples from the Americas.

3. Results

Spondylolysis was observed in 7 of the 35 individuals (20%) from the SP, with all being complete, bilateral fractures. The identified frequencies of spondylolysis for the total sample and classified by sex, age and contextual provenance are shown in Table 2. Fisher's exact statistical analyses showed no significant statistical differences in any case. However, some divergent tendencies among age, sex and chronological and contextual provenance of the samples are suggestive. The prevalence of spondylolysis was lower in pre-contact samples (1 out of 9, 11.1%) than in the sample from the contact period (6 out of 26, 23.1%; Fisher exact test statistic p value is 0.65). Contact period SMLC remains (4 out of 16, 25%) showed a higher prevalence than skeletal remains recovered in extra-missional context (2 out of 10, 20%; Fisher exact test statistic p value is 0.07). Therefore, increased prevalence from pre-contact to contact SMLC sample could be suggested (Table 2). The lesions were more frequent in females (3 out of 10, 30%) than in males (4 out of 25, 16%) in the whole sample (Fisher exact test statistic p value is 0.19). All cases of spondylolysis were identified in young (i.e. 20–35 years-old) and middle adults (i.e. 35–50 years old), mostly in the first age group, except in the individuals from SMLC (Table 2).

Skeleton D14 from the SMLC presented a unilateral anterior separation of right transverse apophysis of the fifth cervical vertebra (Fig. 2). However, as the costal pedicle of the vertebra is involved instead of the neural arch, it was most probably a developmental defect (Barnes, 2012), and it was not considered as a case of spondylolysis. All

Fig. 2. Unilateral lesion in C5 vertebrae of skeleton D14 from Salesian Mission "*Nuestra Señora de La Candelaria*". Right: close up of the right transverse apophysis, separation.

Fig. 3. Spondylolysis recorded in skeletons out of Salesian Mission "*Nuestra Señora de La Candelaria*": A. Bilateral spondylolysis at L5 of skeleton recovered in Acathusún site (Beagle Channel, Tierra del Fuego); B. Bilateral spondylolysis at L5 of Puerto Natales Caverna 3 archaeological site.

other lesions affected the lumbosacral region. No incomplete defects indicating early stages of stress fractures were detected.

Some differences were observed between the skeletons from the SMLC and the individuals found in other archaeological contexts. While three different vertebrae (L4, L5, S1) were affected by bilateral fractures in the SMLC, only bilateral separation of *pars interarticularis* at L5 was observed in skeletons not associated with the mission. Skeletons Caleta Falsa 8.1, Acatushún (Fig. 3A) and Puerto Natales Caverna 3 (Fig. 3B) from archaeological sites outside the mission showed remodeled fractures with lamellar bone and modified structures of the margins, which suggest healed fractures produced long before death (Lovell, 1997). No osteophytes or new bone are present in the apophyseal joints of the affected vertebrae or in the superior endplate of the sacrum, and for that reason slippage or spondylolisthesis cannot be identified in these three cases.

The fractures observed in skeletons recovered from the SMLC presented considerable variability, although all the skeletons showed complete bilateral fractures of the *pars interarticularis*. Skeleton D16 (Bis) displayed lamellar bone on the fracture surface, with variation of the normal morphology producing an expanded surface of the pedicles. The articular facets of L4 and L5 also showed alteration of the joint shape. The vertebra L4 showed porosity and new bone formation in the inferior plate, while in L5 antero-superior marginal osteophytes of 5 mm were observed (Fig. 4A.1 and A.2). Skeleton C13 showed a remodeled bilateral fracture of the *pars interarticularis* of L5 and a non-fusion approximately in the midline of the spinous process (Fig. 4B.1), which is present in two fragments, with lamellar bone. The left side of the vertebral body presented a reduced height of 10 mm with respect to the right side, without evidence of traumatic origin. The superior and inferior endplates showed porosity with new bone formation and marginal osteophytes in the left margin. The inferior adjacent vertebra (i.e. S1) presented marginal osteophytes of between 5 mm and 10 mm, porosity, new bone formation in the superior endplate surface, and two probable unhealed avulsion areas of ca. 1 cm of diameter surrounded by sclerotic and woven bone, probably due to the intrusion of intervertebral cartilage into the endplate of the vertebra (Fig. 4B.2). The sacrum also present *spina bifida occulta* at S1. Skeleton E15-16 (2 Bis) also showed a complete remodeled bilateral fracture of the *pars interarticularis* of L4, with modification of the normal morphological structures. The inferior endplate showed slight new bone formation and porosity, as well as L5 in the superior and inferior endplate of the body, partially lost by taphonomic processes. The structures of these three cases suggest that spondylolysis sufficiently long prior to death that there were notable modifications of the fracture margins. Only skeleton D16 (Bis) revealed sufficient changes at the vertebral margin for a possible slippage of L4 on L5 and spondylolisthesis. Skeleton C11(1) from SMLC showed an unusual spondylolysis of S1 vertebra (Fig. 4C.1), resulting from a stress fracture of *pars interarticularis* of S1 with new bone formation on its left side. Sclerotic bone was present on the right side (Fig. 4C.2). The superior plate of S1 the inferior plate of L5 showed a slight new bone formation and porosity, partially obscured by postmortem loss of bone. The sacrum also showed six vertebral bodies, probably due to the sacralization of the coccygeal vertebra. No spondylolisthesis can be suggested in this case, since the fracture seems to have occurred relatively shortly before death.

Data reviewed from archaeological samples from around the world are presented in Table 3, Figs. 5 and 6. The overall prevalence of spondylolysis ranges between 0% and 71.4%. Continental differences are observed, with more variability recorded from South and North America than in Europe, Oceania, Asia and Africa. Africa shows the lowest values. However, there are more studies of archaeological samples from America and Europe than from Africa, Asia and Oceania. Nevertheless, the distinction between the low variability in African and European populations does appear to contrast markedly with the highly variable American and Asian samples. The low number of samples from Oceania made any interpretation difficult.

Across the Western Hemisphere, spondylolysis affected hunter-gatherer groups more frequently than others (Table 3). Lower values were observed in samples from historical and documented collections (4.3% -Willis, 1923-; 4.2% -Roche and Rowe, 1951-; white 7.9% and black 7% -Lanier, 1939). The exception are the samples from Nebraska studied by Sandness and Reinhard (1992); a historical sample showed 19% with none observed in the pre-contact series (Table 3). Those samples from pre-contact societies with agricultural economic strategies range from 3% (Bright and Bartelink, 2013) to 5.8% (Ponce, 2010). The prevalence is higher in males than in females, with some exceptions (Lester and Shapiro, 1968; Timm, 2008; Sandness and Reinhard, 1992; Owsley et al., 1987). South American populations have approximately the same patterns, but as Fig. 5 shows, the values are lower, except for the sample from Ilhote do Este (Lessa and Carvalho, 2015) with the highest prevalence reported until now (71.4%). However, it must be noted that the sample size in this last case was quite small (5 males and 2 females).

4. Discussion

Spondylolysis is a common condition of the spine in living populations. The prevalence of spondylolysis found in this paper (20%) is higher than those reported for living non-athlete populations, where the prevalence is between 3% and 8% (Leone et al., 2011). The lesions affected mainly lumbar vertebra, complete and bilateral in all cases. Some unusual additional findings are the developmental unilateral non-union of a cervical vertebral pedicle and an unusual case of spondylolysis in a S1 vertebra.

Although not statistically different, females showed a higher prevalence than males in SP. However, this result could be biased by the small size of the sample, particularly from the pre-contact period. In the sample from SMLC, males showed more vertebral lesions than females in a relation nearly to 2:1, as had been observed in modern populations. Several papers state that spondylolysis is frequently produced during childhood or young adulthood, because of predisposing vertebral morphology and physical activity leading to fractures (Leone et al.,

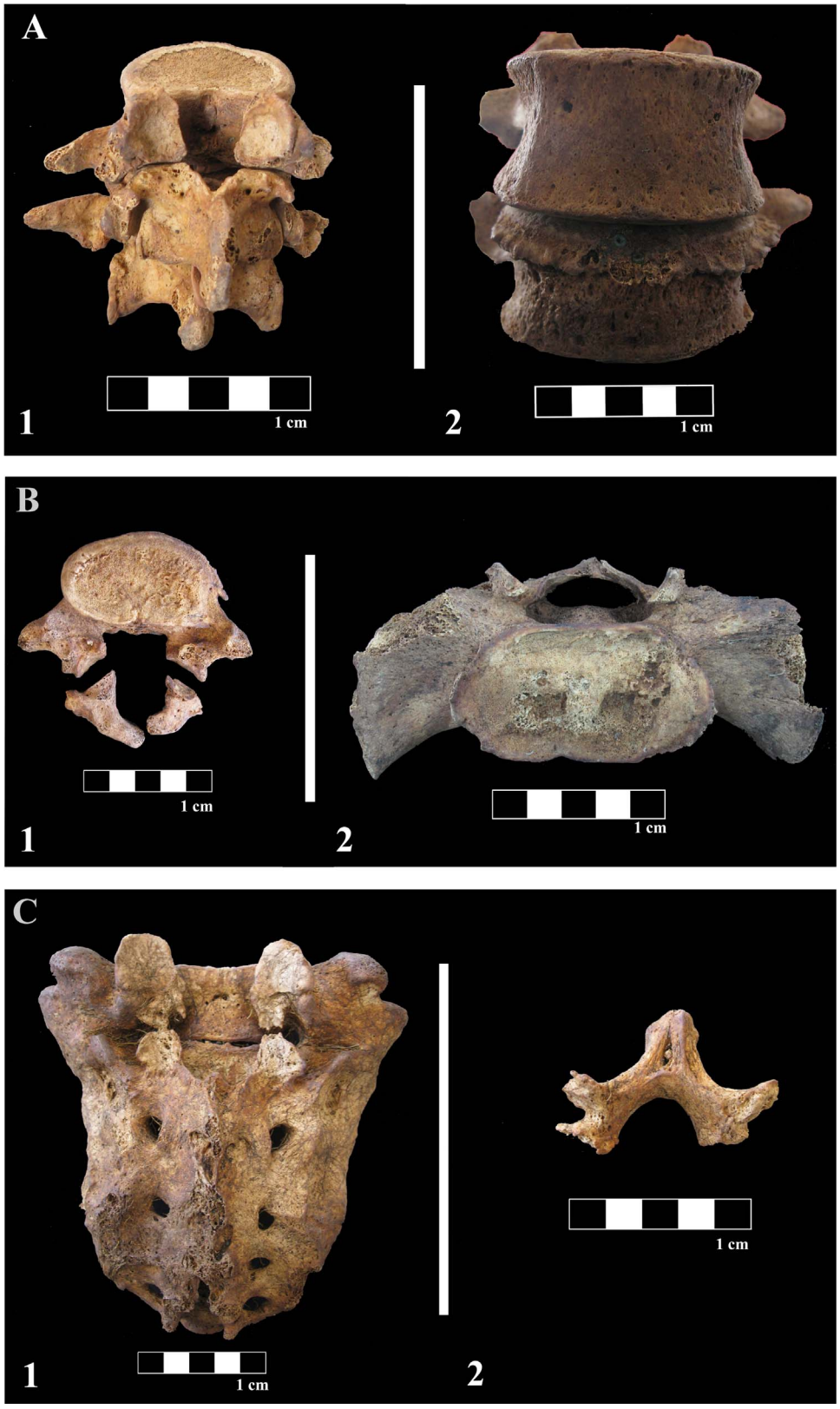

Fig. 4. Spondylolysis recorded in skeletons from Salessian Mission "*Nuestra Señora de La Candelaria*": **A**. Spondylolysis in skeleton D 16 (Bis). 1) Posterior view of the L4 and L5, showing bilateral spondylolysis of L4 2) Anterior view of L4 and L5, showing new bone formation in the inferior plate with anterosuperior marginal osteophytes in L5; **B**. Spondylolysis in skeleton C13. 1) Superior view of L5, showing bilateral complete fracture of pars interarticularis and non-union of spinous process. 2) Superior view of the *sacrum* with marginal osteophytes, porosity, and new bone formation in the superior endplate surface, with two probable unhealed avulsion areas surrounded by sclerotic and woven bone; **C**. Spondylolysis in skeleton C 11 (1). 1) posterior vies, showing bilateral complete fractures in S1. 2) Detail of the arc of S1.

2011). Unfortunately, the analysis of spondylolysis in non-adults is methodologically fraught (Mays, 2007). Therefore, although some of the lesions observed in adults could be produced during childhood, this is uncertain. The results for SP show higher prevalence in young adults (25%) than in middle adults (17.4%). Nevertheless, almost all fractures showed signs of remodelling, suggesting that spondylolysis had been produced earlier in life, except for skeleton C11(1) from SMLC that evidenced healing fracture of the arch of S1.

Different frequencies have been observed across groups that vary geographically, chronologically, and culturally. The skeletons recovered from the SMLC showed a higher prevalence of spondylolysis than those found at other archaeological sites (both during and prior to

Table 3
Prevalence of spondylolysis in skeletal samples around the world. References: Lifestyle: HG: Hunter-gathener; A: Agriculture; HG (M): marine Hunter-gathener; ND: no data.

Continent		Lifestyle	Collection	Period	N	Prevalence	Vertebra	Reference
America	North America	HG	North of Yukon	ND	187	Females: 37.4% (34/91) Males: 40.6% (39/96) Total: 39% (73/187)	L1-L5 and sacrum	Stewart (1931)
			Yukon and south		161	Females: 10.7% (8/75) Males: 16.3% (14/86) Total: 13.7% (22/161)		
			Eskimos almost enterely from Alaska		350	Females: 25.1% (/167) Males: 29.5% (/183) Total: 27.4% (/350)		
		HG	Nushagak and Kvichak Rivers and Bristol Bay, Alaska (USA)	ND	64	Females: 14.3% (5/35) Males: 20.7% (6/29) Total: 17.2% (11/64)	ND	Stewart (1932)
			Yukon River, Alaska (USA)		217	Total: 20.7% (45/217)		
		HG	Ipiutak culture	start Christian era- middle of the first millenium AD	47	Female: 15% (3/20) Male: 30.4% (7/23) Total: 21.3% (10/47)	At least four lumbar vertebrae	Lester and Saphiro, 1968
			Tigara culture	about 15th century	248	Female: 51.8% (43/83) Male: 48.4% (62/128) Total: 44.8% (111/248)		
			Point Hope, Alaska (USA)	ND	295	Total: 41% (121/295)		
			Smith Sound, Greenland (Denmark)	ND	5	Total: 40% (2/5)		
			Amanak Island, Aleutians Islands, Alaska (USA)	ND	6	Total: 33.3% (2/6)		
		HG	Kodiak Island, Alaska (USA)	ND	175	Females: 25.8% (17/66) Males: 36.1% (26/72) Total: 25.7% (45/175)	At least lumbar vertebrae	Gunnes-Hey (1981)
		HG	Greenland (Denmark)	before 18th century	46	Females: 48% (12/25) Males: 61.9% (13/21) Total: 54.3% (25/46)	L1-L5	Simper (1986)
		HG	Archaic HG, Pickwick Basin, Alabama (USA)	6000–1000 BCE	43	Females: 17% (4/23) Males: 20% (4/20) Total: 18.6% (8/43)	Complete lumbar region	Bridges (1989)
		A	Mississipian maize A, Pickwick Basin, Alabama (USA)	1200–1500 AD	ND	Female: (1/)		
					ND	Total: (1/)	Parcial and complete	
		HG/A	Skeletal Collections from Pickwick Basin, Alabama (USA)	ND	157	Females: (7/) Males: (5/) Total: 7.6% (12/157)	lumbar regions	
		HG	Thule culture and early historic eskimo from	1150–1600 AD and later	400	Females: (12/)	Complete spine	Merbs (1996)

(continued on next page)

Table 3 *(continued)*

Continent	Lifestyle	Collection	Period	N	Prevalence	Vertebra	Reference
		Silumiut and Kamarvik sites, Hudson bay (Canada)					
					Males: (32/)		
					Total: 12.7% (51/400)		
	HG	Kamarvik	Thule culture period 1000 AD through the historic period (beginning 17th century) first half 20th century.	68	Females: 8% (1/13)	Complete spine	Merbs (2002)
					Males: 52% (11/21)		
		Silumiut		112	Females: 21% (6/28)		
					Males: 54% (15/28)		
		Sadlermiut		92	Females: 13% (7/52)		
					Males: 30% (12/40)		
		Saglek Bay (Labrador)		38	Females: 25% (4/16)		
					Males: 27% (3/11)		
		Thule culture and historic Inuit from northwest Hudson Bay and Labrador and Sadlermiut from Southampton Island. (Canada)		417	Total: 21.58% (90/417)		
	HG	Golovin collection, Alaska (USA)	ND	33	Total: 54.5% (18/33)	L1-L5	Legge (2005)
		Nunivay collection, Alaska (USA)	ND	20	Total: 5% (1/20)		
	HG	Ipiutak culture, Alaska (USA)	2100–2500 BP	30	Females: 9% (1/11)	ND	Timm (2008)
					Males: 26% (5/19)		
					Total: 20% (6/30)		
	HG	Tigarak culture, Alaska (USA)	800–300 BP	92	Females: 60% (21/42)		
					Males: 50% (30/50)		
					Total: 55.4% (51/92)		
	HG	Ryan Mound site (CA-Ala-329), San Francisco Bay (USA)	2180–250 BP	146	Females: 10.6% (7/66)	L1-S1	Weiss (2009)
					Males: 25.8% (17/66)		
					Total: 16.4% (24/146)		
	HG	Pre-contact California Population (USA)	cal. 720–550 BP	46	Females: 12.1% (4/33)	At least all lumbar vertebrae	Pilloud and Canzonieri (2012)
					Males: 30.8% (4/13)		
					Total: 17.4% (8/46)		
	Hamlet A	CA-SOL-451 (Encinosa Site), California (USA)	cal. 2450–1530 BP	33	Total: 3% (1/33)	ND	Britght and Bartelink
		Caddoan at the Kaufman-Willian site, Texas (USA)	ND	ND	Female true: 4.8% (3/62)	T12, L4 and L5	Loveland et al. (1985)
				ND	Male true: 5.3% (1/19)		
				ND	Total true: 4.9% (4/81)		
		Prehistoric and historic native skeletons from Northeastern Nebraska	1200–1400 AD	18	Total: 0 (-/18)	Complete spine	Sandness and Reinhard (1992)
			1750–1840 AD	21	Female: 25% (3/12)		
					Male: 11.1% (1/9)		
					Total: 19% (4/21)		
		Prehistorical and historical from New Mexico Pueblo sites (USA)	Prehistorical and historical	491	Total: 3.7% (18/491)	L3-S1	Merbs (2001)
		Hamann-Todd Human Osteological Collection, Cleveland (USA)	Historical	ND	Female: (1/)	Complete spine	Willis (1923)
				ND	Male: (30/)		
				748	Total: 4.3% (31/748)		
		Collections of Washington University and Western Reserve University (USA)	Historical	201	Total white: 7.9% (8/101)	Complete spine	Lanier (1939)

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Table 3 *(continued)*

Continent		Lifestyle	Collection	Period	N	Prevalence	Vertebra	Reference
						Total black: 7% (7/100)		
			Terry Anatomical Collection, St. Louis (USA)	Historical	2300	Female white: 2.3% (8/348) Male white: 6.4% (125/1952) Total white: 5.8% (133/2300)	L1-L5	Roche and Rowe (1951)
			Hamann-Todd Collection, Cleveland (USA)		1900	Female black: 1.1% (6/561) Male black: 2.8% (39/1339) Total black: 2.4% (45/1900)		
					4200	Total: 4.2% (178/4200)		
			Urban slave population from New Orleans (USA)	1720–1810	4	Female: 50% (2/4)	L5	Owsley et al. (1987)
					19	Male: 0 (-/19)		
					23	Total: 8.7% (2/23)		
	South America	HG	Núcleo Gran Guaiteca, Chonos natives populations (Chile)	480–340 BP	35	Total: 11.4% (4/35)	ND	Aspillaga et al. (2006)
		HG	Archaeological sites from Santa Catarina State (Brazil)	810–1150 BP	81	Females: 24.2% (8/33) Males: 33.3% (16/48) Total: 29.6% (24/81)	At least all lumbar vertebrae	Lessa (2010)
		HG	Ilhote do Este	3060 ± 40 – 2650 ± 350 BP	7	Females: 50% (1/2) Males: 80% (4/5) Total: 71.4% (5/7)	Thoracic and lumbar vertebrae	Lessa and Carvalho (2015)
			Zé Espinho	2260 ± 160 – 1180 ± 170 BP	12	Females: 0 (-/3) Males: 0 (-/7) Total: 0 (-/12)		
		HG	Chinchorro native cemeteries (Chile), mummies	3rd–2nd millenium BC	61	Females: 3.3% (1/30) Males: 29% (9/31) Total: 16.4% (10/61)	L1-L5	Ponce (2010)
		A	Inland agriculturalists (Chile)	over 1st millenium AD	86	Females: 5.77% (3/52) Males: 5.88% (2/34) Total: 5.81% (5/86)		
		A-HG (M)	Puémaque Temprano	4400 ± 110BP	18	Total: 0 (-/18)	ND	Pezo-Lanfranco and Eggers (2013)
			Puémaque Medio	3960 ± 110 – 3920 ± 110 BP	13	Total: 14.3% (2/13)		
			Puémaque Salinar	2310 ± 30 – 2320 ± 30 BP	20	Total: 5% (1/20)		
			Puémape site, peruvian north coast (Peru)	2500-1 BC	51	Total: 5.9% (3/51)		
			Chinchorro (Chile)	ND	51	Total: 9.8% (5/51)	Not specified	Arriaza (1995)
Europe			Romano-British	ND	214	Females: 3.7% Males: 3.8% Total: 3.7% (8/214)	ND	Waldron (1991)
			Anglo-Saxon	ND	110	Females: 5.5% Males: 3.6% Total: 4.6% (5/110)		
			Medieval	ND	629	Females: 5.2% Males: 5% Total: 5.1% (32/629)		

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Table 3 *(continued)*

Continent	Lifestyle	Collection	Period	N	Prevalence	Vertebra	Reference
		Spitalfields, christ church cementery (England)	18th–19th centuries	706	Females: 0.6% Males: 2.2% Total: 1.4% (10/706)		
		St. Margaret Fyebridgegate cemetery, Norwich (England)	1245–1468 AD	417	Females: 7.4% (5/67) Males: 8.8% (25/283) Total: 6.9% (29/417)	ND	Stirland (1996)
		Lugo de Llanera (Spain)	6th–13th centuries	65	Females: 5.3% (1/19) Males: 3.6% (1/28) Total: 3.1% (2/65)	ND	González Martín et al., 1997
		Lucus Feroniae, near Rome (Italy)	1st–2nd centuries AD	136	Females: 0 (-/72) Males: 0 (-/64) Total: 0 (-/136)	ND	Sperduti (1997)
		Stenjevec cemetery (Croatia)	10th–12th centuries	21	Females: 0 Males: 4.8% (1/21)	Complete lumbar region	Šlaus, 2002
		Leprosery hospital and almshouse of Chichester (England)	12th–16th–18th centuries	271	Females: 7% (/74) Males: 11% (/151)	Complete spine	Sture (2001)
		Cemetery of St. Helen-on-the-Walls, York (England)	12th–16th centuries	385	Females: 3% (/140) Males: 9% (/141)		
		Anglo-saxon cemetery of Raunds (England)	10th–12th centuries	203	Females: 4% (/67) Males: 7% (/88)		
		Cemetery of the Augustinian friary, Kingston-upo-Hull (England	14th–16th centuries	194	Females: 9% (/46) Males: 7% (/119)		
		Cemetery of the parish church of St. Martin, Wharram Percy (England)	13th–19th centuries	377	Females: 8% (/117) Males: 15% (/172)		
		Devin-Hrad, medieval cemetery (Slovakia)	11th–12th centuries	136	Females: 7.7% (5/65) Males: 7.6% (4/53) Total: 7.6% (10/136)	L4-L5	Mascinová and Benus (2003)
		Devín-Zakostolom (Slovakia)	9th century	45	Females: 0 (-/17) Males: 8.3% (2/24) Total: 4.4% (4/45)		
		ATE site (Wales)	5th–11th centuries	42	Female: 5.9% (1/17) Males: 0 (-/17) Total: 5.4% (2/42)	ND	Davidhizar (2005)
		Hickleton, christ church (England)	13th–18th centuries	18	Females: 25% (2/8) Males: 25% (2/8) Total: 16.7% (3/18)	L1-L5	Fibiger and Knüsel (2005)
		Blackfriars, monastic cemetry (England)	13th–16th centuries	117	Females: 3.7% (1/27) Males: 9% (3/33) Total: 3.4% (4/117)		
		Spitalfields, christ church cementery (England)	18th–19th centuries	968	Females: 0.7% (2/312) Males: 1.6% (5/311) Total: 0.7% (7/968)		
		Chichester, leper hospitals (England)	13th–16th centuries	310	Females: 3.5% (3/85) Males: 7.5% (13/172) Total: 5% (16/310)		
		Eccles, cemetery (England)	5th–6th centuries	146	Females: 4.9% (3/61)		

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Table 3 *(continued)*

Continent	Lifestyle	Collection	Period	N	Prevalence	Vertebra	Reference
					Males: 5.6% (4/72) Total: 4.8% (7/146)		
		Towton, mass grave from a battle (England)	1461 BP	38	Males: 5.3% (2/38) Total: 5.3% (2/38)		
		Wharram Percy, North Yorkshire (England)	11th–14th centuries	201	Females: 8.9% (8/90) Males: 14.5% (16/110) Total: 11.9% (24/201)	At least all lumbar vertebrae	Mays (2006)
		Wharram Percy, North Yorkshire (England). Non-adult skeletons	11th–14th centuries	140	Total: 0.7% (1/140)	At least all lumbar vertebrae	Mays (2007)
		Ajvide, Gotland (Sweden)	2750–2300 BC	46	Females: 5.6% (1/18) Males: 21.4% (6/28) Total: 15.2% (7/46)	ND	Molnar (2006)
		Heraklion cemeteries, documented collection (Greece)	1968–1998 BP	ND	Female true: 1.1% (4/358) Male true: 1.6% (6/372) Total true: 1.4% (10/730)	L1-L5	Steyn et al. (2010)
		Skeletons from Argaric sites, Granada (Spain)	Argaric period	105	Males: 6.2% (3/53) Total: 3.2% (3/105)	Vertebral colum was mostly preseve	Jim & nez-Brobeil et al. (2010)
		Herculaneum, Naples (Italy)	79 AD	ND	Total: 8.9%	L5	Petrone et al. (2011)
		Villanueva de Soportilla, christian cemetery, Burgos (Spain)	850–1100 AD	50	Females: 0 (-/24) Males: 14.3% (3 /26) Total: 6% (3/50)	Vertebral columns were	Jim & nez-Brobeil et al. (2012)
		La Torrecilla, muslim cemetery, Granada (Spain)	900–1300 AD	74	Females: 7.1% (2/35) Males: 2.9% (1/39) Total: 4.1% (3/74)	at least 50% preserved.	
		"Banu" church of Iasi (Romania)	16th–19th century	67	Females: 0 Males: 3.4% (1/29) Total: 3% (1/67)	ND	Groza et al. (2014)
		St Michael and St Lawrence church, Fewston, rural	medieval period-1896 AD	ND	Total true: 0.6% (1/156)	Complete spine	Tancock (2014)
		St. Martin's church, Wharram Percy, rural	mid-10th to mid-19th centuries	ND	Total true: 0 (-/168)		
		first Society of Friends Meeting House, North Shields, urban	1711–1841 AD	ND	Total true: 0.7% (4/581)		
		St Hilda's church, South Shields, urban	−1856 AD	ND	Total true: 2% (9/451)		
		All rural and urban sites (England)		ND	Total true: 1% (14/1356)		
		Giecz, christian cemetery (Poland)	11th–12th centuries	180	Females: 7.1% (4/56) Males: 4.8% (5/104) Total: 5% (9/180)	At least 50% of the region was accounted	Agnew et al. (2015)
		Sródka cemetery - beginnings of Christianization- Poznan´ (Poland)	10th–12th centuries	96	Total: 0 (-/96)		
Asia		Ban Chiang (Thailand)	2100 BC-200 AD	ND	Female true: 6.5% (5/77) Male true: 0.9% (1/	L1-L5	Douglas (1997)

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Table 3 *(continued)*

Continent	Lifestyle	Collection	Period	N	Prevalence	Vertebra	Reference
					108) Total true: 3.1% (6/191)		
		Ubayama	Middle-Late Jomon	4	Total: 0 (-/4)	L4-L5	Suzuki (1998)
		Yoshigo	Late Jomon	39	Total: 15.4% (6/39)		
		Tsugumo	Late-Final Jomon	24	Total: 12.5% (3/24)		
		Hobi	Final Jomon	9	Total: 22.2% (2/9)		
		Archaeological sites of Jomon Period (Japan)	ca. 10,000–300 BC	182	Females: 16.7% (12/72) Males: 10.9% (12/110) Total: 14% (24/182)		
		Vat Komnou cemetery, Angkor Borei (Cambodia)	200 BC–400 AD	26	Female: 15.4% (2/13) Males: 0 (-/13) Total: 7.7% (2/26)	L1-L5	Pietrusewsky and Ikehara-Quebral (2007)
		Cemetery Liushui, Autonomous Region Xinjiang (China)	ca 1100/900–760/500 BC	85	Total: 1.2% (1/85)	Available vertebral columns	Gresky et al. (2015)
		Chinese, immigrants that works in mines (South Africa)	First half of 20th century	16	Total: 12.5% (2/16)	At least 80% of vertebral column	Meyer and Steyn (2015)
Africa		Bantu from Anthropological Museum of Witwatersrand University, Johannesburg (South Africa)	ND	82	Females: 5.9% (1/17) Males: 6.4% (4/63) Total: 6.1% (5/82)	L5	Shore (1930)
		Makarere College Collection (Uganda) composed by Bahuti, Bantu, Nilotic, Nilohamitic and Sudanic	ND	206	Total: 4.9% (10/206)	Complete spine	Allbrook (1955)
		Raymond Dart Collection (South Africa)	ND	113 372 485	White female: 5.7% White male: 3.8% Black female: 2.6% Black male: 3.5% Total: 3.5% (17/485)	L1-L5 and sacrum	Eisenstein (1978)
		Guanches form Tenerife (Spain)	Pre-Hispnanic	ND	Total: < 1% (only males)	ND	Campillo and Rodríguez Martín (1994)
		Giza cemetery (Egypt)	2650–2200 BC	272	Total: 0 (-/272)	Complete spine	Sarry El-Din and El Banna (2006)
		Greco-Roman Egypcians, Bahriyah Oasis (Egypt)	332–30 BC	ND	Total true data: 2% (5/256)	Complete spine	Hussein et al. (2009)
		Pretoria Bone Collection (South Africa)	ND	ND ND ND	White female true: 0 (-/478) White male true: 1.5% (7/477) White total true: 0.7% (7/955)	L1-L5	Steyn et al. (2010)
		Raymond Dart Collection (South Africa)		ND ND ND	Black female true: 0 (-/427) Black male true: 0 (-/476) Black total true: 0 (-/930)		
		Dayr Al-Barshā (Egypt)	Old Kingdom 2686–2160 BC Middle Kingdom 2055–1650 BC Zone 9b Old and Middle Kingdom	91 35 7 133	Total: 0 (-/91) Total: 5.7% (2/35) Total: 14.3 % (1/7) Total: 2.3% (3/133)	ND	Malnasi (2010)

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Table 3 *(continued)*

Continent	Lifestyle	Collection	Period	N	Prevalence	Vertebra	Reference
		Sheik said (Egypt)	Middle Kingdom 2055–1650 BC	12	Total: 0 (-/12)		
		Kimberley, mine workers (South Africa)	19th century	82	Total: 8.5% (7/82)	ND	Van der Merwe et al. (2010)
		Rudolf Pöch Collection (Viena) and Musée de L'Homme Collection (Paris) Western Cape, Northern Cape, Eastern Cape, Bostwana and Namibia	ND	122	Total: 0.8% (1/122)	ND	Botha and Steyn (2014)
Oceania		Australian aboriginal from South Australia, Northern Territory, New South Wales, Queensland and Western Australia (Australia)	ND	110	Total: 8.2% (9/110)	L1-L5	Tulsi (1972)
		Mokapu Site, Oahu Island, Hawaii (USA)	pre-European	148	Females: 6.4% (5/78) Males: 10% (7/70) Total: 8.1% (12/148)	L1-L5 (only bilateral defects)	Suzuki (1993)
		Chamorros from Hyatt Site, Guam island (USA)	circa 1200–1521 AD pre-European Latte Period	38	Females: 14.3% (3/21) Males: 29.4% (5/17) Total: 21% (8/38)	Complete spine	Arriaza (1997)
		Chamorros from Apurguan site, Guam island (USA).	1000–1521 AD pre-contact Latte Period	124	Females: 0 (-/40) Males: 9.5% (8/84) Total: 6.5% (8/124)	L1-L5	Douglas et al. (1997)
		Rota	1–1600 AD		Total true: 2.2% (2/92)	L1-L5	Pietrusewsky et al. (2014)
		Tinian	1000–1640 AD		Total true: 2.8% (1/36)		
		Saipan	210–1670 AD		Total true: 1.3% (1/78)		
		Guam	590–1665 AD		Total true: 6.7% (10/149)		
		Chamorros from Mariana Islansds (USA)			Total true: 3.9% (14/355)		

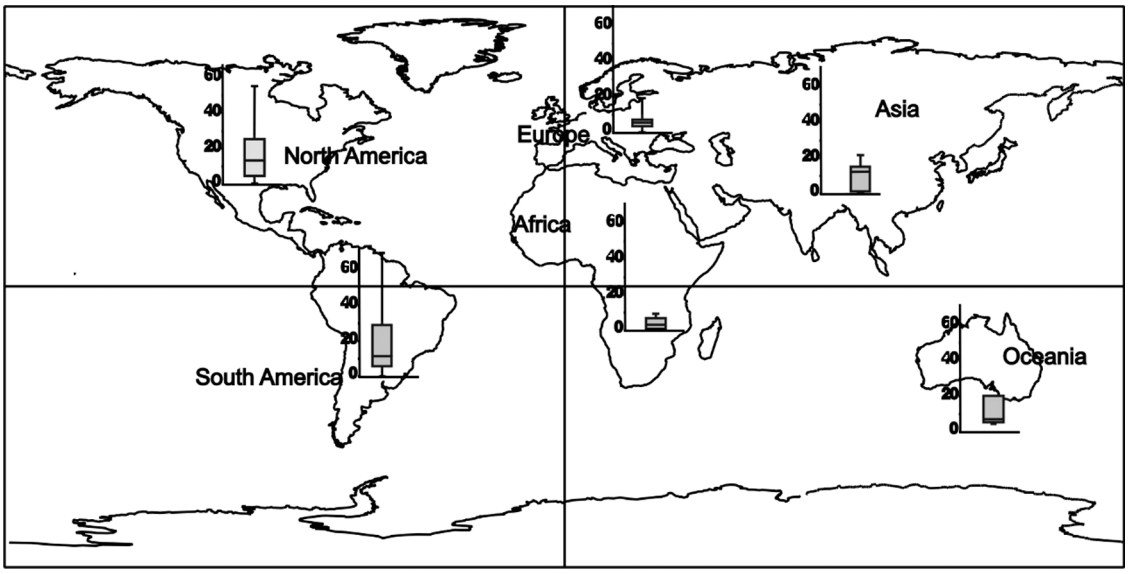

Fig. 5. Map of the world with the corresponding boxplots of spondylolysis frequencies by continent.

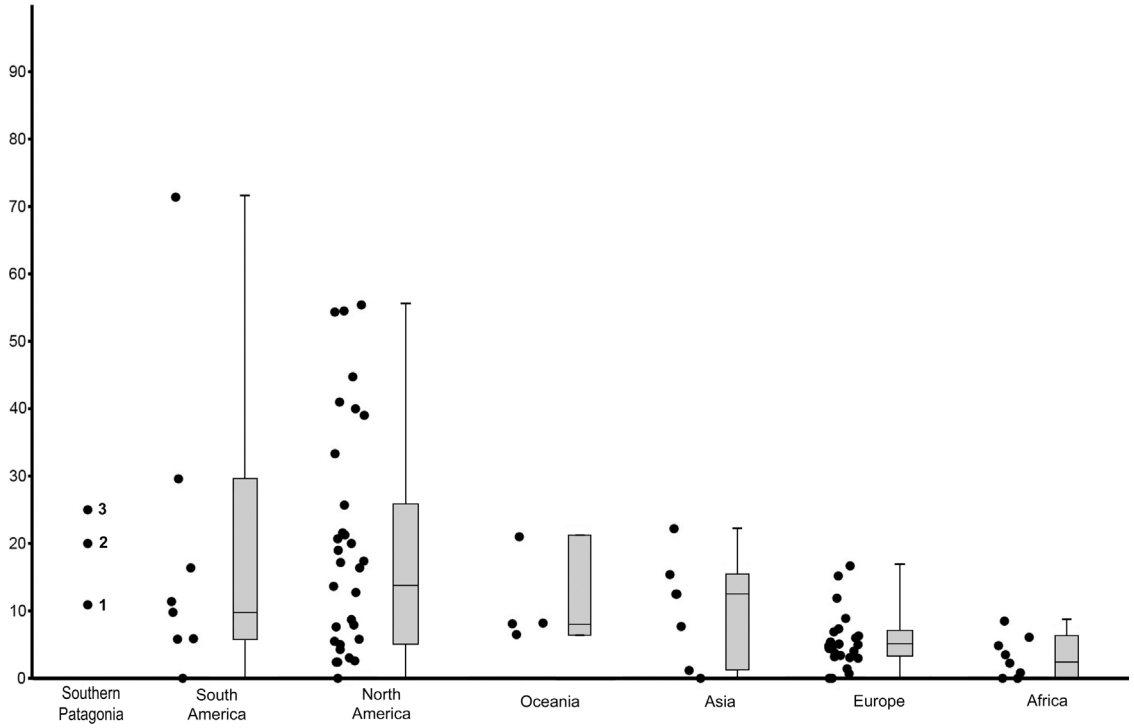

Fig. 6. Jittering and box-plot, each point represents the total percentage of populations with crude data by continents. Points at Southern Patagonia column are: 1) pre-contact, 2) post-contact excluding Salessian Mission "*Nuestra Señora de La Candelaria*", 3) Salessian Mission "*Nuestra Señora de La Candelaria*".

the contact period). Nevertheless, the prevalence in all periods and archaeological contexts in SP are within the values observed in the whole continent (Table 3, Figs. 5 and 6). The only case of probable spondylolisthesis that showed evidence of slippage of L4 on L5 was recorded among the skeletons from SMLC. A change in the lifestyle, and consequently in the physical activity, could be the cause of the higher prevalence in the sample from SMLC. A recent study of historical sources (Casali, 2011) reported that native men living in SMLC worked in taking care of cattle, mainly sheep, and women in wool spinning and the knitting of clothes. These labors, different from those produced as hunter-gatherer lifestyle, could have demanded highly repetitive flexion, extension or rotation of the lumbar spine, which has been proposed as favoring this kind of vertebral fractures (Turner and Bianco, 1971; Goldstein et al., 1980). Similar results associated with changes in lifestyle were reported in a comparative study of skeletal remains from Nebraska (Sandness and Reinhard, 1992), in which higher prevalence of spondylolysis was observed in historic sample (19%) than in pre-historic samples (0%).

As it was mentioned above, the cause of spondylolysis is an issue of debate, particularly because of the recognized impact of physical activity and the possible influence of the morphology of the vertebrae. The postcranial morphology studied by Gusinde ([1931]1982a,b) in the first decades of 20th century showed differences in thoracic structure between terrestrial and maritime hunter-gatherers from Tierra del Fuego. When the sample studied here was considered geographically, 5 out of the 7 cases of spondylolysis were observed in skeletons from the

continent and the north of Tierra del Fuego. Thus, a possible association with different structures of the thorax and with physical patterns related to terrestrial hunter-gathering cannot be discarded. However, no evidence for sustaining this hypothesis is available at the moment, and further anatomical studies of vertebral and axial trunk morphology are needed.

The meta-analysis reported here showed that frequencies of spondylolysis in skeletal samples range between ca. 0% to 71.4%, with the highest percentages observed in skeletons from hunter-gatherers societies. The results obtained from skeletal samples from SP are coincident with the prevalence observed in samples from other hunter-gatherers populations of North and South America. However, the comparative analysis of spondylolysis among samples is challenging due to the nonexistence of a standardized recording methodology, which requires some future consensus.

Four differences were noticed among these studies. For example, while some researchers observed the entire spine, others analyzed only lumbar vertebrae or did not mention the studied segment. In these analyses, segments L1-S1 were more frequently affected. Considering the possible presence of spondylolysis elsewhere, all available vertebrae should be examined, including the sacrum. Secondly, many researchers did not include information regarding laterality and completitude of the lesions. Thirdly, the sex and age of individuals must be considered, because of the observed influence on the development of spondylolysis. Only adults were usually studied, due to the difficulties in diagnosis of spondylolysis in non-adults (Fibiger and Knüsel, 2005; Mays, 2007). However, considering its possible etiology as a developmental disease (Leone et al., 2011), new efforts in the registration and diagnosis in non-adult skeletal remains are necessary. Finally, the frequency and raw data for a complete understanding of the spondylolysis prevalence need to be informed. Nevertheless, if the target is to compare the prevalence among studies, the best option is crude data because most of the studies that examined this pathology used crude data. Second, frequency alone does not allow the researcher to know the number of vertebrae affected by individual.

As we mentioned above, anatomy and genetics have been invoked in explaining the development of spondylolysis. Unfortunately, no data about morphology of the lumbar spine in human populations from SP are available until now. However, the approach of this study included all these aspects, analyzing the complex geographical and temporal dispersion of these interactions through the study of prevalence of spondylolysis in different cultural and ecological contexts. The demographic scenarios of past societies from SP were more isolated than those of current populations, in which genetics and lifestyle are more diverse and, in many cases, more difficult to identify. In this sense, the study of spondylolysis in the past represents a relative advantage to understand the main causes of this condition. The review of published data offered a framework to compare and to understand the results obtained from SP, and at the same time, to analyze the variability of prevalence in other archaeological samples. The results showed regions in which spondylolysis was more frequently studied, as North America or Europe, and others such as Oceania, Africa and Asia in which more data are needed. Most of the results are linked to the dissimilar quality of the samples, but they are guides for future hypothesis.

Patagonia has two characteristics that make this study especially important: 1) isolation of Tierra del Fuego from the continent and, 2) fast and drastic lifestyle changes because of the native-European contact. The data reported here suggests an increment of spondylolysis prevalence during contact due to lifestyle changes, although morphological features of the vertebrae cannot be completely discarded and should be analyzed in future studies. This first step offers new questions that need to be answered by further evidence to elucidate the etiopathogenesis of spondylolysis in these populations.

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