

Pelvic morphology and body size in relation to the preauricular sulcus: Evidence from medieval to modern Iberia

Rebeca García-González¹  | Julia Muñoz-Guarinos¹ | Nico Cirotto¹ |
Sonia Díaz-Navarro^{1,2} | Laura Rodríguez^{1,3}  | José Miguel Carretero^{1,4} 

¹Laboratorio de Evolución Humana. Universidad de Burgos. Edificio I+D+i/CIBA, Burgos, Spain

²Research Centre for Anthropology and Health: CIAS, Coimbra, Portugal

³Departamento de Biodiversidad y Gestión Ambiental, Universidad de León. Facultad de Ciencias Biológicas y Ambientales, León, Spain

⁴Unidad Asociada UBU al CSIC Vidrio y Materiales del Patrimonio Cultural (VIMPAC), Burgos, Spain

Correspondence

Rebeca García-González, Laboratorio de Evolución Humana. Universidad de Burgos. Edificio I+D+i/CIBA, Plaza Misael Bañuelos s/n, 09001 Burgos, Spain. Email: mrgarcia@ubu.es

Funding information

Ministerio de Ciencia, Innovación y Universidades, Grant/Award Number: PID2021-122355NB-C31 PID-2024-156477NB-C33; Junta de Castilla y León and Fondo Europeo de Desarrollo Regional, Grant/Award Number: JCYL BU010P24

Abstract

The preauricular sulcus has long been debated as a pelvic feature variably attributed to obstetric stress, ligamentous traction, and broader biomechanical processes. To clarify its determinants, we analyzed 409 adult individuals from three archeological and one early modern skeletal collection from the Iberian Peninsula, integrating graded sulcus expression with pelvic morphology, body size, and demographic context. Sulcus expression shows marked sexual dimorphism: females exhibit the full morphological spectrum, whereas males display limited variation and are overwhelmingly concentrated in the lowest grades. Hierarchical log-linear models and ordinal logistic regression analyses indicate that preauricular sulcus presence is not associated with stature, body mass, or overall pelvic canal dimensions. Instead, inferior pelvic dimensions, particularly pubic length and outlet measures, emerge as the only consistent morphological predictors, with significant sex-specific interactions restricted to the outlet. Neither population affiliation nor age at death modifies the association between sex and sulcus expression. Taken together, these results support a model in which the preauricular sulcus reflects sex-specific biomechanical environments of the inferior pelvis rather than overall body size or population-level variation. Within this framework, sulcus development is best interpreted as ligament-mediated remodeling shaped by localized mechanical loading and hormonally mediated changes associated with pregnancy, while remaining robust across diverse biocultural contexts and mortality regimes.

KEYWORDS

childbirth, ligament remodeling, pelvic biomechanics, preauricular sulcus

This is an open access article under the terms of the [Creative Commons Attribution-NonCommercial-NoDerivs](https://creativecommons.org/licenses/by-nc-nd/4.0/) License, which permits use and distribution in any medium, provided the original work is properly cited, the use is non-commercial and no modifications or adaptations are made.

© 2026 The Author(s). *The Anatomical Record* published by Wiley Periodicals LLC on behalf of American Association for Anatomy.

1 | INTRODUCTION

Parturition scars are pelvic osseous features traditionally attributed to pregnancy and childbirth (Angel, 1969; Stewart, 1970; Houghton, 1974, 1975; Ullrich, 1975; Putschar, 1976; Arsuaga & Carretero, 1994; McFadden & Oxenham, 2018; Igarashi et al., 2020; Lorkiewicz et al., 2020). They have been linked to soft-tissue stress, ligamentous traction, and pelvic floor loading during late pregnancy and labor (Galloway, 1995; Hirschberg et al., 1998; Ritchie, 2003). However, their obstetric specificity has been repeatedly questioned (Holt, 1978; Ubelaker & De La Paz, 2012; Waltenberger et al., 2022). Their occurrence in males, nulliparous females, and adolescents (McFadden & Oxenham, 2018) along their association with body size and pelvic shape (Waltenberger et al., 2021), shows that childbirth alone cannot account for their formation. This broader etiology has led some authors to advocate replacing the term “parturition scars” with the more neutral term “pelvic features” (Pany-Kucera et al., 2019).

Although often grouped under a single functional label, these traits differ markedly in anatomical location and underlying biomechanical pathways. Features located near the sacroiliac joint (the preauricular sulcus, the *margo auricularis groove*, and the sacral preauricular extension) are structurally and developmentally distinct from those near the pubic symphysis (ventral pubic lesions, dorsal pitting, and the extended pubic tubercle). This heterogeneity suggests multiple etiologies, rather than a unified “obstetric” response.

Evidence from well-documented modern samples further challenges classic obstetric interpretation. Waltenberger et al. (2022) showed that pelvic features exhibit weak or nonsignificant associations with individual parity, whereas age, body mass, stature, and pelvic morphology account for a substantial portion of their variability. Only dorsal pubic pitting correlated significantly with the number of live births, whereas the preauricular sulcus showed no association with parity but did correlate with biometric and structural skeletal variables. These findings indicate that pelvic features are multifactorial traits, and that a strictly obstetric interpretation is both insufficient and potentially misleading.

In archaeological contexts, the preauricular sulcus is often the most accessible of these traits because the ilium is more frequently preserved than the pubic bones. Located along the inferior margin of the auricular surface (Houghton, 1975; Schemmer et al., 1995), it ranges from a slight impression recorded in both sexes to a deep, elongated channel traditionally associated with female parity (Houghton, 1974). Igarashi et al. (2020) also demonstrated that the sulcus does not represent a single

morphological state; rather, graded scoring captures meaningful anatomical and functional variation, distinguishing mild ligamentous impressions from deeply developed grooves likely shaped by greater mechanical or obstetric loading. This variation, driven by differences in biomechanical loading and ligamentous interaction with the auricular surface (Houghton, 1974, 1975; Igarashi et al., 2020), reinforces the need to treat the sulcus as a continuous trait and to employ refined grading schemes when assessing its biological significance.

Despite the extensive debate surrounding pelvic features, few studies have jointly examined sulcus expression, body size, and pelvic morphology, and as far as we know, none have compared multiple archaeological populations with distinct biocultural backgrounds. This gap limits our understanding of whether the determinants identified in modern samples also shape sulcus formation in pre-industrial contexts characterized by different activity patterns, nutritional regimes, and biomechanical demands.

In this study, we investigate the presence and graded expression of the preauricular sulcus across three archaeological and one modern large osteological samples from the Iberian Peninsula, integrating detailed osteometric measurements of body size, the coxal and pelvic canal with both binary and ordinal sulcus classifications. Based on previous literature and biomechanical models, this study tests the following hypotheses: (1) the expression of the preauricular sulcus is sexually dimorphic and remains stable across populations and age groups; (2) sulcus presence is associated with overall body size (stature or body mass); and (3) sulcus expression is preferentially associated with aspects of pelvic morphology. By explicitly testing these hypotheses, we aim to clarify the biomechanical and biological determinants underlying preauricular sulcus formation in past human populations.

2 | MATERIALS AND METHODS

2.1 | Samples

The study analyzes 409 adult individuals (160 females, 249 males) from four Iberian osteological collections dating from the Middle Ages and Early Modern period (Table 1). Except for the Lisbon series, curated at the National Museum of Natural History (Lisbon), all remains are housed at the Laboratorio de Evolución Humana (University of Burgos).

La Magdalena sample (Grañón, La Rioja, northern Spain) comprises 110 individuals recovered from inhumation graves of the Late Medieval (11th–13th) Christian cemetery, mostly simple earth-cut graves, over half

TABLE 1 Distribution of the total sample by collection, sex, and age group for each population.

Age group	La Magdalena			San amaro			San Pablo			Lisbon			All populations		
	Female	Male	Total	Female	Male	Total	Female	Male	Total	Female	Male	Total	Female	Male	Total
	[15-20)	1	—	1	9	17	26	7	11	18	2	5	7	19	33
[20-25)	—	—	—	8	9	17	1	3	4	1	1	2	10	13	23
[25-30)	5	4	9	4	5	9	—	—	—	25	12	37	34	21	55
[30-35)	2	1	3	1	10	11	8	6	14	5	3	8	16	20	36
[35-40)	5	2	7	2	12	14	3	—	3	4	12	16	14	26	40
[40-45)	5	7	12	1	11	12	3	6	9	3	9	12	12	33	45
[45-50)	—	—	—	1	8	9	10	12	22	—	2	2	11	22	33
[50-55)	—	1	1	1	12	13	4	13	17	1	10	11	6	36	42
[55-60)	1	—	1	1	10	11	2	2	4	0	1	1	4	13	17
[60-65)	—	1	1	—	5	5	5	3	8	1	—	1	6	9	15
[65-70)	—	—	—	—	2	2	1	2	3	—	—	—	1	4	5
≥70	1	—	1	4	8	12	16	10	26	6	1	7	27	19	46
Fertile	13	7	20	24	53	77	19	20	39	37	33	70	93	113	206
Mature	6	8	14	4	41	45	19	33	52	4	22	26	33	104	137
Senescent	1	1	2	4	15	19	22	15	37	7	1	8	34	32	66
Total	20	16	36	32	109	141	60	68	128	48	56	104	160	249	409

covered with stone slabs. The sample comprises individuals of both sexes (24 females, 30 males, and 18 of unknown sex) and all ages (41 non-adults and 56 adults). Age could be estimated for 97 of them, revealing high mortality among non-adults (42.27%), particularly in individuals aged 1–4 years (16.5%) and 5–9 years (14.4%). This pattern indicates a natural population with high infant mortality, which decreases after the age of 10 (Acsádi & Nemeskéri, 1970; Ledermann, 1969), and a life expectancy at birth of 26 years.

The San Amaro collection derives from the medieval cemetery surrounding the hermitage of San Amaro in Burgos (Spain), adjacent to the Hospital del Rey. Dated to the 13th–16th centuries, it reflects the long-term use of this burial area associated with the pilgrimage infrastructure. San Amaro displays a mortality pattern that is clearly anomalous compared with preindustrial natural populations (Acsádi & Nemeskéri, 1970; Ledermann, 1969). This is due to the predominance of non-adults, especially adolescents, and a marked underrepresentation of females. Early childhood (0–4 years) is virtually absent, while deaths are disproportionately concentrated in the 10–19 age range, particularly among individuals aged 10–14, who reach unusually high frequencies. This overrepresentation of adolescents, together with the very low presence of infants and the elderly, indicates that the assemblage does not represent a random cross-section of the living population but rather a selective sample.

The Convent of San Pablo holds burials from the 13th–19th centuries in three areas: the Cloister, Church, and Chapter House. The most ancient burials, dating from the 13th century, are situated at the foundation base of the church and within the surveys conducted in the cloister corridors. During the Late Middle Ages burials began to take place inside the church and the cloister, where a vast accumulation of inhumations was found. These burial areas continued to be used until the 18th century (García-González et al., 2024). The age structure of the Cloister reflects a “natural” community-wide mortality pattern, with a very high contribution of infant and juvenile deaths and no marked sex bias. In contrast, the profile of the Church suggests that this area was used for a distinctly selected group dominated by adults. It was likely reserved for special burials (possibly affluent families) and largely excluded infants. This aspect is reflected in the marked contrast in life expectancy at birth between the two areas: 20 years in the cloister and 36.5 in the church. When the two assemblages are considered together, the demographic profile of San Pablo corresponds to a stable living population consistent with pre-Jennerian mortality models (Acsádi & Nemeskéri, 1970; Ledermann, 1969). This composite sample has been extensively studied, overall, in terms of growth and

development. The findings show that some individuals experienced delayed skeletal development, likely linked to malnutrition and illness (García-González et al., 2019; Salazar-Fernández et al., 2025), as well as postponed onset of menarche in some females (Muñoz-Guarinos et al., 2020). Nonetheless, no clear signs of disrupted modeling processes have been reported for the occipital bone or femur (Lozano-Bendicho et al., 2025; Muñoz-Guarinos, García-González, et al., 2025; Muñoz-Guarinos, Rodríguez, Carretero, del Nogal Sánchez, et al., 2025; Muñoz-Guarinos, Rodríguez, Carretero, & García-González, 2025). The pattern of medullary contraction in the femur suggests the most fertile ages around 25 years (Muñoz-Guarinos, Rodríguez, Carretero, del Nogal Sánchez, et al., 2025).

The Lisbon individuals, part of the Luís Lopes Collection, were primarily recovered from early modern urban cemeteries dated to the 19th–20th centuries and also show evidence of delayed growth and development (Cardoso, 2007; Conceição & Cardoso, 2011).

The diversity of these four assemblages provides a uniquely robust framework for evaluating the expression of the preauricular sulcus across different biocultural and demographic contexts. La Magdalena represents a relatively normative mortality sample from a rural medieval community, offering a baseline for sulcus expression under community-wide demographic conditions. San Amaro, by contrast, constitutes a highly selective assemblage, allowing us to explore how non-standard mortality structures and possible activity or health-related stressors influence pelvic features. The Convent of San Pablo provides a large, diachronic sample with both natural and socially selected burial sectors, enabling analyses of sex-specific, status-related, and developmental variation within a single population. Finally, Lisbon individuals offer a documented early modern urban sample with known patterns of delayed growth, providing a comparative reference for evaluating the impact of growth impairment and secular changes on sulcus formation. Together, these collections allow us to investigate whether preauricular sulcus expression reflects consistent biomechanical and morphological determinants across populations, or whether it varies according to local demographic regimes, health profiles, and life-history conditions.

2.2 | Sex and age at death

With the exception of the Lisbon sample, sex was estimated based on osteological features of the pelvis, and where possible, the cranium and mandible (Buikstra & Ubelaker, 1994; Phenice, 1969).

Dental age estimation methods were not employed because developmental methods are not applicable once dental maturation is complete, which is the case for the vast majority of individuals analyzed in this study. Wear-based methods were also avoided, as dental wear reflects not only age but is strongly influenced by diet, cultural practices, and other extrinsic factors. Therefore, age was estimated using Transition Analysis 3 (Ousley et al., 2020). Although TA3 permits scoring traits across the entire skeleton, we focused on the 19 variables of the ilium and pubic bones, as this region provides the highest age-estimation accuracy. Following Ousley et al. (2020), we assessed 10 variables from the innominate, sacroiliac joint, and acetabulum; 4 from the auricular surface; and 5 from the pubic symphysis. Bilateral traits were scored on both sides, yielding up to 38 observations per individual.

Initially, age categories were organized in 5-year intervals, following the standard practice in paleodemographic studies (Buikstra & Ubelaker, 1994; Hoppa & Vaupel, 2002). However, this classification yield very few individuals in some of the sex and age groups. Therefore, these intervals were reclassified into broader categories to facilitate statistical comparison and interpretability. These groups were based on three broader life stages based on biological and demographic criteria: (1) the fertile stage (15–40 years), corresponding to the active reproductive period; (2) the non-fertile or mature stage (40–60 years), which encompasses the perimenopausal and early post-reproductive years; and (3) the senescent stage (>60 years), representing the aging phase of life (Table 1). This classification reflects well-established biological

distinctions in human reproductive potential and is commonly employed in anthropological and demographic studies (Bocquet-Appel, 2008; Chamberlain, 2006).

2.3 | Parturition scars

We first assessed the presence or absence of preauricular sulcus. The degree of development of preauricular sulcus (PAS) was then evaluated following Igarashi's five-type system. Both ilia were examined macroscopically and classified using Types 1–3 correspond to non-obstetric variants—ranging from smooth surfaces to shallow or ligament-related depressions common in both sexes—while Types 4 and 5 represent true PPS (Figure 1). Type 4 is characterized by an enclosed depression whose contour does not parallel the auricular margin, reflecting remodeling linked to pregnancy or parturition. Type 5 denotes more advanced scarring, with nested depressions indicating repeated ligamentous deformation and remodeling. All observations were performed independently by two trained observers (J.M.G. and N.C.) to ensure consistency and minimize inter-observer variation.

2.4 | Association of parturition scars with sex and population

We first evaluated whether the occurrence of the preauricular sulcus varies by sex and population. For each population, independence tests (χ^2 or Fisher's exact test,

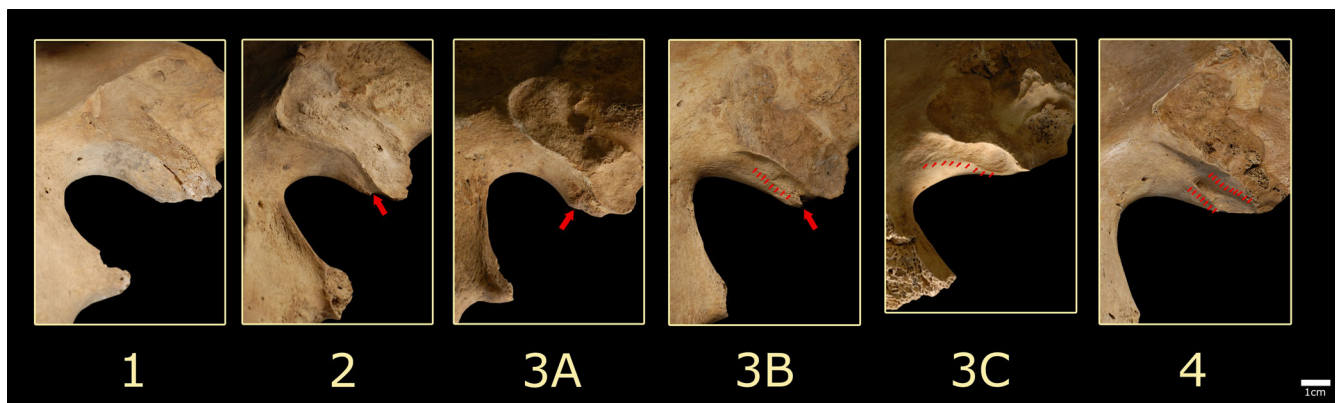


FIGURE 1 Pregnancy and parturition-related changes in the preauricular area of the ilium, classified according to Igarashi et al. (2020). Representative examples of the preauricular groove types defined by Igarashi et al. (2020), based on macroscopic morphology. Type 1: No observable bony change. Type 2: No visible surface modification, but shallow, palpable depressions may be detected. Type 3A (pseudo-depression): A shallow depression delimited by a surrounding bony ridge. Type 3B (open true depression): A true depression whose base lies below the surrounding bone surface, but with an incompletely closed contour. This subtype may occasionally be accompanied by a small bony spine. Type 3C (parallel closed true depression): A true depression with a completely closed contour that runs parallel to the ventral margin of the auricular surface. Despite being a true depression, its parallel orientation distinguishes it from pregnancy parturition scars *sensu stricto*. Type 4: True depression with a completely closed contour that does not run parallel to the ventral margin of the auricular surface; the contour is often irregular and may appear as a groove or as a coalescence of pits.

depending on expected cell frequencies) were applied to assess the association between sulcus presence and sex.

To examine the joint effects of sex, age group, population, and sulcus occurrence, we fitted hierarchical log-linear (HLL) models, which allow the simultaneous evaluation of associations among multiple categorical variables. Analyses began with the saturated model (Sex \times Population \times Age \times Sulcus) and proceeded by step-wise removal of higher-order interactions. Nested models were compared using likelihood-ratio (ΔG^2) tests; interactions were retained only when their removal substantially reduced model fit.

2.5 | Association of parturition scars with body size and pelvic morphology

We then assessed whether preauricular sulcus expression is associated with body size (stature, body mass) and pelvic morphology, and whether these relationships differ by sex or population.

Because complete pelvises are seldom preserved in archaeological contexts, pelvic morphology was quantified using both whole-pelvis dimensions and coxal measurements, maximizing sample coverage while maintaining anatomical relevance.

Coxal variables captured key aspects of pelvic architecture related to sexual dimorphism and obstetric function, including iliac breadth, iliac height, and coxal height (overall pelvic form); anteroposterior inlet diameter and pubic length (inlet and midplane capacity); ischial length and ischiopubic diameter (outlet geometry) (Arsuaga & Carretero, 1994; Betti, 2014) (Figure 2, Table 2).

Whole-pelvis variables provided a complementary assessment of canal geometry. Bi-iliac and bi-acetabular breadths primarily reflect general pelvic breadth and body form (Ruff, 1995), while inlet, midplane, and outlet diameters describe canal morphology across the three obstetric planes (Rosenberg, 1992; Tague, 2000) (Figure 3, Table 2).

Stature and body mass were estimated using Ruff et al. (2012) regression equations, based on femoral length and proximal femoral head diameters (Table 2). Femoral and coxal measurements were recorded with calipers, curved-branch compasses, and an osteometric board. When bilateral values were available, right and left measurements were averaged.

Whole-pelvis variables were obtained through manual or virtual reconstructions, depending on preservation. Physically preserved pelvises were articulated by aligning the auricular surfaces and pubic symphysis, a procedure shown to produce negligible error in pelvic linear dimensions (Bonneau et al., 2012).

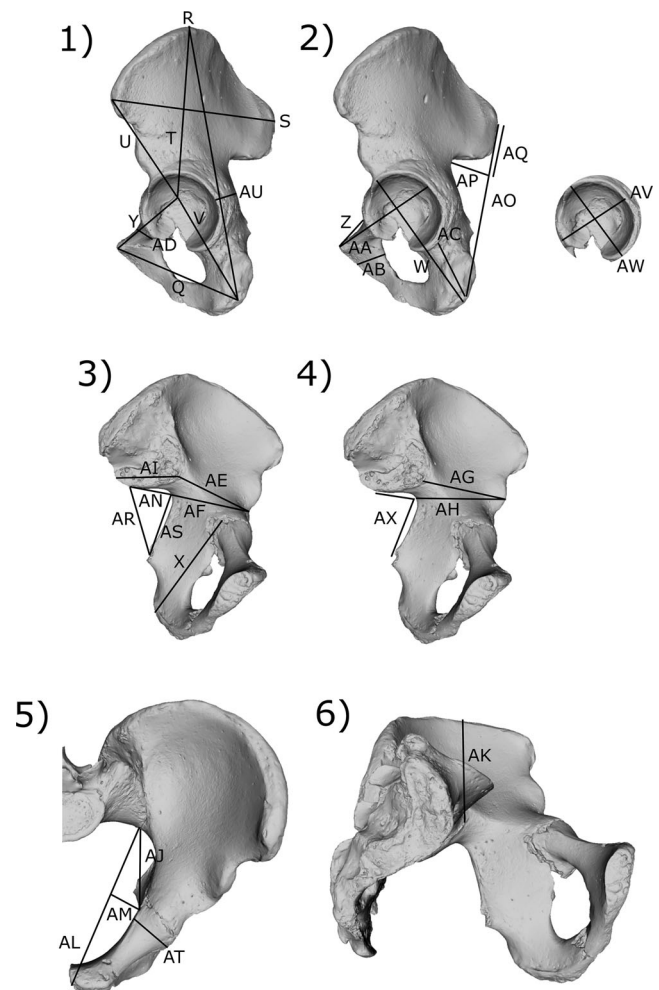


FIGURE 2 Coxal measurements included in the analysis: Ischio-pubic diameter (IPD), coxal height (CH), iliac breadth (IB), iliac height (IH), ischial length (IL), true pelvis height (TPH), and pubic length (PL).

Specimens missing one *os coxa* or other components were digitized with an Artec Spider scanner and virtually reassembled in Slicer 5.6.2 using four reproducible sacroiliac fiducials (Kikinis et al., 2013; Torres-Tamayo et al., 2024) (Figure S1). Fifteen pelvises were measured both physically and virtually; paired-samples tests indicated no systematic differences, confirming equivalence between reconstruction methods (Table S1). All reconstructions were performed by the same observer (J.M.G.).

To test whether body size and pelvic morphology predict sulcus occurrence, we fitted logistic regression models with sulcus presence as the dependent variable. Sex was included as a fixed factor in all models, and each osteometric variable entered as a continuous predictor. To avoid the artifacts associated with ratio indices, variables commonly used to construct ratios (e.g., pubic length and coxal height) were included simultaneously rather than as derived indices.

TABLE 2 Descriptions of measurements^a used in this study.

Type	Measurement	Abbreviation	Description
Pelvic	Bi-iliac breadth	BIB	Maximum distance across the right and left iliac blades
	Bi-acetabular breadth	BAB	Distance between the acetabular points
	Subpubic angle	SA	Angle between the inferior pubic rami.
	Inlet anteriorposterior	IAP	Sacral promontory to dorsomedial superior pubis
	Inlet transverse	IT	Maximum distance between right and left iliopectineal lines
	Inlet oblique	IO	The oblique distance across the pelvic inlet measured from the ilioauricular point to the dorsal surface of the superior pubic symphysis
	Midplane anteriorposterior	MAP	From junction of fourth and fifth sacral vertebrae to dorsomedial inferior pubis
	Midplane transverse	MT	Between ischial spines
	Midplane anterior length	MAL	Ischial spine to dorsomedial inferior pubis
	Midplane posterior length	MPL	S4–S5 junction to ischial spine
	Outlet anterior–posterior	OAP	Apex of fifth sacral vertebrae to dorsomedial inferior pubis
	Outlet transverse	OT	Distance between inner margins of transverse ridge of ischial tuberosities
	Outlet anterior length	OAL	Transverse ridge of ischial tuberosity to dorsomedial inferior pubis
Outlet posterior length	OPL	Apex of S5 to transverse ridge of ischial tuberosity	
<i>Os coxae</i>	Ischio-pubic diameter	IPD	Linear distance between the ischium and the pubis along the superior ischiopubic ramus
	Coxal height	CH	Maximum distance between the most distal point on the ischial tuberosity and the most proximal point on the iliac crest
	Iliac breadth	IB	Maximum breadth of the iliac blade, measured between the most distant points of ASIS–PSIS
	Iliac height	IH	Distance between the most proximal point on the iliac crest and the acetabular point
	Ischial length	IL	Distance between the acetabular point and the most distant point on the ischial tuberosity
	True pelvis height	TPH	Greatest caudal perpendicular to the linea terminalis
	Pubic length	PL	Distance between the acetabular point and the most medial point of the superior pubic symphysis, following the direction of the ascending pubic ramus
<i>Femur</i>	Vertical head diameter	VHD	The greatest vertical distance across the femoral head, taken between the most superior and most inferior points of the articular surface
	Femoral length	FL	Maximum length measured from proximal head to distal condyles

Abbreviations: ASIS, anterior superior iliac spine; GNS, greater sciatic notch; PSIS, posterior superior iliac spine.

^aMeasurement definitions are from Tague (1989), Buikstra and Ubelaker (1994), Kurki (2007, 2013a, 2013b); Arsuaga and Carretero (1994); Arsuaga (1985) and Genovés (1959).

We first examined whether associations between morphology and sulcus expression varied by sex or population using Sex \times measurement and Population \times measurement interactions. Only when these interactions did not improve model fit did we test morphological interactions among measurements (e.g., pubic length \times coxal height) to evaluate shape-related effects. Model selection relied on Akaike Information Criterion (AIC) which provided a complementary measure penalizing model

complexity, allowing us to determine whether a more complex model justified its additional parameters. Only terms whose inclusion led to a clear improvement in model fit by reducing AIC were retained. This approach ensured that final models remained parsimonious, avoiding overfitting while capturing the structure supported by the data.

Before fitting logistic models, we assessed whether body size and pelvic measurements differed by sex and

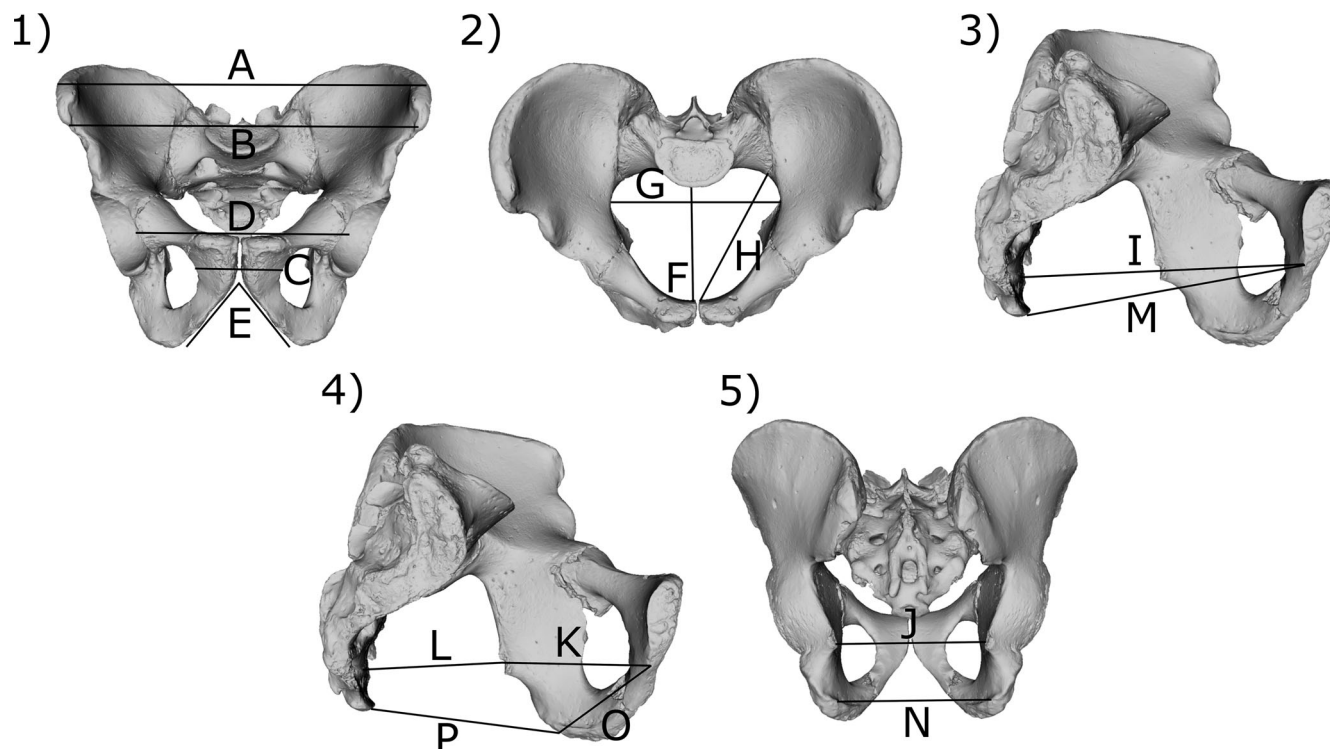


FIGURE 3 Pelvic measurements included in the analysis: bi-iliac breadth (BIB), bi-acetabular breadth (BAB), subpubic angle (SA), inlet anteroposterior (IAP), transverse (IT) and oblique (IO) diameters; midplane anteroposterior (MAP) and transverse (MT) diameters, midplane anterior (MAL) and posterior (MPL) lengths; and outlet anteroposterior (OAP) and transverse (OT) diameters, as well as outlet anterior (OAL) and posterior (OPL) lengths.

population. When sample sizes permitted, we used two-factor ANOVAs; in smaller samples, *t*-tests or graphical inspection were employed. These comparisons characterized the structure of variation in the predictors, ensuring appropriate interpretation of subsequent logistic models.

Following current recommendations, *p*-values are interpreted as graded levels of evidence, avoiding dichotomous “significance” thresholds and enabling a more nuanced evaluation of group differences (Courtenay, 2024).

All analyses were conducted in PAST 4 software and R (v.4.x; MASS::loglm).

3 | RESULTS

3.1 | Association of parturition scars with sex and population

The analysis of sex-related differences for the preauricular sulcus is summarized in Table 3.

Overall, χ^2 and Fisher's exact tests revealed clear sexual dimorphism in the expression of these traits, although the magnitude and statistical significance of the differences varied among populations and age groups. The preauricular sulcus consistently occurred more frequently in females

than in males across all samples, particularly in the fertile and mature groups, whereas differences tended to diminish among senescent individuals.

To evaluate whether these interpopulation and age-related variations altered the overall sex effect, a hierarchical log-linear (HLL) analysis was performed (Table 4). The HLL models showed that none of the higher-order interactions involving sex, population, or age were significant, indicating that the association between sex and sulcus expression is stable across all contexts. The only significant term was the two-way interaction Sex \times Sulcus ($\Delta G^2 = 11.47$, $p = 0.001$), confirming that the preauricular sulcus is consistently more frequent in females, independently of population or age. Taken together, the bivariate and multivariate analyses indicate that the preauricular sulcus represents a robust sexually dimorphic feature of the pelvis.

Although the magnitude of sex differences fluctuates across populations and age groups, the direction of the pattern remains consistent: females display a higher frequency of sulcus expression than males in all contexts examined. These findings suggest that, while local or age-related factors may influence the degree of expression, the underlying sexual dimorphism in this trait is stable and pervasive across human groups.

TABLE 3 Results of X²/Fisher's exact tests for the presence of the preauricular sulcus.

Age group	La Magdalena		San amaro		San Pablo		Lisbon	
	Female	Male	Female	Male	Female	Male	Female	Male
Fertile	84.6% (11/13)	14.3% (1/7)	91.7% (22/24)	43.4%	52.6% 10/19	10% 2/20	51.3% 19/37	12.1% 4/33
Mature	50%	62.5%	100%	46.3%	52.6% 10/19	21.2% 7/33	75% 3/4	22.7% 5/22
Senescent	100%	100%	100%	40%	36.4% 8/22	20% 3/15	85.7% 6/7	0% 0/1
All groups	75.0% (15/20)	43.8% (7/16)	93.7% (30/32)	44.4% (48/108)	46.7% (28/60)	17.6% (12/68)	58.3% (28/48)	17.9% (10/56)
					X²/OR	X²/OR	X²/OR	X²/OR
					15.85	8.31	5.41	11.42
					p < 0.00	p < 0.00	p = 0.02	p = 0.00
					0.60	5.41	9.12*	9.12*
					p = 1.00	p = 0.02	p = 0.07	p = 0.07
					1.0	2.29*	7.00*	7.00*
					p = 1.00	p = 0.47	p = 0.20	p = 0.20
					78.95	11.18	16.56	16.56
					p < 0.00	p < 0.00	p < 0.00	p < 0.00

Note: Asterisk indicates that the *p*-value was calculated using Fisher's exact test. Abbreviation: OR, odds ratio.

Regarding the preauricular sulcus grades, across the four populations, females display a broader distribution of preauricular sulcus grades than males (Figure 4). In contrast, males show a highly skewed pattern dominated almost exclusively by Grade 2. Grade 3A and 3B occur at low frequencies in some male samples, and Grades 3C and 4 are absent in all males. Among females, San Amaro exhibits the highest frequencies of Grades 3A and 3B, while La Magdalena and Lisbon show a more balanced distribution across grades. San Pablo presents intermediate values for all categories. In males, San Amaro again stands out because of the extremely high number of Grade 2 sulci compared with the other populations. Overall, Figure 4, reveals marked sex differences in sulcus expression, with females showing greater morphological variability and higher-grade expressions, whereas males are overwhelmingly concentrated in the lowest grade. It also highlights substantial population-level contrasts, particularly the distinctive dominance of Grade 2 in San Amaro. Neither the chi-square test for females (*p* = 0.7068) nor the Fisher's exact test (*p* = 0.1829) for males indicated significant population-level differences in preauricular sulcus grades.

3.2 | Association of parturition scars with stature, weight and pelvic/coxae dimensions

Tables 5–7 summarize stature, weight, and coxal and pelvic dimensions by population and sex. As is common in archaeological assemblages, preservation variability reduced the number of individuals available for osteometric measurements compared with those assessed for parturition scars. Stature and weight could be estimated for most individuals, whereas coxal and pelvic measurements were more limited. In La Magdalena, only three coxae preserved the necessary landmarks, and the population was excluded from coxal analyses. Whole-pelvis measurements were available only for San Pablo and San Amaro.

Across the coxal variables, population-related differences were most evident in iliac and pubic dimensions, whereas sex differences were more widespread and affected nearly all coxal variables, particularly those reflecting vertical pelvic height and iliac–ischial configuration (Table S2). Evidence for population × sex interaction was limited to a small subset of variables (coxal height, true pelvis height, and pubic length), indicating that for most traits, population and sex exert largely independent effects. In the few variables with interaction effects, the magnitude of sex differences varied modestly among populations.

TABLE 4 Results of hierarchical log-linear (HLL) model comparisons for the presence of the preauricular sulcus.

Comparison	Interaction tested	ΔG^2	Δdf	<i>p</i>
Model with vs. without four-way interaction	Sex*population*age group*Sulcus	9.06	6	0.17
Model with vs. without three-way interaction	Sex*population*Sulcus	4.36	3	0.23
	Sex*age group*Sulcus	1.18	2	0.55
Model with vs. without two-way interaction	Sex*sulcus	11.47	1	0.001
	Population*sulcus	0.91	1	0.34
	Age group*sulcus	0.00	0	1.00

Note: ΔG^2 = increase likelihood ratio. Δdf = increase degrees of freedom.

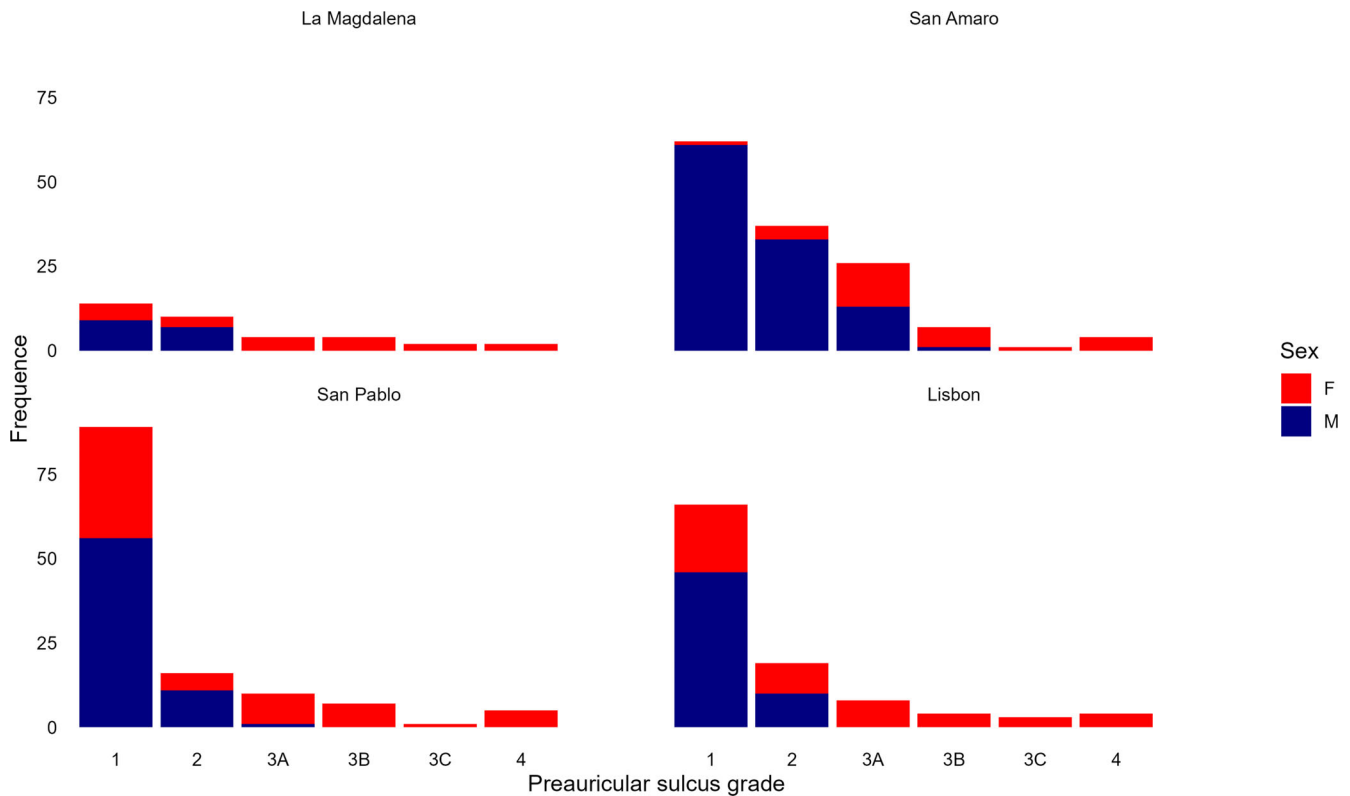


FIGURE 4 Frequencies of preauricular sulcus expression grades by sex across the analyzed collections.

For the whole-pelvis, population effects were strongest in the midplane and outlet (bi-acetabular breadth, inlet oblique diameter, midplane transverse and posterior lengths, and outlet transverse diameter), whereas inlet transverse diameter, bi-iliac breadth, and outlet posterior length showed only weak evidence for differences (Table S3). Sex differences were more pervasive, with strong evidence across inlet, midplane, and outlet diameters, and only weak evidence in bi-iliac breadth. The population \times sex interaction displayed little to no evidence across all variables, indicating that sex-related variation in pelvic canal dimensions does not meaningfully differ among populations.

Both stature and body weight showed very strong evidence of variation by population and by sex, but the

population \times sex interaction provided no indication of differing patterns across groups. (Table S4).

Taken together with the HLL findings, which identified sex*sulcus as the only robust association and showed that neither population nor age modulated this relationship, these results indicate that sex is the primary structuring variable for sulcus expression, and the population-level morphological variation does not meaningfully alter this association. On this basis, logistic regression analyses focused on testing whether body size or pelvic morphology, alone or in interaction with sex, predicted sulcus presence, without including higher-order interactions unsupported by preliminary analyses.

When *os coxae* variables are considered in additive logistic models, sex consistently showed strong evidence

TABLE 5 Statistics of stature and weight for population and sex.

Population	Sex	Stature (cm)		Weight (kg)	
		N	Mean ± SD	N	Mean ± SD
La Magdalena	Female	9	153.60 ± 3.06	9	52.09 ± 3.76
	Male	8	162.87 ± 6.01	8	61.09 ± 9.64
	Total	17	158.13 ± 6.45	17	56.32 ± 8.27
San Amaro	Female	18	153.75 ± 6.83	16	57.22 ± 7.38
	Male	69	165.10 ± 6.63	72	68.24 ± 7.12
	Total	87	162.75 ± 8.08	88	66.24 ± 8.31
San Pablo	Female	39	153.57 ± 5.68	38	56.75 ± 5.73
	Male	52	162.16 ± 7.43	52	65.31 ± 8.55
	Total	91	158.58 ± 8.67	90	61.69 ± 8.58
Lisbon	Female	13	153.29 ± 4.80	13	50.63 ± 3.35
	Male	24	163.12 ± 3.79	24	62.93 ± 5.25
	Total	37	159.30 ± 6.44	37	58.29 ± 7.54
Total	Female	79	153.61 ± 5.51	76	55.25 ± 6.09
	Male	153	163.58 ± 6.71	156	66.00 ± 7.87
	Total	232	160.19 ± 7.90	232	62.48 ± 8.90

TABLE 6 Summary statistics of *os coxae* measurements by population and sex.

Variable	Sex	San Amaro	San Pablo	Lisbon	Total
Isquio-pubic diameter	F	111.50 ± 6.67 (11)	116.11 ± 7.25 (13)	114.27 ± 3.69 (11)	114.00 ± 5.79 (32)
	M	115.31 ± 6.65 (31)	123.0 ± 8.53 (8)	116.48 ± 7.35 (23)	116.65 ± 7.61 (65)
	T	114.31 ± 6.79 (42)	118.74 ± 8.29 (21)	115.76 ± 6.42 (34)	115.78 ± 7.14 (97)
Coxal height	F	188.07 ± 7.51 (14)	199.57 ± 8.92 (30)	191.25 ± 10.44 (12)	194.91 ± 10.18 (56)
	M	200.67 ± 15.54 (31)	212.95 ± 11.14 (44)	209.04 ± 8.59 (23)	208.15 ± 13.23 (98)
	T	196.75 ± 14.70 (45)	207.53 ± 12.19 (74)	202.94 ± 12.51 (35)	203.33 ± 13.75 (154)
Iliac breadth	F	149.32 ± 8.39 (13)	152.48 ± 13.30 (27)	144.25 ± 8.58 (12)	149.79 ± 11.56 (52)
	M	158.96 ± 10.10 (30)	154.34 ± 12.92 (32)	149.68 ± 9.11 (22)	154.77 ± 11.50 (84)
	T	156.04 ± 10.52 (43)	153.49 ± 13.02 (59)	147.76 ± 9.18 (34)	152.87 ± 11.74 (136)
Iliac height	F	114.00 ± 9.93 (14)	119.33 ± 13.12 (31)	121.51 ± 6.12 (11)	118.43 ± 11.46 (56)
	M	124.77 ± 8.88 (31)	130.49 ± 7.94 (42)	126.31 ± 6.91 (23)	127.64 ± 8.36 (96)
	T	121.42 ± 10.41 (45)	125.75 ± 11.77 (73)	124.76 ± 6.96 (34)	124.25 ± 10.57 (152)
Ischial length	F	77.47 ± 5.00 (14)	80.11 ± 10.38 (32)	80.57 ± 3.70 (11)	79.55 ± 8.32 (57)
	M	87.10 ± 5.67 (31)	85.28 ± 8.05 (48)	87.78 ± 4.73 (23)	86.40 ± 6.76 (102)
	T	84.10 ± 7.04 (45)	83.21 ± 9.34 (80)	85.45 ± 5.55 (34)	83.94 ± 8.04 (159)
True pelvis	F	81.81 ± 10.57 (14)	87.85 ± 12.37 (16)	87.33 ± 2.73 (11)	84.60 ± 9.71 (38)
	M	96.80 ± 8.34 (31)	101.14 ± 6.83 (9)	94.69 ± 5.07 (23)	96.76 ± 7.22 (66)
	T	92.14 ± 11.39 (45)	92.64 ± 12.39 (25)	92.31 ± 5.62 (34)	92.31 ± 10.07 (104)
Pubic length	F	88.63 ± 5.40 (12)	82.07 ± 6.88 (16)	77.30 ± 5.06 (11)	83.04 ± 7.23 (36)
	M	88.40 ± 7.41 (31)	85.02 ± 6.27 (9)	70.68 ± 4.78 (22)	81.50 ± 10.30 (65)
	T	88.46 ± 6.85 (43)	83.14 ± 6.69 (25)	72.88 ± 5.75 (33)	82.05 ± 9.31 (101)

of association with sulcus expression, with males exhibiting lower odds across all variables (Table 8). Coxal height and pubic length displayed the clearest effects, the former

reducing and the latter increasing the likelihood of sulcus presence. True pelvis height, ischial length, and isquio-pubic diameter showed only weak negative associations,

TABLE 7 Summary statistics of pelvic measurements by population and sex.

Variable	Sex	San Amaro	San Pablo	Total
Bi-iliac breadth	F	259.54 ± 13.84 (13)	255.72 ± 2.90 (20)	257.22 ± 13.25 (33)
	M	263.05 ± 15.38 (32)	257.93 ± 14.43 (14)	261.50 ± 15.13 (46)
	T	262.04 ± 14.88 (45)	256.63 ± 13.43 (34)	259.71 ± 14.44 (79)
Bi-acetabular breadth	F	136.86 ± 10.76 (13)	145.22 ± 11.85 (21)	142.03 ± 12.01 (34)
	M	134.85 ± 1.45 (32)	139.41 ± 14.51 (15)	136.30 ± 10.70 (47)
	T	135.43 ± 8.92 (45)	142.8 ± 13.15 (36)	138.71 ± 11.53 (81)
Subpubic angle	F	79.33 ± 16.52 (11)	77.76 ± 24.33 (7)	78.72 ± 19.24 (18)
	M	71.36 ± 9.74 (32)	55.5–63.0 (2)	70.65 ± 9.91 (34)
	T	73.40 ± 12.14 (43)	73.64 ± 22.67 (9)	73.44 ± 14.21 (52)
Inlet antero-posterior	F	105.45 ± 3.73 (11)	102.70 ± 12.41 (7)	104.38 ± 12.09 (18)
	M	98.64 ± 9.82 (32)	89.05–110.6 (2)	98.71 ± 9.88 (34)
	T	100.38 ± 10.80 (43)	102.06 ± 12.09 (9)	100.67 ± 10.92 (52)
Inlet transverse	F	127.67 ± 6.87 (13)	131.33 ± 10.12 (21)	129.93 ± 9.08 (34)
	M	122.75 ± 9.12 (32)	123.56 ± 8.65 (15)	123.01 ± 8.89 (47)
	T	124.17 ± 8.75 (45)	128.09 ± 10.18 (36)	125.92 ± 9.55 (81)
Inlet oblique	F	5–117.89 ± 6.34 (11)	121.54 ± 8.02 (12)	119.79 ± 7.35 (23)
	M	112.95 ± 7.36 (32)	119.98 ± 12.62 (6)	114.06 ± 8.58 (38)
	T	114.22 ± 7.37 (43)	121.02 ± 9.44 (18)	116.22 ± 8.55 (61)
Midplane Antero-posterior	F	122.37 ± 8.58 (11)	120.22 ± 10.34 (5)	122.35 ± 8.77 (15)
	M	115.33 ± 9.66 (30)	124.2 (1)	115.50 ± 9.50 (32)
Midplane transverse	T	117.22 ± 9.80 (41)	120.88 ± 9.39 (6)	117.69 ± 9.73 (47)
	F	101.52 ± 11.35 (13)	117.04 ± 11.61 (16)	110.09 ± 13.75 (29)
	M	95.48 ± 9.28 (32)	99.72 ± 9.22 (10)	96.49 ± 9.33 (42)
Midplane anterior length	T	97.23 ± 10.17 (45)	110.38 ± 13.61 (26)	102.04 ± 13.11 (71)
	F	89.50 ± 3.94 (11)	90.36 ± 8.41 (7)	89.83 ± 5.85 (18)
	M	89.41 ± 6.63 (32)	88.88–95.19 (2)	89.57 ± 6.50 (34)
Midplane posterior length	T	89.44 ± 6.01 (43)	90.73 ± 7.48 (9)	89.66 ± 6.23 (52)
	F	69.82 ± 8.54 (13)	71.64 ± 9.10 (11)	71.71 ± 8.52 (21)
	M	61.17 ± 8.40 (30)	65.96 ± 5.51 (8)	62.26 ± 7.89 (41)
Outlet anterior–posterior	T	63.79 ± 9.25 (43)	69.25 ± 8.13 (19)	65.46 ± 9.22 (62)
	F	120.09 ± 7.64 (11)	106.35 ± 10.08 (4)	116.56 ± 10.52 (14)
	M	114.13 ± 9.72 (28)	114.6 (1)	114.17 ± 9.38 (30)
Outlet transverse	T	115.81 ± 9.48 (39)	107.99 ± 9.48 (5)	114.93 ± 9.70 (44)
	F	99.73 ± 11.73 (13)	110.88 ± 15.81 (20)	106.49 ± 15.19 (33)
	M	88.57 ± 10.40 (32)	97.14 ± 14.83 (14)	91.18 ± 12.41 (46)
Outlet anterior length	T	91.79 ± 11.82 (45)	105.22 ± 16.66 (34)	97.57 ± 15.53 (79)
	F	77.91 ± 5.84 (11)	73.58 ± 7.08 (5)	76.56 ± 6.35 (16)
	M	75.01 ± 5.52 (32)	77.97–82.52 (2)	75.32 ± 5.52 (34)
Outlet posterior length	T	75.75 ± 5.68 (43)	75.48 ± 6.76 (7)	75.72 ± 5.76 (50)
	F	92.72 ± 7.99 (13)	86.95 ± 7.63 (12)	91.95 ± 7.90 (20)
	M	84.37 ± 10.77 (28)	80.88 ± 4.89 (5)	83.59 ± 9.47 (38)
	T	87.01 ± 10.63 (41)	85.17 ± 7.35 (17)	86.47 ± 9.75 (58)

TABLE 8 Model comparisons testing the effects of sex, coxal variable, and their interaction on the presence of preauricular sulcus.

Variable (X)	Model	AIC	<i>p</i> (sex)	<i>p</i> (X)	<i>p</i> (sex*X)
Ischio-pubic diameter	Interaction	127.93	0.761	0.317	0.870
	Additive	125.96	0.008	0.103	—
Coxal height	Interaction	187.09	0.319	0.036	0.4197
	Additive	185.75	0.001	0.009	—
Iliac breadth	Interaction	171.74	0.040	0.280	0.08
	Additive	173.24	0.000	0.700	—
Iliac height	Interaction	198.02	0.271	0.366	0.428
	Additive	196.67	0.000	0.582	—
Ischial length	Interaction	198.07	0.691	0.212	0.940
	Additive	196.07	0.000	0.092	—
True pelvis height	Interaction	152.04	0.198	0.096	0.256
	Additive	151.55	0.045	0.090	—
Pubic length	Interaction	128.88	0.491	0.485	0.678
	Additive	127.06	0.003	0.045	—

TABLE 9 Akaike Information Criterion (AIC)-based comparison of models including sex and paired pelvic dimensions forming standard pelvic indices.

Variables	Model	N	AIC	<i>p</i> (sex)	<i>p</i> (X ₁)	<i>p</i> (X ₂)	<i>p</i> (sex*X ₁)	<i>p</i> (sex*X ₂)	<i>p</i> (X ₁ *X ₂)
Pubic length (X ₁)	Full	94	108.24	0.213	0.286	0.802	0.784	0.166	0.391
Coxal height (X ₂)	Reduced interaction	95	107.10	0.313	0.080	0.006	0.444	0.201	—
	Additive model	96	104.04	0.481	0.006	0.0003	—	—	—
Pubic length (X ₁)	Full	94	122.17	0.399	0.106	0.215	0.256	0.936	0.138
Ischial length (X ₂)	Reduced interaction	95	122.82	0.999	0.223	0.152	0.656	0.723	—
	Additive model	97	119.05	0.517	0.005	0.010	—	—	—
Iliac breadth (X ₁)	Full	129	165.46	0.015	0.494	0.531	0.076	0.273	0.371
Iliac height (X ₂)	Reduced interaction	130	164.07	0.018	0.337	0.168	0.103	0.339	—
	Additive model	132	165.87	0.0002	0.510	0.184	—	—	—

and iliac breadth had virtually no effect. Interaction terms with sex did not improve model fit, except for a marginal Sex × iliac breadth interaction that should be interpreted cautiously.

Analyses of combined variables yielded similar patterns (Table 9). Models including anatomically related pairs did not outperform additive formulations, and index-like interaction terms offered no explanatory gain. The predictors driving sulcus variation were the same identified in univariable analyses: pubic length, ischial length, and coxal height, indicating that pelvic morphology influences sulcus expression through independent linear effects rather than through proportional relationships or sex-specific slopes. Overall, the results highlight the primacy of the inferior pelvis in shaping sulcus expression, with iliac morphology contributing little.

Analyses of the inlet dimensions showed limited predictive power for the presence of a sulcus (Table 10).

Neither anteroposterior, transverse, nor oblique inlet measurements exhibited significant effects in the interaction models, and additive models indicated that only sex reached significance in some cases. Overall, inlet morphology did not show meaningful associations with sulcus formation.

Similarly, most midplane dimensions (anteroposterior, transverse, anterior, and posterior) showed no interaction effects and only weak or nonsignificant associations with sulcus presence. In several additive models, sex was a significant predictor, but midplane measurements themselves contributed minimally (Table 10).

In contrast, the outlet was the only pelvic region in which significant sex × measurement interactions were detected. Both the anteroposterior and transverse outlet diameters showed significant interactions, indicating that the relationship between outlet size and sulcus presence differs between males and females. These interactions

suggest sex-specific associations, whereby increases in outlet dimensions have different implications for sulcus formation depending on sex. This pattern aligns with the functional relevance of the outlet as the narrowest segment of the birth canal and the one most directly involved in the final stages of fetal descent. Even subtle sex-related differences in outlet geometry or mechanical loading may therefore reflect distinct biomechanical pathways leading to sulcus development (Table 10).

Taken together, inlet and midplane dimensions exhibit weak and sex-independent associations with sulcus formation, whereas the outlet stands out as the only pelvic region where sexual dimorphism modifies the morphology–sulcus relationship.

The interaction model including stature, body mass, and sex provided no evidence that stature, body mass, or their sex-specific effects were associated with sulcus occurrence (Table 11). Model fit was poor, and interaction terms did not improve performance.

A reduced model excluding interactions confirmed these results: sex remained the only predictor with strong evidence, whereas stature and body mass showed no indication of association with sulcus expression. The reduced model fitted better, further demonstrating that anthropometric dimensions do not contribute to explaining sulcus presence.

Overall, these models demonstrate that body size does not influence the occurrence of the preauricular sulcus, and that the pronounced sexual dimorphism observed in this trait is not mediated by variation in stature or body mass.

4 | DISCUSSION

The preauricular sulcus has long been debated as a feature variably attributed to obstetric stress (Arsuaga & Carretero, 1994; Houghton, 1974, 1975; Igarashi et al., 2020;

Variable (X)	Model	AIC	<i>p</i> (sex)	<i>p</i> (X)	<i>p</i> (sex*X)
Bi-iliac breadth	Interaction	97.90	0.496	0.486	0.421
	Additive	96.55	0.008	0.732	—
Bi-acetabular Breadth	Interaction	94.11	0.0382	0.363	0.051
	Additive	97.27	0.005	0.127	—
Inlet AP	Interaction	74.51	0.198	0.199	0.142
	Additive	74.83	0.0792	0.693	—
Inlet transverse	Interaction	100.87	0.373	0.391	0.466
	Additive	99.41	0.009	0.529	—
Inlet Oblique	Interaction	81.80	0.677	0.631	0.574
	Additive	80.12	0.0182	0.768	—
Midplane AP	Interaction	63.50	0.393	0.460	0.294
	Additive	62.60	0.009	0.215	—
Midplane transverse	Interaction	84.46	0.063	0.065	0.102
	Additive	85.93	0.004	0.089	—
Midplane anterior	Interaction	76.95	0.937	0.936	0.973
	Additive	74.95	0.086	0.848	—
Midplane Posterior	Interaction	75.35	0.530	0.560	0.864
	Additive	73.38	0.000	0.093	—
Outlet AP	Interaction	48.95	0.037	0.056	0.029
	Additive	56.40	0.005	0.485	—
Outlet transverse	Interaction	90.23	0.013	0.016	0.024
	Additive	94.73	0.002	0.105	—
Outlet anterior	Interaction	67.48	0.089	0.068	0.069
	Additive	69.70	0.035	0.546	—
Outlet posterior	Interaction	67.36	0.650	0.458	0.470
	Additive	65.92	0.001	0.843	—

TABLE 10 Model comparisons testing the effects of sex, pelvic variable, and their interaction on the presence of preauricular sulcus.

TABLE 11 Logistic regression models assessing the association between anthropometric variables and the presence of the preauricular sulcus.

Model	Predictor	β (estimate)	Std.error	z	p	AIC
With interactions	Intercept	-5.017	7.052	-0.71	0.477	302.39
	Sex (M)	1.259	8.355	0.15	0.880	
	Stature	0.031	0.051	0.62	0.537	
	Weight	0.009	0.044	0.21	0.831	
	Sex*stature	-0.021	0.060	-0.35	0.725	
	Sex*weight	0.012	0.051	0.23	0.817	
Without interactions	Intercept	-3.182	3.636	-0.88	0.381	298.42
	Sex (M)	-1.339	0.392	-3.42	0.0006	
	Stature	0.016	0.027	0.61	0.545	
	Weight	0.017	0.023	0.76	0.446	

McFadden & Oxenham, 2018; Ubelaker & DeGaglia, 2017), ligamentous attachments (Houghton, 1975; Schemmer et al., 1995), biomechanical loading (McFadden & Oxenham, 2018; Waltenberger et al., 2021, 2022), or multifactorial pelvic adaptation (Pany-Kucera et al., 2019; Waltenberger et al., 2022). By integrating categorical and quantitative approaches across archaeological and modern Iberian samples, the present study provides new robust evidence that support the sulcus expression as a highly stable sexually dimorphic trait. Across all populations and age groups, females consistently show higher frequencies and higher-grade expressions of the sulcus, and hierarchical log-linear modeling confirms that the association between sex and sulcus presence remains invariant across contexts.

Our findings do not support an age-dependent modulation of sulcus presence. The adult pelvis undergoes continuous remodeling under estrogen-regulated gene expression toward a more android configuration (Auerbach et al., 2018; Huseynov et al., 2016; Mitteroecker & Fischer, 2016; Williams & Carroll, 2009), potentially altering ligamentous strain and the preservation of parturition-related features (Waltenberger et al., 2021). Nevertheless, neither bivariate tests nor hierarchical log-linear models detected any significant interaction between age and sulcus presence. This indicates that the probability of expressing a preauricular sulcus remains stable across adult age groups. Given the use of pelvic traits for adult age estimation, it could be argued that age estimates might be influenced by the same biomechanical forces involved in preauricular sulcus formation. However, our analyses show no interaction between age at death and sulcus presence or expression. Moreover, age estimation using TA3 relies on multiple pelvic regions and traits, reducing the likelihood that localized remodeling in the preauricular area would systematically bias age estimates. Therefore, although shared biomechanical influences cannot

be entirely excluded, they are unlikely to account for the observed patterns.

Bone remodeling, however, may still modulate the intensity of sulcus expression once it has formed. Bergfelder and Herrmann (1980) reported an increase in sulcus depth with advancing age in some individuals, suggesting progressive accentuation of the relief in part of the population. Conversely, histological evidence of intense osteoblastic activity in the preauricular region during and immediately after pregnancy, followed by decades of remodeling (Igarashi et al., 2020), indicates that both reinforcement and partial attenuation of the original relief are biologically plausible outcomes. Although sulcus presence does not vary with age in our sample, the reduced number of individuals in the higher sulcus grades precludes a robust evaluation of age-related effects on sulcus intensity. As a result, potential interactions between age groups and sulcus grade could not be formally modeled due to limited statistical power. Yet, the wide dispersion of sulcus grades observed among adult females likely reflects interindividual differences in post-formatonal remodeling trajectories rather than differences in the timing of initial sulcus formation.

Logistic regression models further indicate that overall body size does not contribute meaningfully to explaining sulcus occurrence. Although stature and body mass show clear biological variation, both between sexes and, to a lesser extent, among populations, neither variable, alone nor in interaction with sex, displays a significant association with the presence of a preauricular sulcus. These results align with findings from documented skeletal collections, where the sulcus shows no measurable relationship to body size or pelvic linear dimensions (Igarashi et al., 2020; Waltenberger et al., 2022). Instead, available evidence supports the interpretation of the sulcus as a predominantly sex-linked morphological feature

rooted in localized ligamentous and biomechanical processes rather than size-driven or population-specific variation.

Although some pelvic features have been shown to correlate weakly with overall body mass or pelvic robustness (Waltenberger et al., 2021), such associations have not been reported for the preauricular sulcus itself. Taken together, current evidence suggests that sulcus variability reflects sex-specific pelvic anatomy rather than differences in body size across individuals or populations.

Beyond sex, pelvic shape exerts a secondary yet anatomically structured influence on sulcus formation. Inferior pelvic dimensions, particularly pubic length, emerge as the only consistent morphological predictors, whereas inlet and midplane dimensions contribute little to explaining sulcus presence. This pattern supports the view that sulcus formation is preferentially linked to localized biomechanical environments of the inferior pelvis rather than to overall pelvic canal size. Early hypotheses proposed that large pelves might experience increased ligamentous stress due to reduced stability and altered weight transfer, thus favoring the development of pelvic features (Molleson et al., 1993; Maass, 2012). Our results do not support a generalized size-driven mechanism and instead indicate that only specific structural components of the inferior pelvis are involved.

Notably, the pelvic outlet was the only segment of the pelvic canal in which significant sex-specific interactions were detected, indicating that the relationship between outlet morphology and preauricular sulcus formation differs fundamentally between males and females. The outlet is the region of the pelvis most directly involved in accommodating the mechanical demands of childbirth, particularly during fetal descent and expulsion (Abitbol, 1996; Rosenberg, 1992; Tague, 2000). In this context, the observed association supports a sex-specific functional pathway in which preauricular sulcus development is linked, indirectly and weakly, to the structural and biomechanical conditions of the inferior pelvis that facilitate parturition in females.

Multivariate analyses of documented modern samples have shown that the preauricular sulcus exhibits weak or nonsignificant associations with parity, suggesting that parity is an imperfect proxy for the mechanical conditions relevant to sulcus formation; instead, variance is more consistently explained by age-related remodeling and biomechanical context (Igarashi et al., 2020; McFadden & Oxenham, 2018; Pany-Kucera et al., 2019; Waltenberger et al., 2022). Our results are compatible with this interpretation and refine it by localizing the biomechanical signal to the inferior pelvis: in preindustrial populations with natural fertility and no obstetric intervention, sulcus expression tracks sex and outlet-adjacent

morphology rather than overall pelvic canal dimensions or body size (Holt, 1978; Houghton, 1975; Stewart, 1970).

The anatomical mechanisms linking inferior pelvic dimensions to sulcus formation can be clarified through the biomechanics of the sacroiliac joint. Pubic length and coxal height shape the architecture of the inferior pelvis, modulating iliac orientation and the pathways through which mechanical loads are transmitted across the anterior sacroiliac ligament (ASL). Cadaveric and experimental studies show that the ASL and adjacent ligamentous structures insert directly onto the preauricular region, where repeated, localized traction can induce bone remodeling (Houghton, 1974; Schemmer et al., 1995; Vleeming et al., 2012).

Importantly, inferior pelvic dimensions are expected to influence the direction, concentration, and localization of ligamentous strain at the sacroiliac joint during activities such as gait, pregnancy-related postural change, and sacral nutation in labor, rather than the overall magnitude of load associated with body size. This distinction is consistent with our results showing no association between sulcus presence and stature, body mass proxies, or bi-iliac breadth. In this framework, inferior pelvic dimensions are biomechanically more relevant to sulcus formation than inlet or midplane dimensions, which primarily affect obstetric accommodation rather than ligament-mediated loading (Pool-Goudzwaard et al., 2001; Standing, 2016; Tague, 2000).

This anatomical framework accords with our statistical findings: only dimensions of the inferior pelvis predict sulcus presence, supporting a model in which sulcus development reflects localized, ligament-mediated loading rather than overall pelvic size.

Taken together, our results indicate that preauricular sulcus expression is structured primarily by sex, with a robust and context-independent dimorphic signal not mediated by age, overall body size, or global pelvic canal dimensions. While long-term remodeling may modulate the intensity of sulcus expression once it is formed, sulcus presence per se is not explained by adult age or anthropometric variation, an interpretation consistent with recent findings that pelvic features show weak or nonsignificant associations with age, stature, or body mass (Karsten, 2018; Novak et al., 2012; Spring, 1989; Waltenberger et al., 2022). These results do not argue against an obstetric origin of the trait; rather, they remain fully compatible with interpretations of the sulcus, particularly at advanced grades, as a skeletal response to discrete biomechanical and hormonal events associated with pregnancy and parturition (Houghton, 1974, 1975; Ubelaker & DeGaglia, 2017). Pregnancy involves profound endocrine changes, including elevated relaxin and other reproductive hormones, which induce marked ligamentous laxity

in the sacroiliac and associated pelvic ligaments (Björklund et al., 2000; MacLennan et al., 1986). Under this scenario, soft tissues accommodate obstetric loading, and the bone surface secondarily registers ligament-mediated mechanical stress through localized remodeling in the preauricular region, as proposed by both anatomical and biomechanical studies (Igarashi et al., 2020; Schemmer et al., 1995).

We acknowledge several limitations inherent to the analysis of archaeological skeletal samples. Sex was primarily assessed on the basis of pelvic morphology. Although this approach is widely regarded as the most reliable method for sex estimation in adult skeletal remains, its accuracy may decrease in advanced age due to age-related pelvic remodeling, potentially increasing the risk of misclassification, particularly the assignment of senescent females as males. In contrast, error rates are expected to be minimal in adolescents and young adults, which constitute a substantial proportion of the sample.

We have conducted amelogenin-based genetic sexing on a subset of adolescent individuals, obtaining an 83.30% concordance between molecular and morphological determinations (Muñoz-Guarinos, Rodríguez, Carretero, del Nogal Sánchez, et al., 2025). These analyses are currently being extended to adult individuals and, although the number of adults analyzed to date remains limited, preliminary results also show full agreement with the osteological sex assessments. Because the molecular dataset for adults is still incomplete, these results have not yet been formally incorporated into the present study. Nevertheless, the consistency observed so far suggests that potential sex-estimation error is unlikely to have substantially affected our results. Furthermore, in the Lisbon sample, sex attribution is based on documented biological sex, providing an external reference that supports the robustness of our sex classification.

A second limitation concerns the osteological paradox, whereby skeletal samples may not faithfully represent the living population due to selective mortality, differential frailty, and the complex relationships between skeletal lesions, survival, and health status (DeWitte, 2014; DeWitte & Stojanowski, 2015; Waldron, 2009; Wood et al., 1992). In our case, the osteological paradox is particularly relevant for interpreting sulcus severity. If long-term remodeling can modulate the intensity of sulcus expression, individuals who experienced rapid mortality due to acute complications would have had limited time for skeletal remodeling. Under this scenario, the presence of sharply defined, high-grade sulci could reflect death occurring relatively soon after an obstetric event. Conversely, in individuals who survived longer, sulcus features might appear more remodeled or attenuated.

However, despite comparing samples with markedly different demographic and mortality profiles, including San Amaro, an institutional cemetery with a highly selective mortality regime, we found no significant population-level differences, either in the presence of the preauricular sulcus or in the distribution of grades within each sex. This suggests that, although survival dynamics may influence the microstructure or remodeling state of the sulcus in individuals, such effects do not translate into consistent population-level differences detectable in archaeological assemblages. Rather, sulcus expression appears to be governed predominantly by sex and by localized pelvic biomechanics, with demographic or contextual factors exerting only minor or idiosyncratic influence on its observable morphology.

Finally, the true parity status of the women represented in our archaeological samples is unknown. In the absence of documentary or independent biological indicators of individual reproductive histories, any inference regarding pregnancy or childbirth must remain probabilistic. Although the confinement of advanced sulcus grades to females and their compatibility with threshold-based post-parturition remodeling support an obstetric component, the lack of direct parity information prevents any one-to-one correspondence between sulcus expression and number of pregnancies or births. This limitation reinforces the need for future studies integrating skeletal, molecular, histological, and demographic data.

5 | CONCLUSIONS

This study demonstrates that the preauricular sulcus is a stable and strongly sexually dimorphic pelvic feature, whose presence is independent of adult age, overall body size, and global pelvic canal dimensions. Sulcus formation is primarily structured by sex and secondarily by localized aspects of inferior pelvic morphology, particularly pubic and outlet geometry, supporting a regionally constrained biomechanical model rather than a size-driven mechanism.

While sulcus presence itself is not age-dependent, sulcus intensity likely reflects the interaction between sex-linked formation and long-term remodeling processes. Advanced sulcus grades are confined to females and are compatible with threshold-based post-parturition remodeling, but in the absence of independent parity data they can only be interpreted as probabilistic indicators of pregnancy and lactation. Future progress will require the integration of morphometric, histological, molecular, and demographic data to fully validate the reproductive significance of advanced sulcus grades.

AUTHOR CONTRIBUTIONS

Rebeca García-González: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; resources; software; supervision; validation; visualization; writing – original draft. **Julia Muñoz-Guarinos:** Data curation; formal analysis; investigation; methodology; visualization; writing – original draft; writing – review and editing. **Nico Ciroto:** Formal analysis; methodology; visualization; writing – original draft. **Sonia Díaz-Navarro:** Formal analysis; methodology; visualization; writing – original draft. **Laura Rodríguez:** Data curation; formal analysis; investigation; methodology; visualization; writing – review and editing. **José Miguel Carretero:** Data curation; funding acquisition; investigation; methodology; project administration; visualization; writing – review and editing.

ACKNOWLEDGMENTS

This work would not have been possible without the efforts of the many individuals who have been part of the Laboratorio de Evolución Humana since 2000 and who have contributed to the processing and study of the collections. We are sincerely grateful to all of them. We are very grateful to Alexandre Marçal (Museu Bocage, Museu Nacional de História Natural, Lisbon) and Rosa Sofia da Conceição Neto Westerlain (Coimbra University) for granting us access to the Lisbon collection.



We have benefitted from fruitful discussions with our colleagues from the Laboratorio de Evolución Humana at the University of Burgos.

FUNDING

“Bioarqueología de la reproducción humana: una perspectiva evolutiva sobre los problemas actuales (JCYL BU010P24)” financed by Junta de Castilla y León and Fondo Europeo de Desarrollo Regional. The Atapuerca research project is financed by the Ministerio de Ciencia, Innovación y Universidades Grants PID2021-122355NB-C31 funded by MCIN/AEI/10.13039/501100011033 and “ERDF A way of making Europe” and PID-2024-156477NB-C33. Julia Muñoz Guarinos has a post-doctoral grant associated to the Project “Bioarqueología de la reproducción humana: una perspectiva evolutiva a los problemas actuales (JCYLBU010P24)” funded by Junta de Castilla y León and Fondo Europeo de Desarrollo Regional. The contribution of SDN in this study was supported by a Postdoctoral Fellowship awarded by Juan de la Cierva Programme Grants, MICIU and AEI (ref. JDC2023-050883-I).

ORCID

Rebeca García-González  <https://orcid.org/0000-0002-1035-6655>

Laura Rodríguez  <https://orcid.org/0000-0002-5090-1582>
 José Miguel Carretero  <https://orcid.org/0000-0003-0409-8087>

REFERENCES

- Abitbol, M. M. (1996). The shapes of the female pelvis: contributing factors. *Journal of Reproductive Medicine*, 41(4), 242–250.
- Acsádi, G., & Nemeskéri, J. (1970). *History of human life span and mortality*. Akadémiai Kiadó.
- Angel, J. L. (1969). The bases of paleodemography. *American Journal of Physical Anthropology*, 30, 427–437.
- Arzuaga, J. L. (1985). Antropología del hueso coxal: evolución, dimorfismo sexual y variabilidad (Doctoral dissertation, Universidad Complutense de Madrid).
- Arzuaga, J. L., & Carretero, J. M. (1994). Multivariate analysis of the sexual dimorphism of the hip bone in a modern human population and in early hominids. *American Journal of Physical Anthropology*, 93(2), 241–257.
- Auerbach, B. M., King, K. A., Campbell, R. M., Campbell, M. L., & Sylvester, A. D. (2018). Variation in obstetric dimensions of the human bony pelvis in relation to age-at-death and latitude. *American Journal of Physical Anthropology*, 167(3), 628–643.
- Bergfelder, T., & Herrmann, B. (1980). Estimating fertility on the basis of birth-traumatic changes in the pubic bone. *Journal of Human Evolution*, 9(8), 611–613.
- Betti, L. (2014). Sexual dimorphism in the size and shape of the os coxae and the effects of microevolutionary processes. *American Journal of Physical Anthropology*, 153(2), 167–177.
- Björklund, K., Bergström, S., Nordström, M. L., & Ulmsten, U. (2000). Symphyseal distention in relation to serum relaxin levels and pelvic pain in pregnancy. *Acta Obstetrica et Gynecologica Scandinavica*, 79(4), 269–275.
- Bocquet-Appel, J. P. (2008). Explaining the Neolithic demographic transition. In *The Neolithic demographic transition and its consequences* (pp. 35–55). Springer Netherlands.
- Bonneau, N., Bouhallier, J., Simonis, C., Baylac, M., Gagey, O., & Tardieu, C. (2012). Shape variability induced by reassembly of human pelvic bones. *American Journal of Physical Anthropology*, 148(1), 139–147.
- Buikstra, J. E., & Ubelaker, D. H. (1994). *Standards for data collection from human skeletal remains Arkansas archaeological survey research series* (Vol. 44). Arkansas Archaeological Survey.
- Cardoso, H. F. V. (2007). Environmental effects on skeletal versus dental development: using a documented subadult skeletal sample to test a basic assumption in human osteological research. *American Journal of Physical Anthropology*, 132, 223–233.
- Chamberlain, A. T. (2006). *Demography in Archaeology*. Cambridge University Press.
- Conceição, E. L. N., & Cardoso, H. F. V. (2011). Environmental effects on skeletal versus dental development II: Further testing of a basic assumption in human osteological research. *American Journal of Physical Anthropology*, 144, 463–470.
- Courtenay, L. A. (2024). An open letter to evolutionary and human sciences; Statistics has moved on and so should we. A proposal for more transparent research, and some notes on $p < 0.003$. *Quaternary Environments and Humans*, 2(6), 100041.

- DeWitte, S. N. (2014). The anthropology of plague: Insights from bioarcheological analyses of epidemic cemeteries. *The Medieval Globe*, 1(1), 97–123.
- DeWitte, S. N., & Stojanowski, C. M. (2015). The osteological paradox 20 years later: Past perspectives, future directions. *Journal of Archaeological Research*, 23(4), 397–450.
- Galloway, A. (1995). Determination of parity from the maternal skeleton: An appraisal. *Rivista di Antropologia*, 73, 83–98.
- García-González, R., Carretero, J. M., Rodríguez, L., & Arsuaga, J. L. (2019). Two new methodological approaches for assessing skeletal maturity in archeological human remains based on the femoral distal epiphysis. *Archaeological and Anthropological Sciences*, 11(12), 6515–6536.
- García-González, R., Rodríguez, L., Muñoz-Guarinos, J., Sánchez-Puente, Z., Fernández-Viejo, M., Cirotto, N., Pérez, A. N., Barreiro, M. G., Salazar-Fernández, A., Quintino, Y., Adán-Álvarez, G., & Carretero, J. M. (2024). *Paleodemographic profiles of the populations buried in San Pablo Convent* (pp. 1–33). ENTEMU.
- Genovés, S. T. (1959). *Diferencias sexuales en el hueso (coxal. ed.)*. Universidad Nacional Autónoma de México. Publicaciones del Instituto Nacional de Historia.
- Hirschberg, J., Milne, N., & Oxnard, C. (1998). *The interface between muscle and bone: Biomechanical implications. Presented at the the interface between muscle and bone: biomechanical implications* (p. 96). Wiley-Liss.
- Holt, A. C. (1978). A re-examination of parturition scars on the human female pelvis. *American Journal of Physical Anthropology*, 49, 91–94.
- Hoppa, R. D., & Vaupel, J. (2002). Paleodemography: Looking back and thinking ahead. In *Paleodemography: Age distributions from skeletal samples* (pp. 9–28). Cambridge University Press.
- Houghton, P. (1974). The relationship of the pre-auricular groove of the ilium to pregnancy. *American Journal of Physical Anthropology*, 41(3), 381–389.
- Houghton, P. (1975). The bony imprint of pregnancy. *Bulletin of the New York Academy of Medicine*, 51(5), 655–661.
- Huseynov, A., Zollikofer, C. P., Coudyzer, W., Gascho, D., Kellenberger, C., Hinzpeter, R., & Ponce de León, M. S. (2016). Developmental evidence for obstetric adaptation of the human female pelvis. *Proceedings of the National Academy of Sciences*, 113(19), 5227–5232.
- Igarashi, Y., Shimizu, K., Mizutaka, S., & Kagawa, K. (2020). Pregnancy parturition scars in the preauricular area and the association with the total number of pregnancies and parturitions. *American Journal of Physical Anthropology*, 171(2), 260–274.
- Karsten, J. K. (2018). A test of the preauricular sulcus as an indicator of sex. *American Journal of Physical Anthropology*, 165(3), 604–608.
- Kikinis, R., Pieper, S. D., & Vosburgh, K. G. (2013). 3D Slicer: a platform for subject-specific image analysis, visualization, and clinical support. In *Intraoperative imaging and image-guided therapy* (pp. 277–289). Springer.
- Kurki, H. K. (2007). Protection of obstetric dimensions in a small-bodied human sample. *American Journal of Physical Anthropology*, 133, 1152–1165.
- Kurki, H. K. (2013a). Bony pelvic canal size and shape in relation to body proportionality in humans. *American Journal of Physical Anthropology*, 151, 88–101.
- Kurki, H. K. (2013b). Skeletal variability in the pelvis and limb skeleton of humans: Does stabilizing selection limit female pelvic variation? *American Journal of Human Biology*, 25(6), 795–802.
- Ledermann, S. (1969). *Nouvelles tables-types de mortalité, Travaux et documents (Institut national d'études démographiques, France)*. Presses Universitaires de France.
- Lorkiewicz, W., Karkus, J., Mietlinska, J., Stuss, M., Seweryneck, E., Plažuk, D., & Żądzińska, E. (2020). Did parity affect bone mineral density of women in past populations? Parturition scars and BMD of Neolithic to modern skeletons from north-central Poland. *Journal of Archaeological Science*, 124, 105264.
- Lozano-Bendicho, C., Sánchez-Andrés, Á., Martínez, I., Conde-Valverde, M., Carretero, J. M., Rodríguez, L., Cirotto, N., & García-González, R. (2025). Occipital bone modeling patterns during the first years of life: A preliminary histological and quantitative approach. *Journal of Anatomy*, 247, 885–896.
- Maass, P. (2012). *The Bony pelvis scars of parturition and factors Influencing their manifestation*. University of Cape Town.
- MacLennan, A., Green, R., Nicolson, R., & Bath, M. (1986). Serum relaxin and pelvic pain of pregnancy. *The Lancet*, 328(8501), 243–245.
- McFadden, C., & Oxenham, M. F. (2018). Rate of natural population increase as a paleodemographic measure of growth. *Journal of Archaeological Science: Reports*, 19, 352–356.
- Mitteroecker, P., & Fischer, B. (2016). Adult pelvic shape change is an evolutionary side effect. *Proceedings of the National Academy of Sciences*, 113(26), E3596.
- Molleson, T., Cox, M., Wladron T., Whittaker, D.K. (1993). *The Spitafields project. VOLUME 2. The anthropology*. Council for British Archaeology.
- Muñoz-Guarinos, J. M., González, R. G., García, L. R., & Díaz, J. M. C. (2020). De niña a mujer en la Edad Media: c_omo determinar la menarquia a partir de restos _oseos. In VI Jornadas de Investigadoras de Castilla y Le_on: la aventura de la ciencia y la tecnología (p. 37). Fundación 3CIN.
- Muñoz-Guarinos, J., García-González, R., Carretero, J. M., & Rodríguez, L. (2025). Comparing methods for calculating cross-sectional properties from high-resolution CT scans in dry bone: The case of the non-adult femoral midneck. *American Journal of Biological Anthropology*, 186(3), e70036.
- Muñoz-Guarinos, J., Rodríguez, L., Carretero, J. M., & García-González, R. (2025). Exploring developmental changes in femoral midneck cross-sectional properties. *The Anatomical Record*, 308(8), 2212–2233.
- Muñoz-Guarinos, J., Rodríguez, L., Carretero, J. M., del Noyal Sánchez, M., Casas-Ferreira, A. M., Pavón, J. L. P., & García-González, R. (2025). Tracking adolescent bone remodeling through sex-specific femoral cross-sectional changes. *The Anatomical Record*, 1–19. <https://doi.org/10.1002/ar.70083>
- Novak, L., Schultz, J. J., & Mc Intyre, M. (2012). Determining sex of the posterior ilium from the Robert J. Terry and William M. Bass collections. *Journal of Forensic Sciences*, 57, 1155–1160.
- Ousley, S. D., Milner, G. R., Boldsen, J. L., Getz, S. M., Weise, S., & Tarp, P. (2020). Transition analysis 3. V 0.8.4.
- Pany-Kucera, D., Spannagl-Steiner, M., Argeny, S., Maurer-Gesek, B., Weninger, W. J., & Rebay-Salisbury, K. (2019). Sacral preauricular extensions, notches, and corresponding iliac

- changes: New terms and the proposal of a recording system. *International Journal of Osteoarchaeology*, 29(6), 1013–1021.
- Phenice, T. W. (1969). A newly developed visual method of sexing the os pubis. *American Journal of Physical Anthropology*, 30(2), 297–301.
- Pool-Goudzwaard, A. L., Kleinrensink, G. J., Snijders, C. J., Entius, C., & Stoekart, R. (2001). The sacroiliac part of the ilio-lumbar ligament. *The Journal of Anatomy*, 199(4), 457–463.
- Putschar, W. G. (1976). The structure of the human symphysis pubis with special consideration of parturition and its sequelae. *American Journal of Physical Anthropology*, 45, 589–594.
- Ritchie, J. R. (2003). Orthopedic considerations during pregnancy. *Clinical Obstetrics and Gynecology*, 46, 456–466.
- Rosenberg, K. R. (1992). The evolution of modern human childbirth. *American Journal of Physical Anthropology*, 35(S15), 89–124.
- Ruff, C. B. (1995). Biomechanics of the hip and birth in early Homo. *American Journal of Physical Anthropology*, 98(4), 527–574.
- Ruff, C. B., Holt, B. M., Niskanen, M., Sladek, V., Berner, M., Garofalo, E., Garvin, H. M., Hora, M., Maijanen, H., Niinimäki, S., Salo, K., Schuplerová, E., & Tompkins, D. (2012). Stature and body mass estimation from skeletal remains in the European Holocene. *American Journal of Physical Anthropology*, 148(4), 601–617.
- Salazar-Fernández, A., Carretero, J. M., Quintino, Y., Harvati, K., Rodríguez, L., & García-González, R. (2025). Pre-fusion shape changes of humeral metaphyseal surfaces: A new method for assessing maturity and age in non-adult skeletal individuals. *American Journal of Biological Anthropology*, 186(1), e25063.
- Schemmer, D., White, P. G., & Friedman, L. (1995). Radiology of the paraglenoid sulcus. *Skeletal Radiology*, 24(3), 205–209.
- Spring, D. B. (1989). The radiographic preauricular groove: Its non-relationship to past parity. *American Journal of Physical Anthropology*, 79, 247–252.
- Standring, S. (2016). Section 8: Abdomen and pelvis. In M. D. Stringer & S. M. Gabe (Eds.), *Gray's Anatomy* (41st ed., p. 1584). Elsevier.
- Stewart, T. D. (1970). Identification of the scars of parturition in the skeletal remains of females. In *Personal identification in mass disasters* (pp. 127–135). National Museum of Natural History, Smithsonian Institution.
- Tague, R. G. (1989). Variation in pelvic size between males and females. *American Journal of Physical Anthropology*, 80, 59–71.
- Tague, R. G. (2000). Do big females have big pelvises? *American Journal of Physical Anthropology*, 112(3), 377–393.
- Torres-Tamayo, N., Rae, T. C., Hirasaki, E., & Betti, L. (2024). Testing the reliability of the rearticulation of osteological primate pelvises in comparative morphological studies. *The Anatomical Record*, 307(8), 2816–2833.
- Ubelaker, D. H., & De La Paz, J. S. (2012). Skeletal indicators of pregnancy and parturition: A historical review. *Journal of Forensic Sciences*, 57(4), 866–872.
- Ubelaker, D. H., & DeGaglia, C. M. (2017). Population variation in skeletal sexual dimorphism. *Forensic Science International*, 278, 407–407-e1.
- Ullrich, H. (1975). Estimation of fertility by means of pregnancy and childbirth alterations at the pubis, the ilium, and the sacrum. *OSSA*, 2, 23–39.
- Vleeming, A., Schuenke, M. D., Masi, A. T., Carreiro, J. E., Danneels, L., & Willard, F. H. (2012). The sacroiliac joint: an overview of its anatomy, function and potential clinical implications. *Journal of Anatomy*, 221(6), 537–567.
- Waldron, T. (2009). *Paleopathology*. Cambridge University Press.
- Waltenberger, L., Pany-Kucera, D., Rebay-Salisbury, K., & Mitteroecker, P. (2021). The association of parturition scars and pelvic shape: A geometric morphometric study. *American Journal of Physical Anthropology*, 174(3), 519–531.
- Waltenberger, L., Rebay-Salisbury, K., & Mitteroecker, P. (2022). Age dependent changes in pelvic shape during adulthood. *Anthropologischer Anzeiger*, 79(2), 143–156.
- Williams, T. M., & Carroll, S. B. (2009). Genetic and molecular insights into the development and evolution of sexual dimorphism. *Nature Reviews. Genetics*, 10(11), 797–804. <https://doi.org/10.1038/nrg2687>
- Wood, J. W., Milner, G. R., Harpending, H. C., Weiss, K. M., Cohen, M. N., Eisenberg, L. E., Hutchinson, D. L., Jankauskas, R., #esnys, G., Katzenberg, M. A., Lukacs, J. R., McGrath, J. W., Roth, E. A., Ubelaker, D. H., & Wilkinson, R. G. (1992). The osteological paradox: Problems of inferring prehistoric health from skeletal samples [and comments and reply]. *Current Anthropology*, 33(4), 343–370.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: García-González, R., Muñoz-Guarinos, J., Cirotto, N., Díaz-Navarro, S., Rodríguez, L., & Carretero, J. M. (2026). Pelvic morphology and body size in relation to the preauricular sulcus: Evidence from medieval to modern Iberia. *The Anatomical Record*, 1–20. <https://doi.org/10.1002/ar.70177>