Possible environment influence in spine segmentation anomalies

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SUMMARY

Segmentation anomalies of the spine transformations are relatively common in humans, mainly in adjacent regions. Its aetiology is multifactorial, a combination of genetic, environmental, and epigenetic interaction. A sample of 50 adult individuals of both sexes from two different sites and chronologies of the current Argentine territory was examined. This work proposes a new approach to analyse segmentation anomalies, considering the taphonomic characteristics of the spine, together with the most common occasional contour shifts of such anomalies. Likewise, a bibliographic review was conducted to compile the knowledge achieved to date on this topic. The results showed different patterns of expression of segmentation anomalies among the analysed samples, with the lumbosacral transformations being the most prevalent. The similarities and disparities observed between Southern Patagonian samples and Inuit populations suggest that cold, as an environmental factor, could play an important role in the phenotypic plasticity of human populations. Similarly, hypoxia could influence the sample from Pukará de Tilcara. Due to the scarce existing methodological standardization for addressing segmentation anomalies, a systematization of the methods used to analyse segmentation anomalies is recommended; our approach is a proposal for this purpose.

Key words: Argentina – Boundary regions – Sacralization – Cold – Hypoxia – Holocene

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INTRODUCTION

The alteration of the spine may occur in terms of its number of vertebrae and morphology, which are often related but not necessarily (ten Broek et al., 2012). When these variations occur between two regions of the spine, they are considered segmentation anomalies (SAs), relatively common among humans (White and Folkens, 2005; ten Broek et al., 2012; Singh et al., 2015). Along with genetic factors, the development of the spine can be affected by other effects such as those caused by nutritional, hormonal, or mechanical agents. Variations and spine malformations have a multifactorial origin, resulting from congenital anomalies that arise due to intrinsic (genetic and hormonal) and extrinsic (environmental) factors, or a combination of both (epigenetic interaction). Therefore, it is difficult to determine the aetiology of such pathologies due to the complexity of determining the underlying cause (Barnes, 1994; Sarfo, 2014; Tancock, 2014; Karapetian and Makarov, 2019).

It is important to note that archaeological human bones are often affected by taphonomic processes. Good preservation conditions depend on various extrinsic and intrinsic factors. Vertebral elements are among the skeletal elements most vulnerable to taphonomic process (Holland et al., 1996; Manifold, 2012). Therefore, these processes are a limiting factor in paleopathological analysis, but even more so in paleopathological examination of the spine.

The aim of this study was to explore SAs in two Argentine populations from different periods: a) hunter-gatherers from Southern Patagonia (SP), and b) prehispanic farmers from the Argentinean prepuna. Considering that the first population lived in a cold environment at the sea level and the second in high altitude ecosystems with a large temperature range, the hypothesis of this work is that differences among these two populations are expected for the prevalence of different SAs due to the different microevolutionary processes of adaptation to the environment adopted by each of these populations.

MATERIAL AND METHODS

Two samples of adults from different parts of Argentina were analysed (Fig. 1): 1) a sample of hunter-gatherers from SP; 2) skeletal remains from the Argentinean prepuna, from the *Pukará de Tilcara* site (PT). In the present study, a total of 126 individuals (98 SP and 28 PT) were initially analysed; 50 of them met the desired standards of completeness and preservation: at least the last four thoracic vertebrae, the entire lumbar region and the sacrum, which were used to carry out a more in-depth analysis. Therefore, the final sample for analysis comprised 37 from SP and 13 PT individuals.

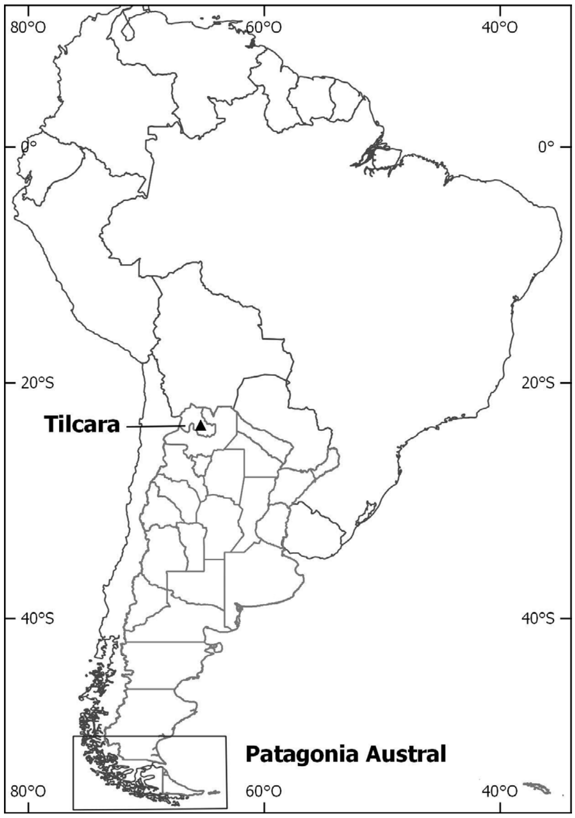

Fig. 1.- Map of South America with the two samples located in Argentina. *Patagonia Austral* (SP) shows the localisation of the hunter-gatherers from SP. Tilcara shows the localization of *Pukará de Tilcara* site (PT).

SP sample (13 women, 22 men and 2 with sex not available -NA), dated from Holocene, between 5000 years B.P. and the 20th century, from different archaeological sites (Table 1) excavated in SP, area behind the 50th parallel South, including the last foothills of the American continent. The bioanthropological information on these individuals comes from *Base de Información Bioantropológica de*

Patagonia Austral -B.I.B.P.A.- (D'Angelo del Campo et al., 2020). These populations were maritime or terrestrial hunter-gatherers, and presented a high degree of isolation from other American populations as shown by previous genetic (Lalueza, 1997a; Pérez et al., 2009; de la Fuente et al., 2015, 2018; Crespo et al., 2018), morphological (Cocilovo and Guichón, 1986, 1999-2000; Guichón, 1993; Varela et al., 1993-94; Lalueza et al., 1996; González-José et al., 2002; Pérez et al., 2007, 2009) and archaeological studies (Borrero, 2001). However, there is an internal homogeneity between them reported both genetically (Lalueza, 1997a; García-Bour et al., 2004; Crespo et al., 2017) and morphometrically (Hernández et al., 1997; González-Jose, 2003; Bernal et al., 2010). With the arrival of allochthonous people at the end of the 19th century, the lifestyle changed drastically, and a great demographic decline took place (García-Moro et al., 1997).

Therefore, the individual SP were classified according to the period and the specific region to which they belonged. The periods were divided according to the arrival of the colonizers, differentiating between 1) precontact, before 1.520 A.D., when the Magellan expedition crossed the Strait of Magellan; 2) post-contact, after that date; and 3) pericontact: because dating methodologies inevitably have precision errors, individuals dated around 1,520 A.D. cannot be classified as pre- or post- contact (Table 1). In addition, we divided the period of post-contact into: (i) individuals who lived at Salesian the Mission "*Nuestra Señora de La Candelaria*" – SMLC – (lat. -53,72º, long. -67,79º) near to Río Grande city (North of Tierra del Fuego, Argentina); and (ii) individuals who lived out of SMLC. To analyse the regional factor, the classification by Borrero et al. (2001) was used. According to it, the SP region is divided the region into six areas: Beagle Channel (BC), San Gregorio-Brunswick (SGB), North of *Isla Grande de Tierra del Fuego* (NIG), Mitre Peninsula (MP), Continent (C) and *Última Esperanza* Mountain (UEM) (see Table 1). However, due to the low number of individuals present in some of these areas, we had to modify this classification and regroup the 6 areas into 3 as follows (Fig. 2): (**1**) Beagle Channel (**BC**); (**2**) *Isla Grande* (**IG**), made up by the union of North of *Isla Grande de Tierra del Fuego* (NIG) and Mitre Peninsula (MP); and (**3**) Continent (**C**), made up by the union of Continent (C), *Ultima Esperanza* Mountain (UEM) and San Gregorio-Brunswick (SGB).

PT sample (6 female, 5 male and 2 NA; Table 2) from the *Pukará de Tilcara*, site from Argentinian prepuna, located in the central sector of the *Quebrada de Humahuaca*, a valley sited in the province of Jujuy connecting the Eastern plains to the Puna and the Southern Mountain hills area. This

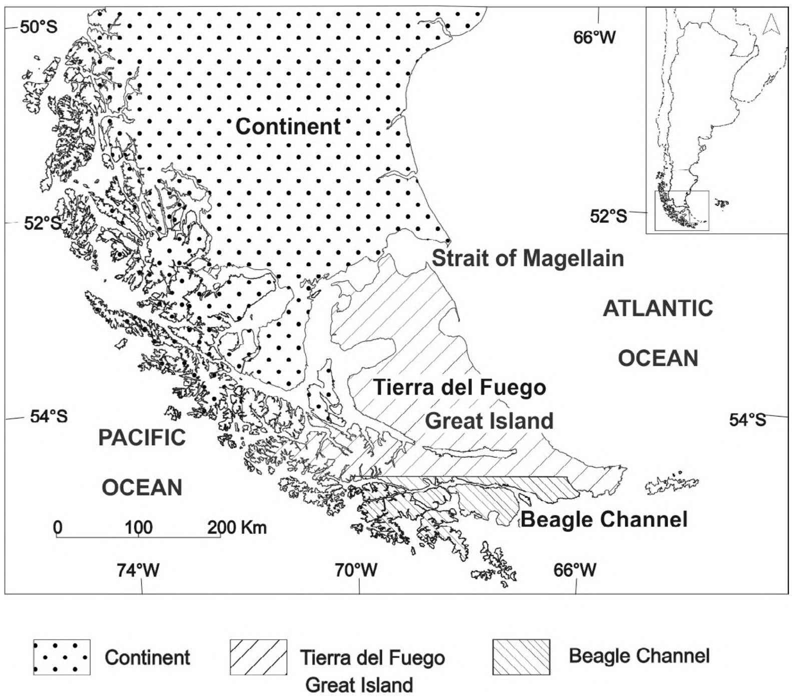

Fig. 2.- Map of SP divided in three regions: Continent (C), Beagle Chanel (BC) and *Isla Grande* (IG). Modified from Borrero et al. (2001).

Table 1. Skeletal remains from Southern Patagonia (SP) analysed in this work.

Individual			Institution[a]	IC[b]	Chronology (years BP)	Region[c]	Sex[d]	Age	C vert.	T vert.	L vert.	S vert.	Co vert.	Total vert.	References
1		La Arcillosa 2	CADIC	-	5205 ± 58	NIG	F	24-28	7	12	5	6	0	29	Saleme et al., 2007a
2		Bahía Felipe 2	IP	50103	1608 ± 45	NIG	M	35-50	7	12	5	5	0	29	Suby, 2014
3		Shamakush 6	MFM	SH-6	1536 ± 46	CB	M	35-45	7	12	5	5	0	29	Suby et al., 2011
4		Paishauaia I	MFM	857	1504 ± 46	CB	F	35-45	7	12	5	5	0	29	Suby et al., 2011
5		Punta Daniel	IP	33949	1090 ± 30	SGB	M	30-40	7	12	5	5	0	29	Suby, 2014
6		Cabo Nose	IP	89014	980 ± 40	NIG	M	20-35	3	11	5	5	1	25	Alfonso-Durruty et al., 2011
7		Caleta Falsa, site 8 (1)	MFM	S8-1	820 ± 40	PM	M	18-23	6	11	5	5	0	27	Guichón & Suby, 2011
8		Seno Lauta 2	IP	288	Pre-contact	CB	F	35-40	7	12	5	6	0	30	Guichón, 1994
9		Isla Hoste (12590)	ME	12590	Pre-contact	CB	M	36	6	12	5	5	0	28	Guichón, 1994
10		Isla Hoste (12589)	ME	12589	Pre-contact	CB	F	A	3	12	5	7	0	27	Guichón, 1994
11		Aleph 3	ME	-	450 ± 60 (Peri-contact)	PM	M	30-39	0	9	5	6	0	20	Lanata, 1995
12		Brazo Norte, Cerro Johny	IP	6784	390 ± 60/480 ± 70 (Peri-contact)	SGB	M	30-50	7	12	5	7	0	31	Guichón, 1994
13		Puesto Pescador	CADIC	-	335 ± 35	NIG	M	22-28	7	12	5	6	0	31	Suby et al., 2008
14		Lengua de Vaca	IP	6780	251 ± 41	NIG	F	30-40	7	12	5	5	1	30	Suby, 2014
15		Las Mandíbulas 1	LEEH	QQN002	1770-1950 A.D.	NIG	M	20-34	7	12	5	5	0	29	Guichón et al., 2000
16		Caverna 3, Puerto Natales	IP	50109	Post-contact	UEM	M	20-25	2	11	5	5	0	23	Prieto 1993-94
17		Cementerio Haberton	MFM	CH 95	Post-contact	CB	M	25-35	5	11	5	5	0	26	Piana et al., 2006
18		Akathusún	MFM	-	Post-contact	CB	F	30-40	4	12	5	5	1	27	Piana et al., 2006
19	Salesian Mission	C11 (1)	LEEH	QQN0058	Post-contact	NIG	M	20-30		12	5	6	0	23	García Laborde, 2016
20	Salesian Mission	D-C 9-10	LEEH	QQN0053	Post-contact	NIG	M	25-40	7	12	5	7	0	31	García Laborde, 2016
21	Salesian Mission	C 13	LEEH	QQN0026	Post-contact	NIG	F	25-35		8	5	5	0	18	García Laborde, 2016
22	Salesian Mission	E 10-11 (1)	LEEH	QQN0049	Post-contact	NIG	M	25-30	7	12	5	6	0	30	García Laborde, 2016
23	Salesian Mission	E 10-11 (2)	LEEH	QQN0055	Post-contact	NIG	F	18-25	7	12	5	5	0	29	García Laborde, 2016
24	Salesian Mission	E 12-13	LEEH	QQN0023	Post-contact	NIG	M	35-45	7	12	5	5	0	29	García Laborde, 2016
25	Salesian Mission	C 14 (2)	LEEH	QQN0033	Post-contact	NIG	F	19-20	7	12	5	5	0	29	García Laborde, 2016
26	Salesian Mission	D 16 (bis)	LEEH	QQN0039	Post-contact	NIG	F	21-53	7	12	5	6	0	31	García Laborde, 2016
27	Salesian Mission	E 15-16 2 (bis)	LEEH	QQN0045	Post-contact	NIG	M	30-40	3	12	5	5	1	26	García Laborde, 2016
28	Salesian Mission	D 15-16	LEEH	QQN0030	Post-contact	NIG	F	35-49	2	10	5	6	0	23	García Laborde, 2016
29		Ushuaia	ME	13276	-	CB	-	A	2	*9	5	5	0	21	Guichón, 1994
30		Zona Industrial, Ushuaia	MFM	2670	-	CB	M	A	7	12	4	6	0	29	This work
31		Parque Nac. La Patria	MFM	2403 (2)	-	CB	M	35-49		12	5	5	0	22	This work
32		Close to SMLC	ME	25884	-	NIG	M	30-35	6	12	5	5	0	28	Schindler, 2001
33		Estancia María Behety	MFM	2667	-	NIG	M	35-49	7	12	5	5	0	29	This work
34		Bahía Chilota	IP	73722	-	NIG	F	A	7	12	5	5	1	30	Alfonso-Durruty et al., 2015
35		Bahía Santiago 4	IP	50112	-	SGB	-	A	7	12	5	5	1	30	This work
36		2671	MFM	2671	-	-	F	20-34	2	*11	5	5	1	19	This work
37		2405	MFM	2405	-	-	M	50		12	5	5	0	22	This work

[a] **CADIC:** *Centro Austral de Investigaciones Científicas,* Ushuaia; Argentina. **IP:** *Instituto de la Patagonia,* Punta Arenas, Chile. **MFM:** *Museo del Fin del Mundo,* Ushuaia, Argentina. **ME:** *Museo Etnográfico Juan B. Ambrosetti,* Universidad de Buenos Aires, Buenos Aires, Argentina, **LEEH:** *Laboratorio de Ecología Evolutiva Humana,* Quequén, Buenos Aires, Argentina.
[b] **IC**: Institution code.
[c] *Norte de Isla Grande de Tierra del Fuego* (NIG); San Gregorio-Brunswick (SGB); Mitre Peninsula (PM); Beagle Channel (CB); *Última Esperanza* Mountain (UEM).
[d] F: Female; M: male.
Vert.: vertebrae.

settlement is placed at a plateau with a maximum height of 2525 m in the middle of the valley in a complex topography, with ladders and fertile valleys. PT can be considered a high-altitude place, with the consequent effects of altitude produce in human physiology. As Frisancho (1993) noted, the results of altitude are perceived at 2000 m during physical activity and 2500 m during rest. The first settlements in this area happened before the 1st millennium A.D., and it was a densely populated area during late pre-Hispanic times (11th to 16th centuries A.D.), reaching its largest size and becoming the main hierarchical center of the region during the Inca period (Debenedetti, 1930; Otero, 2015). Thus, those settlements are pre-contact. Moreover, the sample is composed of individuals whose lifestyle was majorly a combination of farming and shepherding. The collection is located at *Museo Etnografico "J. B. Ambrosetti", Facultad de Filosofía y Letras* at *Universidad de Buenos Aires* (UBA). The analysed individuals have been classified according to their sex as male (M) or female (F), based on the study of the cranium and the hip bones, according to the method proposed by Buikstra and Ubelaker (1994). Age was classified as over and under 30 years at death, estimated by the study of pubic symphyses (Todd 1921a, b; Brooks and Suchey, 1990), auricular surface (Lovejoy et al., 1985) epiphyseal fusion (Buikstra and Ubelaker, 1994) and the metamorphosis of the fourth sternal rib end (Isçan et al., 1984).

SAs changes in transitional vertebrae, column units that are in the boundary regions of the spine, comprise cervicothoracic, thoracolumbar, lumbosacral and sacrococcygeal. The definitions that we have used in this study are the following: Jankauskas (2001); Sarfo (2014); ten Broek et al. (2017) and Karapetian et al. (2019). They all describe: 1) Cranial shift: the vertebra acquires the typical characteristics of the immediately inferior section; 2) Caudal shift: the vertebra acquires the typical characteristics of the immediately superior section of the spine. Caudal and cranial shift diversity are illustrated in Fig. 3, based on previous works (Jankauskas, 2001; Sarfo, 2014; ten Broek et al. (2017; Karapetian and Makarov, 2019). In order to analyse the SAs, a macroscopical study was carried out in all spines to identify each vertebral region, observing the presence or absence of each vertebral element (Fig. 3). Vertebrae were examined attending to the diverse characteristics of each segment (White and Folkens, 2005): foramen, body, arch, pedicle, lamina, spinous process, transverse process, articular facets (superior and inferior) and costal fovea. In the case of the *sacrum*, the promon-

Table 2. Skeletal remains from *Pukará de Tilkara* (PT) analysed in this work.

Individual		Institution[a]	Sex[b]	Age	C vert.	T vert.	L vert.	S vert.	Co vert.	Total vert.
1	17823 (box 132)	ME	F	18-22	7	12	5	5	0	29
2	17846 (box 171)	ME	M	28-45	7	12	5	5	0	29
3	17825 (box 24)	ME	M	35-55	6	12	5	5	0	28
4	17828 (box 26)	ME	I	-	7	12	5	5	1	30
5	17954 (box 50)	ME	F	20-38	6	12	5	6	0	29
6	17952 (box 49)	ME	M	24-55	7	12	4	6	0	29
7	17955 (box 51)	ME	I	18-25	7	12	5	5	0	29
8	17949 (box 47)	ME	F	22-48	7	12	5	6	0	30
9	17951 (box 48)	ME	F	A	6	11	5	6	0	28
10	17852 (box 40)	ME	F	>40	6	12	5	5	0	28
11	17853 (box 41)	ME	M	25-35		12	5	5	0	22
12	17855 (box 43)	ME	F	20-40	6	12	5	5	0	29
13	17833 (box 31)	ME	M	20-27	5	12	5	5	0	29

[a] **ME:** Museo Etnográfico Juan B. Ambrosetti, Universidad de Buenos Aires, Facultad de Filosofía y Letras, Buenos Aires, Argentina.
[b] F: Female; M: male; I: indeterminate.
Vert.: vertebrae.

tory, alae, sacroiliac joint, anterior sacral foramina, transverse lines, superior articular facets, dorsal wall, and median crest were observed. Finally, in the *coccyx*, the articular and transverse processes superiorly and the *cornua* were identified. To identify each vertebra into specific vertebral region, a good preservation of vertebral elements is important. However, preservation of all the vertebral elements is complex because the spine is especially sensitive to taphonomic processes (Manifold, 2012), fundamentally the coccygeal region (Stodder, 2019). Another factor to consider in the study of SAs is where these alterations occur, usually in boundary regions, being the lumbosacral region the most affected (Konin and Walz, 2010) and the cervicothoracic region the least affected (Jankauskas, 2001). Based on these two factors, and since there is still no methodological standardization to study SAs, this work proposes a new approach to study these anomalies by analysing specific regions of the spine instead of the entire structure. In addition, considering the current limitations of preservation of archaeological samples and the high prevalence of SAs existing in lumbosacaral and boundary regions (Fig. 3), this new approach requires a minimal preservation condition of the spine to have the last four thoracic vertebrae, the entire lumbar region and the sacrum. Therefore, in this work, those individuals who did not present the minimum preservation requirements were excluded from the study.

Descriptive analyses were carried out in the SA analysed with the new approach proposed constructing contingency tables for caudal thoracicalization, lumbarization and cranial sacralization, considering sex, grouped age, region (CB, IG and C) and period (precontact, peri-contact, post-contact – out of SMLC and post-contact – in SMLC). Number of Sacral Vertebrae (NSV) frequencies were also studied considering the same factors. Results were in contingency tables. Hypothesis testing for the different levels of the factors contained in the contingency tables was performed with two-sided Fisher's exact test with a confidence level of 95% (α <0.05). This statistical test is recommended for small samples such as our case.

In order to contextualize the results of SP and PT, this paper reviews the literature on SAs in ancient populations, including information from different studies carried out on all continents since the beginning of the 20th century (Table 3).

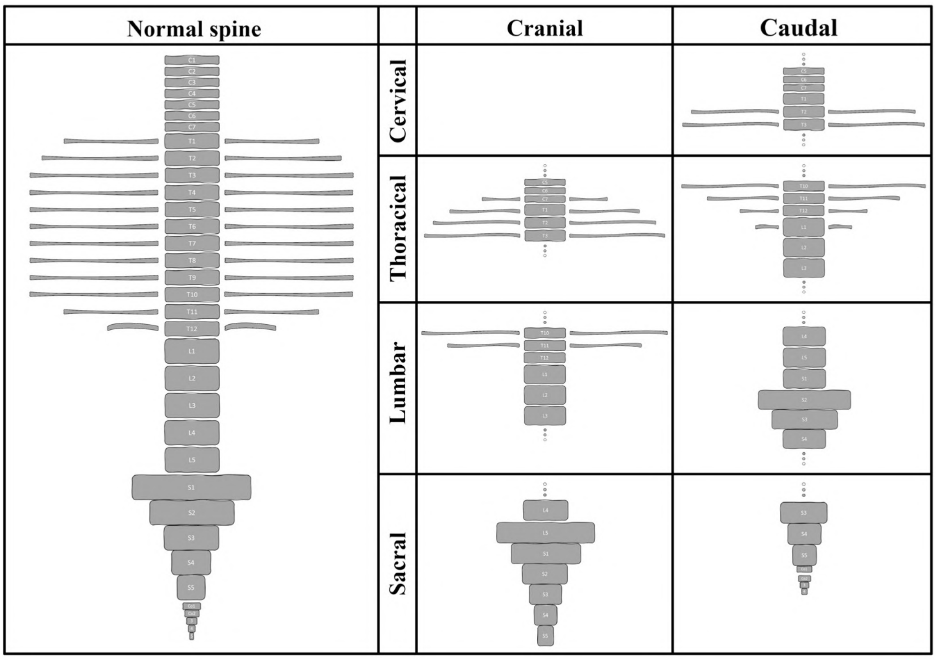

Fig. 3.- Schema of the spine, both normal (left) and with SAs (middle and right): **Caudal cervicalization**: T1 transformation to cervical morphology without ribs. **Cranial dorsalization**: presence of rib facets on the vertebral body of C7. **Caudal dorsalization**: ribs at L1 and/or superior articular process of dorsal type. **Cranial lumbarization**: T12 without rib facets and/or inferior articular process of lumbar type. **Caudal lumbarization**: S1 acquires lumbar form and remains separate from the sacrum. **Cranial sacralization**: L5 is assimilated by the *sacrum* or modify its shape assuming S1 form. **Caudal sacralization**: Co1 acquires sacral vertebrae shape and usually is assimilated by the *sacrum.*

Table 3. Bibliographic information on SAs variation in different skeletal samples around the world. Rows colored in grey represent data from current work. Those cells where no information about the variable is provided remain clear.

Continent	Collection or sample (Country)	Period	Lifestyle	Total individuals	Sacralization							Lumbarization							Dorsalization							References	Observations
					n	Cranial		Methodology	Caudal		Methodology	n	Cranial		Methodology	Caudal		Methodology	n	Cranial		Methodology	Caudal		Methodology		
						n	%		n	%			n	%		n	%			n	%		n	%			
AMERICA	Hamann-Tod Osteological Collection, Cleveland (USA). **Documented collection**	20th century	Urban	Total: 748																						Willis, 1923	
	Departmental collections of Washington University and Western Reserve University	20th century	Urban	Total: 201	Total: 201	28	0,14	Sacralization of L5 (total or partial)																		Lanier, 1939	
	Sadlemiurt, Southampton island. Museum of Man, Ottawa (Canada)	Several hundred years - 20th century	HG	♂: 33	♂: 33	1			22	0		♂: 33	1			14			♂: 33	0			18	0		Merbs, 1974	
				♀: 37	♀: 37	2			13	0		♀: 37	1			10			♀: 37	0			10	0			
				Total: 70	Total: 70	3			35	0		Total: 70	2	8,6	Kühne (1936)	24		Kühne (1936)	Total: 70	0		Kühne (1936)	28	0	Kühne (1936)		
	Northwest Coast Indian (Haida, Kwakiutl, Nootka). Field Museum of Natural History, Chicago (USA)	Before 19th century	ND	Total: 70	Total: 70	3		Kühne (1936)	26		Kühne (1936)	♂: 33	4			23			Total: 70	3			18	0			
												♀: 37															
												Total: 70															
	Eskimo skeletons from the American Museum of Natural History, New York (USA)	1th century A.D	ND	Total: 295	Total: 295	11	3.7																			Lester & Shapiro, 1968	
	Hamann-Tod Osteological Collection, Cleveland (USA) and Robert J. Terry Anatomical Skeletal Collection, Missouri (USA). **Documented collections**	19th- 20th centuries	Urban	♂: 1048	White: 487	36	7.3	High Assimilation of the Sacrum																		Tague, 2009	
					Black: 495	30	6																				
				♀: 1038	White: 433	20	4.6																				
					Black: 540	45	8.3																				
				Total: 2086	Total: 1955	131	6.7																				
	Skeletal sample from the Ryan Mound site, south-eastern side of the San Francisco Bay, San José (USA)	2180 - 250 BP	HG	♂: 66	♂: 50			Barnes (1994)				♂: 50				4	8	Barnes (1994)								Weiss, 2009	
				♀: 66	♀: 41							♀: 41				0	0										
				Total: 146	Total: 91							Total: 91				4	4,4										
	Skeletal remains from the Sully site (39SL4), Arikara natives. National Museum of Natural History (NMNH), Smithsonian Institution, Washington D.C. (USA)	11th-18th centuries a.C.	Horticultural (Agriculture)	♂: 39																							
				♀: 33																							
				Total: 172	Total: 52	4	7,7	Cranial sacralization	5	9,6	Sacralization of coccygeal vertebra	Total: 52	1	1,9	T12 lumbarization	2	3,8	S1 lumbarization (total or partial)					3	5,8	L1 thoracization	Kimmerle, 2010	

Continent	Collection or sample (Country)	Period	Lifestyle	Total individuals	Sacralization							Lumbarization							Dorsalization							References	Observations
					n	Cranial		Methodology	Caudal		Methodology	n	Cranial		Methodology	Caudal		Methodology	n	Cranial		Methodology	Caudal		Methodology		
						n	%		n	%			n	%		n	%			n	%		n	%			
AMERICA	Hamann-Tod Osteological Collection, Cleveland (USA) and Robert J. Terry Anatomical Skeletal Collection, Missouri (USA). **Documented collections**	19th- 20th centuries	Urban	♂: 1617	♂: 1617					43,4	Sacralization of coccygeal vertebra															Tague, 2011	
				♀: 737	♀: 737					37																	
				Total: 2354	Total: 2354				703 273 976	41,5																	
	Hamann-Tod Osteological Collection, Cleveland (USA) and Robert J. Terry Anatomical Skeletal Collection, Missouri (USA). **Documented collections**	19th- 20th centuries	Urban	♂: 569	♂: 569	59	0,104	High Assimilation of the Sacrum																		Tague, 2011b	This work presents a different percentage compared to Tague (2009), because only individuals between 20 and 49 years were considered
				♀: 392	♀: 392	46	0,117																				
				Total: 961	Total: 961	105	10,9																				
	European ancestry north american: Robert T. Terry Anatomical Skeletal Collection, Missouri (USA) and Grant Collection, Toronto (Canada). **Documented Collections**	20th century	Urban	Total: 232	Total: 232		3,3	Cranial shift L5-S1				Total: 232		7	Caudal shift L5-S1		3,1	Presence of ribs at L1 level	Total: 232					0,7	Reduction of 12th pair of ribs	Karapetian & Makarov, 2019	
	African ancestry north american: Robert J. Terry Anatomical Skeletal Collection, Missouri (USA). **Documented Collection**			Total: 70	Total: 70	0	4,5					Total: 70		0			0		Total: 70					3			
	Tilcara's Pukará necropolis. Tilcara (Argentina)	Pre-contact	Agriculture	♂: 2	♂: 2	1	50	Sacralization of L5 (total or partial)	0	0	Sacralization of coccygeal vertebra (total or partial)	♂: 2	0	0	T12 lumbariaztion (total or partial)	0	0	S1 lumbarization (total or partial)					0	0	L1 thoracization (total or partial)	This work	
				♀: 5	♀: 5	1	20		2	40		♀: 5	0	0		0	0						0	0			
				Total: 13	Total: 13	2	15,4		3	23		Total: 13	0	0		0	0						0	0			
	Southern Patagonia (Argentina / Chile)	5.200 B.P. 20th centuries	HG	♂: 22	♂: 22	3	1,3		4	18,2		♂: 22	0	0		0	0						0	0			
				♀: 13	♀: 13	1	7,9		3	23,1		♀: 13	1	7,7		0	0						0	0			
				Total: 37	Total: 37	4	10,8		7	18,9		Total: 37	1	2,7		0	0						0	0			
EUROPE	North-eastern Scottish. Department of Anatomy of the University of Aberdeen (Scotland). **Documented Collection**	20th centuries	Urban	♂: 19					13	68,42	Sacralization of coccygeal vertebra															Saluja, 1988	
				♀: 15					10	66,6																	
				Total: 34																							
	Crypt of St. Bride's Church, Fleet Street, London (England). **Documented collection**	18th - 19th centuries		♂: 54					22	40,7																	
				♀: 40					9	22,5																	
				Total: 94																							

Continent	Collection or sample (Country)	Period	Lifestyle	Total individuals	Sacralization							Lumbarization							Dorsalization							References	Observations
					n	Cranial		Methodology	Caudal		Methodology	n	Cranial		Methodology	Caudal		Methodology	n	Cranial		Methodology	Caudal		Methodology		
						n	%		n	%			n	%		n	%			n	%		n	%			
EUROPE	Skeletal remains from Monte Bibele, Bologna (Italy)	6100-5500 AC (Neolitic)	HG	Total: 95	♂: 50	1	2	Sacralization of L5 (total or partial)																		Brasili, 1997	
					♀: 35	1	2,8																				
					Total: 89	2	2,5																				
	Skeletal sample from Pompeii, Naples (Italy)	79 A.D	Urban	♂: 70	♂: 70	16	23	Sacralization of L5 (total or partial)	8	11	Sacralization of coccygeal vertebra															Henneberg & Henneberg, 1999	Only sacral bones has been examined for this study
				♀: 54	♀: 54	7	13		1	2																	
				Total: 124	Total: 124	23	19		9	7,2																	
	Skeletal series from Oslonki site, near Wloclawek in Kujawy region (Poland)	4300-4000 B.C.	Agriculture	Total: 92		8	13,11	Sacralization of L5 (total or partial)																		Garlowska, 2001	
	Skeletal remains from the Great Moravia cemeteries. Devín-Hrad (Slovakia)	11th-12th centuries	ND	Total: 217	♂: 46	7	15	Sacralization of L5 (total or partial)	6	7,4		♂: 46				1	0,46	S1 lumbarization (total or partial)								Masnicova & Benus, 2003	
					♀: 53	1	2					♀: 53				1	0,53										
					Total: 112	9	8					Total: 112				2	2,24										
	Skeletal remains from the Great Moravia cementeries. Devín-Za costolom (Slovakia)	9th century		Total: 112	♂: 16	1	6					♂: 16				0	0										
					♀: 13	1	8					♀: 13				0	0										
					Total: 29	2	7					Total: 29				0	0										
	Byzantine populations from Eleutherna. Crete island (Greece)	8th-11th centuries	Rural	♂: 52		1	1,9	Sacralization of L5 (total or partial)																		Bourbon, 2010	
				♀: 21																							
				Total: 100		1	1																				
	Byzantine populations from Kefali. Crete island (Greece)	8th-11th centuries		♂: 18		1	5,6																				
				♀: 11																							
				Total: 49		1	2																				
	Human skeletons from the necropolis in the Eastern part of the Princely Court. Curtea domneasca (Romania)	17th centuries	Urban	♂: 70	♂: 66	2	3	Sacralization of L5: sacral bone with an extra foramen				♂: 66				1	1,5	S1 lumbarization (total or partial)								Groza *et al.*, 2012	
				♀: 26	♀: 25	0	0					♀: 25															
				Total: 111	Total: 91	2	2,2					Total: 91				1	1,1										
	Saint-Urnel necropolis, south Finistere (France)	5th - 11th centuries	Rural		Total: 30	1	3,33	Sacralization of L5 (total or partial)								1	3,3	S1 partial lumbarization								Zemirline *et al.*, 2012	
	Bone material from Drustar (Bulgaria)	9th-15th centuries	Rural	Total: 147	Total: 103	3	2,8	Sacralization of L5 (total or partial)																		Toneva & Nikolova, 2013	
	Pamplona muslim cemetery (*maqbara*). Pamplona (Spain)	7th cementery	Urban	Total:177		2	2,25	Sacralization of L5 (total or partial)																		Ibañez, 2016	
						2	2,25																				
	Anthropological Department, Lomonosov Moscow State University, Moscow (Russia). Documented Collection	1950th	Urban	♂: 66	♂: 66		2,8	Craneal shift L5-S1				Total: 232		4,4	Caudal shift L5-S1		1,3	Presence of ribs at L1 level	Total: 232					2,7	Reduction of 12th pair of ribs	Karapetian & Makarov, 2019	
				♀: 14	♀: 14																						
				Total: 80	Total: 80																						
	Kozino village cementery, Moscow region, Lomonosov Moscow State University, Moscow (Russia)	18th century	ND	♂: 78	♂: 78		0					Total: 70		2,8			0		Total: 70					1,9			
				♀: 53	♀: 53																						
				Total: 131	Total: 131																						

Continent	Collection or sample (Country)	Period	Lifestyle	Total individuals	Sacralization							Lumbarization							Dorsalization							References	Observations
					n	Cranial		Methodology	Caudal		Methodology	n	Cranial		Methodology	Caudal		Methodology	n	Cranial		Methodology	Caudal		Methodology		
						n	%		n	%			n	%		n	%			n	%		n	%			
AFRICA	Guanche sample, Canary islands (Spain)	15th century	HG			6		Sacralization of L5 (total or partial)		3							5									Rodríguez, 1995	
	Bantu natives skeletons. Anthropological Museum of Anatomy Department of the University of Witwatersrand (South Africa)	ND	ND	♂: 63																						Shore, 1930	
				♀: 17																							
				Total: 82	Total: 81	1	1,2									3	3,7										
	Exhumed skeletal of Boksburg Municipality, University of the Witwatersrand (South Africa)	20th centuries	Urban	Total: 36		400%	12	Sacralization of L5 (total or partial)																		Meyer, 2013	
	Vertebral columns from the Anthropological Collection in the Department of Anatomy, Marekere College (Uganda)	ND	ND	♂: 179				Sacralization of L5 (total or partial)																		Allbrook, 1955	
				♀: 27																							
				Total: 206	Total: 200	22	11																				
	Human remains excavated in the Bahriyah Oasis (Egypt)	Greco-Roman period	ND		♂:							♂: 41				1	2,4									Hussien *et al.*, 2009	
					♀: 1	1	2,8					♀: -															
				Total: 77	Total: 36	2	2,9					Total: 41				1	2,4										
	Skeletons excavated from Giza and belong to the Old Kingdom (Egypt)	2686 a.C. - 2181 a. C	Elithe and Rural town	♂: 147		♂: 1	0,74	Sacralization of L5 (total or partial)				Total: 135				♂: 1	0,7	Lumbarization total or partial of S1								Sarry el din, 2006	
				♀: 125		♀: 3	2,3									♀: 1	0,7										
				Total: 272	135	Total: 4	2,96									Total: 2	1,5										
	Kelis II Cemendety, Dakhleh Oasis (Egyp)	332 BC-4th century	Urban	♂: 82	♂: 82	7	8,5																			Sarfo, 2014	
				♀: 119	♀: 119	10	8,4																				
				Total: 201	Total: 201	17	8,5																				
ASIA	Thai skeletons from the Bone Collection Unit, Department of Anatomy, Faculty of Medicine, Khon Kaen University (Thailand). **Documented Collection**	ND	ND	♂: 114	♂:	7	6,1	Sacralization of L5 (total or partial)																		Chaijaroonkhanarak *et al.*, 2006	Only cranial sacralization had been analyzed
				♀: 92	♀:	2	2,2																				
				Total: 206	Total:	9	4,4																				
	Human remains from the archaeological site of Jiangjialiang (China)	7000-3000 BP	Elithe and Rural town	Total: 66	Total: 66	4	6,1	Sacralization of L5 (total or partial)																		Hernández, 2009	
	Human remains from the archaeological site of Minhe X, Minhe M and LGS (China)	3000 BP		Total: 96	Total: 96	2	2,1																				
	Human remains from the archaeological site of MXY (China)	3000 BP		Total: 40	Total: 40	3	7,5																				

Continent	Collection or sample (Country)	Period	Lifestyle	Total individuals	Sacralization							Lumbarization							Dorsalization							References	Observations
					n	Cranial		Methodology	Caudal		Methodology	n	Cranial		Methodology	Caudal		Methodology	n	Cranial		Methodology	Caudal		Methodology		
						n	%		n	%			n	%		n	%			n	%		n	%			
ASIA	Chinese sacra from the Department of Anatomy, School of Basic Medical Sciences, Southern Medical University (China). **Documented collection**	20th century	Urban	Total: 208	♂: 129	12	9,3	Sacralization of L5 (total or partial)								6	4,6	Lumbarisation S1								Wu *et al.*, 2009	
					♀: 74	13	17,6									3	4										
					Total: 203	25	12,3									9	4,4										
	Dried human sacra collected from repositories of medical institutions across the central and western provinces of the Indian union (India). **Documented collections**	20th century	Urban	Total: 256	♂: 30	16	53,3	Castelvi (1984)																		Mahato, 2011	
					♀: 33	4	12,1																				
					Total 63	20	31,7																				
	Department of Anatomy and Forensic Medicine and Regional Medicolegal Institute of Bhopal and Raipur (India).	20th century	Urban	♂: 124	♂:	20	9,8	Castelvi (1984)	9	4,4	Sacralisation of coccygeal vertebra					♂: 6	2,9	Lumbarisation S1								Sharma, 2011	
				♀: 82	♀:	9	4,3		7	3,4						♀: 3	1,4										
				Total: 206	Total:	29	14,1		16	7,8						Total: 9	4,3										
	Human sacra from Department of Anatomy, Medical college Vadodara and Government Medical college Surat in Gujarat (India)	20th century	Urban	♂: 115	♂: 115	14	12,2	Sacralization of L5 (total or partial)										Lumbarisation S1								Dharati *et al.*, 2012	
				♀: 74	♀: 74	7	9,4																				
				Total: 189	Total: 189	21	11,1									3	1,3										
	Department of Anatomy, Medical college Vadodara and Government Medical college Surat in Gujarat (India)	20th century	Urban	♂: 115	♂: 115				26 19 45	22,6	Sacralization of coccygeal vertebra															Nagar, 2012	
				♀: 74	♀: 74					25,7																	
				Total: 189	Total: 189					23,8																	
	Sacral bones from the Department of Anatomy, ESIC Medical College & PGIMSR, Chennai (India). **Documented Collection**	20th century	Urban	Total: 50		3	6																			Krishnamurthy & Adibatti, 2016	Only cranial sacralization had been analyzed
	Sacra human bone from the Department of Anatomy and Department of Forensic Medicine, Velammal Medical College Hospital and Research Institute, Madurai (India)	21th century	Urban	♂: 41		7	17,1	Castelvi (1984)								1	1,4	Lumbarization total or parcial S1								Suman & Mahato, 2016	
				♀: 29		4	13,8																				
				Total: 70		11	15,7																				
	Harappa or Indus Valley (Pakistan)	2600 – 1900 BC.	Urban	Total: 84	Total: 19	1	5,26	Sacralization of L5 (total or partial)																		Lovell, 2014	

Continent	Collection or sample (Country)	Period	Lifestyle	Total individuals	Sacralization							Lumbarization							Dorsalization							References	Observations
					n	Cranial		Methodology	Caudal		Methodology	n	Cranial		Methodology	Caudal		Methodology	n	Cranial		Methodology	Caudal		Methodology		
						n	%		n	%			n	%		n	%			n	%		n	%			
ASIA	Skeleton remains recovered from the Pokrovskiy necropolise. Krasnoyarsk State Medical University (Russia)				♂: 61																						
					♀: 31																						
				Total: 327	Total: 213																						
	Skeleton remains recovered from the Voskressens-ko-Preobrajens-kiy necropolise. Krasnoyarsk State Medical University (Russia)				♂: 59																						
					♀: 38																						
		17^{th}-20^{th} centuries	Rural/ urban	Total: 182	Total: 101																					Dabernat *et al.*, 2013	
	Skeleton remains recovered from the Pokrovskiy and Voskresens-ko-Preo-brazhenskiy necropolises. Krasnoyarsk State Medical University (Russia)				♂: 120																						
					♀: 99																						
				Total: 509	Total: 224	3	1,3		3	1,3																	
	Ekven Eskimo collection, Re-search Institute and Museum of the Lomonosov Moscow State University, Mos-cow (Russia)	Old Bering Sea / Okvik culture	HG	♂: 30	♂: 23	0	0					♂: 24	4			2			♂: 30	0	0		0	0		Karapetian & Makarov, 2019	
				♀: 29	♀: 25	0	0	Craneal shift L5-S1				♀: 23	2		Caudal shift L5-S1	1		Presence of ribs at L1 level	♀: 29	0	0	Presence of ribs at C7 level	0	0	Reduction of 12th pair of ribs		
				Total: 59	Total: 48	0	0					Total: 61	6			3			Total: 61	0	0		0	0			
OCEANÍA	Australian Aborigenes from Trench A in Roonka II Flat Dune (Australia)	4000-220 BP	HG	Total: 92		1	1,1	Sacralization of L5 (total or partial)																		Pretty & Kricun, 1989	
	Archaeological survey in Tamuning Municipality, Agana, Guam (USA)	10^{th}-16^{th} centuries a.C.	HG	Total: 152	♂: 11	0	0	Sacralization of L5 (total or partial)				♂: 9				0	0	Lumbarization total or partial of S1								Douglas, 1997	
					♀: 7	0	0					♀: 4				0	0										
					Total: 18	0	0					Total: 13				0	0										

ND*: No Data

RESULTS

From the initial 126 individuals, those without spine (42 SP and 7 PT) were discarded, remaining 56 and 21 individuals, respectively (Table 4). Afterwards, individuals presenting all vertebrae elements and meeting the minimum preservation requirements proposed by the present work were analysed. Thus, 37 SP (37,7%) and 13 PT (46,4%) individuals were finally examined for SAs. 60,3% of the individuals were discarded due to preservation and taphonomical challenges. 37.8% of SP and 30.8% of PT populations presented *coccyx*; 57.1% (8/14) and 75% (3/4), respectively had it fused to the *sacrum* (Table 5). The rest of the analyses were performed with this last sample.

Table 4. Number of individuals according to vertebrae preservation. Results of Fisher Exact Test (FET) in SP and PT samples for sex, age, period, and region variables.

Samples	Initial sample	Individuals with spine	Methodology proposed	Complete column
PT	28	21 (75)	13 (46,4)	6 (21,4)
SP	98	56 (57,1)	37 (37,7)	20 (20,4)

Number of cases and prevalence: n (%).

Table 5. Coccix preserved.

Sample	Coccix	Coccix fused
PT	4/13 (30,8)	3/4 (75)
SP	14/37 (37,8)	8/14 (57,1)

Number of cases and prevalence: n (%).

Results in SP sample showed a prevalence of cranial sacralization (Fig. 4) of 10.8% (4/37), from which 7.9% were women (1/13) and 13.6% men (3/22), more frequent in individuals over 30 years old (15.8%, 3/9) with respect to those under 30 years old (7.9%, 1/13). Regarding chronological differences, 10% (1/10) of pre-contact individuals and 33.3% (3/9) with unknown values for such variable presented the variation, while no positive results were found for other periods. According to regional differences, 4.7% of individuals in IG (1/21), 25% in C (1/4) and 5.4% in NA (2/37) showed this type of sacralisation. Caudal sacralisation was observed in 18.9% (7/37) of the sample, 23.1% (3/13) women and 18.2% (4/22) men, with higher prevalence in older individuals (21%, 4/22) than in younger (7.9%, 1/13), together with two more cases (5.4%) of unknown age. In terms of chronology, 10% (1/10) of pre-contact individual, 50% (1/2) of peri-contact individuals, 25% (4/16) of post-contact individuals (post - out of SMLC: 16.7% -1/6- and post - in SMLC: 30% -3/10-) and 11.1% (1/9) NA presented caudal sacralisation. One case of cranial lumbarization was found in the sample (2.7%, 1/37) – individual C13, a young woman in SMLC from IG region – showing a typical last thoracic arc, as well as a superior articular process reflecting a lumbar conformation with no rib facets (Tables 6 and 7).

Table 6. Sacralization in PT and SP samples according to sex and age.

Sacralization		Sex			Age (years)			Σ
		F	M	ND	≤ 30	>30	ND	
PT	n	6	5	2	6	4	2	13
	Cranial	-	-	-	-	-	-	-
	Caudal	3 (60)	-	-	1 (16.7)	1 (25)	1 (50)	3 (23)
SP	n	13	22	2	13	19	5	37
	Cranial	1 (7,9)	3 (13,6)	-	1 (7,9)	3 (15,8)	-	4 (10,8)
	Caudal	3 (23,1)	4 (18,2)	-	1 (7,9)	4 (21)	2 (40)	7 (18,9)
NSV		**F**	**M**	**ND**	**≤ 30**	**>30**	**ND**	**Σ**
PT	n	6	5	2	6	5	2	13
	5	3 (50)	5 (100)	2 (100)	5 (83.3)	4 (80)	1 (50)	10 (77)
	6	3 (50)	-	-	1 (16.7)	1 (20)	1 (50)	3 (23)
SP	n	13	19	5	13	22	2	37
	5	9 (69,2)	13 (68,4)	3 (60)	8 (61,5)	15 (68,2)	2 (100)	25 (67,6)
	6	4 (30,8)	4 (21,1)	1 (20)	4 (30,8)	5 (22,7)	-	9 (24,3)
	7	-	2 (10,5)	1 (20)	1 (7,7)	2 (9,1)	-	3 (8,1)

Number of cases and prevalence: n (%).
ND: No Data.

Within the numerical variation of the sacrum, 67.6% (25/37) of the total sample showed 5 sacral vertebrae. The 24.3% (9/37) resulted in 6 sacral vertebrae and 8.1% (3/37) in 7 sacral vertebrae. Regarding the period, 70% of peri-contact individuals (7/10) have presented 5 sacral vertebrae, 20% (2/10) 6 sacral vertebrae and 10% (1/7) 7

Table 7. SAs in SP sample according to chronology and region.

	Period						Region				Σ
			Post-contact			ND	CB	IG (NIG + PM)	C (SGB + CUE)	ND	
Sacralization	**Pre-contact**	**Peri-contact**	**Out of SMLC**	**SMLC**	**Total**						
n	10	2	6	10	16	9	10	21	4	2	37
Cranial	1 (10)	-	-	-	-	3 (33,3)	-	1 (4,7)	1 (25)	2 (100)	4 (10,8)
Caudal	1 (10)	1 (50)	1 (16,7)	3 (30)	4 (25)	1 (11,1)	2 (20)	4 (19)	1 (25)	-	7 (18,9)
			Post-contact			**ND**	**CB**	**IG (NIG + PM)**	**C (SGB + CUE)**	**ND**	**Σ**
NSV	**Pre-contact**	**Peri-contact**	**Out of SMLC**	**SMLC**	**Total**						
n	10	2	6	10	16	9	10	21	4	2	37
5	7 (70)	-	5 (83,3)	5 (50)	10 (62,5)	8 (88,9)	7 (70)	13 (61,9)	3 (75)	2 (100)	25 (67,6)
6	2 (20)	1 (50)	1 (16,7)	4 (40)	5 (31,2)	1 (11,1)	2 (20)	7 (33,3)	-	-	9 (24,3)
7	1 (10)	1 (50)	-	1 (10)	1 (6,2)	-	1 (10)	1 (4,8)	1 (25)	-	3 (8,1)

Number of cases and prevalence: n (%).
ND: No Data.

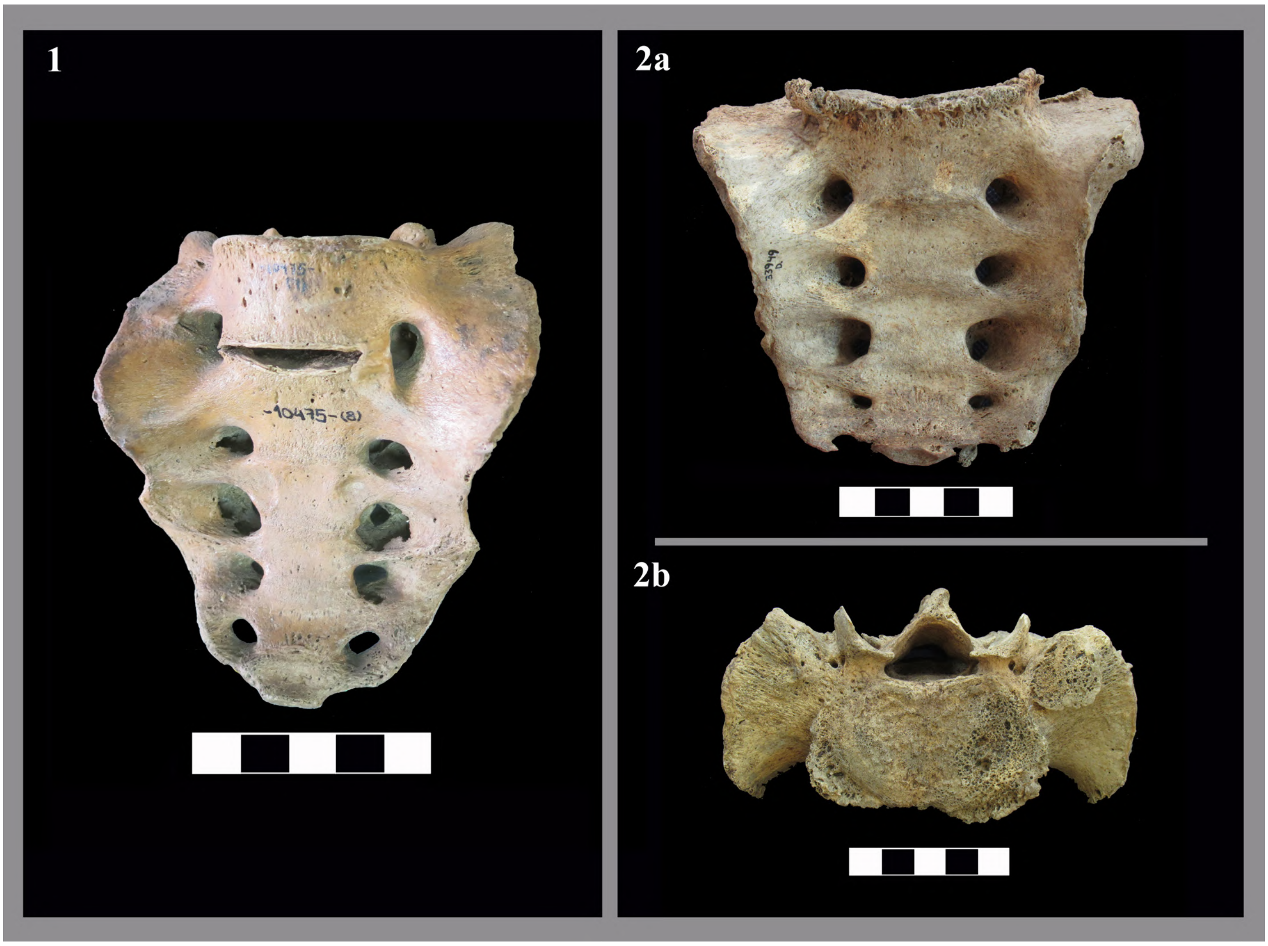

Fig. 4.- Two cases of cranial sacralization: **1**) Complete, individual 10.475/17952 from PT sample. **2 a-b**) Partial, individual 33.949 (*Punta Daniel*) from SP sample.

sacral vertebrae. In the peri-contact period, one case of two (50%) showed 6 sacral vertebrae and the other 7 sacral vertebrae. In post-contact remains, 83.3% (5/6) of out of SMLC exhibited 5 sacral vertebrae and 16.7% 6 sacral vertebrae, while 50% (5/10), 40% (4/10) and 10% (1/10) of post -in SMLC presented 5, 6 and 7 sacral vertebrae respectively. From the 9 individuals identified as NA for chronology, 88.9% (8/9) had 5 sacral vertebrae and 11.1% (1/9) 7 sacral vertebrae. Regarding the regional location, 70% of individuals from the Beagle Channel region (7/10) presented 5 sacral vertebrae, 20% (2/10) 6 sacral vertebrae and 10% (1/10) 7 sacral vertebrae. The IG region registered 61.9% (13/21) individuals with 5 sacral vertebrae, 33.3% (7/21) with 6 sacral vertebrae and 4.8% (1/21) with 7 sacral vertebrae. In the Continent region, 75% (3/4) had 5 sacral vertebrae and 25% (1/4) 7 sacral vertebrae. Two NA individuals were described for such factor, showing 5 sacral vertebrae each (Table 4). No significant differences were found between the levels of the different factors analysed when using Fisher's statistical test (Table 8).

Table 8. Results of Fisher Exact Test (FET) in SP and PT samples for sex, age, period, and region variables.

		p-value (FET)
Sacralization		
Sex	SP	1
	PT	1
Age	SP	1
	PT	1
Period		1
Region		0,4286
NSV*		
Sex	SP	0,5023
	PT	0,1818
Age	SP	0,8605
	PT	1
Period		0,24
Region		0,4553

*Number of Sacral Vertebrae

Results in the PT sample showed an incidence of caudal sacralisation of 23% of the sample (3/13), from which 50% were women (3/6) and no cases were observed in men, less frequent in subjects under 30 years old (16,7%, 1/6) than those over 30 years (25%, 1/4). No cases of cranial sacralization, thoracicalization or lumbarization were observed (Table 3). Regarding the variations in the number of sacral vertebrae, 77% of the total sample (10/13) presented 5 sacral vertebrae and 23% (3/13) showed 6 sacral vertebrae. No cases of sacrum with 4 or 7 vertebrae were observed in the PT sample (Table 3). However, in the sample presenting spine a high prevalence of individuals with 4 sacral vertebrae (9,5%, 2/21) was observed.

The bibliographic review accounted for 40 works reporting evidence on 53 samples, describing a total of 91 SAs distributes among the different types analysed in the present work (Table 3). Most of the studies were performed on American (28.3%), Asian (30.2%) and European (24.5%) samples, being Africa (13.2%) and Oceania (3.8%) the least studied. Cranial sacralization received most of the attention in these works (90%), followed by caudal lumbarization (45%), caudal sacralization (25%), cranial lumbarization (12.5%), caudal thoracicalization (12.5%), and cranial thoracicalization (2.5%), see Table 3. The prevalence of cranial sacralization, under 40% in all works examined, was analysed by means of continent and lifestyle (Figs. 5 and 6). Asian samples presented the highest prevalence, also showing the wider range of frequencies for this SAs, followed by the European, American, African, and Oceanian samples, whose prevalence was the lowest, close to zero. Twenty-one methodologies were described in those studies to describe the five SAs addressed in this work. Seven different methodologies have been used up to date to study cranial sacralization, four for caudal lumbarization, three for cranial lumbarization, three for caudal thoracicalization description, two for cranial lumbarization and two for caudal sacralization research (Table 9).

DISCUSSION

The present work registered information on SAs, considering cranial and caudal lumbarization and sacralization together with caudal thoracicalization. Spine elements are among the most damaged by taphonomic processes, explaining the severely

Table 9. SAs Bibliographic review. considering the type of SAs, methodologies used and the country from where the study was done.

		Continent					Lifestyle						
		Africa	**America**	**Asia**	**Europe**	**Oceania**	**AG**	**HG**	**MIX**	**NA**	**RU**	**UR**	**Methodologies (n)**
Sacralization	Cranial	7	10	13	10	2	3	5	5	9	5	15	7
	Caudal	0	7	3	2	0	2	1	1	2	1	5	2
Lumbarization	Cranial	0	6	1	0	0	2	1	0	1	1	2	3
	Caudal	3	7	5	4	1	2	3	1	5	2	7	4
Dorsalization	Cranial	0	2	1	0	0	0	0	0	1	0	2	2
	Caudal	0	6	1	0	0	2	1	0	1	1	2	3

n = number of studies. Lifestyle: AG (agriculture), HG (hunter-gatherer), MIX (urban and rural), NA (not available), RU (rural) and UR (urban).

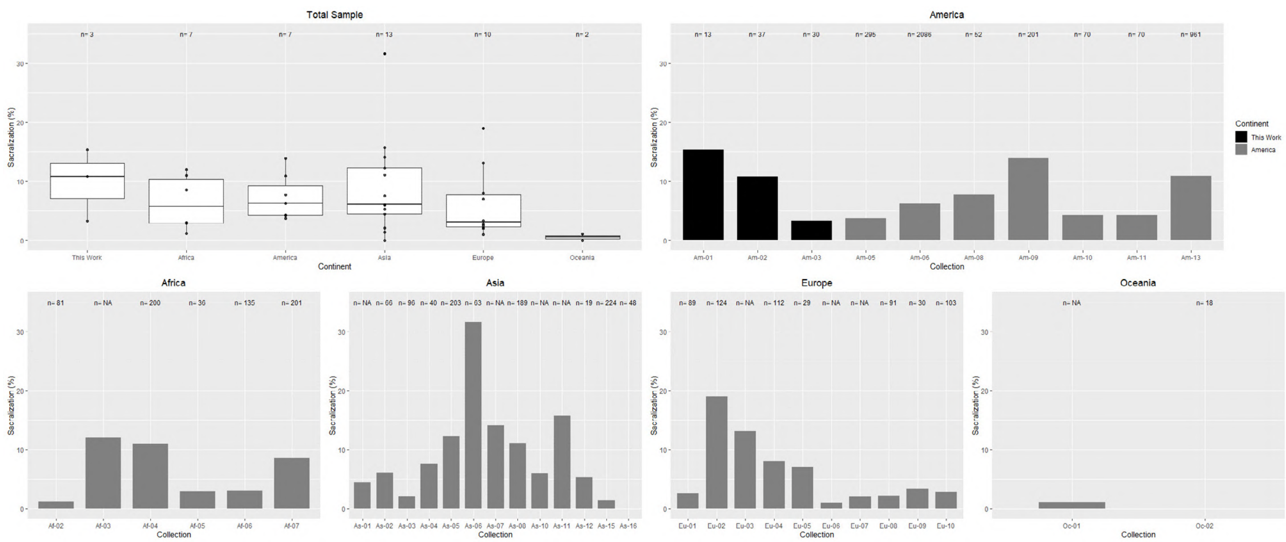

Fig. 5.- Sacralization prevalence worldwide (left and above), considering inter-continental variations (right above and below) for America (Am), Africa (Af), Asia (As) Europe (Eu) and Oceania (Oc); after conducting a bibliographic review (grey columns), including our sample (black columns). Check Table 3 for details about individuals (columns).

limited column regions showed in this work (Holland et al., 1996; Manifold, 2012). In addition, it should be considered that cervical vertebrae and coccyx are usually worse preserved than those located in other regions (Stodder, 2019; Vilas-Boas et al., 2019). Regarding to the coccyx, the results here reported agree with the data of low preservation found in other archaeological sites, as this segment of the column is also difficult to find well preserved in these contexts (Stodder, 2019). The fact that most of the coccyx described by the present study were fused to the sacrum suggests that this kind of fusion is better preserved than the coccyx alone, presumably due to its connection with another bigger bone. Besides, the most common border shifts are in the lumbosacral region, with a presence of 4%-36% in the global population (Barnes, 1994; Bulut et al., 2013; Delport et al., 2006; French et al., 2014; Jankauskas, 2001; Kimmerle, 2010; Konin and Walz, 2010; Nardo et al., 2012; Tang et al., 2014). Furthermore, cervicothoracic shifts show the lowest prevalence, under 3%, reaching 0% in some populations (Aly et al., 2016; Anap et al., 2013; Bost et al., 2011; Galis et al., 2006; Jankauskas, 2001). Such pattern could be related to high frequencies of cranial thoracicalization shifts – characterized by cervical ribs – found in stillbirths (Bots et al., 2011; ten Broek et al., 2012). All these factors make the approach proposed in this study adequate to address this challenge. The present study shows all the stages conducted to achieve the sample selection, allowing to estimate the loss of specimens due to the taphonomic and preservation effects. However, it is difficult to compare our results in this subject with other existing studies, since they do not usually register this variable. In future works, it would be highly advisable to start registering this topic, since it would allow addressing the current taphonomical and preservation bias when analysing the complete spine.

SAs performed in this work show that thoracicalization prevalence is null. Absence or low presence of these alterations coincides with data showed by other authors (Aly et al., 2016; Anap et al., 2013; Chengetanai et al., 2017) that presented values near 1% at the thoracolumbar border. However, higher prevalence closer to 6% has been reported (Kimmerle, 2010). Although slight, an incidence of cranial lumbarization has been described in the current study, between the values of 1.9% and 5% indicated in the analysis of other samples (Jankauskas, 2001; Kimmerle, 2010). No cases of caudal lumbarization are described, which is not surprising, since previous studies have reported values between 0% and 11.4% (Shore, 1930; Masniková and Benus, 2003; Weiss, 2009; Kimmerle, 2010; Karapetian and Makarov, 2019). Sacralizations are the main studied SAs, especially cranial cases (Kimmerle, 2010), with prevalence that varies from 0% to 40% (Jankauskas, 2001; Delport et al., 2006; Kimmerle, 2010; Konin and Walz, 2010; Sharma et al., 2011; Nagar et al., 2012; Nardo et al. 2012; Bulut et al., 2013; Dabernat et al., 2013; French et al., 2014; Tang et al., 2014). The results of the Argentine samples studied oscillate between 3.3% and 18.8%, staying within the range set in previous works. The prevalence of cranial sacralization presented in our samples ranged from 0% to 23%, according to previous works.

SP sample has the particularity that it is possible to study differences between periods and regions as indicated above. Pre-contact individuals present lower values of vertebral alterations than post-contact, and especially those found in SMLC. It is known that these individuals suffered great changes in their lifestyle and were exposed to diseases and situations never lived before (García-Moro et al., 1997; Casali, 2011). These changes are in line with the increase in pathologies, both in number of cases and in different typologies, observed in previous studies (Guichón et al., 2006; García Laborde et al., 2010; Moreno Estefanell et al. 2018; D'Angelo del Campo et al., 2017, 2021). Regarding the region, it seems that this factor has less influence in SAs than chronology.

Numerical variability of the sacrum observed in the present work is comprised within the global ranges of variation previously reported (Table 10, Fig. 6). Thus, the most common number of vertebrae is 5 (60%-86% of the cases), then 6 (4%-28%) and, finally, the least common (0%-4%) is the sacrum with 4 and 7 vertebrae (Shore, 1930; Tulsi, 1972; Jankauskas, 2001; Tancock 2014; Singh, 2015). Infranumerary variations are less common than supranumerary variations (Barnes, 1994), as has been observed in the results of this work. However, there are also studies in which higher percentages of 4SV have been found, close to 7% (Singh, 2015). No cases of infranumerary variations have been found in the initial sample analysed.

The bibliographic review here presented describes different patterns of prevalence for cranial sacralization. Regarding the origin of the studied samples, it would be especially useful to deepen in the study of African and Oceanian populations in order to provide more data to be compared with other populations. That would enormously contribute to the knowledge of spine SAs patterns among populations. Besides, the number of different methodologies applied to determine the different type of variations varies depending on the variation addressed. Thus, cranial sacralization is the topic with more methodologies proposed. On the one hand, it is logic that the most studied variation has more variety of methods for assessing it. On the other hand, it is surprising that almost for every five works there is a new methodology proposed. This fact complicates the discussion of the results obtained by the different works. The high number of methodologies used to study the rest of

Table 10. Numerical variability of the sacrum in different samples around the world.

Continent	Collection	Period	n	SV				Reference
				S4	S5	S6	S7	
Africa	Bantu population. Housed at Raymond A. Dart. Collection, Witwatersrand University (South Africa).	ND	81	0	81 (79)	17 (21.0)	0	Shore, 1930
America	Yukon River, Alaska (USA)	ND	179	2 (1.1)	126 (70.4)	50 (27.9)	1 (0.1)	Stewart, 1932
	Pukará de Tilcara	1000 - 1520 A.D.	♀: 6	0	3(50)	3(50)	0	This work
			♂: 5	0	5 (100)	0	0	
			ND: 2	0	2 (100)	0	0	
			Total: 13	0	10 (77)	3 (23)	0	
	Southern Patagonia	5200 BP - 20th cent.	♀: 15	0	10 (66.7)	4 (26.7)	1 (6.7)	
			♂: 29	0	20 (69)	7 (24.1)	1 (4)	
			Total: 48	0	34 (70.8)	11 (22.9)	3 (6.3)	
Europe	Archaeological remains from Lituania (Lituania)	1000-2000 A.D.	633	7 (1.1)	378 (59.8)	225 (35.5)	23 (3.7)	Jankauskas, 2001
	Populations from Rural and Urban Northeast England (England)	18th-19th cent.	130	2 (1.5)	122 (93.8)	6 (4.6)	0	Tancock, 2014
Oceanía	Australian Aborigens. South Australian Museum and Department of Anatomy, University of Adelaide (Australia)	ND	♀: 48	0	46 (95.8)	2 (4.2)	0	Tulsi, 1972
			♂: 63	1 (1.6)	50 (79)	12 (19)	0	
			Total: 125	1 (0.9)	96 (86.5)	14(12.6)	0	

Number of cases and prevalence: n (%).
ND: No Data.

variations described in the present work face the same challenge. Final considerations regarding previous studies on SAs: First, most authors focus their attention on the study of cranial sacralization, which has been reported to present a prevalence under 40% (Table 3). This may be because many of the studies are done exclusively with the sacrum (Henneberg and Henneberg, 1999; Sharma et al., 2011; French et al., 2014; Singh et al., 2015). Besides, unlike the rest of the alterations, there are specific methodologies for its study and comparison (Castellvi et al., 1984). These facts

Fig. 6.- Numerical variability of the *sacrum*. **1**) 4 SV, individual 12589 from PT sample. **2**) 5 SV, individual 17844 from PT sample. **3**) 6 SV, individual 796 from SP sample. **4**) 7 SV, individual E 10-11 (1) from SP sample.

may cause the authors to prefer to focus their studies on the sacrum.

Extrinsic factor, environment

Environment influence on development becomes of greater importance, instead of the consideration of genetics by itself. For example, it has been observed that when pregnant women are exposed to several environmental conditions in their early stages of gestation, the proper development of the spine of the embryo may result challenging (Sparrow et al., 2012). It has been also shown that some environmental factors like cold or high-altitude environments can cause lasting changes over generations at the physiological and genetic level (Bigham, 2016; Leonard, 2018).

Results of SP sample showed the highest values in the percentage of 7 sacral vertebrae (8.1%) when comparing to other works (Table 5). With respect to sacral numerical variation, similar prevalence was observed between Inuit and SP populations. Existing similarities between both populations have been previously described regarding skull (Lahr et al., 1995; Hernández et al., 1997; Lalueza et al., 1997b), nasal cavity (Noback et al., 2011) long bones (Pearson and Millones, 2005) and rib morphology (García-Martínez et al., 2018), spine pathologies prevalence like spondylolysis (D'Angelo del Campo et al., 2017), sacrum pathologies (D'Angelo del Campo et al., 2021), oral pathologies (Pérez-Pérez and Lalueza Fox, 1992), metabolism, height, stature, body proportions and robustness (Hernández et al., 1997; Pearson and Millones, 2005; Pérez and Monteiro, 2009; Leonard, 2018). However, these populations showed clear differences in DNA analysis (Chiaroni et al., 2009; de Saint-Pierre et al., 2012; Marangoni et al., 2014; de la Fuente et al., 2015). For these reasons, some authors propose that the environment, especially when influenced by cold, could play an important role in the morphological and physiological variation observed, thus resulting in phenotypical plasticity or environmental and climate changes (Hernández et al., 1997; Lalueza et al., 1997b; Pérez et al., 2007, 2011; Pérez and Monteiro, 2009). Regarding SAs occurring in Inuit and SP populations, it is important to note that, while Inuit show high values of caudal lumbarization and low values of cranial sacralization (Karapetian and Makarov, 2019), SP do not show cases of caudal lumbarization but present high prevalence of cranial sacralization. Thus, both samples show high variation in lumbosacral region, however depicting a different shift pattern: cranial-directed in SP and caudal-directed in Inuit. Such observed differences could be also related to a "*possible impact of environmental factors on the pattern of cranio-caudal shifts*" among human populations, as has been already stated by Karapetian and Makarov (2019: 195).

Sacral variation numbers from the PT sample were within the global range. However, if the number of sacral vertebrae in the individuals in the sample presenting spine is considered, the prevalence of individuals exhibiting a sacrum with 4 vertebrae (9.5%) is relevant, since it is the highest observed up to date. The PT sample is considered to come from a high-altitude settlement, highlands regions which are characterized by numerous environmental challenges as cold climate, powerful solar radiation, limited nutritional availability and low oxygen conditions, i.e., hypoxia. The latter is one of the many stressors for human populations, because the partial pressure of oxygen in the atmosphere decreases proportionally with increasing altitude, thereby limiting the passage of gas molecules from the atmosphere to the tissues and the respiratory, cardiovascular, and haematological systems (Beall, 2007; Weinstein, 2007; Frisancho, 2013). Native highlanders are characterized by slow growth and small adult body size, delayed sexual and physical maturation, expanded chest dimensions and functional adaptation to hypoxia conditions – increased lung volume and lung diffusion capacity, along with more efficient transport and diffusion of oxygen to the tissues, among others (Frisancho, 1993, 2013; Beall, 2007; Leonard, 2018). Besides, chest expansion implies clear modifications in thoracic skeletal morphology, sternal and clavicular proportions and rib areas and curvatures (Weinstein, 2007). Furthermore, chronic hypoxia has a critical role on embryonic development orchestrating cellular differentiation and organogenesis (Moore et al., 2011). On one hand, experiments with mice have shown that gestational hypoxia can induce congenital malformations of the spine, an experience that has turned out to be like clinical situations in humans (Ingalls and Curley, 1975; Hou et al., 2018). On the other hand, hypoxia would trigger the alteration of the expression of certain genes involved in somatogenesis, resulting in an example of a congenital defect mediated by the interaction of genetic and environmental factors. (Giampietro et al., 2012; Sparrow et al., 2012). Therefore, it is plausible to think that under hypoxic conditions any type of SA could be expressed at the level of the spine. However, knowledge on this topic is still scarce. The variations observed in this work at sacral level could be a first hint on this matter.

It is difficult to know to what extent environmental, genetic, and epigenetic factors influence the human vertebral alterations in this work due to their multi-etiological nature (Sarfo, 2014). However, the SAs examined in prepuna and SP suggest that the environmental factor plays an important role in their expression. This phenotypic variability observed in response to cold and high-altitude conditions can be explained by microevolutionary responses, since it is possible that genotypic plasticity has limitations when it comes to explaining these phenotypes adapted to extreme conditions. Nevertheless, further studies are recommended to better understand the environmental effect on the expression of phenotypic plasticity among humans.

CONCLUSION

This work describes the variability in the prevalence of five segmentation anomalies located in the spine between two Argentine archaeological populations, Southern Patagonia and Pukará de Tilcara. The most frequent SA was cranial sacralization while no caudal thoracicalization or cranial lumbarization cases were reported. The SP sample presented the highest prevalence for all identified SAs, being the only one to outline caudal lumbarization. Furthermore, this sample showed the highest prevalence of cranial sacralization among different American samples.

Similarities between the SP sample and Inuit populations have been previously reported, proposing environmental factors as modulators of phenotypic expression in humans. In this work, we describe similar patterns in the prevalence of lumbosacral SAs between both populations but with different directions. Although environmental factors such as cold climate could be involved in the expression of similar morphological and physiological characteristics, the different directionality of the shift could be triggered by the effect of other factors, not yet unaddressed, which encourage us to continue with this approach. In PT another environmental factor, hypoxia, could be involved in the variations observed in sacral bones.

Due to a scarce methodological standardization in this field, it is challenging to make any comparison or generation of knowledge about it. In addition, the optimal preservation conditions to carry out this type of study, which include the complete spine, are scarce in past population samples. That is why this paper proposes a new methodology to analyse SAs in archaeological samples. It is easy to replicate and build on previous studies, as well as on insights from the review conducted here, with the aim of establishing a starting point to increase our knowledge about SAs and their aetiology.

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