

## RESEARCH ARTICLE

# Pregnancy parturition scars in the preauricular area and the association with the total number of pregnancies and parturitions

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## Abstract

**Objectives:** The aim of the present study was to clarify the association between the degree of development of pregnancy parturition scars (PPSs) and the total number of pregnancies and parturitions (TNPPs) on the basis of new identification standards for PPS in the preauricular area.

**Materials and Methods:** Preauricular grooves were macroscopically observed on the pelvises of 103 early modern males and 295 females (62 early modern females; 233 present-day females). Three categories of PPS in the preauricular area were defined. The association between the degree of development of PPS in the preauricular area and the TNPP was analyzed in 90 present-day females with detailed lifetime data.

**Results:** PPS could not estimate the exact TNPP. However, it was shown that no PPS indicated no TNPP, weak PPS indicated a lower TNPP, and developed PPS indicated a higher TNPP.

**Discussion:** Even though the possibility remains that some PPS indicate no TNPP, the results showed that the percentage of each PPS category indicated fertility in the population, suggesting that the strength of the association between the degree of development of PPS and the TNPP was affected by the classification system, the reliability of lifetime data, and the statistical methods used for analysis.

## KEYWORDS

fertility in prehistoric populations, Poisson dispersion test, preauricular area, pregnancy parturition scar, total number of pregnancies and parturitions

## 1 | INTRODUCTION

Bony imprints along the pubic symphysis and in the preauricular area on female pelvises have been of interest to many researchers. In the preauricular area, when present, the preauricular groove (PAG) is located between the ventral ridge of the auricular surface of the iliac bone and the upper margin of the greater sciatic notch. The PAG is

more common and pronounced in women, so it has been suggested to be an indicator of female sex (Buikstra & Ubelaker, 1994; Dee, 1981; Derry, 1911; Houghton, 1974, 1975; Maas & Friedling, 2016; MacLaughlin & Cox, 1989; Steckel, Larsen, Sciulli, & Walker, 2006), as have bony changes around the pubic symphysis (Maas & Friedling, 2016; MacLaughlin & Cox, 1989; McArthur, Meyer, Jackson, Pitt, & Larrison, 2016; Stewart, 1957; Todd, 1921). Other studies have

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suggested that the PAG is an indicator of pregnancy and parturition (Brothwell, 1981; Derry, 1911; Houghton, 1974, 1975; Saul & Saul, 1989), while others have suggested the same for bony changes around the pubic symphysis (Angel, 1969; Ashworth, Allison, Gerszten, & Pezzia, 1976; Brothwell, 1981; McArthur et al., 2016; Owsley & Bradtmiller, 1983; Saul & Saul, 1989; Schemmer, White, & Friedman, 1995); however, other studies have not supported this suggestion (Stewart, 1970; Todd, 1921). Moreover, some studies have classified variations in bony changes in the pelvis into stages, with numbers of parturitions allocated to each stage, allowing the number of parturitions of ancient females to be estimated (Nemeskeri, 1972; Phillipps, 1980; Pollock, 1987; Ullrich, 1975).

Putschar (1931, 1976) observed histological bony changes on the pubic symphysis during pregnancy and after parturition in cadavers who had died during pregnancy or just after parturition. He found that during pregnancy, the ligaments connecting the symphysis became swollen, probably under the influence of hormonal effects. He also found that just after parturition, some cysts were embedded among the ligaments. These cysts contained dead cartilage derived from interosseous cartilage that had been damaged during parturition. Thereafter, the cysts decomposed owing to metabolism. Many osteoblasts were recognized during pregnancy and just after parturition, which means that bone remodeling was active during these periods. On the basis of this observation, Putschar explained the process of the bony changes in the pubic symphysis as follows. During pregnancy, swollen ligaments are pressed onto the bone surface, which forms grooves. After parturition, cysts containing degenerated cartilage are pressed onto the bone surface, which forms pits. According to Putschar's study, both pregnancies and parturitions induce bony changes in the pubic bone. Putschar observed bony changes in the pubic symphysis, but at the same time, Abramson, Roberts, and Wilson (1934) showed that relaxation of the pelvic joint was normal in pregnancy, and Tsiaras (2002) showed that delivery produces separation of the sacroiliac joint and pubic symphysis. Matsuoka (2014) indicated that the ligaments around the sacroiliac joints and pubic symphyses are softened by hormones during pregnancy and after parturition. The findings of these studies indicated that similar changes occur around not only the pubic symphyses, but also the sacroiliac joints. Thus, the etiology of the PAG on female pelvis would be expected to be the same as Putschar's explanation.

At the same time, many scholars have attempted to confirm whether the degree of development of bony changes on the pelvis is associated with the number of pregnancies and/or parturitions. Some studies have concluded that the degree of development of the PAG is associated with the number of pregnancies or parturitions (Dunlap, 1979; Igarashi, 1992; Işcan & Dunlap, 1984; Kelley, 1979; Schemmer et al., 1995), while others have not (Cox & Scott, 1992; McFadden & Oxenham, 2018; Spring, Bender, & Lovejoy, 1984; Spring, Lovejoy, Bender, & Derr, 1989). In addition, some studies have concluded that the degree of bony changes on the pubic bone is associated with the number of pregnancies or parturitions (Bergfelder & Herrmann, 1980; Dunlap, 1979; Galloway, Snodgrass, & Suchey, 1998; Işcan & Dunlap, 1984; Kelley, 1979; McArthur et al., 2016; Snodgrass & Galloway, 2003; Suchey, Wiseley, Green, & Noguchi, 1979), while others have

not (Cox & Scott, 1992; Gilbert & McKern, 1973; Holt, 1978; McFadden & Oxenham, 2018).

If bony changes on the pelvis were found to be an indicator of the number of pregnancies and/or parturitions, the fertility of prehistoric groups could be estimated, which would allow population structures such as the pattern of fertility and longevity in prehistoric societies to be reconstructed.

However, although Putschar (1931, 1976) indicated that pregnancies and parturitions induce bony changes on the pubic bone, a variety of factors other than pregnancy and parturition would also affect the bony changes on female pelvis, so it is difficult to clarify the association between the degree of development of bony changes and the number of pregnancies and/or parturitions. Therefore, this association remains to be clarified.

On the basis of previous studies, we considered three primary factors that prevent this association from being clarified: the identification standard for bony changes, the reliability of fertility data, and the statistical methods. Therefore, we decided to develop new identification standards for bony changes, to attempt to improve the reliability of fertility data, and to adopt new statistical methods.

The aim of the present study was to elucidate the association between the degree of development of pregnancy parturition scars (PPSs) and the number of pregnancies and/or parturitions. We focus on PPS in the preauricular area because the degree of bony changes has been shown to be more prominent in the preauricular area than on the pubic bones (Houghton, 1974, 1975).

In a previous study, the first author had investigated the association between the degree of development of the PAG and the total number of pregnancies and parturitions (TNPPs) (Igarashi, 1992); however, in that study, there was an inadequate number of samples for ensuring the association. Therefore, in the present study, we increased the number of samples to perform new statistical analyses with reliable fertility data. After slightly revising Igarashi's (1992) definition of PPS in the preauricular area, we sought to clarify the association between the degree of development of PPS and the TNPP.

## 2 | MATERIALS AND METHODS

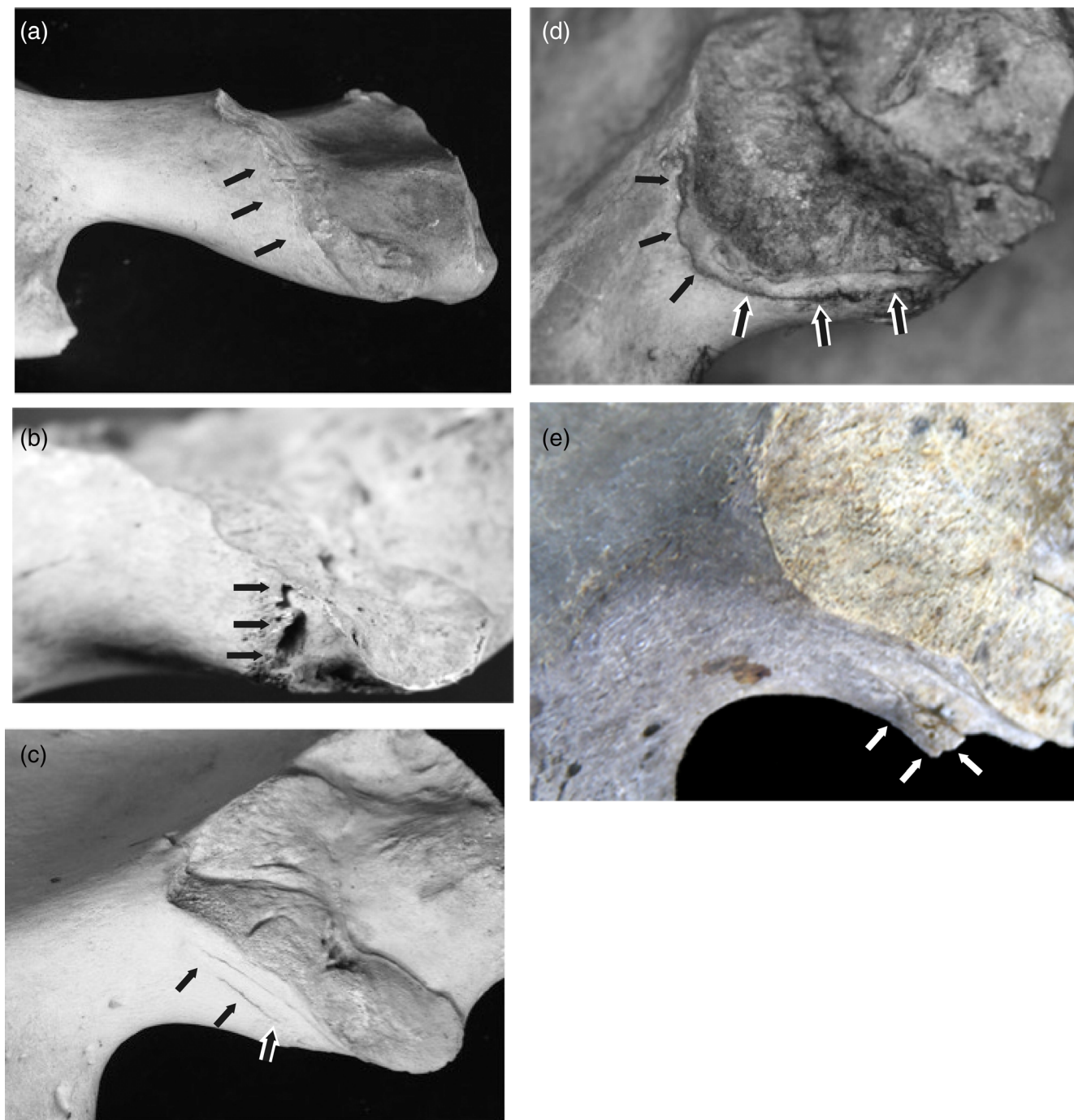
### 2.1 | Materials

The pelvises of 103 early modern males aged 14–81 years and 295 females (62 early modern females aged 14–74 years; 233 present-day females aged 49–106 years) were examined. The early modern samples were skeletal samples of individuals who died around AD 1900 in Tokyo Prefecture stored in the University Museum, University of Tokyo. The data available for analysis include name, sex, date of birth, date of death, and place where the individual died. The present-day samples are the pelvises of cadavers who donated their body for the practice of dissections in systematic anatomies from 1989 to 2016 to Nihon University School of Dentistry at Matsudo, Tohoku University School of Medicine, Osaka City University School of Medicine and Faculty of Medicine, Kansai Medical University, Showa University School of Medicine, Sapporo Medical University,

and Dokkyo Medical University. The data for these samples include name, sex, and dates of birth and death, and were recorded when they were registered at the associated university. The early modern samples were examined to establish new identification standards for bony changes, and the present-day samples were examined for the purpose of ascertaining the association between the degree of development of PPS and the number of pregnancies and/or parturitions.

## 2.2 | Definition of PPS

We aimed to establish a classification system that is objective, easy to understand, and easy to use. If metric data (length, breadth, and depth) are used, standardization according to the size of the pelvis is needed, so we selected a nonmetric classification system.



**FIGURE 1** (a) Type 1 preauricular groove (PAG). No bony changes in the preauricular area (arrows). (b) Type 3 PAG. Arrows show a pseudo depression surrounded by a bony ridge. The bottom is not below the bone surface. (c) Type 3 PAG. Arrows show a true depression, but the contour of this depression is not completely closed. (d) Type 3 PAG. Arrows show a true depression with a completely closed contour, but this groove runs parallel to the ventral edge of the auricular surface. (e) Type 3 PAG. Arrows show the spine with Type 3 PPS

We set up a classification system for PPS on the basis of examinations of the PAG in early modern individuals. In total, we examined 158 male iliac bones derived from 103 early modern males and 102 female iliac bones derived from 62 early modern females. The bone surface was macroscopically observed using a portable light without any magnification. The preauricular area on the iliac bone was observed on the left and right sides. As a result, the shape of the PAG could be classified into five categories. Types 1–3 were found in both males and females, but Types 4 and 5 were found only in females. The five categories are described as follows:

**Type 1:** No change is found on the bone surface; the bone surface is smooth (Figure 1a). The bone surface of subadults is also this type.

**Type 2:** No observable change is found, but some palpable depressions are recognized.

**Type 3:** Observable depressions (pits or groove) are recognized. In this type, three categories are included. The first is a pseudo depression (Figure 1b). The pseudo depression is surrounded by a bony ridge, but its bottom is not below the bone surface, so this type of depression is not a true depression; this category was not defined in Igarashi (1992). The second is a true depression with a contour that is not completely closed (Figure 1c). The third is a true depression with a completely closed contour that runs parallel to the ventral edge of the auricular surface (Figure 1d). In the second and third categories, the depression is sometimes accompanied by a spine (Figure 1e).

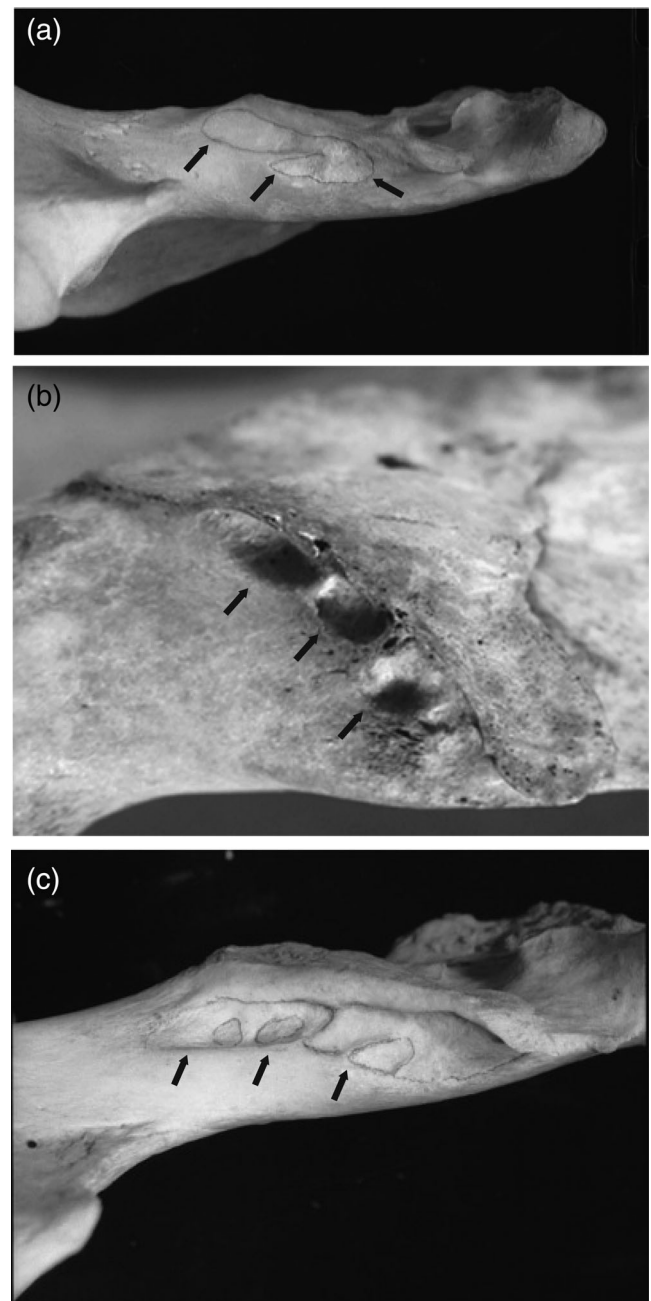
**Type 4:** This type includes a true depression with a completely closed contour that does not run parallel to the ventral edge of the auricular surface. This type of contour is often irregular and singular (Figure 2a,b). The depression sometimes looks like a groove (Figure 2a) or a coalescence of a series of pits (Figure 2b). In accordance with the definition in Igarashi (1992), the first category in Type 3 (Figure 1b) was included in the type corresponding to Type 4.

**Type 5:** This type includes a true depression with a contour similar to that of Type 4, but is double. Namely, inner contours exist inside the outer contour (Figure 2c). The bottoms of the inner depressions are often lower than those of the outer depressions.

Types 4 and 5 were recognized only in females, so we tentatively defined these types as PPS. At the same time, according to these shapes, we judged that Type 4 was a weak type and Type 5 a strong type. On the other hand, Types 1–3 were found in both males and females, so these were excluded from PPS. Types 2 and 3 might be caused by factors other than pregnancy and parturition, such as ligamentous attachment.

### 2.3 | Lifetime data

To ascertain the association between the degree of development of PPS and the number of pregnancies and/or parturitions, fertility data from females are needed. With the aim of improving the reliability of fertility data, information regarding lifetimes was obtained through questionnaires conducted on the bereaved family members or guardians of the cadavers. The questionnaire was composed of items such as age at parturition(s), and for each parturition, the weight and size of



**FIGURE 2** (a) Type 4 pregnancy parturition scar (PPS). Arrows show a true depression with a completely closed contour that does not run parallel to the ventral edge of the auricular surface. The contour is singular and looks like a groove. (b) Type 4 PPS. Arrows show a true depression with a completely closed contour that does not run parallel to the ventral edge of the auricular surface. The contour is singular and looks like a coalescence of a series of pits. (c) Type 5 PPS. Arrows show a true depression with a contour similar to that of Type 4, but is double. Namely, inner contours exist inside the outer contour

the newborn, type of parturition (e.g., vaginal delivery, forceps delivery, vacuum extraction, caesarian section), and time required for and difficulty of the delivery. Other question items included the age at early deliveries and miscarriages, as well as the mother's stature,



weight, and history of injuries and diseases, work, and sports, and for each early delivery or miscarriage, the duration of pregnancy.

## 2.4 | Statistical methods

Statistical analyses were performed using the chi-squared goodness-of-fit test, the likelihood ratio test, the Poisson dispersion test, a conditional test, an unconditional test, and the Bayesian index. The chi-squared goodness-of-fit and likelihood ratio tests were conducted to evaluate the equality of proportions in two multinomial distributions. The Poisson dispersion test was used to test whether a Poisson distribution fit to a dataset, and the conditional and unconditional tests (Krishnamoorthy & Thomson, 2004) were used to examine whether two Poisson samples had the same means. The Bayesian index (Kawasaki & Miyaoka, 2012) is defined by the probability  $\Pr(\lambda_{\{1,\text{post}\}} < \lambda_{\{2,\text{post}\}})$ , where  $\lambda_{\{1,\text{post}\}}$  and  $\lambda_{\{2,\text{post}\}}$  denote the Poisson parameters ("a parameter of a distribution" is only used to denote quantities that appear explicitly in the specification of the distribution) in the posterior distributions when gamma distributions are used as conjugate priors for the Poisson likelihood functions. In this analysis, the Bayesian index using noninformative priors as a limiting case of gamma priors (Kawasaki & Miyaoka, 2012) was calculated. The Bayesian index equals approximately 1 minus the  $p$  value of the conditional test.

## 2.5 | Process of the observation of the present-day female cadavers

For the present-day female cadavers, after the dissection practice was finished, the soft tissues and ligaments were removed from the bone surface of the pelvis. The bone surface was macroscopically observed using a portable light without any magnification. The preauricular area on the iliac bone was observed on the left and right sides. All judgments of the types of PAGs on the iliac bones were blinded relative to the cadaver's available fertility data.

This study was approved by the ethics committee of the Nihon University School of Dentistry at Matsudo (EC 06-020).

## 3 | RESULTS

### 3.1 | Intraobserver and interobserver errors for PAGs

Intraobserver errors for PAGs were evaluated for these types for over a 7-year period (Table 1). On 53 male iliac bones, the percentage of incorrect judgments was 0%. On 52 female iliac bones, the percentage of incorrect judgments was 3.8%, namely, two Type 3 PAGs were misjudged to be Type 4 (shown by underline). These Type 3 PAGs were true grooves with incomplete contours and small spines. Care

should therefore be taken when examining Type 3 PAGs, but the intraobserver error was deemed negligible.

Interobserver errors have not yet been evaluated, so we decided that interobserver error tests should be conducted after this classification system is published and many scholars have had the chance to become familiarized with this method.

### 3.2 | Bony changes were more prominent in the preauricular area than on the pubic bone

We checked whether bony changes were more prominent in the preauricular area than on the pubic bones (Table 2). We judged the types of scars in the preauricular area and on the pubis on the same hip bones. On 60 female hip bones, the bony scars were examined both in the preauricular area and on the posterior surface of the pubis (Table 2a). On 58 female hip bones, the bony scars were examined both in the preauricular area and on the anterior surface of the pubis (Table 2b). Table 2a shows that there was only one hip bone on which the type score was larger on the pubis than in the preauricular area (shown by underline), whereas there were 53 hip bones on which the type score was larger in the preauricular area than on the pubis (shown in italics). The frequency of visible scars (Types 3–5) was 97% (58/60) in the preauricular area and 17% (10/60) on the pubis. Table 2b shows that there were two hip bones on which the type score was larger on the pubis than in the preauricular area (shown by underline), whereas there were 48 hip bones on which the type score was larger in the preauricular area than on the pubis (shown in italics). The frequency of visible scars (Types 3–5) was 97% (56/58) in the preauricular area and 36% (21/58) on the pubis. These results suggest

**TABLE 1** Intraobserver errors on modern Japanese skeletons

Male	Original	Judgment
Type 1	8	8
Type 2	1	1
Type 3	44	44
Type 4	0	0
Type 5	0	0
Total	53	53
Female	Original	Judgment
Type 1	1	1
Type 2	1	1
Type 3	<u>15</u>	<u>13</u>
Type 4	<u>34</u>	<u>36</u>
Type 5	1	1
Total	52	52

Note: In male, the percentage of incorrect judgments was 0%. In female, the percentage of incorrect judgments was 3.8%. Two Type 3 PAGs were misjudged to be Type 4. All intraobserver errors were deemed negligible. Abbreviation: PAG, preauricular groove.

**TABLE 2** Comparison between the types of PAGs and the types of scars on the pubic bones for 60 modern Japanese female hip bones

(a) Posterior surface of the pubic bone (types)						
Preauricular area (types)	1	2	3	4	5	Total
1	1	0	0	0	0	1
2	1	0	0	0	0	1
3	11	0	3	<u>1</u>	0	15
4	35	0	4	2	0	41
5	2	0	0	0	0	2
Total	50	0	7	3	0	60
(b) Anterior surface of the pubic bone (types)						
Preauricular area (types)	1	2	3	4	5	Total
1	0	0	0	<u>1</u>	0	1
2	1	0	0	0	0	1
3	9	0	7	<u>1</u>	0	17
4	25	0	11	1	0	37
5	2	0	0	0	0	2
Total	37	0	18	3	0	58

Note: Underlined values indicate the hip bones on which the type score was larger on the pubis than in the preauricular area. Values in italics indicate the hip bones on which the type score was larger in the preauricular area than on the pubis.

Abbreviation: PAG, preauricular groove.

that bony changes are more prominent in the preauricular area than on the pubic bones, as Houghton (1974) and (1975) reported.

### 3.3 | The frequency of each type of PAG

The frequency of each type of PAG is shown in Table 3. In early modern males, Type 3 accounted for 123 (77.8%) iliac bones, Type 2 for 16 (10.1%), and Type 1 for 19 (12.0%). That is to say, even in males, perceptible grooves (Type 3) were recognized in 78% of the iliac bones. In early modern females, Type 4 accounted for 70 (68.6%) iliac bones, Type 3 for 21 (20.6%), and Type 5 for 8 (7.8%). In present-day females, Type 4 accounted for 301 (65.2%), Type 5 for 115 (24.9%), and Type 3 for 42 (9.1%). In both early modern and present-day females, more than 90% of the iliac bones were accompanied by visible grooves (Types 3–5). In early modern and present-day females,

**TABLE 3** The frequencies of each type of PAG

	Type 1	Type 2	Type 3	Type 4	Type 5	Total
Early modern male	19	16	123	0	0	158
Early modern female	2	1	21	70	8	102
Present-day female	3	1	42	301	115	462
Total female	5	2	63	371	123	564
Total	24	18	186	371	123	722

Abbreviation: PAG, preauricular groove.

76 and 90% of the iliac bones were accompanied by PPS (Types 4 and 5), respectively; the most frequent type in both was Type 4, while the second-most frequent types were Types 5 and 3 in present-day and early modern females, respectively. In early modern females, Type 5 was the third-most frequent type. Both the frequency of PPS (Types 4 and 5) and that of Type 5 were higher in the present-day than in the early modern females. The results of the chi-squared goodness-of-fit and likelihood ratio tests indicated that the type distributions were significantly different between the early modern and present-day females ( $p < .001$ ).

### 3.4 | Association between the development of PPS and the TNPP

The aim of the present study was to elucidate the association between the degree of development of PPS and the number of pregnancies and/or parturitions. In other words, we attempted to identify the strength of this association. We supposed that different variables affected the strength of the association, and thus, selecting proper variables was important. Therefore, we attempted to determine the proper variables that represent the development of PPS and the number of pregnancies and/or parturitions.

As the variable for the number of pregnancies and/or parturitions, we defined the TNPP as the total number of vaginal deliveries, forceps deliveries, vacuum extractions, caesarian sections, early deliveries, and miscarriages. We tested the association between the development of PPS and the number of pregnancies and/or parturitions using several variables, such as the number of vaginal deliveries, the number of all kinds of deliveries, the number of pregnancies, and so on. As a result, we concluded that the TNPP would be the most useful variable.

Considering that both pregnancies and parturitions induce bony changes in the pelvis (Abramson et al., 1934; Matsuoka, 2014; Putschar, 1931, 1976; Tsiaras, 2002), it is conceivable that the TNPP would be the variable most likely to be associated with the development of PPS.

Table 4 shows the mean ages of the females for every category of the TNPP. No clear association was found between mean age and the TNPP.

Regarding the variables representing the development of PPS, at first, we expressed the types of PAGs as numbers. We allocated a score of 0 to Types 1–3 because these types were excluded from

PPS. On the other hand, Types 4 and 5 were PPS. Type 4 was weak and Type 5 was strong PPS. Considering that bony changes around the sacroiliac joints occur in every pregnancy and parturition, bony scars would accumulate, and thus, Type 5 PPS, which was strong PPS with double contours, could be considered to be formed by the superimposition of several scars. Thus, we hypothesized that Types 4 and 5 indicate low and high fertility, respectively. Accordingly, we allocated a score of 1 to Type 4 and a score of 2 to Type 5. We judged the PPS score (0, 1, or 2) on the left and right iliac bones.

We tested the difference in scores between the left and right sides, and as a result, no significant differences were seen (likelihood ratio test  $p = .38$ , goodness-of-fit test  $p = .29$ ). Thus, this is one way that the score from only one side (left score or right score) can be used to ascertain the association between the development of PPS and the TNPP. We then tentatively tested the associations between the score from only one side and the TNPP. However, no clear associations were found. Therefore, we summed the left and right scores as the total score for the individual. Fortunately, all individuals were endowed with both left and right scores. The total score therefore ranged from 0 to 4 (Table 5).

Moreover, bony changes around the sacroiliac joint during pregnancies and parturitions would not necessarily be symmetrical, judging from the process of the bony changes around the pelvic joint during pregnancies and parturitions (Putschar, 1931, 1976; Tsiaras, 2002). Therefore, we supposed that the score on only one side (left or right) cannot precisely represent bony changes during pregnancies and parturitions, but rather, that the total score of the individual (total of the left and right scores) would reflect events more precisely during pregnancies and parturitions; this was another reason to regard the total score of the individual as the more suitable variable.

Table 5 shows the combination of scores for each iliac bone, the total score, the class of the total score (which will be mentioned later), and the number of individuals. Regarding the total score of 0 (TSO), the scores on each iliac bone were 0 and 0. For the total score of 1, the combination of scores was 0 and 1. For the total score of 2, the combinations of scores were 1 and 1 in 54 individuals, and 0 and 2 in one individual. For the total score of 3, the combination of scores was

**TABLE 4** Mean age of the females for every TNPP

TNPP	Mean age (years)
0	74.7
1	87
2	81.1
3	78.7
4	85.5
5	86.4
6	86.3
7	86
8	105
9	87

Abbreviation: TNPPs, total number of pregnancies and parturitions.

**TABLE 5** The combination of scores<sup>a</sup>, the total score<sup>b</sup>, the class of the total score, and the number of individuals

Combination of scores <sup>a</sup>	Total score <sup>b</sup>	Class of total score	The number of individuals
0-0	0	TSO	4
0-1	1	TSL	2
1-1	2		54
0-2	2		1
1-2	3	TSH	10
2-2	4		19

Abbreviations: TSO, total score 0; TSH, total score higher; TSL, total score lower.

<sup>a</sup>Two figures in combination of scores show a score of one side of iliac bone and a score of the other side in one individual. Score 0 was allocated to Types 1, 2, and 3. Score 1 was allocated to Type 4. Score 2 was allocated to Type 5.

<sup>b</sup>Total score is the total of left score and right score. TSO (total Score 0), TSL (total Scores 1 and 2), and TSH (total Scores 3 and 4).

**TABLE 6** Mean age of the females for every class of total score

Class of total score	Mean age (years)
TSO	71.3
TSL	86.9
TSH	83.2

Note: TSO (total score 0), TSL (total Scores 1 and 2), and TSH (total Scores 3 and 4).

Abbreviations: TSO, total score 0; TSH, total score higher; TSL, total score lower.

1 and 2, and for the total score of 4, the combination of scores was 2 and 2.

Next, we examined the association between the total score of the individual and the TNPP; although there appeared to be an association, it remained unclear. Thus, we integrated the total scores into three classes: a TSO, which included the TSO, a total score lower (TSL), which included the total scores of 1 and 2, and a total score higher (TSH), which included the total scores of 3 and 4 (Table 5).

Table 5 shows that all individuals with TSO (including total Score 0) had only score 0. Most of the individuals with TSL (including total Scores 1 and 2) had Scores 0 and 1 (56/57), and one with TSL had 0 and 2. All individuals with TSH (including total Scores 3 and 4) had Scores 1 and 2. The mean age of the females with TSO was 71.3 years, that of the females with TSL was 86.9 years, and that of the females with TSH was 83.2 years (Table 6). No clear association was observed between the mean age and the class of the total score.

Finally, TSO, TSL, and TSH were determined as the variables to represent the development of PPS. We then examined the association between PPS score (TSO, TSL, TSH) and the TNPP.

First, we examined the number of females for every PPS score and the TNPP (Table 7 and Figure 3). In this analysis, the total number of samples was 90 (Table 7) because only the respondents of these

**TABLE 7** The number of females for every PPS score and the TNPP

	TNPP											Total	
		0	1	2	3	4	5	6	7	8	9		
PPS score	TS0	4	0	0	0	0	0	0	0	0	0	0	4
	TSL	3	11	14	12	5	6	4	1	1	0	57	
	TSH	0	2	7	9	5	2	2	1	0	1	29	
	Total	7	13	21	21	10	8	6	2	1	1	90	

Note: TS0 (total Score 0), TSL (total Scores 1 and 2), and TSH (total Scores 3 and 4).

Abbreviations: PPS, pregnancy parturition scars; TNPPs, total number of pregnancies and parturitions; TS0, total score 0; TSH, total score higher; TSL, total score lower.

90 donors could answer the question items regarding the numbers of miscarriages and early deliveries among the donors. These respondents were mainly close relatives, such as husbands, children, and siblings.

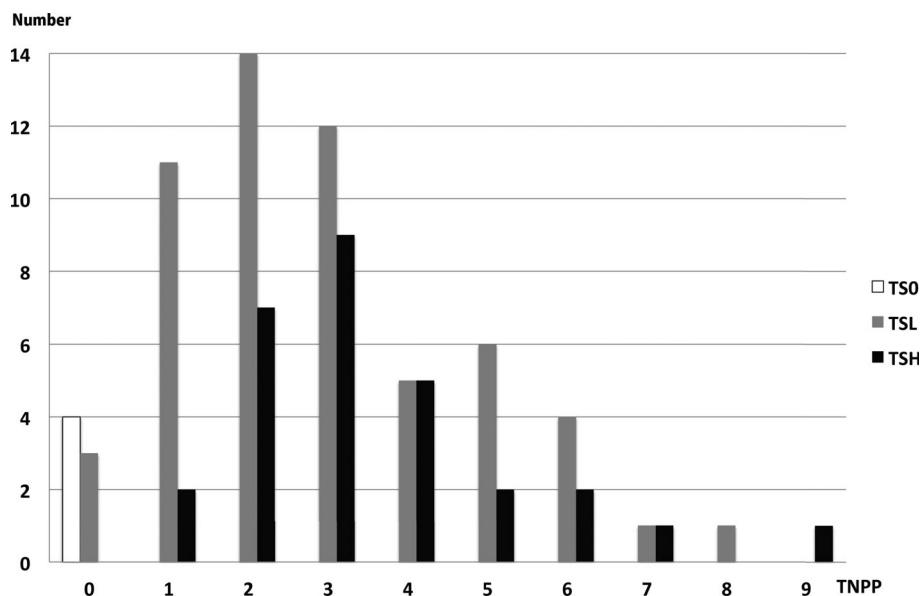
In Figure 3, the horizontal axis shows the TNPP and the vertical axis shows the number of individuals. The white bar indicates the number of females with TS0. Gray bars indicate the number of females with TSL, and black bars indicate the number of females with TSH.

The white bar existed on only the 0 value of the horizontal axis, which means that none of the females with TS0 (no PPS on either iliac bones) experienced a pregnancy or parturition.

Gray bars (TSL) were distributed from 0 to 8 on the horizontal axis, and the maximum value (14) was 2 on the horizontal axis. Black bars (TSH) were distributed from 1 to 9 on the horizontal axis, and the

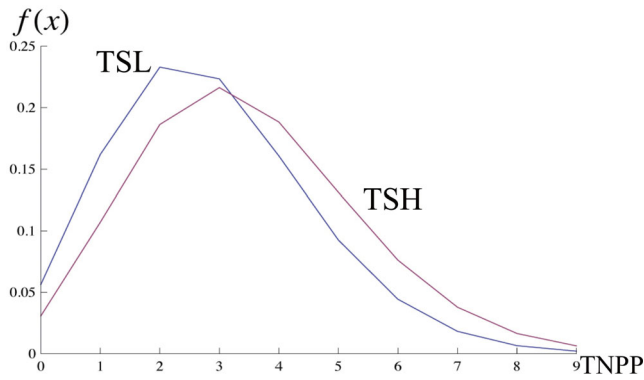
maximum value (9) was 3 on the horizontal axis. Figure 3 shows that the distributions of TSL and TSH could not be completely divided by the TNPP. However, at the same time, Figure 3 shows that TSH tended to be distributed on larger values on the horizontal axis than did TSL, and that the peak of the distribution of TSH was situated on a larger value on the horizontal axis than was that of TSL. The means for TSH and TSL were 3.48 and 2.88, respectively.

Next, we compared the distributions of TSL and TSH. The sample numbers were different between TSL and TSH (Table 7), so we calculated the relative frequencies of TSL and TSH. Regarding TSL and TSH for every category of the TNPP, we divided the frequency by the total number. In other words, the relative frequency for every category of the TNPP was the probability that the female with TSL (or TSH) had that value of the TNPP.



**FIGURE 3** Association between pregnancy parturition scars (PPS) (total score class) and the total number of pregnancies and parturitions (TNPPs). The horizontal axis shows the TNPP, and the vertical axis shows the number of individuals. The white bar indicates the number of females with TS0 (total score 0). The white bar exists on only the 0 value of the horizontal axis, which means that none of the females with TS0 (no PPS on either ilium) experienced a pregnancy or parturition. Gray bars indicate the number of females with total score lower (TSL) (Scores 1 and 2), and black bars indicate the number of females with total score higher (TSH) (Scores 3 and 4). TSH tended to be distributed on larger values on the horizontal axis than did TSL, and the peak of the distribution of TSH was situated on a larger value on the horizontal axis than was that of TSL. The means for the TSH and TSL were 3.48 and 2.88, respectively





**FIGURE 4** The association between pregnancy parturition scars (PPSs) (total score) and the total number of pregnancies and parturitions (TNPPs). The horizontal axis shows the TNPP, and the vertical axis shows the probability function:  $f(x)$ . For the females whose TNPP was under 4, the probability that the total score was total score lower (TSL) was higher than the probability that the total score was total score higher (TSH). For the females whose TNPP was 4 and over, the probability that the total score was TSH was higher than the probability that the total score was TSL

At the same time, we performed the Poisson dispersion test and found that TSL ( $\chi^2 \approx 66.09, p \approx .168$ ) and TSH ( $\chi^2 \approx 26.20, p \approx .562$ ) followed Poisson distributions. Therefore, we fitted Poisson distributions to the relative frequencies (probabilities) of TSL and TSH.

Figure 4 shows the estimated probability functions of the Poisson distributions of TSL and TSH. The vertical axis shows the probability function and the horizontal axis shows the TNPP. The probabilities of TSL increased from 0 to 2, and after that, decreased. The probabilities of TSH increased from 0 to 3, and after that, decreased. Figure 4 shows that the probabilities of TSH were distributed on larger values of the TNPP than were those of TSL. Figure 4 also indicates that from 0 to 3, the probabilities of TSL were higher than those of TSH, and after that, the probabilities of TSH were higher than those of TSL. In

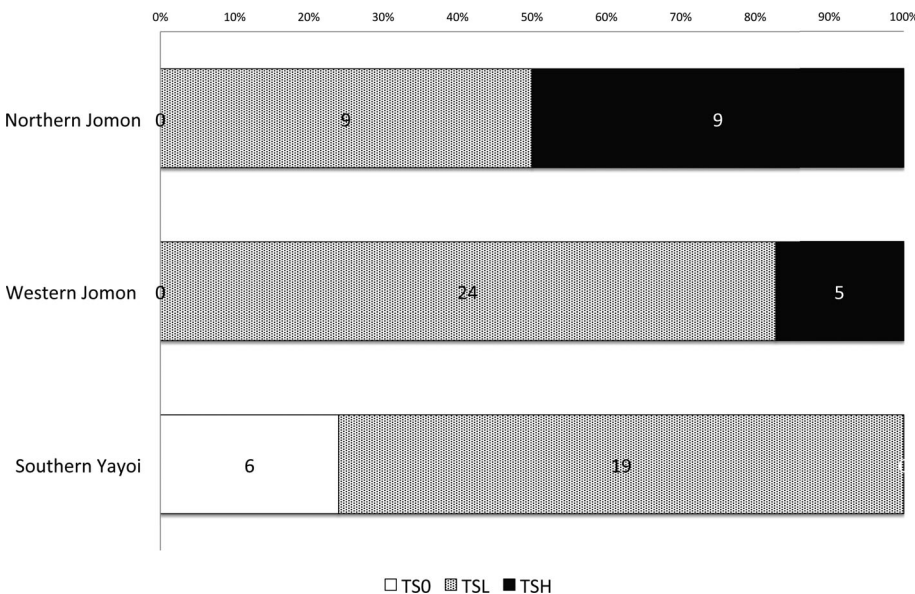
other words, in the females whose TNPP was under 4, the probability that the total score was TSL was higher than the probability that the total score was TSH, and in the females whose TNPP was 4 and over, the probability that the total score was TSH was higher than the probability that the total score was TSL. Thus, Figure 4 suggests that in the females with a fewer TNPP, the probability of TSL was higher than that of TSH, and in the females with a greater TNPP, the probability of TSH was higher than that of TSL.

Next, we performed a conditional test and an unconditional test. From a conditional test ( $p \approx 0.075$ ) and an unconditional test ( $p \approx 0.067$ ), there was evidence to indicate that the means of the Poisson distributions of TSL and TSH were significantly different ( $p < 0.1$ ). We also performed a Bayesian analysis and obtained an approximate value of 0.931 as the Bayesian index ( $\theta$ ). The value  $\theta = 0.931$  approximated 1—the  $p$ -value of the conditional test ( $1 - 0.075 = 0.925$ ). The result that the parameter in the posterior distribution of TSH was larger than that of TSL with high probability ( $\theta = 0.931$ ) did not contradict the observation that TSH were distributed on larger values of the horizontal axis (TNPP) than were TSL.

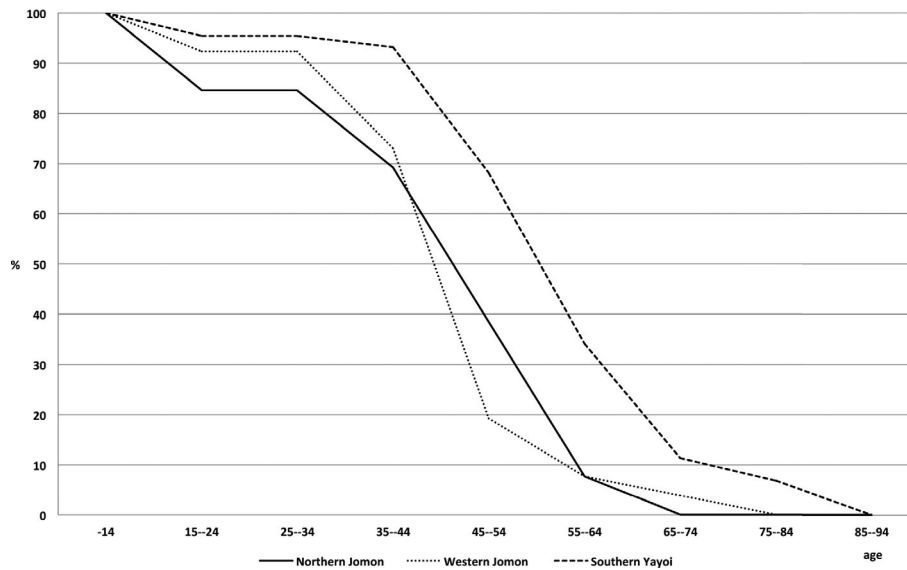
The results of these statistical analyses suggest that TSH were distributed on larger values of the TNPP than were TSL, and this difference was statistically significant (Figure 4).

Table 7 and Figure 3 show that all TSO were distributed on no TNPP, and that all TSH were distributed on more than no TNPP. On the other hand, 95% (54/57) of TSL were distributed on more than no TNPP, but 5% (3/57) of TSL were distributed on no TNPP. Three individuals with TSL and no TNPP had a total score of 2, with the combination of scores being 1 and 1.

On the other hand, Figure 4 shows that both of the probability functions of TSL and TSH were above 0 on 0 TNPP. Thus, we cannot deny the possibility that individuals with TSL or TSH would have no TNPP in a larger sample. Namely, we cannot conclude that individuals with TSL or TSH must always have at least



**FIGURE 5** The percentages of TSO (total score 0), TSL (total score lower), and total score higher (TSH) in Northern Jomon (2,000–4,000 BP), Western Jomon (Tsukumo site) (2,000–4,000 BP), and Southern Yayoi (2,000 BP). The sample numbers were 18 in Northern Jomon, 29 in Western Jomon, and 25 in Kyusyu Yayoi. The percentages of the PPS scores differed among populations and indicated that the fertility was highest in Northern Jomon and lowest in Southern Yayoi



**FIGURE 6** Survival curves of the Northern Jomon, Western Jomon, and Southern Yayoi female populations. The vertical axis shows the percentage, and the horizontal axis shows the age range. The sample numbers were 13 in Hokkaido Jomon females, 24 in Western Jomon females, and 44 in Southern Yayoi females. Age was estimated by the surface morphology of the auricular surface of the iliac bone, as in Igarashi et al. (2005). The longevity of Southern Yayoi females appeared to be longer than the other two populations, whereas the longevity of Northern Jomon females appeared to be shorter than that of Southern Yayoi females. This pattern of survival curves was also indicated by the age estimation method of Buckberry and Chamberlain (2002)

one TNPP. However, Figure 4 also shows that most of the probabilities of TSL and TSH were above 0 for TNPP. Therefore, we consider that the TNPP of individuals with TSL and TSH can be above 0: it is possible that most individuals with TSL and TSH can be parous, though there remains the possibility that some of them are nulliparous.

Based on these results, we propose that TSO indicates null parity, TSL and TSH indicate parity, TSH indicates a greater TNPP, and TSL indicates a fewer TNPP; however, it remains possible that TSL and TSH both indicate null parity.

## 4 | DISCUSSION

### 4.1 | Cause of the difference in the percentages of PAG types between early modern and present-day females

Table 3 shows that in early modern females, Type 4 was 68.6% and Type 5 was 7.8%, and in present-day females, Type 4 was 65.2% and Type 5 was 24.9%. The frequencies of both PPS (Types 4 and 5) and Type 5 were significantly higher in the present-day than in the early modern females.

The cause of this difference might have been the differences in age. In the present-day females, the mean age was 83 years (range 49–106 years). On the other hand, in the 38 early modern females with relevant data, the mean age was 43 years (range 14–74 years), and 18 were under the age of 40 years. Actually, Type 4 was found in females who were over the age of 17 years, but Type 5 was found only in females who were over the age of 53 years; this would account for the frequency of Type 5 being lower in the early modern than in the present-day females.

Moreover, if the PPS (Types 4 and 5) indicated pregnancies and/or parturitions, then the following explanation could be provided. Judging from age, almost all present-day females had completed their reproductive period, but many of the early modern females might have died beforehand. This could explain why the frequency of PPS (Types 4 and 5) was higher in the present-day and lower in the early modern females.

### 4.2 | How can we utilize PPS?

As described in the chapter of introduction, we proposed that if PPS could be an indicator of the number of pregnancies and/or parturitions, the fertility of groups could be estimated and the population structure could be reconstructed. The results of the present study have confirmed that PPS are an indicator of the TNPP; therefore, we now discuss how to reconstruct population structures such as the pattern of fertility and longevity based on PPS.

We examined PPS in several prehistoric skeletal samples and reconstructed the pattern of fertility and longevity using PPS. Although we are still in the process of collecting new data, we provide a few examples as follows.

Figure 5 shows the percentages of TSO, TSL, and TSH in three prehistoric populations: Northern Jomon (Hokkaido district) (2,000–4,000 BP), Western Jomon (Tsukumo site in Okayama Prefecture) (2,000–4,000 BP), and Southern Yayoi (Kyusyu district) (2,000 BP). In Figure 5, we see that the percentages of PPS scores were different among populations. In Northern Jomon, there was no TSO, while TSL and TSH accounted for 50%. In Western Jomon, there was no TSO, but TSL accounted for 83% and TSH for 17%. In Southern Yayoi, TSO accounted for 24%, and TSL accounted for 76%; no

TSH was found. We had already concluded that TSO indicates no pregnancies or parturitions, TSL indicates fewer pregnancies and parturitions, and TSH indicates more pregnancies and parturitions. Thus, the differences in the percentages of PPS scores can suggest differences in the fertility of these populations. In these cases, the fertility appeared to be highest in Northern Jomon and lowest in Southern Yayoi. Indeed, there is a possibility that some females with TSL and TSH had no pregnancies or parturitions, so the percentage of females with no pregnancies and parturitions could be higher than that of TSO. Taking these possibilities into account, we estimated that we could still identify differences in the percentages of PPS scores, and therefore, differences in fertilities among populations. In this way, we can estimate the differences in fertility among prehistoric populations by estimating the percentages of PPS scores.

At the same time, we constructed survival curves of these populations. Figure 6 shows the survival curves of the Northern Jomon, Western Jomon, and Southern Yayoi female populations. Age was estimated using the method of Igarashi, Uesu, Wakebe, and Kanazawa (2005). The vertical axis shows the percentage, and the horizontal axis shows the age range. Figure 6 shows that the survival curve of Southern Yayoi females was higher than those of the other populations, which suggests that Southern Yayoi females had the greatest longevity. Figure 6 also shows that the survival curve of Northern Jomon females was situated lower than that of Southern Yayoi females, which means that Northern Jomon females had a shorter longevity than did Southern Yayoi females. This pattern of survival curves was also indicated by the age estimation method of Buckberry and Chamberlain (2002).

Combining the results in Figures 5 and 6, we can estimate that in the Southern Yayoi female population, fertility was relatively low and longevity was relatively high, while in the Northern Jomon female population, fertility was relatively high and longevity was relatively low. In this way, by examining PPS scores and estimating the age of individuals, we can estimate the pattern of fertility and longevity in populations.

### 4.3 | Classification of PAGs

The shapes of PAGs have been described and classified in many former studies (Buikstra & Ubelaker, 1994; Cox & Scott, 1992; Houghton, 1974; Steckel et al., 2006; Ullrich, 1975). We compared the PAG classification system in the present study with those in former studies, in which PAGs were macroscopically examined.

Houghton (1974) defined two types of grooves: pregnancy grooves (GPs) and ligament grooves (GLs). GPs were defined as grooves with an uneven floor and undulating margin, giving the impression of a coalescence of a series of pits. If a groove was not unequivocally GP, it was classified as GL. Namely, Houghton narrowly defined GP. GL-type grooves are commonly narrow, short, straight-edged, and shallow. GP-type grooves are found only in females, whereas GL-type grooves are common to both males and females. GL-type grooves resemble a kind of Type 3 groove in the present study, but at the same time, the definition of Type 4 in the present

study is a groove with a completely closed contour that does not run parallel with the ventral edge of the auricular surface, so some kinds of Type 4 could have a flat floor, which is characteristic of GL-type grooves. Namely, GL-type grooves would include not only some kinds of our Type 3, but also some kinds of our Type 4, whereas GP-type grooves would include some kinds of Types 4 and 5 in the present study.

Ullrich (1975) defined five stages of PAGs taking the size of grooves into account. However, our classification system did not take the size of grooves into account; therefore, we judged the correspondence from their figures. Stage 0 includes Types 1–3 and 5 in the present study, Stage I is equivalent to our Type 4, and Stages II–IV are equivalent to our Type 5.

Cox and Scott (1992) described the PAGs as Types 1–4. Their Type 1 is GP (Houghton, 1974), so their Type 1 would include some kinds of our Types 4 and 5. Their Type 2 is GL (Houghton, 1974), so their Type 2 would include some kinds of our Types 3 and 4. For example, their Type 2 example (Cox & Scott, 1992) is judged to be Type 4 by our method, because the contour of the groove does not run parallel with the ventral edge of the auricular surface. In addition, their Type 3 would correspond to our Types 4 and 5, judging from the contour of the grooves in the figures. Some “grainy” floor in their Type 3 might show the inside depression of our Types 4 and 5. Their Type 4, judging from the description, would correspond to our first category of Type 3 (pseudo depression).

Buikstra and Ubelaker (1994) defined five stages. They also took the size of grooves into account; therefore, we judged the correspondence from their descriptions and figures. Stage 0 would be equal to Types 1 and 2 in the present study. Stages 1 and 2 would be equal to GP by Houghton (1974), so Stages 1 and 2 would include some kinds of our Types 4 and 5. Stage 3 is accompanied by a bony ridge, so Stage 3 would include some kinds of our Type 3. At the same time, Stage 3 would include some kinds of our Type 4, because some Stage 3 grooves have undulating walls. Namely, Stage 3 would include our Types 3 and 4. Stage 4 would include some kinds of our Types 3 and 4, judging from the figure.

Steckel et al. (2006) defined five scores. Score 0 would be equal to Types 1 and 2 in the present study. Score 1 was defined as having a preauricular sulcus with no clear evidence, so Score 1 would be equal to our Type 3. Scores 2–4 were defined as having a clearly present preauricular sulcus, and each stage was classified by the degree of development of the sulcus. Judging from the figures, Score 2 would include some kinds of our Types 3 and 4, and Scores 3 and 4 would include some kinds of our Types 3–5.

In the classification system by Houghton (1974), Ullrich (1975), Cox and Scott (1992), Buikstra and Ubelaker (1994), and Steckel et al. (2006), some kinds of Types 3 and 4 (or Types 3–5) in the present study would be included in the same category. Therefore, the classification systems in former studies cannot always correctly distinguish between PPS (Types 4 and 5) and non-PPS (Type 3).

Next, the total frequencies of all types of PAGs are discussed. In Houghton (1974), 81% of male pelvises had the GL-type, and 92% of female pelvises had both the GL and GP types. In Cox and Scott (1992), the frequency of all types of PAGs was 88% in females. These results

do not contradict those in the present study: 77.8% of male iliac bones had Type 3 and 99% of female iliac bones had all types of PAGs (Table 3). In Schemmer et al. (1995), 59% of females had PAGs. This frequency is lower than that observed in the present study, which might be because Schemmer et al. examined radiological data, so very weak scars could not be recognized.

#### 4.4 | Association between the development of PPS and the number of pregnancies and/or parturitions

In previous studies, conclusions have differed in regards to the association between the development of scars on the pelvis and the number of pregnancies and/or parturitions. Some studies concluded that the degree of development of PAGs is correlated with the number of pregnancies (Igarashi, 1992; Işcan & Dunlap, 1984; Schemmer et al., 1995) or parturitions (Dunlap, 1979; Işcan & Dunlap, 1984; Kelley, 1979). By contrast, other studies have concluded that the degree of development of PAGs is not correlated with the number of pregnancies (McFadden & Oxenham, 2018; Spring et al., 1984, 1989) or parturitions (Cox & Scott, 1992; McFadden & Oxenham, 2018).

Some studies have concluded that the degree of bony changes in the pubic bone is correlated with the number of pregnancies (Işcan & Dunlap, 1984; McArthur et al., 2016; Suchey et al., 1979) or parturitions (Bergfelder & Herrmann, 1980; Dunlap, 1979; Galloway et al., 1998; Işcan & Dunlap, 1984; Kelley, 1979; Snodgrass & Galloway, 2003), while others have concluded that the degree of bony changes in the pubic bone is not correlated with the number of pregnancies (Gilbert & McKern, 1973; McFadden & Oxenham, 2018) or parturitions (Cox & Scott, 1992; Gilbert & McKern, 1973; Holt, 1978; McFadden & Oxenham, 2018).

Why are these conclusions different in each study? The main reason could be that numerous factors affect the degree of development of bony scars. In addition, we suggest three other possible causes.

First is the determination of bony scars. In the present study, we defined PPS as PAGs that are specific to females (Types 4 and 5). The other type of PAG (Type 3) exists not only in females, but also in males, and 78% of males had Type 3 PAGs. Therefore, we assumed that Type 3 was influenced by factors other than pregnancy and parturition, such as ligamentous attachment. In previous studies, if the PAGs that corresponded to Type 3 in the present study were counted as PPS, or if the PAGs that corresponded to Type 4 in the present study were not counted as PPS, it is possible that the development of PAGs was not correlated with the number of pregnancies and/or parturitions. Actually, as discussed above, based on the former classification system, some kinds of Types 3–5 were included in the same category, so some PPS (Types 4 and 5) and non-PPS (Type 3) would not be correctly distinguished.

Houghton (1974) defined GP- and GL-type grooves, which were adopted by Cox and Scott (1992). Houghton defined GP-type grooves as those resulting from pregnancy and parturition; the range of GP was defined to be narrow, namely, only PAGs that looked like a

coalescence of a series of pits (cf. Figure 2c) were included in GP, so some types of our PPS (mainly Type 4) would be excluded from GP and included in GL.

Ullrich (1975), Buikstra and Ubelaker (1994), and Steckel et al. (2006) considered size when they classified PAGs, but our classification system does not; rather, we use only the morphology of the scars. As a result, our PPS and non-PPS were classified into the same stages (Stage I by Ullrich, Stages 3 and 4 by Buikstra and Ubelaker, and Scores 2–4 by Steckel et al.). Consequently, classification based on morphology is more suitable than that based on metric data for distinguishing PPS and non-PPS.

The distinction between PPS and non-PPS is important for analyzing the association between the degree of development of PPS and the TNPP. Therefore, we suggest that a classification system is key to ascertain the association between variations in scars on the pelvis and parity status.

Second is the reliability of the fertility data. In the present study, the TNPP was adopted as a variable that represents fertility. To obtain the TNPP, we need to know the number of early deliveries and miscarriages, but these data are hard to obtain. Actually, the number of early deliveries and miscarriages were obtained for only 90 of the 233 present-day females. However, at the same time, because of their confidentiality, the data from these 90 females were considered to be very reliable, and the informants of these 90 females must have been very intimate with them and known many of their personal details.

Actually, most of the informants of these 90 females were husbands, children, and siblings. On the other hand, in the cases where the informants were not so close to the donors, such as cousins or guardians (e.g., administrators, city hall staff), some informants answered that the donor had no children because she was not married; information such as this cannot be trusted. In another case, new information that was not provided in the questionnaire was obtained when the first author talked with the informants at a ceremony for returning ashes. A niece completed the questionnaire regarding her aunt and answered that she had no children. However, the niece mentioned that her aunt had in fact had a child, but she could not marry the baby's father, so she put the baby up for adoption. The aunt had told the niece that story, but it could not be confirmed, so the niece answered "no children" in the questionnaire (this person was included for the analysis as having one TNPP). We cannot deny the existence of other similar cases. Namely, the possibility remains that we did not obtain accurate answers from the questionnaires, even though they were completed by close relatives. Information concerning pregnancies and parturitions is generally very delicate, so obtaining accurate data remains very difficult.

In previous studies, information regarding fertility was obtained from historical records (Cox & Scott, 1992), death certificates with the data originating from the family or the persons taking responsibility for the dead persons (Galloway et al., 1998; Snodgrass & Galloway, 2003; Suchey et al., 1979), hospital records and soft tissue analysis (Gilbert & McKern, 1973; Holt, 1978; Kelley, 1979; Schemmer et al., 1995), and medical records (Bergfelder & Herrmann, 1980; McArthur et al., 2016; Spring et al., 1989). We could not check the reliability of

the fertility data in those studies. However, in our experience, in general, it is very difficult to ascertain the reliability of these data, which is crucial in assessing the result of the analyses.

Third is the statistical methods. In many previous studies, the associations between the degree of development of scars on the pelvis and parity status were examined using chi-squared tests (Cox & Scott, 1992; Holt, 1978; Kelley, 1979; Schemmer et al., 1995; Spring et al., 1989). Two studies affirmed the association (Kelley, 1979; Schemmer et al., 1995), and three denied it (Cox & Scott, 1992; Holt, 1978; Spring et al., 1989). Additional studies in which other statistical analyses were conducted, such as multiple regression analysis (Suchey et al., 1979), factorial analysis of variance and stepwise multiple regression analysis (Snodgrass & Galloway, 2003), and Pearson correlation coefficient and multivariable logistic regression modeling (McArthur et al., 2016), affirmed the association. Therefore, we considered that the type of statistical analysis conducted influences the results, because the association was rather weak. In the present study, the chi-squared test was tentatively used to test the null hypothesis that there was no statistically significant difference between PPS score and fertility. As shown in Table 7, a statistically significant difference ( $df = 2$ ,  $p < 0.01$ ) was observed between three rows of scores (TSO, TSL, and TSH) and two columns of the TNPP (0 and 1 and above). The reason for this was that all females with TSO were nulliparous and all females with TSH were multiparous. The next test was performed between two rows of scores (TSL and TSH) and two columns of the TNPP (0 and 1 and above); no statistically significant differences were observed ( $df = 1$ ,  $p = 0.21$ ) (Table 7). This result shows that the chi-squared test cannot detect differences in the TNPP between TSL and TSH. Only the Poisson dispersion test and Bayesian index can detect differences in the TNPP between TSL and TSH.

The etiology of bony changes in the pubic bone was previously discussed by Putschar (1931, 1976). He deduced that swollen ligaments during pregnancy imprint the grooves as evidence of pregnancy, and that cysts containing degenerated cartilage imprint the pits as evidence of parturition. Other studies support this explanation. Thorp and Fray (1938) noted that 44% of females in pregnancy and labor experienced a widening of the pubic symphysis. Boland (1933a, 1933b) noted that delivery produces separation of the pubic symphysis. Kowalk, Perdue, Bourgeois, Whitehill, and Charlottesville (1996) suggested that the separation of the pubic symphysis during pregnancy and labor was caused by progesterone and relaxin. Relaxin has been shown to play an important role in bony changes around the pelvic joint. Relaxin contributes to pelvic joint activity (Vøllestad, Torjesen, & Robinson, 2012) and stimulates osteoclast differentiation and activation (Ferlin, Pepe, Faccioli, Giancesello, & Foresta, 2010) and bone resorption (Kristiansson, Holding, Hughes, & Haynes, 2006).

Both around the pubic symphyses and the sacroiliac joints, relaxin is secreted, and the joint is relaxed during pregnancy and separated during parturitions (Abramson et al., 1934; Matsuoka, 2014; Tsiaras, 2002). Therefore, the bony changes around the preauricular area during pregnancy and parturition would be similar to those explained by Putschar (1931, 1976). Thus, the etiology of PPS around the auricular area would be the same as Putschar's explanation.

At the same time, the attachment of ligaments has been indicated to cause grooves around the preauricular area (Derry, 1911). The ligamentous band of fibers around the sacroiliac joints counteracts the rotation of the sacrum by weight, and as a result, the attachment of a strong ligamentous band of fibers produces a deep-grooved sulcus around the preauricular area (i.e., the ligament prevents the sacrum from rotating because of body weight) (Derry, 1911). The strength of the strain of the ligamentous band of fibers is related to body weight and the shape of the pelvis (Derry, 1911; Maas & Friedling, 2016). Although Derry (1911) advanced his theory to explain the reason why a deep-grooved sulcus was produced in the female pelvis, the explanation by Derry shows the mechanism of formation of non-PPS (Type 3). Of course, this explanation cannot fully explain the mechanism of non-PPS, but this would be one convincing argument, even though a variety of other factors can influence PAG formation.

Considering these studies, PPS are considered to represent a superposition of bony changes during pregnancies and parturitions and the impression of the mechanical stress induced by the attachment of ligaments, which is the reason why PPS cannot indicate the exact TNPP. Moreover, other factors have been shown to affect the bony changes of the pelvis. Maas and Friedling (2016) showed that the development of PAGs and dorsal pubic pitting were affected by body size: bony changes tended to occur in small-bodied individuals with large pelvises. Snodgrass and Galloway (2003) showed that parity, age, and body mass index were associated with pitting on the dorsal aspect of the pubis. Other factors that have been suggested to influence PAGs and dorsal pubic pitting include weight-bearing (Derry, 1911; Maas & Friedling, 2016; Snodgrass & Galloway, 2003), obstetrical care (Kelley, 1979; Stewart, 1957), obesity (Andersen, 1988), body shape (Snodgrass & Galloway, 2003), maternal birth canal diameter (Kelley, 1979), infant size (Kelley, 1979; Snodgrass & Galloway, 2003; Tague, 2000), activity levels during pregnancy (Ashworth et al., 1976; Kelley, 1979; Snodgrass & Galloway, 2003), occupation (Andersen, 1988), habitual squatting (Andersen, 1988), osteitis condensans ilii (Schemmer et al., 1995), trauma (Andersen, 1988), hormone levels (Kelley, 1979; Snodgrass & Galloway, 2003), age at time of death (Kelley, 1979), interval since last pregnancy (Snodgrass & Galloway, 2003), and placement of soft tissue (Snodgrass & Galloway, 2003). This is why we collected detailed information regarding the donors' lives. The effects of these factors on PPS should be analyzed in the future.

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