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ORIGINAL ARTICLE

Anatomical identification of ischial spines applicable to intrapartum transperineal ultrasound based on magnetic resonance imaging of pregnant women

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ABSTRACT

Objective: Intrapartum transperineal ultrasound is considered useful in judging fetal head descent; however, the inability to detect ischial spines on ultrasound images has been a drawback to its legitimacy. The current study aimed to determine the anatomical location of ischial spines, which can be directly applied to intrapartum transperineal ultrasound images.
Method: Based on magnetic resonance imaging (MRI) of 67 pregnant women at 33^{+2} [31^{+6}-34^{+0}] weeks gestation (median [interquartile range: IQR]), we calculated the angle between the pubic symphysis and the midpoint of ischial spines (midline symphysis-ischial spine angle; mSIA), which is theoretically equivalent to the angle of progression at fetal head station 0 on ITU, by determining spatial coordinates of pelvic landmarks and utilizing spatial vector analysis. Furthermore, we measured symphysis-ischial spine distance (SID), defined as the distance between the vertical plane passing the lower edge of the pubic symphysis and the plane that passes the ischial spines.
Results: As a result, mSIA was 109.6° [105.1–114.0] and SID 26.4 mm [19.8–30.7] (median, [IQR]). There was no correlation between mSIA or SID and maternal characteristics, including physique.
Conclusions: We established a novel method to measure the components of the pelvic anatomy by analyzing the three-dimensional coordinates of MRI data and identified the anatomical location of ischial spines which can be applied to ultrasound images. Our results provide valuable evidence to enhance the reliability of intrapartum transperineal ultrasound in assessing fetal head descent by considering the location of ischial spines.

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Intrapartum transperineal ultrasound; angle of progression; ischial spines; station 0; magnetic resonance imaging

Introduction

Intrapartum transperineal ultrasound (ITU) has been proposed for evaluating labor progression. The angle of progression (AoP), defined as the angle between the midline of the pubic symphysis and a line running from the inferior edge of the symphysis to the fetal skull, is regarded as more reliable in accuracy and reproducibility than vaginal Examination (VE) to assess fetal head descent [1–5]. However, some researchers have questioned the accuracy of ITU in assessing fetal head descent because ischial spines, the most important landmark in evaluating fetal head station (St), cannot be obtained by ultrasound [6,7]. Previous studies have tried to identify the anatomical position of the ischial spines using magnetic resonance imaging (MRI) or computed tomography (CT) images, as applicable to the assessment of fetal head station by ITU [6–12]. Tutschek et al. depicted a line perpendicular to the pubis, which runs ischial spines (level of ischial spines) on ITU images and reported that the AoP of 116° corresponds to St 0 [11,12], which is covered by the International Society of Ultrasound in Obstetrics and Gynecology (ISUOG) practice guidelines [13]. However, the level of ischial spines in their study was defined based on a symphysis-ischial spine distance (SID) of 3 cm, which was obtained from single CT images of only one non-pregnant woman [10]. Considering the

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anatomical changes of the pelvis during pregnancy and the differences in pelvic structure among individuals [14], this reference remains arguable.

To date, there is only one report from France by Arthuis et al. that has evaluated the anatomical position of ischial spines by analyzing pelvic images during pregnancy [7]. By analyzing CT images of pregnant women, they calculated the angle between the upper-lower edge of the pubic symphysis and the midpoint of ischial spines in a mid-sagittal plane (midline symphysis-ischial spine angle; mSIA) and reported that it was 110°. This angle was considered nearly equivalent to the AoP at St 0, and it contributed to the understanding of the fetal head location on ITU images.

Considering racial or physique differences in pelvic anatomy [15,16], it has not been clarified whether mSIA of 110° can be applied to other races; thus, more evidence needs to be accumulated to determine ischial spines or St 0 on ITU images universally. Additionally, if there is a method to evaluate the components of the bony pelvis more easily, we can evaluate the pelvic structure and apply this further to ITU. Therefore, by calculating the structural relationship between the pubis and other bony birth canal components, we can establish an absolute index that divides the pelvic cavity, or the positional relationship between the pubis and fetal head changes, quantitatively along the pelvic curve.

The current study aimed to quantify the relative position between ischial spines and the pubic symphysis to assess St 0 on ITU images in an East Asian population by establishing a novel and practical method to evaluate pelvic anatomy that can be applied to ITU by analyzing three-dimensional coordinates of MRI images in pregnant women.

Material and methods

Under the approval of the Institutional Review Board of the University of Tokyo [3053-(4)], we retrospectively analyzed MRI images performed during pregnancy for the evaluation of placental abnormality (placental previa, low set placenta, or placenta accreta), fetal anomaly, or maternal complication (Klippel-Trenaunay-Weber syndrome) between January 2016 and December 2018 in our hospital. This was a retrospective observational study and was carried out by the opt-out method of our hospital website in accordance with the request of the ethics committee and guidelines. Either MRI, 1.5 T MAGNETOM Avanto (Siemens, Germany), or 1.5 T EXCITE HDX (GE Healthcare, United States) were used. The mid-sagittal plane of T2-weighted images (T2WI) and axial and coronal planes of fast-suppressed T1-weighted images (T1WI) were taken with the patient placed in a supine position with their knees bent. In 1.5 T MAGNETOM Avanto (Siemens, Germany), T2WI were acquired by 2D single shot fast spin echo with the following settings: time of echo (TE) of 75 ms, time of repetition (TR) of 1500 ms, and slice interval of 5 mm; fast-suppressed T1WI were acquired by 3-D spoiled gradient echo with TE of 1.07, TR of 3.2, and slice interval of 5 mm. In 1.5 T EXCITE HDX (GE Healthcare, United States), T2WI were acquired by 2D single-shot fast spin echo with TR of 1268 ms, TE of 91.50, and slice interval of 5 mm; fast-suppressed T1WI were acquired by 3D spoiled gradient echo with TR of 3.532, TE of 1.688, slice interval of 1.5 mm.

MRI data were analyzed with OsiriX Lite (Pixmeo SARL, Switzerland), free and open source of the Digital Imaging and Communications in Medicine (DICOM) viewer. OsiriX Lite can simultaneously evaluate three cross sections of DICOM images: horizontal, coronal, and sagittal sections. By selecting any point on the image, the spatial coordinates (x, y, z) are automatically measured when the image is constructed in 3D. The identification and measurement of each anatomical were conducted by the same obstetrician (E. Y.) under the guidance of a radiologist (S. H.).

Data of background characteristics were expressed as median (interquartile range [IQR]). Correlation analysis was conducted using Spearman's rank-order correlation with JMP pro version 15 (SAS Institute Inc., Japan). Statistical significance was defined as $p<.05$.

Results

There were 76 cases whose MRI scans were performed during pregnancy between January 2016 and December 2018; 67 cases were analyzed as nine cases were excluded due to any landmarks, including the superior or inferior edge of pubic symphysis or ischial spines, being unclear. Table 1 shows the maternal characteristics; age, height, pre-pregnancy body mass index (BMI), and the gestational age when the MRI was taken (35 years old [31–39] (median [interquartile range: IQR]), 159 cm [156–162], 20.0 kg/m^2 [19.1–21.2], and 33^{+2} weeks [31^{+6}–34^{+0}], respectively). Fifty patients (74%) were primiparous. The indications for MRI were placental previa, low set placenta, or placenta accreta (59 cases [88.0%]); fetal malformation (4 cases [5.9%]); and birth canal evaluation for maternal complication with Klippel–Trenaunay–Weber

Table 1. Maternal characteristics.

Characteristics	Value
Age (years)	35.0 [31.0–39.0]
Height (cm)	159.0 [156–162]
Pre-pregnancy weight (kg)	51.0 [48.0–54.0]
Weight gain during pregnancy (kg)	7.0 [5.2–9.0]
Pre-pregnancy BMI (kg/m^2)	20.0 [19.1–21.2]
Gestational age when MRI was taken	33^{+2} [31^{+6}–34^{+0}]
Parity	
Nulliparous	50 (74.6)
History of vaginal delivery	11 (16.4)
History of cesarean section	6 (8.9)
Indication for MRI	
Placenta previa or low set placenta	59 (88.0)
Fetal malformation	4 (5.9)
Other	1 (1.5)
Race (East Asian)	67 (100)

The values are expressed as median [interquartile range] or number (%). BMI: body mass index; MRI: magnetic resonance imaging.

syndrome (one case [1.5%]]. All pregnant women were East Asians.

We measured the spatial coordinates of the following points on MRI images: superior and inferior edge of the pubic symphysis and bilateral ischial spines. We identified the superior and inferior edge of the pubic symphysis (A, B) using mid-sagittal and axial views and measured each coordinate: A (Ax, Ay, Az) and B (Bx, By, Bz) (Figure 1(a–d)). The left and right ischial spine (C, D) were identified by evaluating the axial and coronal views of T1WI and measuring each coordinate: C (Cx, Cy, Cz) and D (Dx, Dy, Dz) (Figure 1(e,f)). The point corresponding to the level of the ischial spine in the mid-sagittal plane was calculated as the midpoint of the bilateral ischial spines (E).

$$E\ (Ex,\ Ey,\ Ez) = \left(\frac{Cx + Dx}{2}, \frac{Cy + Dy}{2}, \frac{Cz + Dz}{2}\right) \quad (1)$$

The vector connecting the inferior and superior edge of the pubic symphysis is defined as the vector BA, and the vector connecting the inferior edge of the pubic symphysis and midpoint of the ischial spines is defined as the vector BE. The angle between the vector BA and BE is defined as θ, which corresponds to the midline symphysis-ischial spine angle (mSIA) on MRI (Figure 2(a,b)).

$$\text{Vector BA} = (Ax - Bx,\ Ay - By,\ Az - Bz) \quad (2)$$
$$\text{Vector BE} = (Ex - Bx,\ Ey - By,\ Ez - Bz) \quad (3)$$

Angle θ can be expressed by the length of vector BA (|BA|), the inner product of the vector BA and the vector BE (BA ▫ BE) and the Arc cos function as follows:

$$|BA| = \sqrt{(Ax - Bx)^2 + (Ay - By)^2 + (Az - Bz)^2} \quad (4)$$

$$BA \cdot BE = (Ax - Bx)\cdot(Ex - Bx) + (Ay - By)\cdot(Ey - By) + (Az - Bz)\cdot(Ez - Bz) \quad (5)$$

$$\theta = \text{Arc}\ \cos\left(\frac{BA \cdot BE}{|BA||BE|}\right) \quad (6)$$

Angle θ was calculated as 109.6° [105.1–114.0] (median [IQR]). There was no significant statistical correlation between mSIA and maternal characteristics (age, gestational days, height, body weight, BMI, or parity) (Supplemental Table 1).

The infrapubic plane, which is defined as the plane perpendicular to the pubis, which passes the inferior edge of the pubis, and the level of the ischial spines, which is defined as the plane parallel to the infrapubic plane, which runs ischial spines, and the distance between two planes is defined as the symphysis-ischial spine distance (SID). E′ is the foot of the perpendicular line drawn from the midpoint of the ischial spine (E) to the extension of the pubis; the distance corresponding to SID was calculated as the distance |BE′| between the infrapubic plane and the level of the ischial spine (EE′) (Figure 2(a,c)). SID can be calculated as follows:

$$SID = |BE'| = |BE| \cos(180 - \theta) = -|BE|\cos(\theta) \quad (7)$$

$$|BE| = \sqrt{(Ex - Bx)^2 + (Ey - By)^2 + (Ez - Bz)^2} \quad (8)$$

The median SID was 26.4 mm [19.8–30.7] (median [IQR]). There was no significant statistical correlation with maternal characteristics (Supplemental Table 1).

Discussion

The current study demonstrated the anatomical angles and distance that can help identify the location of ischial spines on ITU by analyzing the anatomical relationship between the pubic symphysis and ischial spines using MRI data from pregnant women in the third trimester. In this study, we also established a novel method to measure the components of the pelvic anatomy by analyzing the three-dimensional coordinates of MRI.

Although several studies have attempted to identify St 0 or ischial spines on ITU images, there is only one report by Arthuis et al. prior to the current study that measured the anatomical relationship between the ischial spines and the pubis on the mid-sagittal plane using images during pregnancy [7]. Since it is known that there are differences in pelvic size and structures depending on race or physique [15,16], it has been questioned whether the mSIA of 110° calculated by Arthuis et al. can be applied to other races. In the current study, we demonstrated that the mSIA was 109.6° [105.1–114.0] (median [IQR]), regardless of the differences in maternal characteristics, including

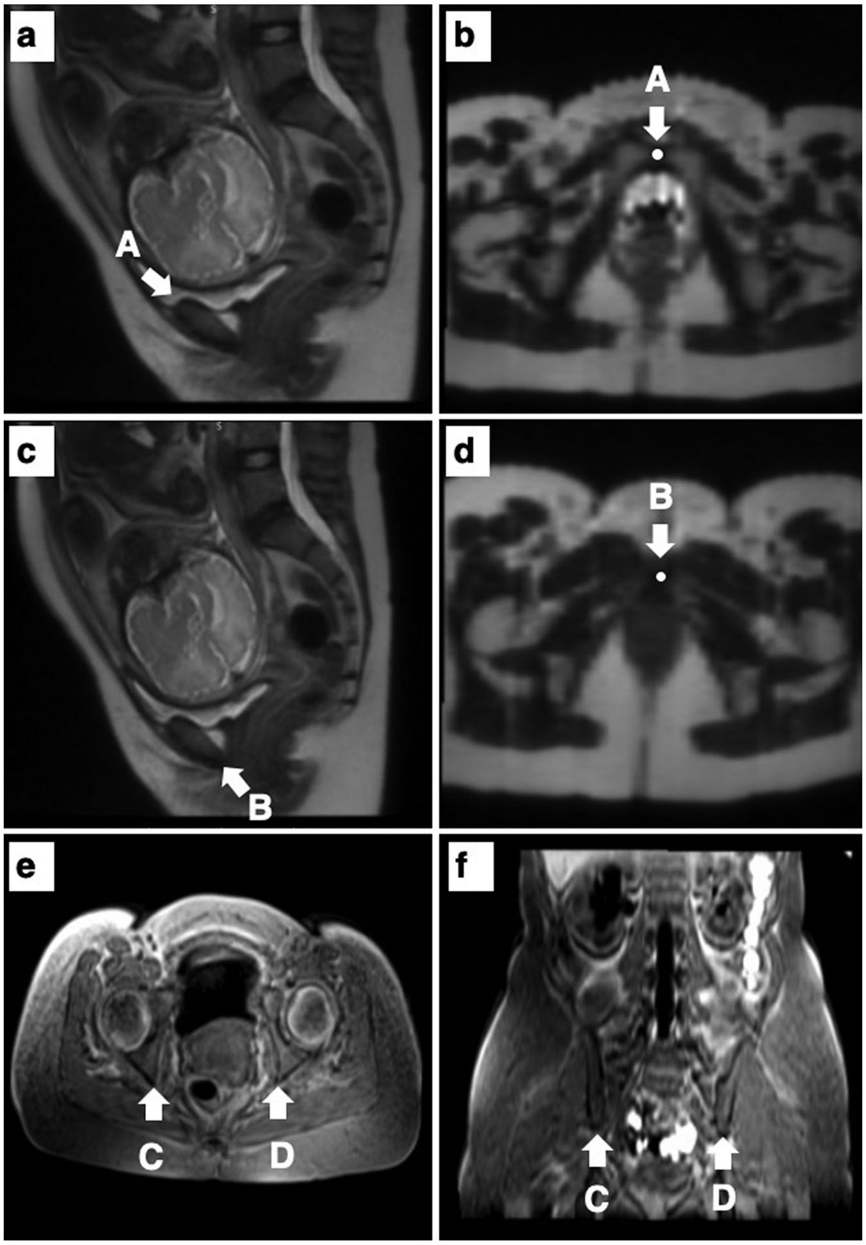

Figure 1. Identification of superior and inferior edge of the pubic symphysis and bilateral ischial spines on magnetic resonance imaging (MRI). The superior edge of the pubic symphysis (A) and inferior edge of the pubic symphysis (B) on mid-sagittal plane of T2-weighted images (T2WI) and axial plane of T1-weighted images (T1WI) (a–d). Right and left ischial spines (C, D) on axial and coronal plane of T1WI (e,f).

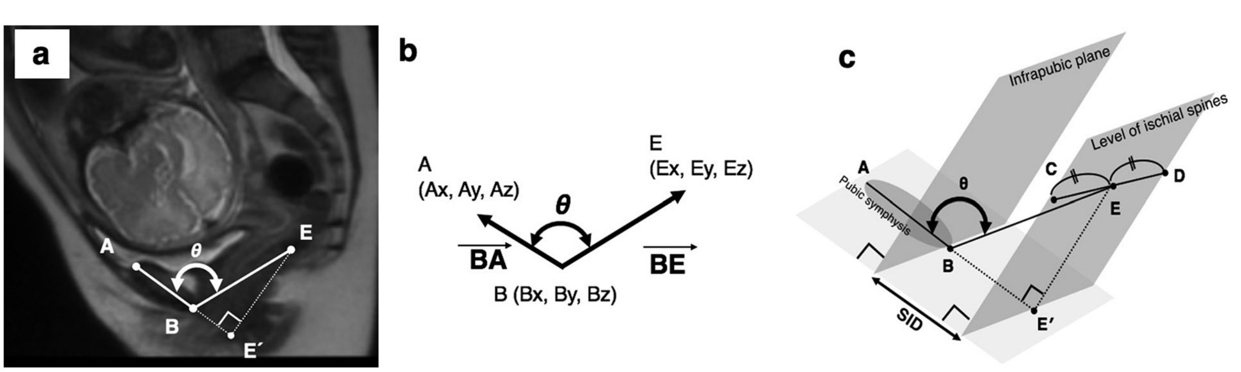

Figure 2. The relationship of midline symphysis-ischial spine angle (mSIA) and symphysis-ischial spine distance (SID). (a) θ is the angle between the superior and inferior edge of pubic symphysis (A, B), and the midpoint of ischial spines (E) on the mid-sagittal plane of MRI. E′ is defined as the foot of the perpendicular line drawn from E on the extension line of the pubis. (b) Schema of the relationship between vector BA, vector BE and θ. (c) Schema of the relationship between SID, pubic symphysis, infrapubic plane, and level of ischial spines.

height. Arthuis et al. also demonstrated that the angle between the pubis and left ischial spine was 106° [105-109] (median [IQR]). Based on our analysis, the angles between the pubis and left or right ischial spine were 105.5° [102.0-107.9] and 106.8° [101.9-109.3] (median [IQR]), respectively. Intriguingly, these values are almost equal to those reported by Arthuis et al. Although they did not describe the target race, the height was 164 cm [160-169] (median, [IQR]), which is different from ours, 159 cm [156-162] (median [IQR]), obtained from our Japanese and East Asian population. This comparison shows that a mSIA of 109.6° can be considered as a universal value corresponding to St 0 in applying to ITU, regardless of race or physique.

According to ISUOG practice guidelines [13], AoP equivalent to ITU head station 0 is 116°, which is a result calculated based on single CT images of only one non-pregnant woman reported by Tutchek et al. [11,12]. They calculated this value, 116°, by depicting the level of ischial spines on ITU images by drawing a perpendicular line to the pubis, which passes 30 mm from the lower edge of the pubis. The rationale for this distance was based on the measurement of the symphysis-ischial spine distance (SID), which was 30 mm, although this was obtained from only one non-pregnant woman. Therefore, their result remains controversial to be used as a universal value. In our study, we calculated SID to be 26.4 mm [19.8-30.7] (median [IQR]). Intriguingly, this SID value was almost the same at 26.1 mm [23.4-29.5] (median [IQR]) as Arthuis et al. reported [7], implying that SID may be consistent among pregnant women. The pelvic cavity changes gradually but dramatically during pregnancy, such as an increase in the mobility of the sacroiliac joint and pubic symphysis [14]. Barbera et al. calculated mSIA as 99° using 3DCT of non-pregnant women [4], which is clearly different from our current result of 109.6°. Therefore, we speculate that mSIA increases during pregnancy, which implies that the value obtained from non-pregnant women should not be directly applied to pregnant women. Taken together, we must reconsider the value obtained from one non-pregnant woman in assessing fetal head descent, which is still used to assess head station in the ISUOG guidelines. The figure calculated from multiple pregnant women is more reliable in accurately assessing fetal descent.

Arthuis et al. analyzed 3DCT of pregnant women and reported the angle between the pubis and the left ischial spine as 106° [105–109] (median [IQR]) [7]. However, since the view equivalent to the ITU images is the mid-sagittal plane, this angle cannot be directly applied to ultrasound. Although the midpoint of the ischial spines can be used as an index for the ischial spine on ITU images, it cannot be measured directly by their method. Thus, they calculated the angle between the pubis and the midpoint of the ischial spine (mSIA) as 110° by using the distance measurement by 3DCT and trigonometric function. In contrast, the method that we newly developed enables us to calculate the mSIA directly and easily by measuring the spatial coordinates and applying them to vector calculation. Thus, the anatomical relationship on the mid-sagittal plane can be easily obtained. Furthermore, as our method enables the evaluation of anatomical landmarks other than the ischial spines, we can assess other components of the birth canal, which has not been evaluated in previous studies, but is of value in determining fetal descent, including the sacrum. We can easily quantify the positional relation of the pubis, sacrum, and fetal head. According to the American College of Obstetricians and Gynecologists (ACOG) forceps delivery classification [17], namely mid/low/outlet, clinicians rely on VE to assess fetal descent, and its correspondence to ITU findings is still undetermined. With our novel method for calculating the exact position of the pubis, sacrum, and ischial spines, we might be able to theoretically divide the pelvic cavity into a mid/low/outlet in relation to the position of pubic symphysis as a future study, which would ultimately lead to safer application of operative vaginal delivery.

The limitation of our study is that we did not consider the fetal head. Since the fetal head progresses in the birth canal three-dimensionally, the presenting part does not necessarily exist on the mid-sagittal plane. Since the presenting part is evaluated on the mid-sagittal plane when evaluating AoP, there may be a discrepancy from VE findings. Another limitation is that the spatial relationship of pelvic landmarks might be influenced by the anatomical change that could occur during the intrapartum period, as it has been reported that the pubic symphysis structure changes throughout pregnancy [18]. To determine the position of the ischial spines more accurately during labor, angle evaluation during labor may be necessary. Another limitation is that we did not examine intra-observer or inter-observer differences. However, identification of ischial spines and pubis on MRI images is easy, and it is unlikely that a significant error will occur.

We established a novel method to analyze the pelvic anatomy by evaluating spatial coordinates on MRI images and calculated the mSIA as 109.6° and SID as

26.4 mm in pregnant women in the third trimester, which can be applied to ITU as positional landmarks of ischial spines. Furthermore, since these values are almost equivalent to the value from other races and physiques, our figure can be a universal parameter. With this index, the anatomical relationship between the fetal head and the ischial spines can be evaluated on ITU images, and it should increase the reliability and accuracy of labor progression assessment using ITU.

Author contributions

E.Y. and T.I. designed the research. E.Y. and S.H. analyzed MRI images and acquired the data. E.Y., T.I., and S.S. wrote the manuscript. M.I, M.T., T.S., K.S., K.K., T.N., and K.K. have made substantial contribution to study design, interpretation of data, and made critical comments on the manuscript. T.F. and Y.O. organized this research as project managers.

Disclosure statement

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Data availability statement

All data generated or analyzed during this study are included in this published article.

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