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Magnetic resonance imaging pelvimetric measurements as predictors for emergent cesarean delivery in obstructed labor

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ABSTRACT

Objective: This study aimed to investigate the usefulness of various magnetic resonance imaging (MRI) pelvimetric parameters for predicting emergent cesarean delivery due to obstructed labor.

Study design: This was a prospective observational study. MRI pelvimetry was performed in cases of a clinically suspected maternal narrow pelvis, maternal short stature, fetal overgrowth, and abnormal placental position. MRI pelvimetry was performed at 34.7 ± 4.2 gestational weeks using a 1.5 T MRI system. The pelvic inlet angle, pelvic inclination, obstetric conjugate, sacral outlet diameter (SOD), and coccygeal pelvic outlet were measured in the sagittal section. The interspinous diameter and intertuberous diameter were measured in coronal sections. Fetal anomalies, cesarean deliveries before the onset of labor, and non-reassuring fetal status were excluded from the analysis.

Results: MRI pelvimetry was performed in 154 patients. After excluding 76 cases, including 19 cases of absolute cephalopelvic disproportion, 78 cases of trial of labor were included. Of these, 63 were vaginal deliveries and 15 were emergent cesarean deliveries due to obstructed labor. The cut-off value for body mass index (BMI) was 22.2, with an area under the curve (AUC) of 0.69, for predicting obstructed labor. The cut-off value for the SOD was 10.7 cm with an AUC of 0.69. BMI alone had a sensitivity of 80%, specificity of 66%, positive predictive value (PPV) of 36%, and negative predictive value (NPV) of 93%. When BMI and SOD were combined, sensitivity was 53%, specificity was 90%, PPV was 57%, and NPV was 89%. The odds ratio for emergent cesarean delivery was 5.42 (95% confidence interval 1.06–27.6, $p = 0.041$) if the SOD was less than the cut-off value in the binomial logistic regression analysis in cases with an BMI > 22.

Conclusion: We confirmed that MRI pelvimetry was a reliable tool for better patient selection for obstructed labor. The SOD was the best predictor of obstructed labor, with a cut-off value of 10.7 cm for women with a low BMI.

Introduction

Cephalopelvic disproportion (CPD) is a mismatch between the fetal head and the maternal pelvis that interferes with the physiological progression of delivery. Obstructed labor [1] is often caused by CPD and carries the risk of failed vaginal delivery or the need for instrumental delivery. In addition, cesarean section during labor generally leads to higher morbidity than cesarean section before the onset of labor. Therefore, it is important to identify women at risk for CPD and choose the most appropriate delivery method at an early stage of pregnancy [2].

Recently, obstructed labor has been discussed as both an old and new problem. Since the evolution of human beings, bipedal gait might have affected maternal pelvis tightness, and it is hypothetically speculated that there is a correlation with obstructed labor. At least one million pregnant women might suffer from this problem per year [1]. Therefore, analyzing maternal pelvic proportions is essential.

Pelvimetry and ultrasound are conventionally used to predict CPD [3–6]. X-ray and computed tomography (CT) pelvimetry are not considered ideal imaging methods for pregnant women because fetal exposure to ionizing radiation may increase the risk of childhood cancer [7]. However, magnetic resonance imaging (MRI) pelvimetry has the advantage of non-ionizing radiation and is more accurate than conventional pelvimetry methods [8]. Conventional imaging, such as the Guthmann and Martius methods [8], have a measurement error of approximately 10%, even if the exposure of X-ray is permitted, whereas MRI has a measurement error of approximately 1% [8]. Currently, MRI

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is recommended as an alternative to conventional X-ray and CT for maternal pelvimetry, mainly because of its safety and accuracy [9–13]. However, it has been reported that the conventional parameters of MRI pelvimetry alone are not accurate enough to predict obstructed labor [14].

The relationship between pelvimetry and the prognosis of cephalic vaginal delivery has not been adequately investigated, even with the classical Guthmann and Martius methods, especially regarding the usefulness of the pelvic outlet parameters. This study aimed to investigate the usefulness of various MRI pelvimetric parameters for predicting emergent cesarean delivery due to obstructed labor.

Materials and methods

Study participants and inclusion and exclusion criteria

This was a prospective observational study of Japanese participants at a single tertiary perinatal facility between April 2019 and March 2022. The flowchart of the study participants and exclusion criteria are shown in Fig. 1. The inclusion criteria for MRI pelvimetry were suspected narrow pelvis on internal examination by a clinical obstetrician; estimated fetal weight or biparietal diameter greater than + 1.5 standard deviation (SD) [15]; identification of placenta accreta spectrum; detailed findings of fetal structural abnormalities; short maternal stature, < 145 cm; and detailed findings of uterine ovarian tumors during pregnancy. The exclusion criteria were breech presentation, multiple pregnancies, severe intrauterine growth restriction, lethal congenital malformations, chromosomal abnormalities, and contraindications for MRI imaging.

Obstructed labor was diagnosed in women who experienced cervical arrest for over 4 h with normal uterine contractions after the cervix was dilated to at least 4 cm, or when fetal head descent was not achieved at least 2 h after the cervix was dilated to 10 cm. "Normal uterine contraction" in this study was defined as uterine contractions with maternal abdominal pain or anal pressure observed at least 3 times in 10 min on the uterine external tocometer. The diagnosis of obstructed labor also included the absence of a non-reassuring fetal status. All women diagnosed with obstructed labor underwent cesarean delivery.

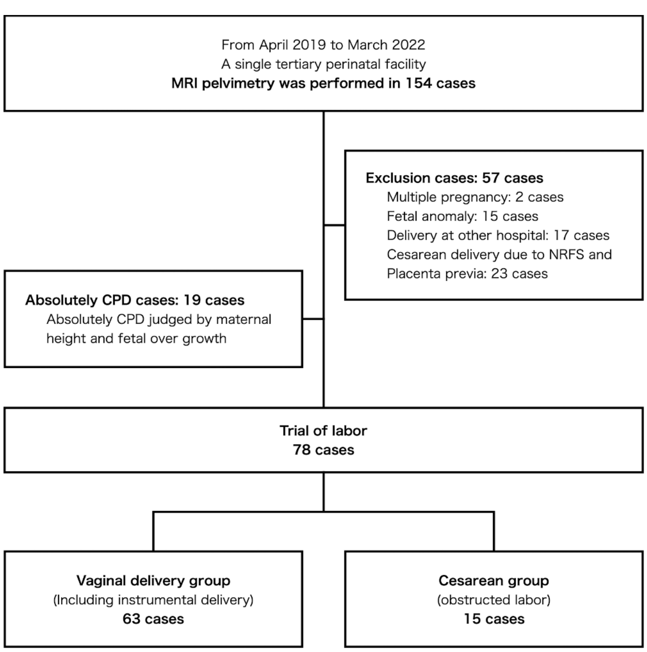

Fig. 1. Flowchart of the study participants and exclusion criteria. MRI, magnetic resonance imaging; NRFS, non-reassuring fetal status; CPD, cephalopelvic disproportion.

MRI pelvimetry measurement

MRI pelvimetry was performed at 34.7 ± 4.2 gestational weeks using a 1.5 T MRI system (Symphonie, Siemens Healthcare, Erlangen, Germany) with the patients in the supine position. An integrated body coil was used. A T2-weighted half-Fourier acquisition single-shot turbo spin-echo sequence was performed in the sagittal and coronal orientations. The slice thickness was 5 mm for both sequences. Special patient preparation and the use of contrast agents were unnecessary.

In the sagittal section, the pelvic inlet angle (PIA), pelvic inclination (PI), obstetric conjugate (OC), sacral outlet diameter (SOD), and coccygeal pelvic outlet (CPO) were measured (Fig. 2). The interspinous diameter (ISD) and intertuberous diameter (ITD) were measured in the coronal section. Measurements were calculated as follows: PIA, the angle between a line on the ventral surface of the first sacral vertebra and a line on the ventral surface of the caudal lumbar vertebra; PI, the angle between the OC and a line on the superior surface of the first sacral vertebra; OC, from the anterior cortical surface of the sacral promontory to the closest point on the convex posterosuperior aspect of the pubic symphysis; SOD, from the inferior edge of the pubic symphysis to the inferior end of the ventral surface of the fifth sacral vertebra; CPO, from the inferior edge of the pubic symphysis to the inferior end of the coccyx; ISD, the distance between the ischial spines; and ITD, between the inner edges of the ischial tuberosity.

All MRI images were anonymized and outputted on a separate computer. Each parameter was measured by an investigator blinded to the delivery outcome using ImageJ (U. S. National Institutes of Health, Bethesda, Maryland, USA) to set the coordinates of the pelvic landmarks [16].

Neonatal measurement

Neonatal head circumference was measured as a proxy for fetal head circumference. Neonatal measurements were extracted retrospectively from the maternal delivery charts. These measurements were recorded by the attending midwife within 30 min of delivery. The head circumference was measured using a tape measure around the widest possible

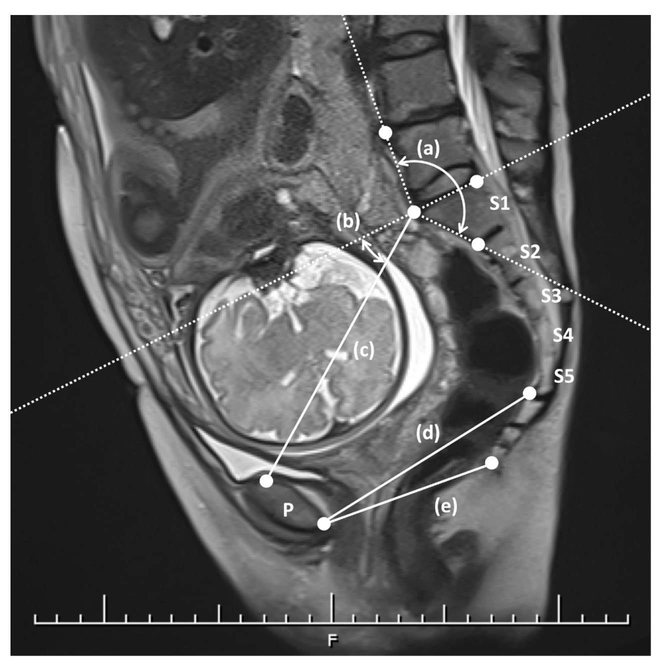

Fig. 2. MRI pelvimetry shows the sagittal section image. Landmarks in the sagittal section image of MRI pelvimetry. (a) Pelvic inlet angle (PIA). (b) Pelvic inclination (PI). (c) Obstetric conjugate (OC). (d) Sacral outlet diameter (SOD). (e) Coccygeal pelvic outlet (CPO). P, pubic bone; S, sacral vertebra.

circumference of the newborn head, moving along the broadest part of the forehead above the eyebrow, above the ears, and along the most prominent part of the back of the head.

Statistics

Continuous variables were presented as mean ± SD, and categorical variables were indicated as percentages. The Fisher's exact probability and chi-square tests were used to compare categorical variables. The Kolmogorov–Smirnov normality test was used for continuous variables, followed by the t-test when normality could be assumed and the u-test when normality could not be assumed. Pearson's correlation analysis was used to evaluate the bivariate correlations. A receiver operating characteristic (ROC) curve was constructed to estimate the predictive value of OC, SOD, and body mass index (BMI) for obstructed labor. The area under the curve (AUC) was calculated. A binomial logistic regression analysis was performed for the factors involved in obstructed labor.

Statistical analyses were performed using EZR [17], a graphical user interface for R (R Foundation for Statistical Computing, Vienna, Austria). Statistical significance was set at $p < 0.05$.

Ethical approval

Written informed consent was obtained from all participants. The study was conducted in accordance with the Declaration of Helsinki, and the protocol for this study was approved by the ethics committee of the Gifu Prefectural General Medical Center, Gifu, Japan (approval number: 502–2019).

Results

MRI pelvimetry was performed in 154 patients, 78 of whom were included in the analysis. Sixty-three vaginal deliveries and 15 emergent cesarean deliveries due to obstructed labor were included. MRI pelvimetry was performed in all eligible cases. None of the patients who completed the study had any complications or major complaints during MRI.

Table 1 shows the comparison of maternal characteristics, neonatal characteristics, and MRI pelvimetry findings between the cesarean (C) and vaginal (V) delivery groups. In terms of maternal characteristics, BMI was significantly higher in the C-group than in the V-group (24.9 ± 5.3 vs. 22.4 ± 4.0, p = 0.046, effect size=0.513). There was no difference in maternal age between the two groups (34 ± 6 vs. 32 ± 5 years, p = 0.283). In terms of neonatal characteristics, there was no difference between the two groups in gestational age at birth (40w2d ±8d vs. 39w5d±8d, p = 0.119), birth weight (3397 ± 519 g vs. 3205 ± 402 g, p = 0.121), and neonatal head circumference (35 ± 2 cm vs. 34 ± 3 cm, p = 0.522). MRI pelvimetry findings showed a significantly smaller OC (12.4 ± 0.9 cm vs. 13.0 ± 1.0 cm, p = 0.047, effect size=0.507) and SOD (10.7 ± 0.7 cm vs. 11.4 ± 1.1 cm, p = 0.019, effect size=0.646) in the C-group compared to the V-group. To predict the obstructed labor, the cut-off value for the SOD was 10.7 cm with an AUC of 0.694. The cut-off value for the OC was 12.3 cm with an AUC of 0.678. The cut-off value for BMI was 22.2 with an AUC of 0.686. Fig. 3 shows the ROC curves for SOD, OC, and BMI. Only 6.6% of patients with BMI less than 22 (45/78 cases) had emergent cesarean delivery for obstructed labor (3/15 in the C-group).

Table 2 shows sensitivity, specificity, positive predictive value, and negative predictive value of the combination of BMI, SOD, and OC for predicting emergent cesarean delivery for obstructed labor. The highest sensitivity was 80% for BMI alone, and the specificity of BMI alone was 66%. When the SOD or OC was combined with BMI, sensitivity was reduced at 53%, but specificity was higher at 90%.

In the binomial logistic regression analysis of emergent cesarean delivery for obstructed labor in patients with an BMI > 22, the odds ratio for emergent cesarean delivery was 3.87 (95% confidence interval [CI] 0.76–19.9, p = 0.104) if the OC was less than the cut-off value (12.3 cm) and 5.42 (95% CI 1.06–27.6, p = 0.041) if the SOD was less than the cut-off value (10.7 cm).

Table 3 depicts the correlation analysis of MRI pelvimetry findings with BMI, height, and weight.

BMI was not significantly correlated with any of the MRI pelvimetry findings. There was a weak positive correlation between maternal height and the SOD (correlation coefficient (CC): 0.336, p < 0.001), OC (CC: 0.584, p < 0.001), ISD (CC: 0.452, p < 0.001), and ITD (CC: 0.376, p < 0.001).

Table 1
Comparison of maternal characteristics, neonatal characteristics, and MRI pelvimetry findings between cesarean deliveries and vaginal deliveries.

	VD (n = 63)	ECS (n = 15)	p	ES
Maternal characteristics				
Maternal age (years)	32 ± 5	34 ± 6	0.283	
Body mass index	22.4 ± 4.0	24.9 ± 5.3	0.046	0.513
Height (cm)	158 ± 6	155 ± 5	0.049	
Weight (kg)	56 ± 10	60 ± 14	0.215	
Primiparous	14 (22%)	1 (7%)	0.278	
Neonatal characteristics				
Gestational age	39w5d± 8d	40w2d± 8d	0.119	
Birth weight (g)	3205 ± 402	3397 ± 519	0.121	
Head (cm)	34 ± 3	35 ± 2	0.522	
Chest (cm)	33 ± 3	34 ± 2	0.221	
Height (cm)	49 ± 3	50 ± 2	0.395	
MRI perimetric characteristics				
Pelvic inlet angle (°)	36 ± 9	36 ± 14	0.873	
Obstetric conjugate (cm)	13.0 ± 1.0	12.4 ± 0.9	0.047	0.507
Sacral outlet diameter (cm)	11.4 ± 1.1	10.7 ± 0.7	0.019	0.646
Interspinous diameter (cm)	11.4 ± 0.9	11.2 ± 0.7	0.325	
Intertuberous diameter (cm)	11.9 ± 1.1	11.6 ± 1.0	0.296	

ECS, emergency cesarean section; VD, Vaginal delivery; ES, effect size

Discussion

Obstructed labor due to CPD can result in maternal and fetal injuries or death. It is interesting that childbirth, a process so important to our species' existence, can cause such serious complications. The "obstetric dilemma" is a well-known explanation for human altriciality, which has important implications for human social and behavioral evolution [1]. The antagonistic choice between the large brain of the newborn and the narrow birth canal adapted to bipedalism has made childbirth problematic. As a result of changes in pelvic anatomy and delivery, childbirth has changed from a solitary event, as in nonhuman primates and other mammals, to a social and cultural event [18–23]. As the human birthing process evolved, women who sought help from others during childbirth were selected as a result of natural selection. This suggests that the women's desire for a familiar person to support them during childbirth is deeply rooted in human evolutionary history [24]. However, despite appropriate delivery assistance, obstructed labor requiring cesarean section can occur. This study may provide useful information on the problems of obstructed labor that surround pregnant women due to the obstetric dilemma.

In this study, we found that the SOD was associated with emergent cesarean delivery for obstructed labor. The C-group had a significantly smaller SOD than the V-group. The cut-off value for the SOD to predict cesarean delivery was 10.7 cm. Binomial logistic regression analysis in patients with an BMI of ≥ 22 showed that the emergent cesarean delivery rate was approximately five times higher when the SOD was < 10.7 cm and nearly twice as high when the OC was < 12.3 cm. None of the cases with an SOD < 8.9 cm resulted in vaginal delivery. However, if the SOD was solely used in delivery method determination, a significant number of unnecessary cesarean sections would be performed, since the positive predictive value of the SOD itself for emergent cesarean delivery was 35%.

Lower BMI alone showed the highest predictive value for successful

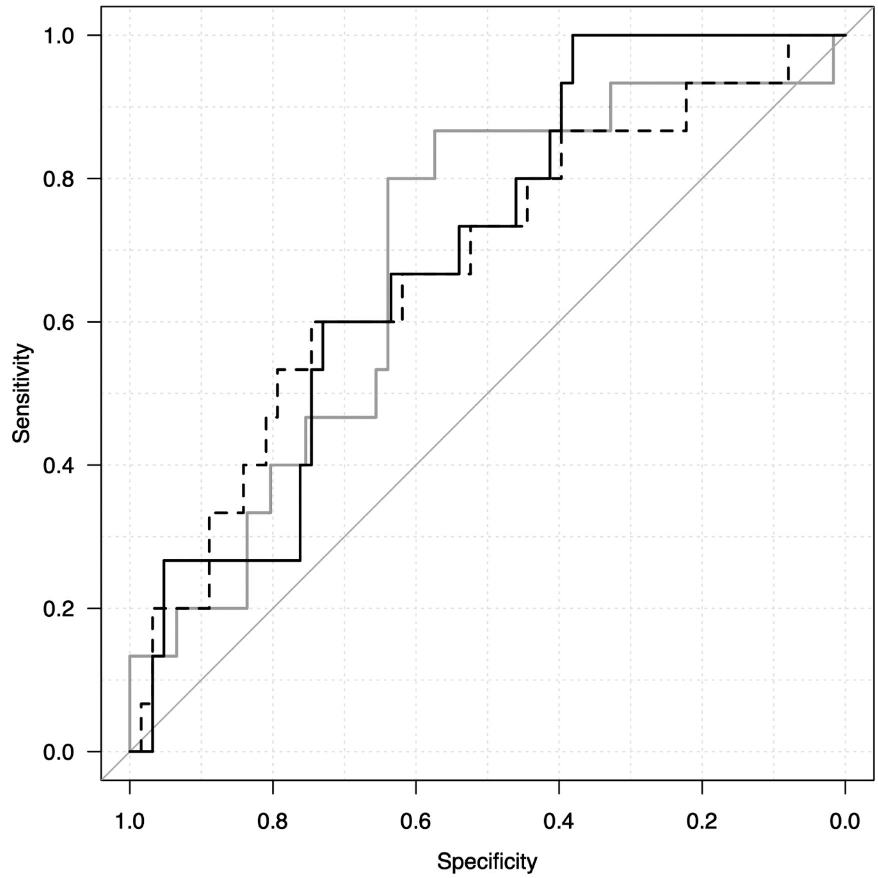

Fig. 3. Receiver operating characteristic curves of the sacral outlet diameter, obstetric conjugate, and body mass index for predicting obstructed labor. Black solid line: sacral outlet diameter. Black dotted line: obstetric conjugate. Gray solid line: body mass index.

Table 2
Sensitivity, specificity, positive predictive value, and negative predictive value of the combination of body mass index, sacral outlet diameter, and obstetrical conjugate for predicting emergency cesarean delivery for obstructed labor.

	Sensitivity	Specificity	PPV	NPV
BMI	80	66	36	93
BMI+SOD	53	90	57	89
BMI+OC	53	90	57	89
BMI+SOD+OC	27	97	67	85
SOD	60	73	35	88
SOD+OC	27	87	33	83
OC	60	75	36	89

PPV, positive predictive value; NPV, negative predictive value; BMI, body mass index; SOD, sacral outlet diameter; OC, obstetrical conjugate

vaginal delivery in the physical parameters, but it had a low positive predictive value of 36%. Thus, we need additional parameters to predict obstructed labor more precisely in cases with an BMI of ≥ 22. When BMI was combined with pelvic parameters, SOD, or OC, the specificity increased from 66% to 90%. Thus, pelvic parameters such as the SOD or OC might be candidates to raise the success rate of prediction with a BMI of ≥ 22. The odds ratio of the SOD for cesarean delivery was 5.1 in cases with an BMI of ≥ 22, exceeding that of the OC in predictive accuracy. Thus, the addition of pelvic parameters to BMI has important implications for predictive cesarean delivery for obstructed labor. Furthermore, among the BMI factors, only maternal height was clearly correlated with pelvic parameters. We believe that it is self-evident that maternal height correlates with pelvic parameters. It is suggested that taller pregnant women will have larger fetuses because the fetal growth is shaped by maternal phenotype rather than by external ecological factors. [25] In these cases, pelvic measurement parameters that indicate pelvic shape

Table 3
The correlation analysis of MRI pelvimetry findings with BMI, height, and weight.

	BMI				Height				Weight			
	CC	95%CI		P	CC	95%CI		P	CC	95%CI		P
		lower	upper			lower	upper			lower	Upper	
Pelvic inlet angle	-0.064	-0.245	0.120	0.495	-0.155	-0.325	0.025	0.092	-0.115	-0.292	0.070	0.222
Pelvic inclination	-0.064	-0.213	0.153	0.739	0.120	-0.060	0.293	0.191	0.013	-0.171	0.195	0.894
Coccygeal pelvic outlet	-0.042	-0.224	0.142	0.654	0.120	-0.061	0.293	0.192	-0.004	-0.187	0.179	0.968
Sacral outlet diameter	0.030	-0.154	0.212	0.748	0.336	0.166	0.486	< 0.001	0.155	-0.029	0.329	0.099
Obstetric conjugate	-0.176	-0.347	0.008	0.060	0.584	0.451	0.691	< 0.001	0.035	-0.149	0.217	0.709
Interspinous diameter	-0.010	-0.193	0.174	0.917	0.452	0.297	0.584	< 0.001	0.145	-0.039	0.320	0.122
Intertuberous diameter	-0.075	-0.255	0.109	0.424	0.376	0.211	0.520	< 0.001	0.060	-0.125	0.240	0.527

BMI, body mass index; CC, correlation coefficient; CI, confidence interval as well as maternal height would still be important to predict cesarean section due to obstructed labor.

We would like to emphasize the usefulness of the SOD in our study. The clinical flowchart shown in Fig. 4 may allow clinicians to predict emergency cesarean section due to obstructed labor based on clinical information, such as maternal height, and suggests interventions in delivery management using BMI and SOD as breakpoints. Triage of the risk of needing to change to cesarean delivery in advance is clinically very important from the perspective of prioritizing high-risk cases for perinatal management. In addition, women who require an emergency cesarean delivery due to obstructed labor suffer through prolonged labor with no defined duration, have strong concerns about the health of the fetus, and often experience these conditions during their first delivery. Furthermore, the expectant mother may detect that the delivery is not progressing smoothly from the conversation and atmosphere, despite the medical staff's endeavors and advice. For pregnant women in such distress, we believe that changing to cesarean delivery as quickly as possible is advantageous for "birth happiness," when the mother looks back on the delivery; the formation of a bond between mother and child; and avoiding postpartum depression.

The inability to identify a threshold above which every woman delivers vaginally may be due to multiple factors which contribute to successful vaginal delivery, in addition to pelvic passage alone. These include fetal heart rate monitoring, rotation, and position and uterine contractions. A large fetal head circumference has been associated with a considerable proportion of assisted vaginal births and unplanned cesarean deliveries [26–28]. However, various studies indicate that considering the fetal head circumference exclusively may lead to unnecessarily high cesarean section rates [29,30]. Ideally, both maternal pelvic parameters and fetal head circumference should be considered when predicting obstructed labor [31]. However, in this study, there

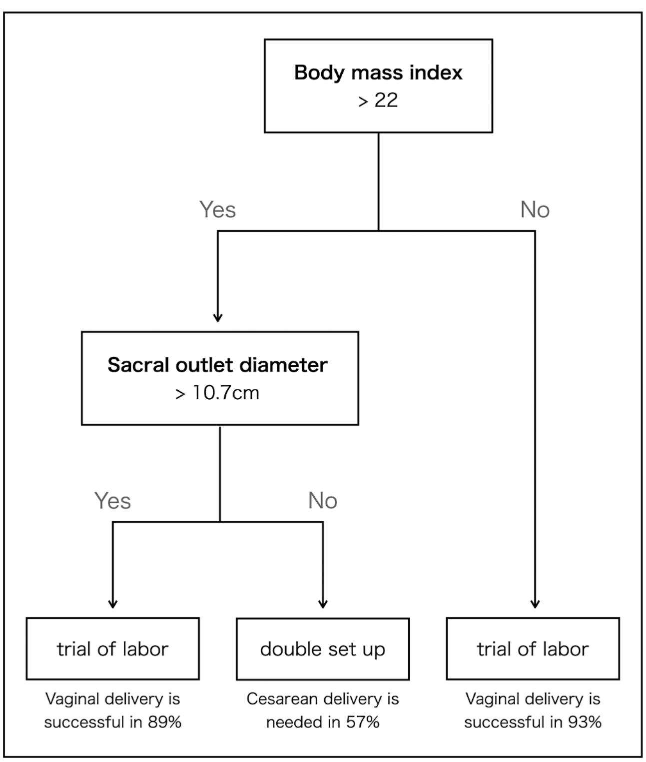

Fig. 4. Clinical flowchart based on the results of this study. "Double set up" refers to the management for a trial of vaginal delivery, with preparations in place for a quick transition to an emergency cesarean delivery. This entails conducting all preparative examinations, obtaining informed consent, ensuring the availability of operating rooms and manpower, and imposing restrictions on the oral intake of solid foods.

was no difference in neonatal head circumference between the C- and V-groups. Maternal pelvic parameters may be preferable to fetal head circumference for objective assessment before labor onset.

The MRI pelvimetric parameters indicated that the overall systematic bias per observer was small [32]. Parameter agreement was best when landmark edges were clearly defined and poorest when more "reader judgment" was needed [33]. OC measurements require the judgment of the reader to determine medial pubic landmarks. However, for SOD measurements, landmarks are easier to determine, and the high contrast between the bone and adjacent low-signal structures reduces the variability of the measurements. Thus, the SOD may be a more desirable parameter for MRI pelvimetry than the OC. Furthermore, MRI measurements of the maternal pelvis vary slightly with a woman's posture, but remain stable throughout pregnancy, delivery, and the postpartum period if there are no postural changes [34–36].

Finally, MRI enables the evaluation of the maternal and fetal soft tissue. The thickness of the subcutaneous fat tissue of the fetus and the soft birth canal of the maternal pelvis can be observed. Fetal overgrowth has been observed in sporadic cases, particularly in pregnancies complicated by glucose tolerance. In such cases, the fetal abdominal circumference and thickened shoulder width are overdeveloped, resulting in the risk of severe fetal dysfunction and delivery trauma due to shoulder dystocia. These cases may provide helpful information in making clinical decisions about delivery methods. Although the disadvantages of MRI include loud noise, exposure to 1.5 T MR in utero has no adverse effects on neonatal hearing function and birth weight percentiles [37].

A limitation of our study was the selection bias regarding cases in which vaginal delivery was attempted. Women who did not consider vaginal delivery or who had contraindications did not undergo vaginal delivery. MRI pelvimetry could have been used to select women with small pelvimetric measurements for cesarean delivery, thus avoiding a trial of labor. Other limitations of MRI pelvimetry during pregnancy are that it is more expensive than conventional pelvimetry and is not easily available at all facilities. Unfortunately, clinicians cannot assess the SOD size by the usual cost-free obstetrical internal examination. Our internal exam might diagnose a narrow size of the final outlet portion, such as the CPO, but this factor did not show significant prediction of final success of vaginal delivery. X-ray pelvimetry has been shown not to be necessary because its accuracy in predicting obstetric outcomes is comparable to that of internal examinations [38]. MRI pelvimetry may be more useful than internal examination or X-ray perimetry in evaluating the SOD, which is more accurate predictor of obstetric outcome than the CPO. Furthermore, our study was conducted in Japanese women. There are regional skeletal differences worldwide [39], thus our results may not be generalizable.

Conclusions

SOD measurements complement clinical assessment when selecting the method of delivery. MRI pelvimetry provides additional information that cannot be accurately assessed by manual examination, ultrasound, or conventional radiographic pelvimetry. MRI pelvimetry is not an absolute prerequisite for vaginal delivery; however, the SOD justifies its use as an additional parameter for decision-making. We confirmed that MRI pelvimetry is a reliable tool for better patient selection for vaginal delivery. The SOD was the best predictor of emergency cesarean delivery for obstructed labor.

Role of the funding source

This research received no external funding.

Authors' contributions

RS designed the research study and analyzed the data. All the authors performed the operation and collected the data. YT supervised the study. All the authors approved the final version of the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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