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RESEARCH ARTICLE

Are parturition scars truly signs of birth? The estimation of parity in a well-documented modern sample

Lukas Waltenberger[1,2] | Katharina Rebay-Salisbury[1] | Philipp Mitteroecker[2]

[1]Austrian Archaeological Institute, Austrian Academy of Sciences, Vienna, Austria

[2]Department of Evolutionary Biology, University of Vienna, Vienna, Austria

Correspondence
Philipp Mitteroecker, Department of Evolutionary Biology, University of Vienna, Djerassiplatz 1, 1030 Vienna, Austria.
Email: philipp.mitteroecker@univie.ac.at

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Abstract

Parturition scars have been frequently studied in the last decades, but their association with pregnancy and birth is still controversial. Other biomechanical, biometric, and lifestyle factors are also likely to influence the development of pelvic features. Most previous studies of pelvic features were based on skeletal collections with no reliable information on parity or even sex and thus were unable to disentangle these factors. Here, we study the association of pelvic features with birth and other body variables (age, stature, weight, osteoarthritis, and centrum–collum–diaphyseal angle) using multiple regression and path modeling in a modern sample of female individuals from New Mexico (USA) with detailed background information ($n = 150$). We also explored the utility of pelvic features to predict the number of births. To this end, we scored the expression of the preauricular sulcus, sacral preauricular extension, extended pubic tubercle, exostosis at the pectineal line, dorsal, and ventral pubic pitting using CT scans from the New Mexico Decedent Image Database. Quantitative measurements of pelvic features were then used as predictors of parity. Overall, the regression models accounted only for relatively small fractions of variance in pelvic feature expression. The only feature significantly associated with the number of births was dorsal pubic pitting ($R^2 = 0.2372$), whereas the expression of most pelvic features increased with age, independent of parity. Presumably, the development of dorsal pubic pitting is affected both by biomechanical stress and the increased hormonal secretion during pregnancy and birth. The individual prediction of parity based on pelvic features is too imprecise for forensic or archeological applications. However, using a size score of dorsal pubic pitting allowed us to estimate the mean parity in groups of individuals relatively well. Hence, pelvic features may still be used to compare average parity across recent or historic populations.

KEYWORDS
childbirth, dorsal pubic pitting, human pelvis, parturition scars, regression models

1 | INTRODUCTION

Parturition scars are depressions, pits, grooves, or exostoses at the bony pelvis, which are commonly attributed to pregnancy and birth (Angel, 1969; Houghton, 1974; Houghton, 1975; Igarashi et al., 2019; Lorkiewicz et al., 2020; McFadden & Oxenham, 2017; Praxmarer et al., 2020; Putschar, 1976; Stewart, 1970; Ullrich, 1975). However, the causes of parturition scars are still not well understood because some parous women never express them whereas some nulliparous women or even men develop them (Holt, 1978). The association with stature, as well as pelvic shape and size, suggests that biomechanical strain also influences the expression of parturition scars (Decrausaz, 2012; Waltenberger, Pany-Kucera, et al., 2021). Because of the multiple factors involved in the development of "parturition scars," we use the more neutral term "pelvic features" (Pany-Kucera et al., 2019) to refer to the structures traditionally described as parturition scars.

Pelvic features are located next to the sacroiliac joint (preauricular sulcus, margo auricularis groove, and sacral preauricular extension) and near the pubic symphysis (ventral pubic lesions, dorsal pubic pitting, and extended pubic tubercle). The preauricular or paraglenoid sulcus (Loehr, 1884; Schemmer et al., 1995; Zaaijer, 1866) is a horizontal groove at the inferior border of the ilium next to the sacroiliac joint. It is more frequently in female individuals than in males and more pronounced in old individuals. Houghton (1974) distinguished two types: the groove of pregnancy (GP) with an uneven, scooped out floor, which is limited to females and presumably related to parity, and the groove of ligament (GL), which is shallow and exhibits a smooth floor and can be observed in both sexes. Cox (1989) detected higher frequencies of the preauricular sulcus in android pelves, albeit this trend was not statistically significant. Molleson et al. (1993) and Maass (2012) also proposed that pelvis size is an important factor in the development of pelvic features. Large pelves may cause increased stress to the pelvic ligaments due to reduced stability and an altered weight transfer. A second feature close to the sacroiliac joint is the sacral preauricular extension, which is limited to females. This is a thin, ventrally pointing osseous extension at the ventrosuperior margin of the sacral wings (Pany-Kucera et al., 2019). Pany-Kucera et al. (2019) proposed that microtraumata emerging from ligament laxity and increased compression during birth stimulate heterotrophic ossification in the ligaments. At the dorsal side of the pubis, sometimes, one or several small circular pits or a vertically oriented, irregularly shaped groove can be visible (dorsal pubic pitting). Higher frequencies of dorsal pubic pitting are observed in multiparous women compared with nullipara and men (Gilbert & McKern, 1973; Stewart, 1970); frequencies also increase with age (Snodgrass & Galloway, 2003). A hypertrophic posterior transverse ligament and also traumata and inflammatory processes are suspected to create dorsal pubic pitting (Angel, 1969; Ashworth et al., 1976; Becker et al., 2010; Kamieth & Reinhardt, 1955). Two different structures have been referred to as an extended pubic tubercle: Bergfelder and Herrmann (1980) and Ullrich (1975) described an elongation of the anatomical pubic tubercle as extended pubic tubercle, whereas others described an exostosis located somewhere along the arcuate line of the superior pubic ramus (Angel, 1969; Decrausaz, 2012; Maass, 2012; Snodgrass & Galloway, 2003). Cox (1989) and Bergfelder and Herrmann (1980) detected an association with parity, but others also reported a correlation with body height, age, and sex (Aurigemma, 2015; Decrausaz, 2012; Maass, 2012; Snodgrass & Galloway, 2003).

Pelvic ligament relaxation, induced by the hormone relaxin (Hisaw, 1926; Weiss et al., 1977), and increased stress to these ligaments during pregnancy generate hemorrhages and microtraumata at their attachment sites (Abramson et al., 1934; Angel, 1969; Bergfelder & Herrmann, 1980; Houghton, 1974; Young, 1940), which are likely to lead to the formation of pelvic features. Additionally, a hyperlordosis of the lumbar vertebrae caused by maternal weight gain and the increasing size of the gravid uterus can amplify the strain to the pelvic ligaments (Galloway, 1995; Ritchie, 2003). Sulci and pits are probably provoked by lateral tensions to the pelvic ligaments, whereas the extended pubic tubercle is influenced by longitudinal stress of the rectus abdominal muscle (Hirschberg et al., 1998). In both sexes, pelvic features are also related to body weight, the size and shape of the pelvic inlet (Decrausaz, 2012; Waltenberger, Pany-Kucera, et al., 2021) and age. The preauricular sulcus, for instance, becomes deeper during an individual's lifetime (Bergfelder & Herrmann, 1980). Similarly, the pelvis continues remodeling during adult lifetime in response to estrogen-regulated gene expression, which can affect the strain to the pelvic ligaments (Auerbach et al., 2018; Huseynov et al., 2016; Mitteroecker & Fischer, 2016; Waltenberger, Rebay-Salisbury, & Mitteroecker, 2021; Williams & Carroll, 2009). Moreover, women have higher rates of degenerative joint disease and osteoarthritis at the pubic symphysis (Meindl et al., 1985; Todd, 1921), which is likely induced by increased strain to the pelvis during pregnancy and birth.

Detailed obstetric and biometric recordings about the deceased are crucial for testing the association of pelvic features and possible causes. However, most earlier studies on pelvic features were based on prehistoric and modern skeletal collections with no obstetric recordings (Andersen, 1986; Driscoll, 2010; Stewart, 1970; Ullrich, 1975) or historic collections with baptism registers (Cox, 1989; Decrausaz, 2012). Only few studies could make use of obstetric background information about the individuals (Galloway, 1995; Igarashi et al., 2019), which may account for the contradictory results in the literature on pelvic features.

1.1 | Aim of the study

The associations between pelvic features and obstetrics, as well as between pelvic form and biomechanical strain, are still controversial and inconclusive. Here, we study pelvic features in a modern sample with detailed information on the number of births and pregnancies, age, body size, and weight as well as on health, ancestry, and socioeconomic background. Using multiple regression and path modeling, we analyze the association of pelvic feature expression with the number of births (as the main explanatory variable) and with several other variables that may affect pelvic features independently of birth (age, weight, height, centrum–collum–diaphyseal [CCD] angle, and osteoarthritis) to disentangle the direct causal effects of these variables. Based on these models, we chose pelvic features that were strongly associated with parity to develop a statistical model to predict the number of births from pelvic feature expression, which is of interest in forensic anthropology and bioanthropology.

2 | MATERIAL AND METHODS

Our sample comprises anonymized forensic CT data of 183 bodies from the New Mexico Decedent Image Database (Edgar et al., 2020). This database contains whole-body CT scans of over 15,000 New Mexicans, scanned in the years 2010–2017 with a Philips Brilliance Big Bore 16 CT scanner. We worked with CT data of the torsos, which were scanned following the Office of the Medical Investigator (OMI) protocol for adults and thin sectioned bone (pixel size: 0.5 mm, slice thickness 1 mm).

Data on ancestry, body variables, socioeconomic details, the number of pregnancies and births, death information, and many other variables were available. These data were provided by the OMI metadata database and next-of-kin interviews for the NMDID database. For our sample, we selected 45 cases of nullipara, unipara, and multipara each (a total of 135 female individuals). To ensure an equal age distribution, all parity groups are composed of three age groups of equal size ($N = 15$): 19–29, 30–49, and over 50 years. Additionally, 15 juvenile female individuals were included (12 to 17 years old, all nullipara) to cover the onset of sexual maturity and the development of the sexual dimorphism in pelvic shape in response to sex steroid hormone secretion during puberty (Fischer & Mitteroecker, 2017; Huseynov et al., 2016), which probably affects the development of pelvic features (Waltenberger, Rebay-Salisbury, & Mitteroecker, 2021). In total, we analyzed a sample of 150 individuals. Exclusion criteria were artificial hip or knee joints, traumata to the femora or the pelvis, heavily decomposed cadavers, mummification, congenital defects, neoplastic diseases, and illnesses that might influence pelvic shape. As bodyweight can affect the femora and the pelvis (Auerbach & Ruff, 2004; Chevalier et al., 2016; Keisu et al., 2019; Ruff, 1988; Ruff et al., 2012), only individuals with a BMI between 15 and 35 were selected. We only chose individuals identified by next of kin as "European ancestry" to decrease interpopulation variation in our data. Pelvic shape and size differ among recent human populations due to environmental and climatic adaptions (Ruff, 2002; Wells et al., 2012), nutritional intake (Dos Santos et al., 1979), and neutral evolutionary processes (Betti, 2017; Betti et al., 2013). These interpopulation differences have been shown to be associated with obstructed birth and pelvic floor disorders (Mitteroecker et al., 2021; Pavličev et al., 2020) and might thus also affect the expression of pelvic features. From the full sample, 16 individuals had to be excluded during data collection for various reasons (traumata at the pelvis, missing parts of femora and pelvis).

We semi-automatically segmented the bony pelvis from the CT data in Amira 6.7 following the segmentation protocol of Spoor et al. (1993). Manual segmentation was necessary at the inferior portion of the sacrum, coccyx, and femoral head. The segmented model was exported as surface mesh (.obj) for further analysis (Figure 1a). We represented the expression of pelvic features by ordinal variables separately for the left and right sides based on the methods of Cox (1989), Houghton (1974), Houghton (1975), Maass (2012), Pany-Kucera et al. (2019), Rebay-Salisbury et al. (2018), Stewart (1970), and Ullrich (1975). Definitions of these categories are presented in Table 1. The expression of pelvic features was analyzed visually on 3D surface meshes of the pelves obtained from the CT scans (Figure 1b). Furthermore, we measured the CCD angle of both femora on coronal cross-sections of the femoral CT data (the angle between the femoral neck and femoral diaphysis, measured in the center of the femur) and surveyed osteoarthritis of the lumbar vertebrae based on the categories of Steckel et al. (2006). We measured the maximal length of the sacral preauricular extension (measured in the middle of the preauricular extension, from the edge of the sacral preauricular surface to the tip of the preauricular extension) and the maximal depth, width, and height of the dorsal pubic pitting on 3D surface meshes of the pelves obtained from the CT scans. The maximal depth was measured as the distance from the level of the dorsal bone surface of the pubis to the deepest point of the deepest dorsal pubic pitting lesion. This measurement was taken perpendicular to the dorsal pubic surface. The width was measured as the maximal breadth of dorsal pubic pitting in the transverse plane. Height was measured as the distance from the lowest point of dorsal pubic pitting to the highest point. If several lesions were visible, this measurement was taken from the lowest point of the most inferior lesion to the highest point of the most superior lesion. A size score for dorsal pubic pitting was calculated as the geometric mean of these three measurements:

$$\sqrt[3]{depth * width * height}.$$

The statistical analysis was performed in R 3.6.1 (R Core Team, 2013). Relationships between body variables, pregnancy, birth, and the expression of pelvic features were analyzed with multiple linear regressions, ordinal logistic regressions, and binomial logistic regressions using the packages MASS 7.3-51.6 (Venables & Ripley, 2002) and lavann 0.6-7 (Rosseel, 2012). For each variable, left and right measurements were averaged. All variables were z-transformed to make the regression coefficients comparable. If the relationship between two variables was not linear, the data were log-transformed.

To statistically assess the influence of the different variables on pelvic feature expression, the number of births, age, weight, stature, CCD angle, and the osteoarthritis score were taken as independent variables, and regression models were calculated separately for each pelvic feature as dependent variables. Subsequently, we developed a path model to further disentangle the direct and indirect causal effects of the variables on pelvic feature expression. Age at death was considered causally prior to the other variables, all of which can

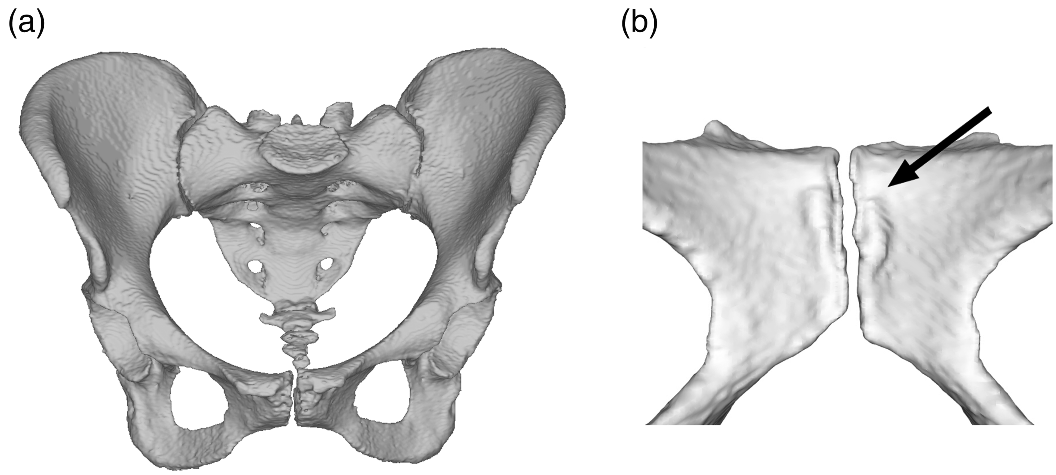

FIGURE 1 (a) Example of a surface mesh of the segmented CT scan of a pelvis. (b) This example shows the pelvis of a female individual with deep dorsal pubic pitting (Stage 2)

TABLE 1 Categories used to evaluate the expression of pelvic features

Dorsal pubic pitting[a,b]	Ventral pubic lesions[c]	Preauricular sulcus type[d]	Preauricular sulcus stage[e]	Margo auricularis groove[b]	Extended pubic tubercle[f]	Sharp ridges at the pectineal line[b]	Sacral preauricular extension[g]
Calculated score: cubic root from product of max. depth × max. width × max. height	0 = smooth surface, no lesion present 1 = small lesion present (<2 mm) 2 = medium to large lesion present (>2 mm)	0 = area is smooth, with no clear evidence of a sulcus 1 = groove of ligament 2 = groove of pregnancy	0 = area is smooth, with no clear evidence of a sulcus 1 = shallow, poorly marked 2 = shallow, straight-edged even floor 3 = developed, well-defined platform 4 = developed pitted 5 = irregular floor and/or margins, projecting dorsal margin	0 = area is smooth, with no clear evidence of a sulcus 1 = shallow, poorly marked 2 = shallow, straight-edged even floor 3 = developed, well-defined platform 4 = developed pitted 5 = irregular floor and/or margins, projecting dorsal margin	0 = absent 1 = present	0 = smooth pectineal line 1 = sharp ridged exostosis present at the pectineal line	Maximal length

[a]Adapted from Stewart (1970).
[b]Adapted from Ullrich (1975).
[c]Adapted from Rebay-Salisbury et al. (2018).
[d]Adapted from Houghton (1974).
[e]Adapted from Cox (1989) and Houghton (1975).
[f]Adapted from Maass (2012).
[g]Adapted from Pany-Kucera et al. (2019).

potentially affect pelvic feature expression. Standardized path coefficients were estimated by series of multiple regressions based on the *z*-transformed variables. Statistical significance was only interpreted for the regression coefficient of the number of births, as this represented our main hypothesis. All *p* values were corrected with the Bonferroni–Holm method to avoid a cumulation of alpha errors. The associations of all other variables with pelvic feature expressions were interpreted in an exploratory way (based on the standardized regression coefficients and the total R^2 of the model). To estimate parity from pelvic features, as in forensic or archeological contexts, the number of live births was taken as dependent variable and the size score of dorsal pubic pitting as independent variable. We estimated out-of-sample prediction performance by leave-one-out cross-validation.

3 | RESULTS

Age at death of the sampled individuals ranged from 12 to 92 years, with a mean of 44.5 years. Body weight ranged from 33.6 to 107 kg (mean 68.5 kg) and body height from 145 to 185 cm (mean 164.0 cm). Most women were socially from the middle class (44.8%), followed by the lower class (15.7%). Scoliosis and osteoporosis rarely occurred (2.2% and 1.1%, respectively). On average, the women had 1.8 pregnancies and 1.6 live births. Only for 13% of the women the reported number of pregnancies exceeded the number of births. As both variables led to very similar results, we present only those for the number of live births here. A preauricular sulcus occurred in 93.7% of all women at least weakly at one side. Of them, 55.5% exhibited a GL and 44.5% a GP. The sacral preauricular extension occurred in 37.3% of all women, dorsal pubic pitting in 27.0%, and sharp ridges at the pectineal line in 25.4%. Ventral pubic lesions (13.4%), extended pubic tubercles (10.3%), and the margo auricularis groove (1.5%) were rarely present. The margo auricularis groove was thus excluded from further analysis. More details about the recordings and frequencies of the pelvic features are provided in Tables 2 and S1–S6.

All regression models yielded relatively small explained variances of pelvic feature expression ($R^2 < 0.174$ for all pelvic features). The R^2 increased for all features when restricting the sample to individuals younger than 45 years (Table 3), which indicates the presence of highly variable factors of feature expression in higher ages that were not covered by our independent variables. Therefore, only the regression models for the age group younger than 45 years will be presented in the main text (see Table S7 for the regression models for all age groups).

Only dorsal pubic pitting was significantly associated with birth (adjusted $R^2 = 0.2372$, regression coefficient for the number of live births: $\beta = 0.7428$, $p < 0.001$). For all other pelvic features, the association with the number of births was weak and not statistically significant, whereas age influenced all features. Two of the individuals with unilaterally expressed sharp exostoses were outliers with regard to the number of births (more than three times the interquartile range) and thus were excluded for further analysis. Sharp exostoses occurred in only three of the individuals younger than 45 years and thus were not included in the regression analysis for the younger age group. In the full sample, the regression model accounted for only a small fraction of variance in sharp exostoses expression ($R^2 = 0.0919$). Similarly, the extended pubic tubercle was expressed bilaterally in only two individuals and unilaterally in eight individuals. Surprisingly, all individuals with an extended pubic tubercle were younger than 45 years; none of the older individuals expressed it. With our sample size, it remains unclear if this is a sample artifact or reflects a remodeling of the tubercle in high age (cf. Waltenberger, Rebay-Salisbury, & Mitteroecker, 2021). We thus refrained from further analysis of this feature. Osteoarthritis was rarely present in individuals younger than 45 years and was thus excluded as a covariate in this age group.

As only dorsal pubic pitting showed a clear association with the number of births, both in the younger age group and in the full sample

TABLE 2 Descriptive statistics of the sample distribution

	Mean	SD	Minimum	Maximum	Variance
Age at death (years)	44.54	21.553	12	92	464.551
Body weight (kg)	68.55	14.682	33.57	107.00	215.561
Body height (cm)	163.90	7.633	145.00	185.00	58.258
BMI	25.44	4.638	14.99	34.72	21.515
No. of pregnancies	1.82	2.130	0	13	4.538
No. of live births	1.56	1.684	0	10	2.837
CCD angle (°)	130.13	4.793	116.19	143.11	22.974
Osteoarthritis at L3 to L5 (composite score; adapted from Steckel et al., 2006)	4.59	1.763	3.00	9.00	3.109

TABLE 3 Regression formulas to evaluate the association between pelvic features, live births, and body variables of individuals younger than 45 years

	Partial regression coefficient					
Dependent variable	No. of live births	Age	Body height	Body weight	CCD angle	Adjusted R^2
Preauricular sulcus stage	0.5509 ($p = 0.1560$)	0.6666	−0.3170	−0.0599	−0.5704	0.0460
Sacral preauricular extension	0.5208 ($p = 0.0826$)	−0.1537	0.0912	0.1540	0.2498	0.0354
Ventral pubic lesions	0.0678 ($p = 0.8977$)	−0.1493	0.0145	0.4230	0.2328	0.0202
Sharp exostoses at the pectineal line	−1.6927 ($p = 0.1309$)	2.3293	1.5649	−0.6195	0.6698	0.2862
Dorsal pubic pitting	0.4918 ($p = 0.0002$)	0.0289	0.0849	−0.1658	0.0532	0.1171

Note: All *p* values were Bonferroni–Holm corrected.

(Tables 3 and S7), we developed a path model for this pelvic feature to estimate the direct causal effects of the variables (Figure 2). Age and the number of births, independent of age, positively affected dorsal pubic pitting expression, but the direct effect of the number of births was more than three times as strong as that of age (0.72 vs. 0.21). Age had positive effects on the number of births and body weight, but neither body weight nor height had considerable effects on feature expression.

We also used dorsal pubic pitting for predicting the number of live births. The best model was achieved when using a quantitative measure of the size of the dorsal pubic pitting (geometric mean of maximal depth, width, and height). As in the above results, the prediction of births in individuals younger than 45 years yielded a higher R^2 than for the whole sample ($R^2 = 0.2372$ and $R^2 = 0.1814$, respectively). Hence, we tested if the regression model differs between the two age groups by a multiple regression of the number of births on the size score, a dummy variable encoding the age group, and an interaction term. Both the dummy variable and the interaction term had small and nonsignificant coefficients, indicating that the regression does not differ between the age groups despite the heteroscedasticity of the residuals (Table S8). The scatter plot (Figure 3) confirms that the older individuals vary more around the regression line but do not seem to differ in their association from the younger individuals. Therefore, we used the full sample for the prediction but excluded one individual with no dorsal pubic pitting and 10 births because it was a clear outliner with regard to the number of children. This resulted in an adjusted R^2 of 0.1743 ($p < 0.001$) for the number of birth and a regression slope of $\beta = 0.8289$ (Tables 4 and S9). The leave-one-out cross-validation yielded an R^2 of 0.1805 (root mean square error = 0.7754, mean absolute error = 0.5825). The relatively low R^2 is also reflected by the wide prediction bands in Figure 4 and indicates that the number of births cannot be predicted well for single individuals.

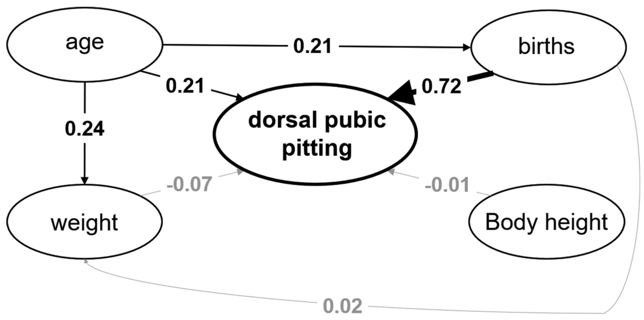

FIGURE 2 Path models showing the effects of the different variables on dorsal pubic pitting in females younger than 45 (adjusted $R^2 = 0.205$). The values on the paths are standardized regression coefficients, which quantify the direct causal effect of this variable (estimated via multiple regressions). Paths with a coefficient smaller than 0.1 are shown in gray

4 | DISCUSSION

4.1 | Dorsal pubic pitting: A scar of parturition

Parturition scars have been excessively studied in anthropology to prove an association with parity, but most of these studies did not

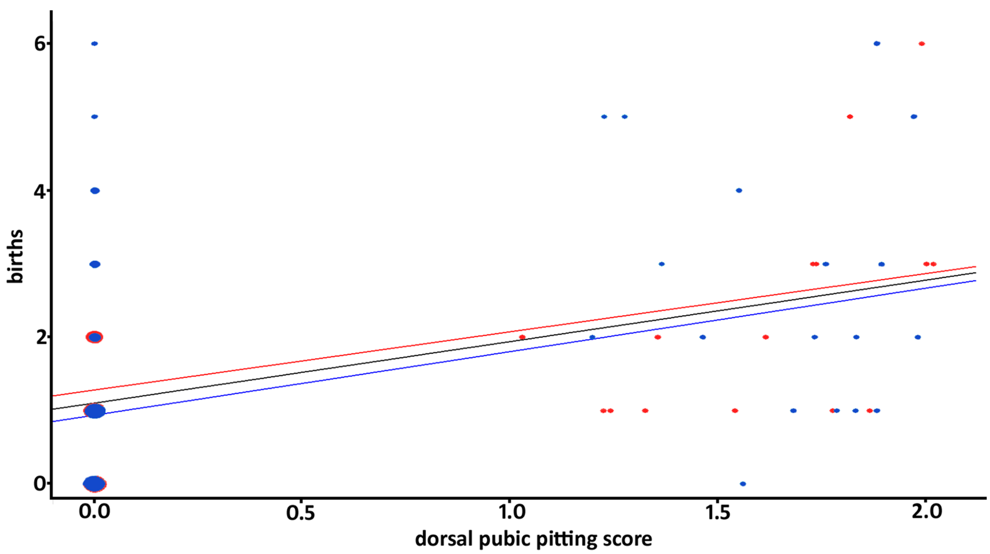

FIGURE 3 Scatterplot of the number of births against the dorsal pubic pitting score. The regression lines indicate the association of these variables within the whole sample (black), females younger than 45 years (red line and red dots), and females older than 45 years (blue line and blue dots) [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 4 Regression formulas for the estimation of the number of live births

	β		
Dependent variable	Dorsal pubic pitting	Intercept	Adjusted R^2
No. of live births	0.8289 ($p < 0.001$)	1.1028	0.1814 ($p < 0.001$)

Note: All *p* values were Bonferroni–Holm corrected.

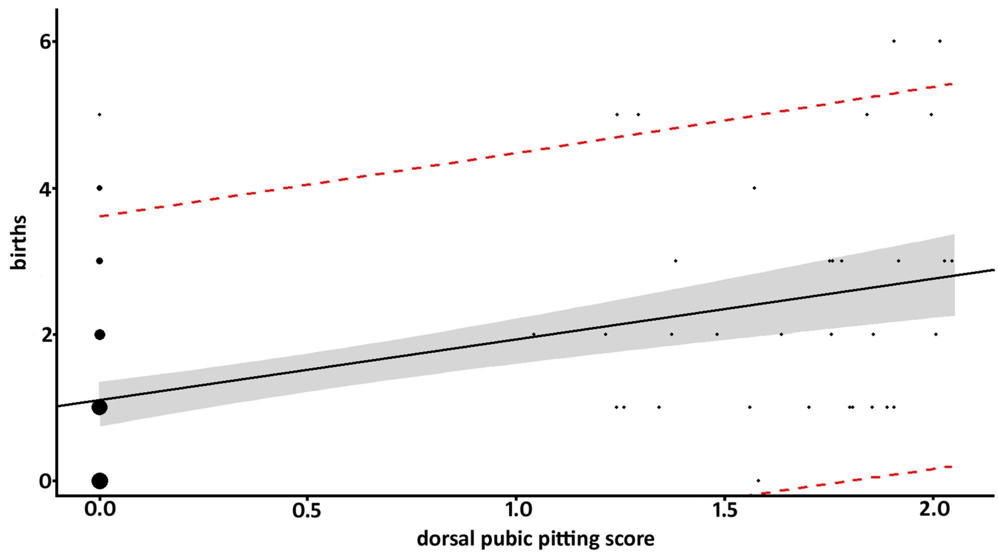

FIGURE 4 Scatterplot of the number of births versus the size score of dorsal pubic pitting. The solid line represents the linear regression (Table 3), the gray area the 95% confidence band, and the red dotted curves the 95% prediction band [Colour figure can be viewed at wileyonlinelibrary.com]

include data on parity and thus could not apply appropriate statistical methods. In consequence, the causes of parturition scars have remained largely unknown (Jugert et al., 2018; Maass, 2012; McLaughlin & Cox, 1989; Ubelaker & De La Paz, 2012). By using multiple regression in a well-documented sample, we found only dorsal pubic pitting significantly associated with the number of live births, whereas for all other features, the association with birth was weak and nonsignificant. This is in line with the results presented in previous studies (Snodgrass & Galloway, 2003; Suchey et al., 1979), although no prediction model for parity was presented in these studies. The expression of the preauricular sulcus and the extended pubic tubercle clearly increased with age, independent of the number of births.

Despite the significant association of dorsal pubic pitting with the number of births, the actual mechanisms that lead to the development of this pelvic feature are unclear, especially as several multipara in our sample did not exhibit dorsal pubic pitting. In addition to the birth process, other factors such as birth trauma, obstructed birth, or the increased hormone levels during pregnancy may contribute to pelvic feature formation. The posterior pubic ligament, which inserts at the dorsal side of the pubis just above dorsal pubic pitting, is the thinnest and weakest of all pubic ligaments (Vsianska, 2007). Hence, stress to these ligaments can lead to inflammation, hypertrophy, and cyst formation which may be related to the development of pubic pitting (Ashworth et al., 1976; Becker et al., 2010; Kamieth & Reinhardt, 1955). Another factor contributing to dorsal pubic pitting development might be pelvic floor damage. During birth, the levator ani muscle, which originates at the dorsal pubis, is stretched to up to 3.5 times its size (Ashton-Miller & DeLancey, 2007; Ashton-Miller & DeLancey, 2009; Dietz & Lanzarone, 2005; Lien et al., 2004; Svabik et al., 2009). In consequence, pelvic floor damage and a partial or complete rupture of the levator ani often occur at the pubic side, especially during the first birth (Ashton-Miller & DeLancey, 2007; DeLancey et al., 2003; Miller et al., 2010; Weidner et al., 2006). Besides mechanical strain, parturition scars might also be associated with steroid hormones, especially estrogen, which strongly affects bone metabolism and accounts for the sexually dimorphic pelvic growth during puberty (Coleman, 1969; LaVelle, 1995; Rogol et al., 2002). Pelvic features can be first seen in teenagers (Rebay-Salisbury et al., 2018; Waltenberger, Rebay-Salisbury, & Mitteroecker, 2021) and increase in expression during the reproductive period. In this period, pelvic shape also remodels to a more gynecoid pelvis, presumably due to increased estrogen production during pregnancy (Fischer et al., 2021; Fischer & Mitteroecker, 2017; Huseynov et al., 2016; Kjeldsen et al., 2021; Waltenberger, Rebay-Salisbury, & Mitteroecker, 2021).

All the statistical associations between pelvic feature expression and the other variables were stronger in individuals younger than 45 years as compared with the older individuals. Presumably, the altered bone metabolism after menopause and the reduction of bone mineral density during pregnancy and lactation increase variation in pelvic form and make the pelvis more susceptible to biomechanical influences (Affinito et al., 1996; Kent et al., 1990; Pearson et al., 2004; Prentice, 1994; Purdie et al., 1988; Sowers, 1996). Also, in our regression models, age influenced dorsal pubic pitting independent of birth, suggesting that dorsal pubic pitting remodels during lifetime. Hence, the development of dorsal pubic pitting is not a punctual event. Birth traumata can permanently damage tissue in this area, and pubic symphysis laxity permanently increases strain to the adjacent soft tissue. Differences in bone metabolism and mineral density may have variable effects on dorsal pubic pitting in different women, especially in older ages. Future studies, especially histological studies, are needed to further assess the association of the pelvic floor and the posterior pubic ligament with dorsal pubic pitting. If dorsal pubic pitting is indeed related to pelvic floor damage, this would have the potential to evaluate the risk of pelvic floor disorders on dry bone material.

Sharp exostoses predominantly occurred in individuals older than 45 years and thus were largely associated with age in our sample. The effect of the number of births was about half in magnitude compared

TABLE 5 The predicted number of births for three groups with different expression of dorsal pubic pitting

	Group 1: No dorsal pubic pitting ($n = 18$)	95% confidence interval	Group 2: Dorsal pubic pitting score smaller than 1.5 ($n = 10$)	95% confidence interval	Group 3: Mean dorsal pubic pitting score larger than 1.5 ($n = 13$)	95% confidence interval
Predicted number of births	1.10	0.810–1.396	2.17	1.813–2.539	2.65	2.133–3.157
True number of births	1.28	-	2.10	-	2.61	-

Note: For all individuals, the expression of pelvic features was averaged across left and right sides. The number of births was predicted using the regression model of Table 3.

with the age effect. This suggests that sharp exostoses are probably related to age-dependent calcification of the Cooper's ligament, presumably as a result of biomechanical strain during lifetime. Sharp exostoses commonly occur at the lateral portion of the pectineal line, where the Cooper's ligament is the thinnest (Miranda, 2014). However, sharp exostoses are difficult to assess and to score because they vary considerably in morphology, ranging from a small exostosis to a sharp crest that covers large areas of the pectineal line. All this makes the sharp exostosis not ideal for estimating parity from skeletal remains.

4.2 | Estimating parity from pelvic features

Based on the measured dimensions of the dorsal pubic pitting, we developed a regression model to estimate the number of birth events. The estimated average number of births clearly related to dorsal pubic pitting size, but the individual variation in parity around this mean estimate was large and increased with age. The explained variance of the model was not high enough to estimate parity for single skeletal remains as needed for disaster victim identification and forensic cases. For older individuals, the prediction error was even higher.

Despite the inability to estimate *individual* parity, the model may still be useful to estimate the *average* parity in a group of individuals. To illustrate this, we selected a random subset of individuals with no dorsal pubic pitting ($n = 18$), a low degree of dorsal pubic pitting (score ≤ 1.5; $n = 10$), and deep dorsal pubic pitting (score > 1.5; $n = 13$). We estimated the mean number of births for each group based on dorsal pubic pitting size (cf. the prediction formula in Table 4) and compared these estimates to the actual average number of births in these three groups. Overall, the estimated mean number of births was remarkably close to the actual mean number of births, with deviations of −0.18 births (no dorsal pubic pitting), +0.07 births (weak dorsal pubic pitting), and +0.04 births (deep dorsal pubic pitting) between predicted and true mean number of births (Table 5).

The literature has documented different frequencies of dorsal pubic pitting in different historic and archeological populations (e.g., Cox, 1989; Maass, 2012; Rebay-Salisbury et al., 2018; Waltenberger, Pany-Kucera, et al., 2021). Our model can be used to estimate and compare the average parity in these groups. However, the model needs to be tested on historic anatomical collections with known obstetrical recordings and on samples of different modern populations. Different lifestyles and obstetric practices, including cesarean sections, may influence the expression of pelvic features.

In conclusion, we showed that only dorsal pubic pitting may be considered a true parturition scar. Other pelvic features are primarily caused by factors unrelated to childbirth. Measures of dorsal pubic pitting expression do not allow for a reliable prediction of parity for single skeletal remains, but it may be used to estimate the average parity in different human groups.

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CONFLICT OF INTEREST

The authors do not have a conflict of interest to declare.

AUTHOR CONTRIBUTIONS

L.W. is responsible for project design, data collection, data analysis, manuscript drafting, editing, and revision. P.M. is responsible for project design, data analysis, manuscript editing, revision, and project supervision. K.R.-S. is responsible for manuscript editing, revision, project supervision, and funding.

DATA AVAILABILITY STATEMENT

Based on the regulations of the NMDID, no raw data from the database may be distributed. NMDID case numbers of individuals used in this study and the expression of pelvic features for each case are available upon request.

ORCID

Lukas Waltenberger https://orcid.org/0000-0002-9670-6117
Katharina Rebay-Salisbury https://orcid.org/0000-0003-0126-8693
Philipp Mitteroecker https://orcid.org/0000-0002-5308-3837

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