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Research Article

Archives of Biology & Life Sciences

Pelvic Scarring: A Result of Gravidity and Parity, or Simply Evidence of Biological Potential?

Georgina Ives[1]*, Sarah E. Johns[2] and Chris Deter[3]

[1]*The School of anthropology and Conservation at the University of Kent, Canterbury, Kent, UK and the School of Sciences at the University of Bath Spa, Bath, UK*

[2]*The Kent and Medway Medical School, Pears Building, Parkwood Road, Canterbury, Kent, UK and Birthrights, Lise Meitner Research Group, Max Planck Institute for Evolutionary Anthropology, Leipzig, Germany*

[3]*The School of Chemistry and Forensic Science at the University of Kent, Canterbury, Kent, UK*

Corresponding Author
Georgina Ives, School of Anthropology and Conservation at the University of Kent, Canterbury, Kent, UK.

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Abstract

Background

Despite extensive research in recent decades, the association between pelvic scarring and obstetric events remains contentious, with discrepancies exacerbated by sample and methodological inconsistencies. This study revisits the investigation of a potential link between gravidity (pregnancy) and parity (childbirth) events and commonly observed scar sites on the modern pelvis using standardised analysis.

Method

A known sample from the Texas State Donated Skeletal Collection (TXSTDSC), comprising 169 females and 51 males, was utilised in the morphometric analysis of four key scar features around the pubic and auricular areas of the pelvis. Associations between each scar feature and obstetric events were examined within mixed-sex and female-only samples. Cross-tabulation and Chi-square analyses were utilised to assess simple scar occurrence, while potential associations with scar dimensions underwent Kendall's tau-B testing.

Results

Combined-sex analyses revealed significant associations between gravidity and parity, and all scar features but pubic tubercle extension ($p = <0.001 – 0.003$). However, associations decreased upon the removal of male samples, with statistical significance remaining for only the preauricular sulcus (gravidity: $p = 0.022$; parity: $p = 0.047$) and superior interosseous cavity (gravidity: $p = 0.002$; parity: $p = 0.004$).

Conclusion

Detailed analysis of results highlights that while the sulcus development is influenced by obstetric events, biological sex plays a more significant role in presence and severity. The superior cavity appears to be most influenced by the biomechanical stress caused by pregnancy and vaginal birth – thus making this feature of particular interest and warranting further investigation with consideration of clinical practice and osteological study.

Keywords: Osteology, Pelvic Scarring, Parturition, Gravidity, Obstetrics

1. Introduction

In recent decades, osteologists have focused on the theory that obstetric events can cause macroscopic alterations around the pubic and auricular joints, including the dorsal pubic surface, pubic tubercle, and both the preauricular and retroauricular areas of the ilium [1-4]. Early studies first highlighted the potential obstetric association as an explanation for observed pelvic scar dimorphism [5-8]. Further studies have since supplied evidence of dimorphic scar presentation, with multiple studies indicating obstetric events, most frequently parity, to be the cause of this variation [3, 7-9, 11, 18-20]. However, considerable research has cautioned against definitive obstetric association, suggesting alternative causes such as general variation in pelvic shape and size, or dimorphic pelvic flexibility [1, 3, 4, 14, 16, 18, 21-23].

1.1. The Basis of Obstetric Pelvic Scar Theory

Musculoskeletal strain during pregnancy can be directly related to foetal growth, impacting maternal posture and skeletal load-bearing, and placing stress on associated muscles and their attachment sites [24-26]. Studies reveal an increase in pelvic pain with pregnancy, particularly in the last trimester [27-31]. As the foetus grows, the anterior abdominal and pelvic floor muscles endure significant strain leading to potential osteological evidence of gravidity, with areas around the pubis serving as anchor sites for these muscles [32-34]. Pelvic girdle stability is primarily maintained by the pubic and sacroiliac joints [35]. Hormone-induced softening of associated ligaments leads to joint instability, microtrauma, and joint inflammation potentially resulting in cortical changes. Late pregnancy significantly strains the sacroiliac joint due to uterine shift and increased lower back and posterior pelvis pressure [36-38].

The birth process causes further acute stress, with significant pelvic changes required for successful vaginal delivery [36, 39]. Joint diastasis, particularly at the pubis, can result in traumatic joint distortion, while sacroiliac joint nutation increasing the diameter of the pelvic outlet further strains the sacroiliac joint [40-43]. Post-natal ligament tightening can lead to persistent malalignment of the sacroiliac joint, resulting in permanently increased ligament tension [44]. Additionally, the pelvic floor muscles undergo remarkable stretching during delivery, causing significant strain at the bone-muscle interface and potential for tearing and detachment [45-47].

1.2. Osteological Research

Ullrich [8] suggested an association between pubic pitting and parity (vaginal birth) history, but subsequent studies express caution in linking the two [1, 6, 8, 18, 19, 21, 48]. McArthur et al. and Snodgrass & Galloway partially supported Ullrich's findings, with Snodgrass & Galloway concluding that parity incidence and count were associated with pubic pitting in females under 50 [11, 23]. McArthur et al. observed a strong association for pubic pitting, but only with parity incidence. Waltenberger et al. noted positive pitting associations with parity count until age 40-45, although the predictive potential was limited [3, 4]. Initial preauricular studies by Houghton [7], Ullrich, and Kelley noted associations between sulcus development severity and parturition, with Igarashi et al. later confirming associations with both gravidity and parity up to age 40 [7, 8, 18, 20]. However, many studies have failed to replicate these findings consistently [1, 4, 11, 14. 19, 22].

Waltenberger et al., Ullrich Cox & Scott and Snodgrass & Galloway investigated the association between pubic tubercle extension and obstetric history [3, 4, 19, 23]. Ullrich suggested its utility in obstetric history interpretation, while Waltenberger et al. found associations with parity up to age 50 [3, 8]. Cox & Scott reported associations with parity incidence and count, later disputed by Snodgrass & Galloway and Waltenberger et al. [4, 19, 23]. Houghton posited parturition as a potential cause of bone loss at the site of interosseous ligament insertion, with Waltenberger et al.'s study detailing an association with parity at this site until age 50. However, other studies have found it unreliable as an obstetric indicator [1, 3, 4, 7].

1.3. Methodological Considerations

Early investigations by Houghton and Ullrich utilised samples lacking biological records - thus reliant on the accuracy associated with any osteological estimation methods used to identify biological groups [7, 8]. Some studies have since relied on information obtained from archaeological records for at least part of their sample, presenting the risk of factual inaccuracy [14, 19]. Similarly, some studies utilised modern anonymous autopsied samples, requiring the estimation of parity status through soft tissue assessment alone [1, 18, 48]. Canty used a subsample of scans from a CT repository, while Waltenberger et al. conducted an entirely scan-based study [3, 4, 14]. While these benefit from associated complete medical data, it should be noted that pelvic scarring can be difficult to identify radiographically [49, 50]. Furthermore, McFadden observed considerable methodological variation in pelvic scar studies, commenting on the difference in the number of scar sites assessed in each study and a variation in analysis methods across key sites [51]. This can hinder full cross-study comparison or even intra-study conclusions where different methods are utilised for individual scar sites.

1.4. Study Aims

To date, the association between obstetric events and osteological evidence lacks clarity, thus highlighting the need for further research addressing the methodological limitations of previous studies. Therefore, this research uses a modern skeletal sample with a comprehensive known biological history to apply uniform analysis methods across multiple key pelvic scar sites, adapting existing methods where necessary. This study will facilitate the development of more accurate and insightful conclusions regarding the aetiology of pelvic scarring, thereby contributing to our knowledge of obstetric biomechanics and refining osteological investigation techniques.

2. Materials and Methods

2.1. Skeletal Sample and Data Collection

This study involved the analysis of 169 adult females and 51 adult males from the Texas State Donated Skeletal Collection (TXSTDSC), following ethical approval from the University of Kent (ID: 2022164607329563). This collection provides access to a large modern American population with detailed personal data, including the number of pregnancies and births. In roughly one-third of cases, personal information is provided by the donor upon registration, with the remaining two-thirds reliant on next-of-kin knowledge [52]. However, the Forensic Anthropology Center at Texas State (FACTS) ensures high accuracy by accepting only family donations from close family members proven not to be estranged from the deceased [52].

Skeletal samples were excluded where bilateral pubic symphyseal or sacroiliac fusion was present, or skeletal trauma impeded the observation of all pelvic scar sites (n = 18). Data was typically collected from the left os coxa, with the right assessed where features on the left were too damaged to analyse or the associated pelvic elements were absent. The final sample included all 169 curated adult females that met the necessary criteria alongside a smaller sample of 51 adult males, to avoid complete sex bias in this study. This also allowed for more

even sampling across positive and negative obstetric groups, with only 34.1% of females having never been pregnant. Unfortunately, ancestral variation was limited, with almost 90% of the individuals in the sample being white - representative of the ancestry bias of the skeletal collection highlighted by Gocha et al. [52]. Table 1 below presents the number of individuals in each obstetric subsample group.

Table 1: Obstetric Group Demographics

Sample Group	N
Full sample	220
Gravid	126
Nulligravid (full sample)	94
Nulligravid (female-only)	43
Parous	121
Nulliparous (full sample)	99
Nulliparous (female-only)	48
Comparative male sample	51

2.2. Pelvic Scar Analysis

2.2.1. Dorsal Pubic Pitting

When assessing pitting on the dorsal pubic surface, the process outlined by Waltenberger et al. was used. Maximum pit width was recorded as the widest point of indentation perpendicular to the symphyseal surface. Meanwhile, depth was measured using the calliper rod as the maximum distance from the dorsal pubic surface to the bottom of the deepest pit [3, 4, 16]. Pitting length was recorded as the full expansion of the pit parallel to the symphysis (see Figure 1). In the case of multiple independent pits, length was recorded across all pits, as well as the longest pit separately.



Figure 1: The Dorsal Pubic Surface of the Left os Coxa Featuring a Single Large Pit. The White Line Represents Pit Length, and the Yellow Line Indicates Width.

2.2.2. Preauricular Sulcus

Width and depth measurements of the preauricular sulcus were recorded as outlined by Maass [2]. Width was measured at the widest point perpendicular to the anterior edge of the auricular surface, and sulcus depth was recorded as the difference between the unaffected preauricular surface and the deepest point of the sulcus floor. As first detailed in the research of Ives et al. an additional length measurement was taken of the depression as it runs parallel to the auricular surface (see Figure 2) [17]. Note that where the depression of the preauricular sulcus is exceptionally shallow, it may be difficult to perceive through visual observation. However, the perimeter should still be palpable and traceable to facilitate measurement.

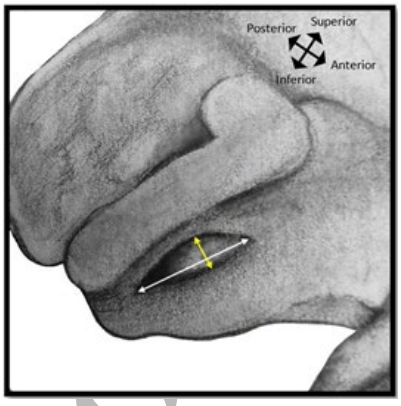


Figure 2: The Auricular Surface of the Left Os Coxa Featuring a Preauricular Sulcus. The White Line Represents Length, and the Yellow line Indicates Width.

2.2.3. Pubic Tubercle Extension

The methodology developed by Snodgrass & Galloway was followed with minimal deviations in the analysis of pubic tubercle extension [23]. A single measurement was recorded as the maximum distance of the centre of the tubercle extension apex from the line of the natural pubis curve (see Figure 3). However, in contrast to most previous research, this study preserves metric readings and avoids using generalised descriptive categories.

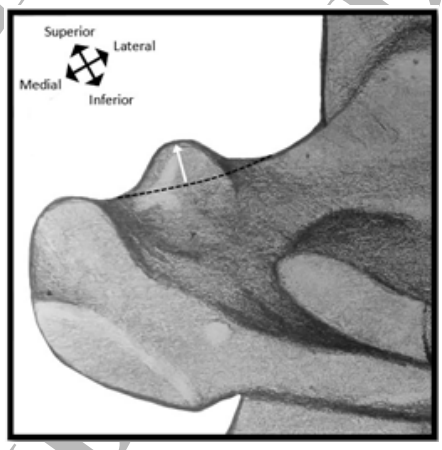


Figure 3: Anterior View of The Left Pubis Featuring A Large Pubic Tubercle. The Black Dashed Line Indicates the Natural Pubis Curve from Which the White Line Presents the Maximum Extension Measurement to The Tubercle Apex.

2.2.4. Interosseous Cavitation

The study of interosseous scarring typically involves the assessment of the width and depth of the full attachment site of the interosseous ligament [2, 4, 7, 8, 16]. However, this research focuses solely on the cavity formed by auricular surface lipping at the dorsal edge(s) (see Figure 4) as conducted by Ives et al. [17]. Measurement of cavity length reflects Maass' method, by accounting for the entire length of the inferior ramus cavity. In this study, length measurement was also taken along the superior dorsal edge in cases where cavitation continued. Note that where this does occur, it always follows a small hiatus [17]. In terms of cavity depth and width, both are determined by the auricular lipping. Even in minor cases, cavity width can be ascertained by measuring the space between the retroauricular floor and auricular lipping. Meanwhile, depth is defined as the measurement from the edge of the auricular lip to the deepest point of the cavity (see Figure 4). When cavitation is particularly shallow or narrow, minor interruptions in cavitation along the inferior or superior lengths may occur, but for the purpose of simplifying maximum length measurements, these were disregarded.

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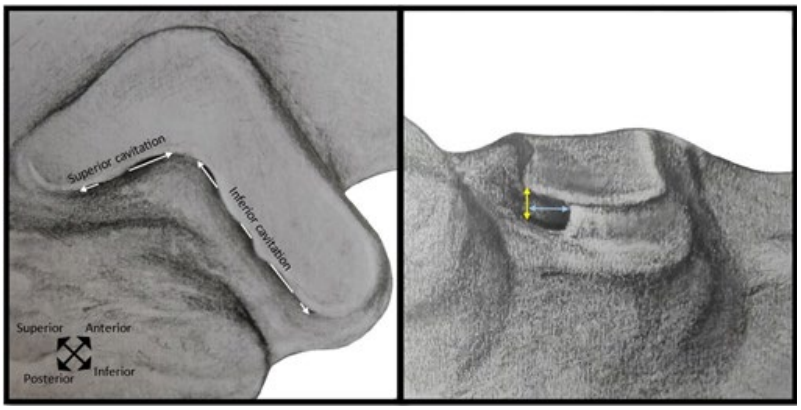


Figure 4: Diagrams Showing Cavitation on The Left Auricular Surface - Medial View (Left) And Inferior View (Right). The Left Illustration Indicates Superior and Inferior Length Measurements, Represented by White Lines. The Adjacent Illustration Shows the Inferoposterior View of The Inferior Cavity, From the Base of The Auricular Demiface Apex. This Image Indicates Width (Yellow) And Depth (Blue) Measurement

2.3. Statistical Analyses

All analyses were conducted using IBM SPSS Statistics version 28, and results were considered significant at $p < 0.05$. Although inter-observer study was not possible as part of this research due to time and logistical constraints, diligent intra-observer testing was conducted. This involved analysis of the first ten percent of the skeletal sample one week after the initial recording before continuing analysis for the remaining 200 cases. Secondary intraobserver measures were taken blind to the original results, and the difference between the two sets was assessed using Cronbach's Alpha internal consistency test [53]. Phi was interpreted based on the criteria established by Rea & Parker as follows: negligible (<0.099), weak (0.1 - 0.199), moderate (0.2 – 0.399), moderately strong (0.4 – 0.599), strong (0.6 – 0.799), and very strong (>0.8). Data was cross-tabulated, and Chi-square ($\chi 2$) with Phi (φ) analyses were performed to quantify associations between binary obstetric group variables and scar feature presence. Kendall's Tau-b (τb) testing was used to investigate relationships between obstetric events and scar measurements, with significant correlations classified as strong at 0.3+ [54, 55]. The data satisfied all necessary test assumptions for each analysis.

3. Results

3.1 Intra-Observer Testing

Repeat measure testing for all scar variables across all 20 cases produced a maximum pair difference of 6.15mm but an average difference of just 0.06mm. A test of internal consistency subsequently produced a high Cronbach's Alpha ($\alpha = 0.999$), reflecting excellent consistency between test pairs and high measurement precision [56]. This is further evident in Table S1, which presents the intra-observer results as mean values for each scar measurement variable.

3.2. Descriptive Statistics

Table 2 provides the descriptive statistics for the scar feature measurements within each obstetric group, including gravid, nulligravid (mixed-sex and female-only), parous, and nulliparous (mixed-sex and female-only). Please note that standard minimum value data is absent, as this value is consistently 0.0mm across all subgroup measurement variables - except for pubic tubercle extension in nulligravid and nulliparous female groups, at 0.62mm.

Table 2: Scar Measurement Data for Obstetric Groups, Including Mixed-Sex and Female-Only Results for Negative Groups and The Comparative Male Sample

Measurement variable	Gravid (n = 126)			Nulligravid (mixed-sex) (n = 94)			Nulligravid (females) (n = 43)			Parous (n = 121)			Nulliparous (mixed-sex) (n = 99)			Nulliparous (females) (n = 48)			Males only (n = 51)		
	Max (mm)	Mean (mm)	Std. dev	Max (mm)	Mean (mm)	Std. dev	Max (mm)	Mean (mm)	Std. dev	Max (mm)	Mean (mm)	Std. dev	Max (mm)	Mean (mm)	Std. dev	Max (mm)	Mean (mm)	Std. dev	Max (mm)	Mean (mm)	Std. dev
Pit length – Single	18.78	1.82	4.021	15.97	0.55	2.193	15.97	0.75	2.605	18.78	1.82	4.021	15.97	0.61	2.27	15.97	0.84	2.692	9.45	0.44	1.878
Pitting length – Multi	26.36	2.42	5.281	15.97	0.64	2.389	15.97	0.69	2.534	26.36	2.45	5.281	15.97	0.69	2.458	15.97	0.79	2.632	9.45	0.55	2.211
Pitting width	6.47	0.91	1.743	3.01	0.21	0.632	3.01	0.32	0.778	6.47	0.92	1.743	4.29	0.24	0.741	4.29	0.38	0.939	2.43	0.11	0.462
Pitting depth	4.54	0.47	0.927	1.91	0.12	0.38	1.91	0.19	0.472	4.54	0.48	0.927	1.91	0.13	0.394	1.91	0.2	0.485	1.34	0.07	0.267
Sulcus length	52.52	25.29	9.647	54.06	13.79	11.75	54.06	20.4	11.75	52.52	25.35	9.647	54.06	14.3	11.7	54.06	20.75	11.25	26.23	8.23	8.462
Sulcus width	18.75	6.6	2.888	12.13	3.45	3.388	12.13	5.75	3.525	18.75	6.6	2.888	12.13	3.6	3.429	12.13	5.82	3.474	5.26	1.52	1.594

Sulcus depth	4.76	1.62	1.01	3.55	0.89	0.872	3.55	1.28	0.902	4.76	1.63	1.01	3.55	0.92	0.874	3.55	1.31	0.883	3.54	0.55	0.695
Superior cavity length	29.24	4.61	6.678	22.66	1.58	4.535	22.66	2.28	6.044	29.24	4.72	6.678	22.66	1.6	4.456	22.66	2.26	5.774	11.27	0.99	2.605
Superior cavity width	4.61	0.7	1.047	2.87	0.24	0.618	2.87	0.28	0.733	4.61	0.7	1.047	2.87	0.26	0.634	2.87	0.32	0.747	1.90	0.2	0.505
Superior cavity depth	4.37	0.61	1.022	2.41	0.16	0.435	1.47	0.14	0.384	4.37	0.62	1.022	2.41	0.17	0.437	1.47	0.16	0.396	2.41	0.18	0.477
Inferior cavity length	36.62	20.61	7.683	36.44	17.21	9.765	36.44	20.8	8.291	36.62	20.84	7.683	36.44	17.11	9.779	36.44	20.22	8.644	32.18	14.18	9.959
Inferior cavity width	7.51	2.76	1.265	6.04	1.75	1.15	6.04	2.5	1.18	7.51	2.79	1.265	6.04	1.77	1.165	6.04	2.42	1.203	2.40	1.16	0.715
Inferior cavity depth	7.94	2.96	1.754	6	1.64	1.434	6	2.58	1.47	7.94	3.01	1.754	6	1.65	1.426	6	2.52	1.46	2.86	0.84	0.773
Pubic tubercle exten-sion	8.31	3.07	1.695	9.18	3.72	1.642	9.18	3.4	1.862	8.31	3.11	1.695	9.18	3.65	1.636	9.18	3.28	1.8	7.52	4	1.392

3.3. Non-Metric Analysis

Tables 3 and 4 provide data on the presence of each scar feature in association with gravidity and parity across the complete sample and the female-only sample. Analysis indicated multiple significant moderate associations between feature presence and both obstetric events in the combined sex sample, with the exclusion of pubic tubercle presence, which was not statistically significant. The preauricular sulcus presence was most strongly associated with gravidity ($\chi2(1) = 29.777$, $\varphi = 0.368$), present in 96% of gravid individuals, but also 69.1% of nulligravid individuals (including biological males). The same feature also presented the strongest relationship with parity ($\chi2(1) = 26.381$, $\varphi = 0.346$), appearing in 95.9% of parous individuals and 70.1% of nulliparous.

The number and strength of associations between feature presence and obstetric events were considerably reduced upon the removal of the male sample. In the female-only sample, only preauricular sulcus and superior cavity presence were significantly associated with gravidity and parity. Sulcus presence and gravidity for the female group were weakly associated ($\chi2(1) = 5.253$, $\varphi = 0.176$). 86% of nulligravid females had evidence of a preauricular sulcus, compared to 96% of gravid females. The association between sulcus presence and parity was further reduced ($\chi2(1) = 3.954$, $\varphi = 0.153$). Where almost 96% of parous females presented with a preauricular sulcus, so did 87.5% of nulligravid females. Notably, these results demonstrated a weaker relationship than observed between obstetric events and any of the significantly associated features for the mixed-sex group.

Superior interosseous cavitation was most strongly related to obstetric events in females. The association between superior cavitation and female gravidity was moderate ($\chi2(1) = 9.579$, $\varphi = 0.238$). This feature was present in 39.7% of gravid females and 14% of nulligravid females. Chi-square analysis of parity groups indicated a moderate but reduced association with superior cavitation presence ($\chi2(1) = 8.207$, $\varphi = 0.22$). Parous individuals were, again, more likely to have the feature (39.7%) than nulliparous (16.7%), but the difference between positive and negative groups was reduced compared to female-sample gravidity analysis. Furthermore, despite presenting the strongest obstetric associations for the female-only groups, superior cavitation associations were weaker than two of four feature relationships (including superior cavitation) for the mixed-sex sample in both obstetric groups.

3.4. Metric Analysis

All scar feature measurements significantly correlated with gravidity and parity in the mixed-sex sample (see Table 5). Most correlations were at least moderate across both gravidity and parity analyses ($\tau b > 0.2$), excluding single pit length, inferior cavity length, tubercle extension, and the addition of multi-pit length in the assessment of parity. All preauricular sulcus measurements and all but the length measurement for the inferior interosseous cavity were strongly associated with both obstetric variables – with the maximum sulcus length value providing the strongest correlation across both (gravidity = τb 0.399; parity = τb 0.387). However, the number of significant correlations was again reduced for the female-only sample for both gravidity and parity analyses. Of those that remained statistically significant, correlations were classified as low to moderate in strength. Only the superior cavity depth values proved to be moderately correlated with gravidity and parity status in the female-only sample (τb 0.226 and 0.216, respectively).

Table 3: Cross-Tabulated Data for Individual Feature Occurrence – Presenting Full and Female-Only Results for Obstetric Groups Alongside the Comparative Male-Only Sample

		Gravidity				Parity				Male-only Sample (n = 51)	
		Full Sample (n = 220)		Female-only Sample (n = 169)		Full Sample (n = 220)		Female-only Sample (n = 169)			
Pelvic scar feature		Feature absent	Feature present	Feature absent	Feature present	Feature absent	Feature present	Feature absent	Feature present	Feature absent	Feature present
Dorsal pubic pitting	Negative Group*	84 (89.4%)	10 (10.6%)	36 (83.7%)	7 (16.3%)	88 (88.9%)	11 (11.1%)	40 (83.3%)	8 (16.7%)	n/a	
	Positive Group*	92 (73%)	34 (27%)	92 (73%)	34 (27%)	88 (72.7%)	33 (27.3%)	88 (72.7%)	33 (27.3%)		
	Total	176 (80%)	44 (20%)	128 (75.7%)	41 (24.3%)	176 (80%)	44 (20%)	128 (75.7%)	41 (24.3%)	48 (94.1%)	3 (5.9%)
	Correctly Predicted	118 (53.6%)		70 (41.4%)		121 (55%)		73 (43.2%)		n/a	
Preauricular sulcus	Negative Group*	29 (30.9%)	65 (69.1%)	6 (14%)	37 (86%)	29 (29.3%)	70 (70.7%)	6 (12.5%)	42 (87.5%)	n/a	
	Positive Group*	5 (4%)	121 (96%)	5 (4%)	121 (96%)	5 (4.1%)	116 (95.9%)	5 (4.1%)	116 (95.9%)		
	Total	34 (15.5%)	186 (84.5%)	11 (6.5%)	158 (93.5%)	34 (15.5%)	186 (84.5%)	11 (6.5%)	158 (93.5%)	23 (45.1%)	28 (54.9%)
	Correctly Predicted	150 (68.2%)		127 (75.1%)		145 (65.9%)		122 (72.2%)		n/a	
Superior interosseous cavity	Negative Group*	80 (85.1%)	14 (14.9%)	37 (86%)	6 (14%)	83 (83.8%)	16 (16.2%)	40 (83.3%)	8 (16.7%)	n/a	
	Positive Group*	76 (60.3%)	50 (39.7%)	76 (60.3%)	50 (39.7%)	73 (60.3%)	48 (39.7%)	73 (60.3%)	48 (39.7%)		
	Total	156 (70.9%)	64 (29.1%)	113 (66.9%)	56 (33.1%)	156 (70.9%)	64 (29.1%)	113 (66.9%)	56 (33.1%)	43 (84.3%)	8 (15.7%)
	Correctly Predicted	130 (59.1%)		87 (51.5%)		131 (59.5%)		88 (52.1%)		n/a	
Inferior interosseous cavity	Negative Group*	12 (12.8%)	82 (87.2%)	2 (4.7%)	41 (95.3%)	12 (12.1%)	87 (87.9%)	2 (4.2)	46 (95.8%)	n/a	
	Positive Group*	2 (1.6%)	124 (98.4%)	2 (1.6%)	124 (98.4%)	2 (1.7%)	119 (98.3%)	2 (1.7%)	119 (98.3%)		
	Total	14 (6.4%)	206 (93.6%)	4 (2.4%)	165 (97.6%)	14 (6.4%)	206 (93.6%)	4 (2.4%)	165 (97.6%)	10 (19.6%)	41 (80.4%)
	Correctly Predicted	136 (61.8%)		126 (74.6%)		131 (59.5%)		121 (72%)		n/a	
Pubic tubercle extension	Negative Group*	0 (0%)	94 (100%)	0 (0%)	43 (100%)	0 (0%)	99 (100%)	0 (0%)	48 (100%)	n/a	
	Positive Group*	3 (2.4%)	123 (97.6%)	3 (2.4%)	123 (97.6%)	3 (2.5%)	118 (97.5%)	3 (2.5%)	118 (97.5%)		
	Total	3 (1.4%)	117 (98.6%)	3 (1.8%)	163 (98.2%)	3 (1.4%)	117 (98.6%)	3 (1.8%)	163 (98.2%)	0 (0%)	51 (100%)
	Correctly Predicted	123 (55.9%)		123 (72.8%)		118 (53.6%)		118 (69.8%)		n/a	

†Groups: Gravidity (negative = nulligravid; positive = gravid), Parity (negative = nulliparous; positive = parous)

Table 4: Chi-Square and Phi Strength of Association Results for Each Scar Feature Occurrence, Comparing Full and Female-Only Results Across Gravidity and Parity Groups

Pelvic scar feature	Gravidity						Parity					
	Full Sample (n = 220)			Female-only Sample (n = 169)			Full Sample (n = 220)			Female-only Sample (n = 169)		
	Chi-square value ($\chi 2$)	Strength of association (φ)	Test significance (p)	Chi-square value ($\chi 2$)	Strength of association (φ)	Test significance (p)	Chi-square value ($\chi 2$)	Strength of association (φ)	Test significance (p)	Chi-square value ($\chi 2$)	Strength of association (φ)	Test significance (p)
Dorsal pubic pitting	8.99	.202	.003	1.999	.109	.157	8.889	.201	.003	2.104	.112	.147
Preauricular sulcus	29.777	.368	<.001	5.253	.176	.022	26.381	.346	<.001	3.954	.153	.047

Superior interosseous cavity	16.037	.27	<.001	9.579	.238	.002	14.587	.257	<.001	8.207	.22	.004
Inferior interosseous cavity	11.29	.227	<.001	1.302	.088	.254	10.014	.213	.002	.94	.075	.332
Pubic tubercle extension	2.269	-.102	.132	1.042	-.079	.307	2.488	-.106	.115	1.212	-.085	.271

Table 5: Kendall's Tau-B Correlation Results for All Scar Feature Measurements, Comparing Full and Female-Only Sample Gravidity and Parity Group Associations

	Gravidity				**Parity**			
	Full Sample (n = 220)		**Female-only Sample (n = 169)**		**Full Sample (n = 220)**		**Female-only Sample (n = 169)**	
Variable measurements (mm)	Correlation (τb)	sig. (*p*)	Correlation (τb)	sig. (*p*)	Correlation (τb)	sig. (*p*)	Correlation (τb)	sig. (*p*)
Maximum pit length – single	0.198	0.002	0.118	0.104	0.196	0.002	0.118	0.106
Maximum pit length – multi	0.2	0.002	0.121	0.097	0.199	0.002	0.122	0.094
Maximum pit width	0.207	0.001	0.122	0.094	0.204	0.001	0.121	0.096
Maximum pit depth	0.204	0.002	0.117	0.107	0.202	0.002	0.119	0.102
Maximum sulcus length	0.399	<.001	0.168	0.008	0.387	<.001	0.168	0.008
Maximum sulcus width	0.382	<.001	0.083	0.189	0.37	<.001	0.087	0.167
Maximum sulcus depth	0.329	<.001	0.122	0.055	0.315	<.001	0.116	0.068
Maximum superior cavity length	0.256	<.001	0.192	0.007	0.253	<.001	0.191	0.007
Maximum superior cavity width	0.248	<.001	0.198	0.005	0.237	<.001	0.184	0.01
Maximum superior cavity depth	0.258	<.001	0.226	0.001	0.251	<.001	0.216	0.002
Maximum inferior cavity length	0.136	0.014	-0.011	0.857	0.147	0.008	0.014	0.826
Maximum inferior cavity width	0.328	<.001	0.068	0.282	0.335	<.001	0.094	0.137
Maximum inferior cavity depth	0.324	<.001	0.074	0.24	0.331	<.001	0.101	0.109
Maximum pubic tubercle extension	-0.161	0.004	-0.048	0.45	-0.134	<.001	-0.017	0.79

4. Discussion

4.1. Combined Sex Analyses

In the initial non-metric analysis including both sexes, a significant association emerged between obstetric events and the presence of all scar features except pubic tubercle extension. The preauricular sulcus result proved most robust, accurately identifying the highest percentage of gravidity and parity groups, followed by the superior and then inferior interosseous cavities. However, these features were often observed in comparable percentages of positive and negative obstetric groups, echoing previous findings, thereby diminishing the predictive potential of scar occurrence analysis for obstetric events [1, 14, 21, 22, 48]. Significant correlations were also evident across all scar feature measurements. The preauricular sulcus displayed the strongest relationships with obstetric events, except for sulcus depth in parity assessment. In the case of parity groups, width and depth measurements of the inferior interosseous cavity produced higher correlations. These findings align with previous studies, emphasising obstetric-related strain around the sacroiliac joint and providing potential osteological evidence of posterior pelvic stress associated with pregnancy and birth [7, 8, 18, 20]. The remaining positive correlations at least partially corroborate additional prior obstetric investigations, all of which indicate scar severity increase at varying sites in connection with

obstetric events [3, 8, 11, 19]. The sole exception is pubic tubercle extension, where our results revealed a negative correlation with both gravidity and parity, contradicting the positive correlation observed by Waltenberger et al. and Cox & Scott [3, 19].

4.2. Female-only Analyses

The predictive power of binary scar analysis diminished across all scar features in the female-only group. Significance was retained only for the preauricular sulcus and superior interosseous cavity, with the latter presenting the strongest relationship - although this remains lower than evident in the full sample group. This indicates a primary relationship between all scar feature variables and biological sex. However, the persistent significance of the preauricular sulcus and superior interosseous cavity with obstetric events indicates further marginal obstetric influence. Similarly, metric analysis revealed a reduction in the strength and significance of all results across both gravidity and parity groups, with only preauricular sulcus and superior interosseous cavity measurements remaining significantly associated with obstetric events. Studies conducted previously by Andersen, Waltenberger et al., Stewart, Kelley, Cox & Scott, Suchey et al., Snodgrass & Galloway, and Holt provide support for the observed decline in significance across all other metric scar variables. Interestingly, these scar sites that are no longer significant correspond with key muscle attachment sites of the pelvis, suggesting that obstetric events may not exert sufficient tension to yield prolonged cortical changes [1, 3, 6, 18, 19, 21, 23, 48].

4.3. Biological Sex or Obstetric Events?

The consistent reduction in result significance between the full and female-only samples indicates a greater influence of biological sex across all scar variables. Specifically, dorsal pubic pitting, pubic tubercle extension, and inferior interosseous cavitation showed no significant association with obstetric events in the female-only sample, subsequently indicating an association with biological sex. Previous studies support this conclusion regarding dorsal pitting, the full attachment site of the interosseous ligament [1, 10, 12], and pubic tubercle extension [1, 10-12, 15, 17]. The latter studies also explain the inverse correlation with tubercle extension, noted in our complete sample results. The development of the preauricular sulcus also appears to be primarily influenced by biological sex, as supported by numerous studies [1, 7, 9, 10, 13-15, 17]. However, our findings suggest that obstetric events may increase the likelihood or severity of the preauricular sulcus in biological females, albeit to a lesser extent than biological sex.

As the only other study to analyse interosseous cavitation, specifically, Ives et al. also identified a strong association with biological sex. However, according to Ives et al. [17], inferior cavitation was more significant in the estimation of biological sex than superior cavitation - in support of general interosseous groove studies - although both were found to be positively correlated with female sex. Comparatively, our research presents an increase in superior cavity correlation beyond that identified in Ives et al.'s biological sex study, with particular emphasis on superior cavity depth. These results therefore indicate increased strain on the superior margin of the interosseous ligament during obstetric events, with the higher superior interosseous correlation values observed in the mixed-sex sample likely a product of biological sex and the more significant obstetric influence in combination [17].

5. Conclusion and Recommendations

Our comprehensive study highlights the relationships between pelvic scarring, biological sex, and obstetric events. This study identified significant links between obstetric events and most scar features in both sexes. However, when focusing on females, the predictive power of scar analysis decreased – remaining significant for only the preauricular sulcus and superior interosseous cavity. Further investigation concluded that the preauricular sulcus primarily reflects sexual dimorphism, but obstetric events may exacerbate its severity in females. The superior interosseous cavity shows a stronger correlation with obstetric events than biological sex, making it an area of potential interest in further osteological obstetric research.

These insights underscore the importance of considering both obstetric history and biological sex when interpreting pelvic scarring patterns. Through the observable impact on pelvic morphology, this research has identified the sacroiliac joint as the most significant area of biomechanical stress associated with pregnancy and birth, with emphasis on superior interosseous cavitation. However, it would be beneficial to investigate variation in pelvic scarring across multiple populations and any additional biological factors that may further influence scar morphology. Continuing these endeavours will enhance our understanding of pelvic biomechanics, assisting in the development of osteological practice across a range of contexts

Data Availability Statement

The primary data relevant to the key results presented in this research is available by request made to the first author directly.

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