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An assessment of the anatomical variability and contributing factors of female pelvis shape using principal component analysis

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ABSTRACT

Background & aim: Pelvic shape has important effects on obstetrical outcomes. Therefore, this study aimed to determine the etiologic factors that contribute to the formation of female pelvis and describe its variability.

Methods: This study was conducted on 131 women referring to Saint Joseph Hospital, Marseille, France, from March 29, 2011, to December 10, 2013. These women underwent a pelvic scan, and then completed a questionnaire to assess their exposure to several environmental influences, including adolescent physical activity, mode of acquiring an erect posture, diet, birthplace, socioeconomic status, presence of a spinal disorder, and age. A total of 43 pelvic variables were measured. Pelvic variability was analysed using principal component analyses (PCAs). Only the first two components of the PCA were analysed in this study.

Results: Based on our results, the age of acquisition of erect posture was not associated with any pattern of pelvic variability. In addition, diet found to have no effect on the inlet shape. Spinal disorders, age, and physical activities did not exert any impact on pelvic shape. Geographic origin was found to be the only factor related to specific pelvic patterns.

Conclusion: The pelvic shape variability of our study population was not explained by the four categories previously proposed by Cadwell and Moloy in 1993. It is recommended that midwife teachers should be more cautious about adherence to this classification. Geographic origin seemed to be related to different pelvic shape patterns, suggesting the effect of the neutral population history in pelvic variability.

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Introduction

Based on the evidence, pelvic shape in adults has a wide variation. Abitbol (1) suggested that the anatomical pelvic variability is greater in females than in males. Many authors have proposed a classification of female pelvic variability, based on radiographic examinations, to determinate the risk of obstetric difficulties during childbirth (2-4). Since birth, the canal is divided into three planes, which correspond to the three steps of fetal head descent during the birth process.

The shape of these three planes, especially the upper plane (*i.e.,* the inlet), is the most important criterion of these classifications. Since 1933, obstetricians have usually described pelvic shape as “anthropoid” (i.e., long narrow oval-shaped pelvis), “platypelloid” (i.e., transversally oval-shaped pelvis), “android” (i.e., pear-shaped pelvis), or “gynaecoid” (i.e., round-shaped pelvis) types. In addition to these four “classic” or”pure” types, Cadwell and Moloy (2) suggested the higher probability of combinations (i.e., mixed types). According to these authors, the most frequent type is gynaecoid (41.4%), followed by android (32.5%), anthropoid (23.5%), and platypelloid (2.6%) in “white female” population (2).

Rare types (i.e., non-gynaecoid types) are

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supposed to be associated with a higher frequency of forceps delivery and cesarean section (2). However, recent studies have questioned this morphologic classification based on four pelvic patterns (5, 6). Kuliukas *et al.* (5) used principle component analyses (PCAs) and found an amorphous, cloudy continuum of female pelvic shape variation. They recommended the teachers and authors of midwifery, gynecological, and obstetric texts to be more cautious about their adherence to Caldwell-Moloy classification.

Bouhallier (6) found only three of the four types, described by Cadwell and Moloy. Pelvic shape has important effects on obstetric outcomes (7) and birth mechanism (8). For example, a woman will be more at the risk of the arrest of labor if she has a narrow maximum transverse inlet, reduced diagonal inlet, or small posterior space (7). Moreover, the arrest of labor leads to cesarean section and its related intraoperative risks (*i.e*., surgical site infection (9), as well as the side effects occurring during the postpartum period (*i.e.*, thromboembolic complications) (10).

Accurate assessment of pelvic shape requires a scanopelvimetry; however, this imaging technique is rarely performed (11) due to the risk of prenatal exposure to ionizing radiation. The pelvic shape of pregnant women is unknown to the midwives or obstetricians most of the time; therefore, it is crucial to determine the factors contributing to female pelvic shape. These factors are supposed to be related to environmental exposure or childhood history (1). Identification of the associated risk factors could help midwives to assess the obstetric prognosis.

Abitbol (1) identified several factors affecting the shape of female pelvis. However, the method used to identify the given factors or pelvic shapes is poorly reproducible. Accordingly, the current challenge is to determine the etiologic factors involved in the formation of female pelvis. With this background in mind, the present study was conducted to describe pelvic shape variability using an appropriate method often used in morphological studies (i.e., PCA) and identify factors with a reproducible questionnaire.

Materials and Methods

This cross-sectional study was performed on 131 women referring to the Obstetric Department of Saint Joseph Hospital, a large community hospital, in Marseille, in the south of France, from March 29, 2011 to December 10, 2013. A total of 10,614 women gave birth at this hospital during the research period.

The inclusion criteria were: 1) singleton birth, 2) computed tomography (CT) scan of the pelvis, and 3) cephalic presentation. On the other hand, the exclusion criteria incuded: 1) cesarean delivery due to abnormal fetal heart rate, 2) abnormal uterine contractions, 3) twin pregnancies, 4) iterative cesarean delivery, and 5) cesarean section 2 h before the arrest of labor.

A sampling method was not required since the CT scan exam was rare (circ. 2.5% of birth in our hospital) (7). The population investigated in this study was not divided into different groups. The attrition process is shown in the flowchart presented in Figure 1.

Figure 1. Flow chart of study process; (The figure was redrawn with permission from Frémondière [7].)

Since CT scan induced the risk of prenatal exposure to ionizing radiation, the patients enrolled in this study were subjected to CT scans during the routine care in case of observing such classical indications as scar at the uterus, breech presentation (but cephalic at the first stage of labor), suspicion of fetal-pelvic disproportion, and body size less than 1l.50 m. This study was approved by the Ethical Institutional Review Board «Sud-Méditerranée II» (ID-RCB 2011-A00072-39). In addition, written informed consent was obtained from all participants.

The imaging was performed by a 16-slice Siemens SOMATOM Definition Flash strip scanner. Different imaging settings for low, standard, and high adiposity were 100 kV/25 mA, 100 kV/35 mA, and 120 kV/35, respectively. The level of irradiation had a range of 15-35 mg/cm. The pelvises were virtually reconstructed and measured by means of Amira software (version: 5.0.0; FEI Visualization

Sciences Group, Zuse Institute Berlin) with an intersection gap of 0.6-1 mm. A total of 43 pelvic variables were measured in this study (Figure 2).

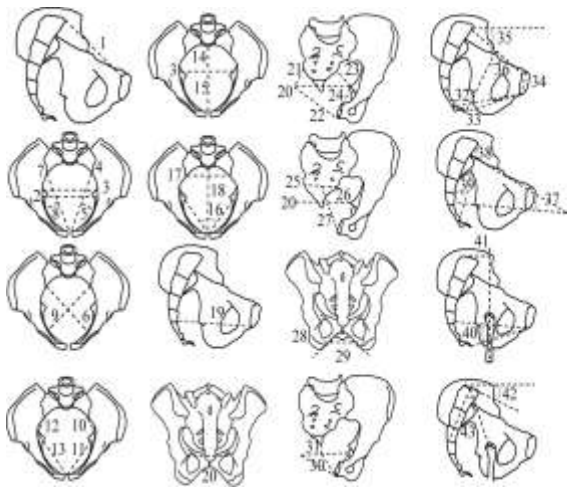

Figure 2. Pelvic variables considered in the study; 1) obstetric-conjugate (oc), 2) medial-transverse-inlet (meti), 3) maximal-transverse-inlet (mati), 4) left-ilio-pectineal cord length (licl), 5) left-ilio-pectineal cord subtense (lics), 6) right-oblique-inlet (roi), 7) right-ilio-pectineal cord length (ricl), 8) right-ilio-pectineal cord subtense (rics), 9) left-oblique-inlet (loi), 10) left-inlet-posterior space (lips), 11) left-inlet-anterior space (lias), 12) right-inlet-posterior space (rips), 13) right-inlet-anterior space (rias), 14) sagittal-posterior-inlet (spi), 15) sagittal-anterior-inlet (sai), 16) pectineal angle (pa), 17) inlet-sacral breadth (isb), 18) inlet-antero-posterior (iap), 19) midplane-antero-posterior (map), 20) interspinous (isp), 21) right-midplane-posterior space (rmps), 22) right-midplane-anterior space (rmas), 23) left-midplane-posterior space (lmps), 24) left-midplane-anterior space (lmas), 25) midplane-sacral breadth (msb), 26) sagittal-posterior-midplane (spm), 27) sagittal-anterior-midplane (sam), 28) transverse-outlet (tout), 29) subpubic angle (spa), 30) sagittal-anterior-outlet (sao), 31) sagittal-posterior-outlet (spo), 32) outlet-antero-posterior (oap), 33) pubococcygeus length (pcl), 34) pubic-symphysis height (psh), 35) obstetric-conjugate slope (ocs), 36) obstetric-conjugate-umbiliccoccygeal angle (ocua), 37) inlet-midplane angle (ima), 38) sacral-cord length (scl), 39) sacral-cord subtense (scs), 40) midplane-outlet angle (moa), 41) sacral overhang (over), 42) sacral slope (sslop), 43) sacral incidence (inc) (The figure was redrawn with a permission from Frémondière [8]).

The validity and reliability of the measurement technique were assessed with the intraclass correlation and standard error of measurement (6) (12). According to these variance assessments, the measurement technique was considered valid and reliable (7).

The purpose of this study was to investigate the environmental factors responsible for the variations in female pelvic shapes. All 131 women were asked to complete a questionnaire covering such information as age, physical activity performed during adolescence, mode of acquiring an erect posture, diet, birthplace, socioeconomic status, and presence of a spinal disorder.

In the mentioned questionnaire, the women were required to report the age at which they stood up for the first time on their own (i.e., before or after 14 months). In addition, performing exercise in adolescence was recorded in three groups of intense, moderate, and none, which were divided according to their biomechanical impact on the hips and spine. In this regard, activities with the ground reaction force peaks of > 3 and < 3 were placed in the intense (*e.g.,* basketball and volleyball) and moderate (*e.g.,* riding, swimming) activity groups, respectively (13). In addition, "none" referred to the lack of participation in any physical activity in adolescence. Horse riding activity was considered "intense" group given its important biomechanical impact on the pelvic.

Diet in adolescence was explored based on the frequency (1-6) of six food categories (i.e., meat, fish, diary, vegetable/fruit, starches, and legumes). Then, these combinations were identified as "energetic" group (*e.g.*, diet mostly based on meat), "nutritional" (*e.g.,* diet mostly based on vegetable/fruit), and "diversity" (*e.g.,* equal frequency of the given six categories) (14).

Socioprofessional positions were determined according to the classification of the Institut National des Statistiques et des Etudes Economiques or National Institute of Statistics and Economic Studies (15).

The occupation was classified into independent positions (mainly self-employed; *e.g,.* shopkeepers, craftspeople, and company directors), managerial positions, intermediate occupation (*e.g.,* teachers), employed status (*e.g.,* secretary), and physical occupations (*e.g.,* farm laborer). The geographic origin was confirmed by asking the participants about their birthplace. Then, the birthplaces were grouped into Africa, North Europe, Mediterranean, America, or Asia. Furthermore, spinal disorders were defined by a review of each participant's medical records and a specific examination of the anesthetist during the 8 months of pregnancy.

Most of the existing statistical shape analysis methods rely on PCA (16). Therefore, this analysis was chosen for the interpretation of the female pelvic shape variability. The PCA gives a representation of the largest possible variance, using an orthogonal transformation to convert a set of data tables. The orthogonal representation (i.e., perpendicular components) captures the essential data variability (17). This analytical method is the only statistical tool used in the current study. As suggested by Bonneau *et al.* (18), only the first two components were represented in the result section. This analysis was performed in SPSS software, version 17.0.0 (SPSS Inc, Chicago).

Results

The results of PCA (Figure 3) demonstrated the distribution of different pelvic shapes along PC1 (25.4% of variance) and PC2 (11.8% of variance). The positive part of the first component and the right side of the PCA discriminated the sagittally elongated inlet (sai, oc, iap, ricl, and licl). The positive part of the second component and the upper side of the PCA discriminated the transversally elongated inlet, midplane, and outlet (mati, meti, isb, tout, and isp). Between these two components, at the Upper and right side of the PCA, the obliquely elongated inlet was represented (roi, loi, rias, and lias).

The inlet with large pectineal angle plotted to the negative part of the first component and the left side of the PCA. The inlet variables explained most of the variability of the pelvic shape rather than the variables related to the midplane, outlet, curvature of the birth canal, or pelvic balance in the standing position (Figure 3).

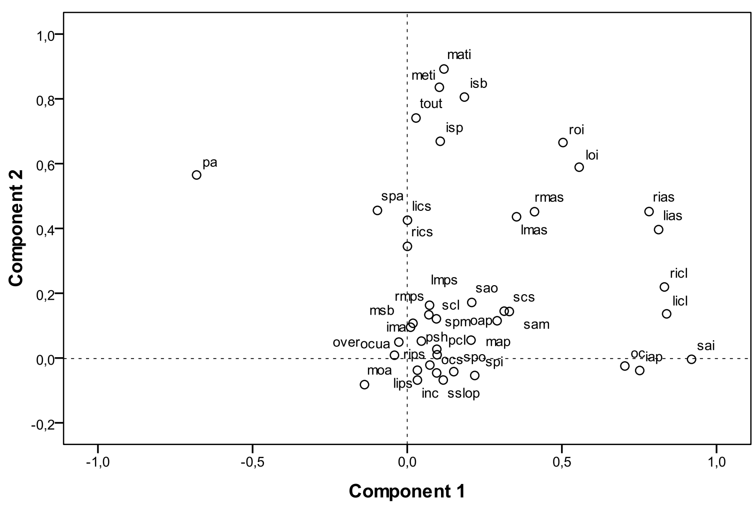

Figure 3. Principal component analysis representing pelvic variability with the first two components

Environmental factors working at early childhood and adolescence were not associated with any specific female pelvic shapes (Figure 4).

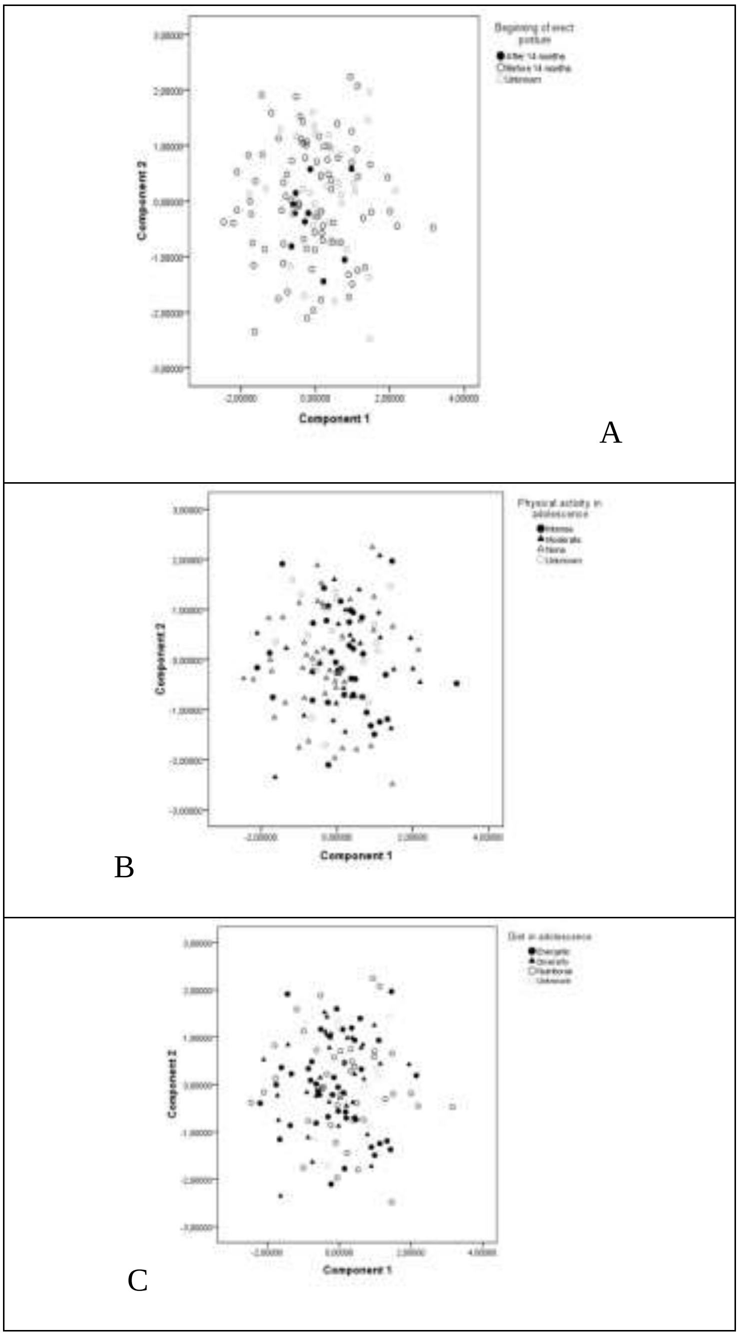

Figure 4. Principal component analysis with factors related to early childhood and adolescence

As displayed in Figure 4A, the females acquiring erect posture before 14 months were not clearly separated from the other ones. In addition, the females with intense activity did not show a clear discrimination from the others (Figure 4B). Furthermore, the subjects with nutritional diet overlapped the other females (Figure 4C). Figure 5 illustrates the distribution of the subjects according to the three environmental factors (Figure 5).

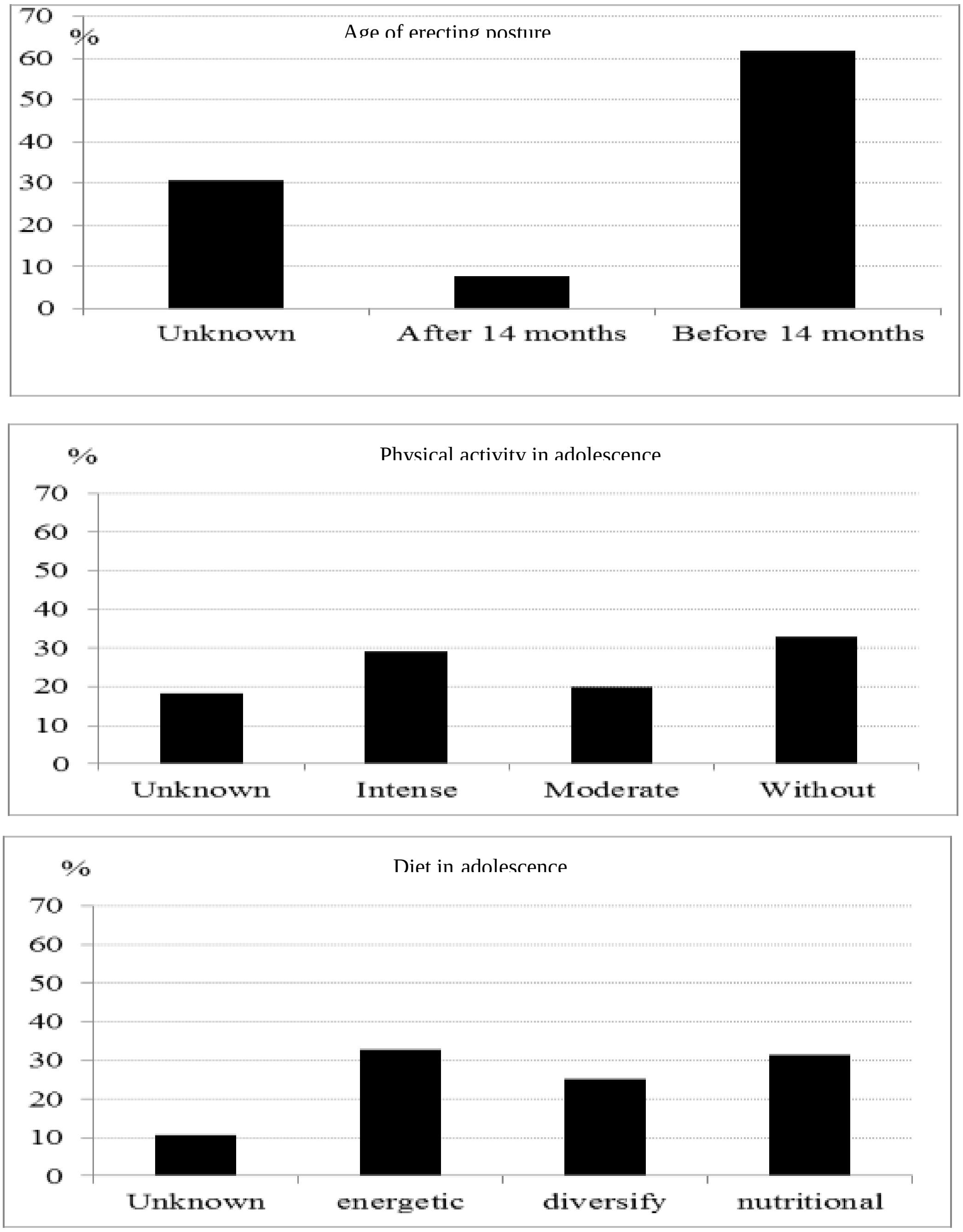

Figure 5. Distribution of study population based on three environmental factors

Demographic and health factors are considered in Figure 6. The females were labeled according to their socioprofessional conditions as depicted in Figure 6A. The results revealed no separation in the six socioprofessional conditions of the subjects. In this regard, there were some overlaps among these socioprofessional conditions. Four types of spinal disorders, including six sacral variability scoliosis, protruding disc, and the partial fusion at the L5-S1 level, were identified in the study population.

There was no distinction between the females without spinal disorders and the others females in the PCA. The females without any spinal disorders overlapped the other females with spinal disorders (Figure 6D). In Figure 6B, the subjects were labeled according to their birthplace. The PCA discriminated between two groups of females, namely those reporting Africa as the birthplace and the ones with North Europe as the birthplace. In this respect, Africa birthplaces were in the lower and left side of the PCA, whereas North Europe birthplaces were in the upper and right side of the PCA. Furthermore, Mediterranean birthplaces overlapped both Africa and North Europe. The females born in America belonged to the North Europe variability, whereas the two females born in Asia were between the African and North Europe variability.

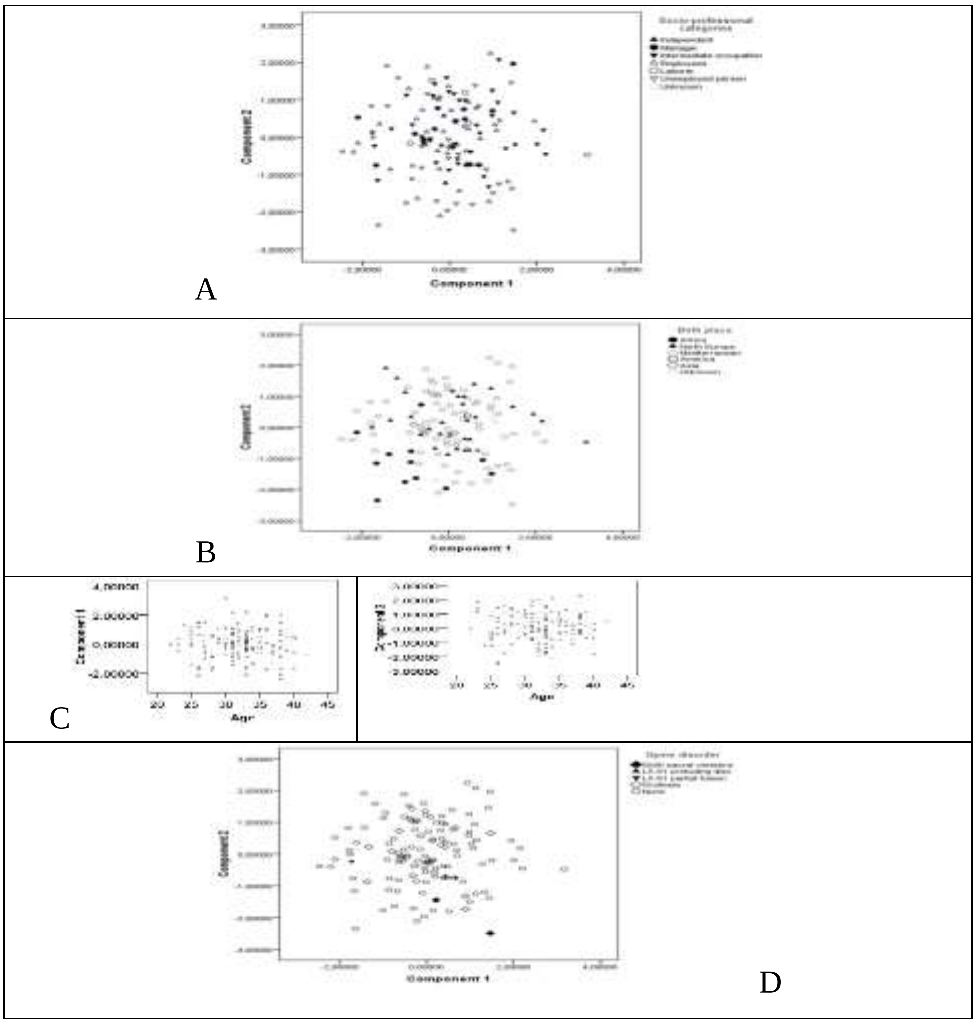

Figure 6. Principal component analysis with demographic and health factors

Figure 7 illustrates the distribution of the participants based on demographic and health factors.

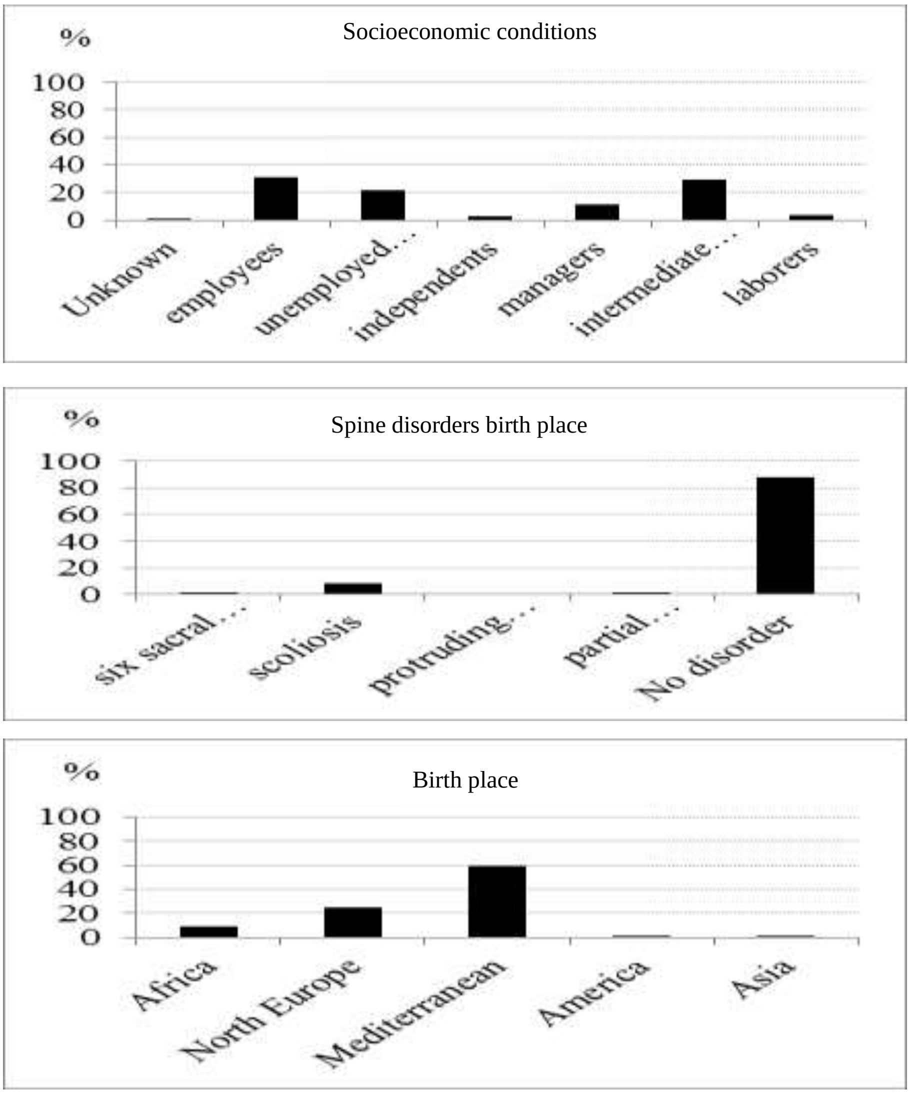

Figure 7. Distribution of study population based on demographic and health factors

Discussion

The results of this study did not support the previous classification described by Cadwell and Moloy in 1993 (2), which is in line with the most recent studies (5, 6). Among all the factors considered in this research, birthplace was the only effective factor that played a role in pelvic shape. In our study, the first component discriminated the sagittally elongated inlet, while the anterior space was sagittally elongated in the positive part. The negative part of the first component discriminated the sagittally reduced inlet with a wide anterior space, contributing to the opening of the pectineal angle.

The positive part of the second component discriminated the transversally elongated inlet, midplane, and outlet. These anatomical traits are shared "gynaecoid" or "android" types according to the classification of Cadwell and Moloy (2). Considering this classification, the "anthropoid" type was described as sagittally elongated, with a wide subpubic angle (1, 2). If such a shape existed, the PCA would present a tighter cluster for "subpubic angle", "inlet anteroposterior", and "obstetric conjugate" (1). Therefore, our study questioned the relevance of the anthropoid type as a specific pattern of pelvic variability.

Thes results are consistent with those of a previous study performed by Bouhallier (2002), investigating pelvic shape variability in a large sample of pelvises from osteological collections using PCA (6). In the current study, PCA discriminated the transversally elongated pelvic with the second component and round-shaped inlet with the first component. Furthermore, "gynaecoid", "android", and "platypelloid" types were represented as pelvic patterns; however, this was not the case for "anthropoid" (6). In our study, most of the investigated factors did not play a role in the formation of pelvic shape. This is not in line with the study conducted by Abitbol in 1996. In the mentioned study, the anthropoid pelvis was encountered more often when the acquisition of erect posture was delayed beyond the age of 14 months, whereas a platypelloid pelvic was more frequent when this acquisition was before 14 months (1).

It is worth mentioning that we did not find the anthropoid shape in our study. This could explain the inconsistency between our findings and those reported by Abitbol (1996). Moreover, the effect of biomechanical load on adult pelvic shape in early childhood was complex. The age of the first step is an interesting variable since a member of the patient's family, usually the mother, has a vivid recollection of this age (1).

However, it does not reflect the biomechanical load on the pelvis at this stage of life accurately. Before the beginning of erect posture, the baby attempts to stand up leaning hands against a surface, such as a wall or a chair. After this age of erect posture, the child is able to experience a range of locomotor behavior, from bipedal to all-four locomotion. The beginning of erect posture cannot be summed up to the age of the first step but consists of successive psychomotor acquisitions. These successive acquisitions should be accurately investigated to analyze the relationship between adult pelvic shape and early childhood history.

In this study, physical activities did not play a role in the formation of pelvic shape. This finding was inconsistent with the results obtained by Abitbol, where android pelvis was supposed to be affected by the strenuous activities performed during early childhood and adolescence (1). However, Abitbol's definition of "strenuous activity" is difficult to replicate in other studies.

Physical activity was assigned three degrees of nil (0), moderate (+), and intense (++); however, the way of allocation was not specified. Abitbol also recorded early strenuous physical work and heavy lifting; nonetheless, the females included in our study had not experienced such traumatic events, which could explain the difference between our findings and those of Abitbol.

Kelley and Angel (1987) found that nutritional factors affect the pelvic brim index (19). In our study, the qualitative aspect of the diet was not related to a specific pattern of pelvic shape. Kelley and Angel (19) showed that nutritional stress and starvation are associated with the platypelloid pelvis. According to our results and those of previous studies, the quantitative aspect of diet rather than the qualitative one can affect growth during childhood and inlet pelvic shape.

Huseynov *et al.* (20) showed that the shape of female pelvis is round near the time of maximum fertility; thereafter, it returns to an ontogenetic trajectory similar to the male development. Our study failed to find such a developmental shape change. However, we excluded postmenopausal females, and only women of childbearing age were included. The age range considered in our study was probably limited (*i.e.,* 22-42 years) to identify this complex developmental trajectory, previously described, during the female's lifetime.

Geographic origin seemed to be the only factor explaining the two patterns of pelvic shape in our study. The Mediterranean was an intermediate geographic region between Africa and North Europe and seemed to have an intermediate range between African and North European variability. In 2002, Baragi *et al.* studied the shape of the pelvic floor area of African American and European American women and found that posterior pelvic floor area was 10.4% smaller in African American women (21). This finding was in agreement with our results.

Geographical effect on pelvic variability has been demonstrated in a recent study performed by Betti and Manica (2018) (22), pinpointing the ancient population history as the main cause of variation. For Betti and Manica (22), the shape of the pelvic bone is related to the effects of ancient demographic events, such as founder effect or migration, on contemporary genetic diversity. The effects of demographic past history are also called "neutral population history" and are correlated with geography since the origin of human expansion in Africa.

For Betti and Manica, the neutral population history shaped the human pelvic bone (22). Our results showed that geographic origin could affect pelvic variability, which is in line with the results reported by Betti and Manica (22). However, if neutral evolution had been responsible for the observed pattern of morphological diversity, we would have expected a larger African variability than European and Mediterranean ones. Since only 9% of women were born in Africa, it is required to perform another study with a greater sample size.

The strength of the study lied in its use of PCA in a modern obstetric samples, where environmental, demographic, and health factors were identified with a reproducible questionnaire. Some of the limitations of this study included the use of landmarks rather than metric variables, which improve the analysis of anatomical variability. Therefore, a morphometric analysis is required to confirm our results so as to generate "log-size" and "log-shape" variables, as suggested by Mosimann and James (23). This generation can decrease the skewness of data and analyze the contribution of size and shape in the total variance.

Conclusion

The pelvic shape variability of our samples was not explained by the four categories previously proposed by Cadwell and Moloy (2). Our results are consistent with the findings obtained by Kuliukas *et al*. (5). Based on our results, midwifery teachers are recommended to be more cautious about adherence to the classification of Cadwell and Moloy (2). None of the factors related to early childhood, adolescence health, or demographic data explained the pelvic shape variability. Geographic origin seemed to be related to different pelvic shape patterns, suggesting the effect of neutral population history on pelvic variability.

Acknowledgements

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Conflicts of interest

The authors declare no conflicts of interest.

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