



Research Article

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Neural network approach for predicting outcomes of external cephalic version for breech presentation: a retrospective cohort study

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Abstract: The procedure of external cephalic version (ECV) is an important option in the management of breech presentation. However, there is still a lack of effective methods to accurately predict the likelihood of ECV success on the basis of individual conditions. With the aim of better predicting the outcomes of ECV and subsequent delivery modes, this study developed neural network-based models. We conducted a retrospective cohort study of women with singleton pregnancies who underwent an ECV for breech presentation at a single, tertiary, university-affiliated hospital between January 2016 and September 2023. Data on the demographic characteristics, comprehensive preoperative ultrasound assessment, and conditions during the ECV procedure were extracted from the hospital's electronic record system. A neural network algorithm was implemented to establish prediction models for the success or failure of ECV, as well as subsequent delivery modes. The performance of the models was improved by increasing the number of iterations. A total of 378 patients were retrospectively included, including 279 successful and 99 failed cases, showing an overall success rate of 73.8%. Univariate analysis revealed that gravidity, parity, systolic blood pressure, presence of uterine fibroids, and amniotic fluid index (AFI) indicated by preoperative and intra-operative ultrasound were positively associated with ECV success, while thicker maternal abdominal walls and the use of anesthesia were correlated with failure. Multivariate analysis determined that parity, uterine fibroids, AFI, and the use of anesthesia were independent determinants of ECV outcomes. The samples were then divided into training and testing sets in a 1:1 ratio. By increasing the number of iterations, the true positive rates for the successful and failed versions both reached 100%. The overall accuracy was 82.5% for

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predicting ECV outcomes. A total of 291 samples with delivery records were included for the prediction of delivery modes. The neural network-based model achieved a predictive accuracy of 78.8% after 2000 iterations, with the true positive rates for vaginal delivery and cesarean section both reaching 100%. These algorithms output exact predicted probabilities instead of providing the outcomes alone. An external validation set was also employed to further confirm the algorithm's performance. Collectively, prediction models formulated on the basis of neural network algorithms were developed to assess the ECV outcomes and subsequent delivery modes, with both models demonstrating favorable results and great performance. For women eligible for ECV, the application of these models can potentially assist in the crucial clinical decision-making process.

Key words: External cephalic version (ECV); Neural network; Outcome prediction; Individualized assessment

1 Introduction

Breech presentation occurs in 3%–4% of all term pregnancies and is more prevalent in preterm deliveries and nulliparous women (Impey et al., 2017; American College of Obstetricians and Gynecologists, 2020). Considering the increased risk of adverse perinatal outcomes, vaginal breech delivery remains rare in most countries (Impey et al., 2017; Bresson et al., 2023). Cesarean section has been the most common mode of delivery for pregnant women with breech presentation; thus, this condition is an important contributor to the frequency of cesarean section (Impey et al., 2017; de Castro et al., 2020; Long et al., 2022; Vogel et al., 2024). For women willing to opt for vaginal delivery, external cephalic version (ECV) is a reasonable choice, which raises the chance of vaginal birth by applying pressure to the abdomen and turning the fetus to a cephalic presentation (Isakov et al., 2019). Yet, there is a certain risk of failure with the procedure, along with a small probability of adverse outcomes (Kishkovich et al., 2023). Therefore, the precise assessment of the likelihood of a successful ECV based on individual conditions is essential to make a choice between the diverse options for dealing with breech presentation. However, there is still a lack of effective methods to accurately predict the likelihood of a successful external version on the basis of individual conditions.

The reported success rates of ECV are highly variable among studies, ranging from 35% to 86%, depending on the inclusion criteria and the populations investigated (Isakov et al., 2019). Numerous studies have been dedicated to analyzing the factors influencing the success or failure of ECV attempts. It was reported that parity, amniotic fluid of normal or increased amounts, and tocolytic therapy are all related to a successful ECV, while nulliparity, anterior placenta, low station, and fetal weight of <2500 g are associated

with a failed version (American College of Obstetricians and Gynecologists, 2020; Kishkovich et al., 2023). Meanwhile, evidence is contradictory about the impact of other factors in predicting a successful ECV. For example, Londero et al. (2023) found that high pre-pregnancy body mass index (BMI) and high BMI at delivery are associated with an increased risk of failure, while Svensson et al. (2021) suggested that maternal obesity does not impair the success rate. Since the ECV procedure involves the surgeons applying a certain pressure on the woman's abdomen using their hands to manually rotate the fetal head and hip to achieve a cephalic presentation, the thickness of the maternal abdominal wall and the detailed position of the fetus are highly likely to affect the difficulty of the surgeons' manipulation, which may in turn influence the success rate of ECV. However, few measures have been proposed to objectively evaluate the thickness of maternal abdominal wall or the concrete fetal position before the ECV attempt, and the impacts of these factors on the success rate of ECV have not been elucidated. Overall, there is still a lack of an effective method to predict the outcome of ECV. Recently, neural network techniques have been extensively evaluated in the application area of maternal and fetal medicine. In fact, the introduction of such approaches has markedly improved the predictive and diagnostic accuracy of models in various clinical scenarios (Plotka et al., 2023; Kasera et al., 2024; Sun et al., 2024). To our knowledge, however, few studies have attempted to predict the outcomes of ECV using neural network-based approaches.

In this study, we first introduced a group of novel ultrasonic parameters to assess the patient's abdominal wall thickness and the detailed fetal position, and then established neural network-based models to predict the outcomes of ECV (Fig. 1). This study aimed to examine the potential value of neural networks for the prediction of successful ECV by using a combination

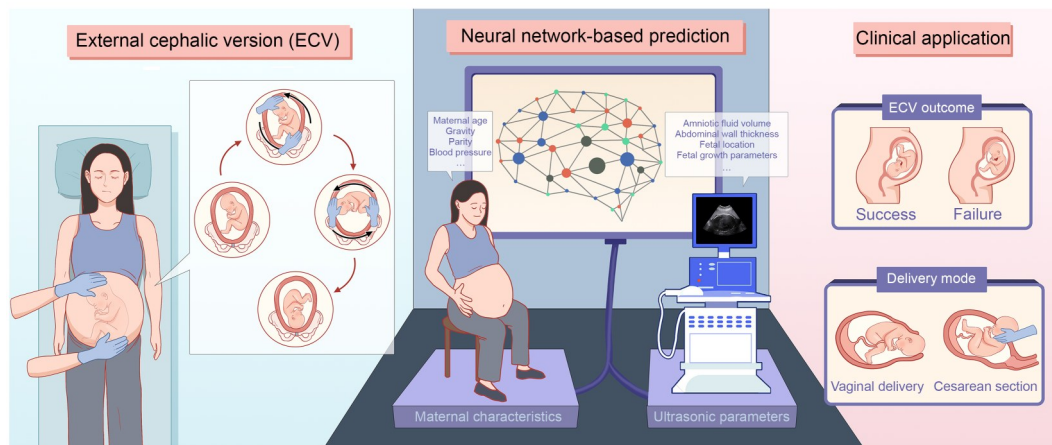


Fig. 1 Schematic of the neural network approach for predicting external cephalic version (ECV) outcome and mode of delivery based on demographic characteristics and preoperative ultrasonic assessment. For pregnant women who were candidates for ECV, data on the demographic characteristics were extracted and a comprehensive ultrasonographic evaluation was scheduled. Subsequently, a neural network was introduced to predict the success of ECV and delivery mode based on various physiological and ultrasonic parameters.

of demographic characteristics and comprehensive preoperative ultrasonic assessment.

2 Methods

2.1 Study population

We conducted a retrospective cohort study at a single, tertiary, university-affiliated medical center. Women with singleton pregnancies who attempted ECV for breech presentation between January 2016 and September 2023 were included. This study was approved by the Institutional Review Board of the Tenth Affiliated Hospital, Southern Medical University (No. KYKT2024-010).

Eligible participants met the following criteria: (1) singleton pregnancy of ≥ 36 gestational weeks; (2) breech presentation; (3) patients willing to attempt an ECV procedure; and (4) the umbilical cord wrapped no more than two times around the fetal neck. Patients with more than two loops were excluded according to our institutional protocol, consistent with prior evidence linking such entanglement to elevated fetal distress risk (Schreiber et al., 2019).

Women were excluded if they met any of the following: (1) clinical signs of placental abruption, placenta previa, active labor, prelabor rupture of membranes, fetal distress, major fetal anomalies, uterine rupture, abnormal fetal Doppler findings, or antepartum hemorrhage occurring within the past 7 d;

(2) presence of other factors necessitating a cesarean section irrespective of the fetal presentation; (3) patients with a scarred uterus, including prior cesarean delivery, myomectomy, uterine perforation, or other uterine procedures; and (4) cases with incomplete medical records.

2.2 Preoperative ultrasonic assessment

Pregnant women who were candidates for an ECV procedure were routinely scheduled for a comprehensive ultrasonographic evaluation by experienced sonographers prior to the procedure. This evaluation involved a detailed examination of the following parameters: (1) fetal growth parameters, including biparietal diameter (BPD), head circumference (HC), abdominal circumference (AC), and femur length (FL) of the fetus; (2) the detailed fetal position; (3) umbilical artery Doppler; (4) placental location (anterior or non-anterior) and any potential abnormalities (including battledore placenta); (5) amniotic fluid volume (AFV) and amniotic fluid index (AFI); (6) thickness of the maternal abdominal wall; (7) umbilical cord around fetal neck; and (8) abnormalities of maternal reproductive system, such as fibroids or other pelvic lesions (if applicable).

Specifically, the abdominal wall thickness was measured to adhere to established institutional criteria. Briefly, a pregnant woman took a supine position and relaxed her abdomen. An appropriate amount of ultrasound gel was applied to the surface of the abdomen, and the ultrasonic probe was gently placed on the umbilicus. When measuring the thickness of the abdominal

wall, the outer boundary was considered as the surface of the skin, and the inner boundary was the peritoneal layer. The directions on the maternal abdomen were represented according to the clock method (Fig. 3a). Starting from the navel, the probe was moved laterally towards the left anterior axillary line in the direction of 3 o'clock, and the maximum measurement value was taken as the thickness of the abdominal wall at the 3 o'clock direction. Throughout the measurement process, no pressure was to be applied, and the measurement line must be perpendicular to the abdominal wall to obtain accurate results. The thickness of the abdominal wall at the 6, 9, and 12 o'clock directions was measured similarly by taking the maximum values from the navel to the upper edge of the pubic bone, the navel to the right anterior axillary line, and the navel to the fundus of the uterus, respectively.

The concrete directions of the fetal head, breech, and spine in the maternal abdomen were also recorded using the clock method. The direction from 0 to 3 o'clock was marked as the first quadrant. Similarly, the directions from 3 to 6 o'clock, from 6 to 9 o'clock, and from 9 to 12 o'clock were recorded as the second, third, and fourth quadrants, respectively. The position of the fetal head referred to the location of the standard measurement plane for BPD; the direction of the breech referred to the direction where the plane of the fetal median sagittal section showing the sacral and coccygeal vertebrae was located; the direction of the spine's thoracic segment referred to the direction where the plane of the fetal median sagittal section showing the thoracic vertebrae was located. For these novel metrics, two investigators (both with more than five years of obstetric ultrasound experience) independently measured the abdominal wall thickness and determined the fetal spine position on stored images from a random subset of 40 participants. Both examiners were blinded to each other's results. On the basis of our internal records, the inter-rater intraclass correlation coefficient for abdominal wall thickness was determined as 0.92 (95% confidence interval (CI) 0.86–0.96), and the agreement with the clock-face method was excellent ($\kappa=0.88$; 95% CI 0.80–0.95).

2.3 ECV procedure

Candidates for ECV were admitted to the inpatient ward on the day of the procedure. Comprehensive

assessment of eligibility was performed, encompassing a detailed maternal and obstetrical history, physical examination, and ultrasonographic evaluation. Cardiotocography was used to evaluate fetal status and to identify any uterine contractions. In cases where contractions were observed by cardiotocography tracing or during clinical examination, a tocolytic agent was used 30 min prior to the procedure.

Bedside ultrasound was employed throughout the ECV attempt to provide continuous visualization of fetal heart rate and presentation. The procedure was carried out in accordance with the protocol reported by Rodgers et al. (2017) and our team (Xiang et al., 2026). The obstetrician exerted firm pressure through the maternal abdominal wall onto the fetal breech, disengaging it from the pelvic inlet and shifting it toward the lateral aspect of the maternal pelvis. Continuous firm pressure was subsequently applied to the fetal breech and head until the fetus attained a cephalic orientation. The initial approach was typically a forward roll. In the event of failure, a second attempt was made using a backward roll. Unless the operator determined that additional attempts were clinically justified and the patient gave informed consent, the procedure was abandoned after three failed attempts. In line with previously published work (Kuppens et al., 2017; Isakov et al., 2019) and with our center's practical experience (Xiang et al., 2026), the ECV attempt was terminated under any one of the following criteria: (1) successful conversion to a cephalic position; (2) a total elapsed time of 30 min of fetal manipulation (doing one attempt and then waiting for few minutes before reattempting, instead of continuous manipulation); (3) patient request for discontinuation due to pain or any other cause; (4) onset of rupture of membranes, vaginal bleeding, or severe abdominal pain, or bedside ultrasonographic evidence of umbilical cord prolapse, non-reversible fetal bradycardia, or placental abnormalities; and (5) the obstetrician decided that continuing the procedure would be unlikely to yield success. All ECV procedures at our center were performed by Director Zhongjun LI's team, with every operator being experienced (a minimum of 20 prior ECV procedures).

After the procedure, fetal presentation was verified by ultrasound and cardiotocography was performed to evaluate the fetal heart rate pattern. In the absence of any maternal or fetal complication, the patient was

discharged the next day and waited until labor began spontaneously or obstetrical indications prompted the induction of labor.

2.4 Data collection

Data were retrieved from the electronic patient record system of our institution. The following information was systematically collected: (1) maternal characteristics, including maternal age, gestational weeks, gravidity, parity, blood pressure, maternal weight, BMI, fundal height and AC, and engagement status of the fetal breech; (2) preoperative ultrasonic parameters, such as location of placenta, structural abnormality of the umbilical cord and placenta, Doppler flow pattern of the umbilical artery, AFV, AFI, cord around the neck, as well as BPD, HC, AC, and FL of the fetus, detailed fetal positioning, and maternal abdominal wall thickness; (3) information about the ECV procedure, such as time from ultrasound to ECV procedure, tocolytic therapy, the number of ECV attempts performed, forward or backward rolls, procedure outcome, and indications to stop the procedure; (4) complications, including vaginal bleeding, rupture of membranes, significant abdominal pain, prolapse of umbilical cord, placental abruption, or the need for emergency cesarean section for any reason (if applicable); and (5) mode of delivery (if applicable).

2.5 Statistical analysis of comparisons between groups

Comparisons of the patient characteristics between two groups were performed using Statistical Product and Service Solutions (SPSS) Version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables conforming to a normal distribution were expressed as mean $\pm$ standard deviation (SD) and their inter-group comparisons were conducted using a two-tailed Student's *t*-test. Continuous variables that did not conform to normal distribution were represented by median and interquartile range and their inter-group comparisons were made using the Mann-Whitney *U*-test. Categorical variables were described as number (percentage) and their inter-group comparisons were made using the Chi-square test or Fisher's exact test as appropriate. To assess factors independently associated with ECV outcome, a multivariable logistic regression analysis was further performed. The results were reported as odds ratio (OR) and 95% CI. A *P*-value of <0.05 was considered as indicative of statistical significance.

2.6 Neural network approach and outcome prediction

In this study, a neural network was used to predict the success of ECV and delivery mode on the basis of various physiological and ultrasonic parameters of pregnant women. The neural network algorithm consisted of an input layer with 37 neurons for predicting the ECV outcomes or 38 neurons for predicting delivery modes, three hidden layers with 1024, 512, and 256 neurons, respectively, and an output layer with two neurons. The hyperbolic tangent (tanh) function was utilized as the activation function between the hidden layers to construct a nonlinear neural network algorithm suiting complex computational applications. The rectified linear unit (ReLU) function was used as the activation function between the last hidden layers, and the predicted probability of each type was output from the output layer. To prevent overfitting, each neuron was set with a 15% probability of not being activated. For the training of neural network, the training iterations were set to 2000 times, the learning rate was 0.02, and the initial conditions were random. After training, the weight parameter file was obtained, loaded into the neural network classification algorithm, and used to predict the ECV outcome and delivery mode (for those with successful ECVs). To further confirm the algorithm's performance, an external validation set comprising 106 samples (78 successful and 28 failed cases) was employed.

3 Results

3.1 Demographic characteristics of the study population

This study enrolled a total of 378 patients with breech presentation who underwent ECV procedures at the Tenth Affiliated Hospital, Southern Medical University, Dongguan, China. Among them, ECV was successful in 279 cases and failed in 99 cases, with an overall success rate of 73.8% (279/378). Among the 378 procedures, two complications (0.53%) were documented: one case of vaginal bleeding and one case of umbilical cord presentation, both occurring during the procedure. When comparing the two groups, both gravidity and parity in the successful cases were significantly higher than those in the failed group. The proportion of multiparous women in the successful

group was also significantly higher. Interestingly, the systolic blood pressure in the ECV failure group was markedly higher than that in the success group, while no significant difference in diastolic blood pressure was observed. Uterine myomas were more frequent in the success group. There were no significant differences

between two groups in terms of maternal age, weight, and BMI on the day of ECV, fundal height, maternal AC, engagement of fetal presentation, or the presence of uterine adhesions or septate uterus. The detailed patient characteristics are shown in Fig. 2 and Table 1.

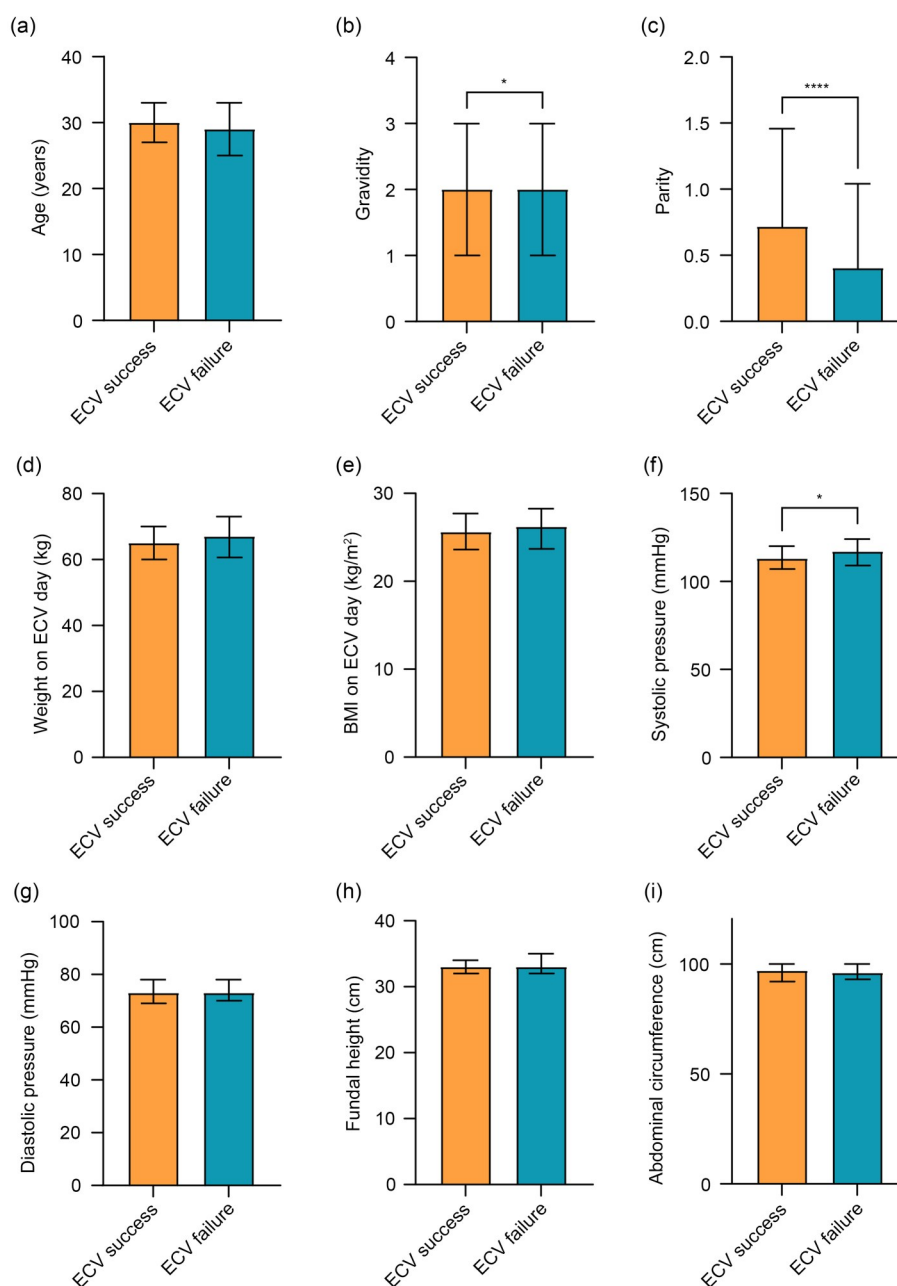


Fig. 2 Demographic characteristics of the participants with successful and failed external cephalic version (ECV). Comparisons of maternal age (a), gravidity (b), parity (c), weight on ECV day (d), body mass index (BMI) on ECV day (e), systolic pressure (f), diastolic pressure (g), fundal height (h), and maternal abdominal circumference (i) between two groups (ECV success, $n=279$; ECV failure, $n=99$). BMI was normally distributed and expressed as mean $\pm$ standard deviation (SD), whereas other variables were non-normally distributed and expressed as median [25th–75th percentile]. Significant difference at * $P<0.05$ and **** $P<0.0001$.

Table 1 Maternal characteristics of the study population

Maternal characteristics	Overall (n=378)	Successful ECV (n=279)	Failed ECV (n=99)	P-value
Maternal age (years)	29 [27, 33]	30 [27, 33]	29 [25, 33]	0.057
Gravidity	2 [1, 3]	2 [1, 3]	2 [1, 3]	0.034
Parity	1 [0, 1]	1 [0, 1]	0 [0, 1]	<0.0001
Multiparous				<0.001
Yes	187 (49.47%)	121 (43.37%)	66 (66.67%)	
No	191 (50.53%)	158 (56.63%)	33 (33.33%)	
Weight on ECV day (kg)	65.5 [60.0, 70.9]	65.0 [60.0, 70.0]	67.0 [60.8, 73.0]	0.092
BMI on ECV day (kg/m ²)	25.90±3.06	25.87±3.01	25.99±3.21	0.754
Systolic pressure (mmHg)	114 [108, 121]	113 [107, 120]	117 [109, 124]	0.021
Diastolic pressure (mmHg)	73 [69, 78]	73 [69, 78]	73 [70, 78]	0.369
Fundal height (cm)	33 [32, 34]	33 [32, 34]	33 [32, 35]	0.679
Abdominal circumference (cm)	97 [93, 100]	97 [92, 100]	96 [93, 100]	0.926
Engagement of fetal presentation				0.482
Yes	365 (96.56%)	271 (97.13%)	94 (94.95%)	
No	13 (3.44%)	8 (2.87%)	5 (5.05%)	
Intrauterine adhesion				0.456
Yes	376 (99.47%)	278 (99.64%)	98 (98.99%)	
No	2 (0.53%)	1 (0.36%)	1 (1.01%)	
Uterine myoma				0.005
Yes	370 (97.88%)	277 (99.28%)	93 (93.94%)	
No	8 (2.12%)	2 (0.72%)	6 (6.06%)	
Septate uterus				>0.999
Yes	377 (99.74%)	278 (99.64%)	99 (100.00%)	
No	1 (0.26%)	1 (0.36%)	0 (0.00%)	

Normally distributed data are expressed as mean±standard deviation (SD), whereas non-normally distributed data are expressed as median [25th percentile, 75th percentile]. Categorical variables were described as number (percentage). BMI: body mass index; ECV: external cephalic version.

3.2 Comprehensive ultrasonic assessment before ECV

Each patient eligible for ECV underwent a pre-operative ultrasound assessment to thoroughly assess the fetal size, fetal position, placental location, AFV, and maternal abdominal wall thickness. The ultrasound measurement parameters for the two groups are detailed in Fig. 3 and Table 2. Specifically, the AFI in the successful group was significantly higher than that in the failed group, although no between-group differences were demonstrated in AFV. The maternal abdominal wall thickness at the 3, 6, and 9 o'clock directions in the failed group was significantly greater than that in the successful group. This suggested that, as anticipated, the thickness of the maternal abdominal wall was significantly correlated with the success rate of the ECV procedure. However, the specific positions of the fetal head, breech, and spine showed no

significant correlation with ECV success. Besides, although previous studies have reported that placental position (Levin et al., 2019; López-Pérez et al., 2020; Svensson et al., 2021; Sium et al., 2023) and birth weight (Hakem et al., 2021; Londero et al., 2023) may affect the success rate of ECV, our results indicated that the proportion of anterior placenta and fetal growth parameters did not differ significantly between the two groups.

3.3 Comparison of ECV procedure between groups

The ECV conditions for the two groups are detailed in Fig. 4 and Table 3. The AFI indicated by intra-operative ultrasound was significantly correlated with the success of ECV, while there was no significant difference in AFV between the two groups, consistent with the AFI and AFV indicated by preoperative ultrasound assessment. At our center, ECV is typically

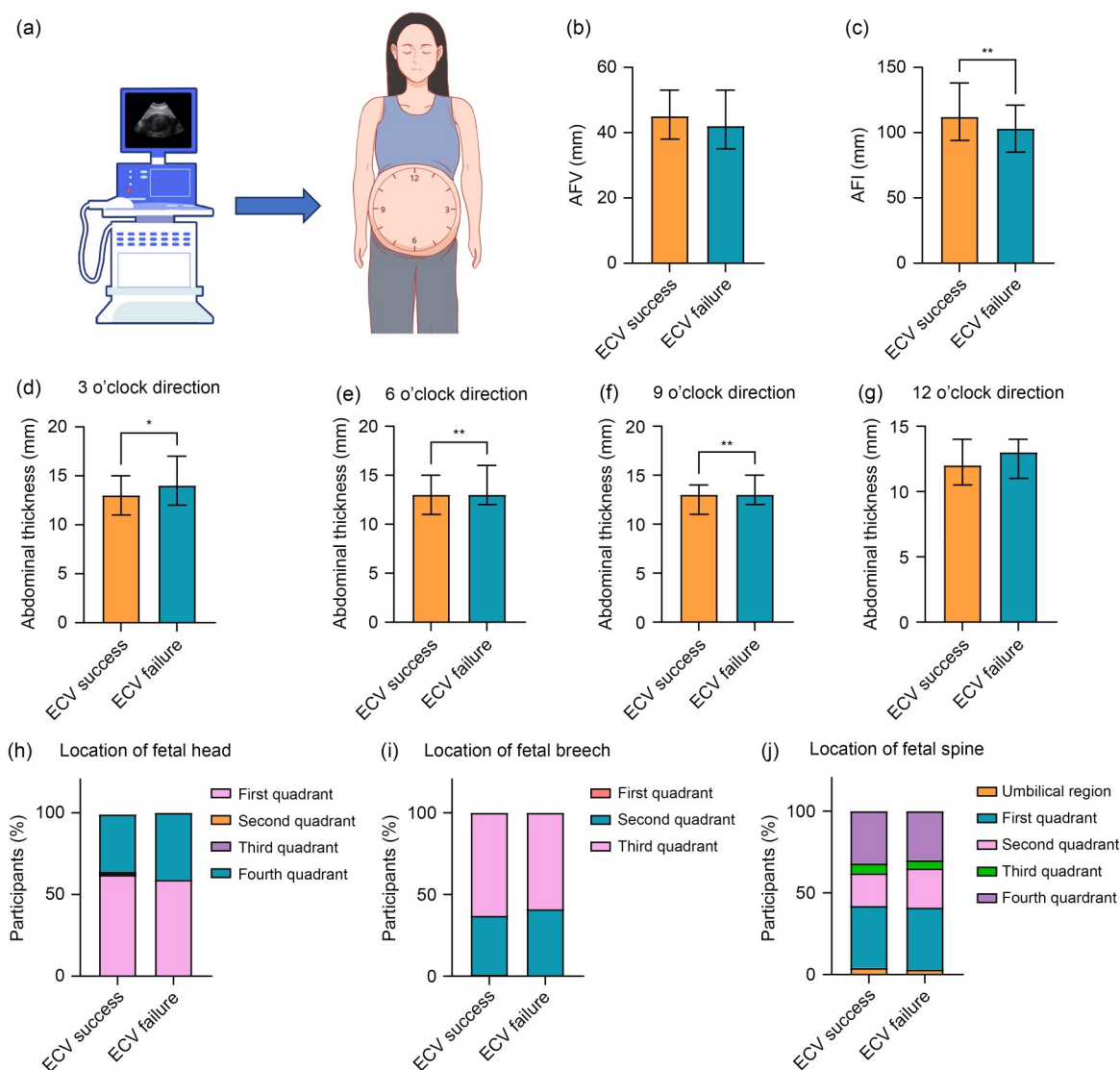


Fig. 3 Preoperative ultrasonic assessment with successful and failed external cephalic version (ECV) (ECV success, $n=279$; ECV failure, $n=99$). (a) The directions on the maternal abdomen were represented according to the clock method. (b, c) Comparisons of amniotic fluid volume (AFV) and amniotic fluid index (AFI) between the two groups. (d–g) Measurements of the thickness of maternal abdominal wall in different directions. (h–j) Recording of the concrete directions of the fetal head (the standard measurement plane for biparietal diameter), breech (the plane of the fetal median sagittal section showing the sacral and coccygeal vertebrae), and spine (the plane of the fetal median sagittal section showing the thoracic vertebrae) using the clock method. AFV, AFI, and abdominal thickness at all directions were non-normally distributed data and presented as median [25th–75th percentile]. Significant difference at * $P<0.05$ and ** $P<0.01$.

performed without anesthesia due to the short duration of the procedure and minimal patient discomfort. However, if anesthesia is requested by the patient, ECV is performed under epidural anesthesia. Our findings suggested that patients without anesthesia were more likely to achieve a successful ECV outcome. In addition, the number and direction of ECV attempts were significantly associated with the outcome: patients

with successful ECV had significantly fewer rotations than those who did not; most patients with successful ECV had forward rolls, whereas a higher proportion of patients with failed ECV attempted forward and then backward rotations.

To identify independent factors predictive of successful ECV, all variables that demonstrated statistical significance in the univariate analysis—including

Table 2 Ultrasonic characteristics of the study population

Ultrasonic characteristics	Overall (<i>n</i> =378)	Successful ECV (<i>n</i> =279)	Failed ECV (<i>n</i> =99)	<i>P</i> -value
Fetal growth parameters				
BPD (mm)	91 [89, 93]	92 [89, 94]	91 [88, 93]	0.132
HC (mm)	332.19±9.85	332.32±9.60	331.81±10.58	0.658
AC (mm)	326.70±12.09	326.99±11.86	325.88±12.73	0.431
FL (mm)	70 [68, 71]	70 [68, 71]	70 [68, 71]	0.419
Placenta location				0.888
Non-anterior	218 (57.67%)	162 (58.06%)	56 (56.57%)	
Anterior	160 (42.33%)	117 (41.94%)	43 (43.43%)	
Battledore placenta				0.100
No	369 (97.62%)	275 (98.57%)	94 (94.95%)	
Yes	9 (2.38%)	4 (1.43%)	5 (5.05%)	
Umbilical cord around fetal neck (round)				0.573
0	209 (55.29%)	150 (53.76%)	59 (59.60%)	
1	161 (42.59%)	123 (44.09%)	38 (38.38%)	
2	8 (2.12%)	6 (2.15%)	2 (2.02%)	
AFV (mm)	45 [37, 53]	45 [38, 53]	42 [35, 53]	0.156
AFI (mm)	110 [92, 135]	112 [94, 138]	103 [85, 121]	0.001
Thickness of maternal abdominal wall (mm)				
3 o'clock direction	13.0 [11.3, 15.5]	13.0 [11.0, 15.0]	14.0 [12.0, 17.0]	0.012
6 o'clock direction	13.0 [11.0, 15.0]	13.0 [11.0, 15.0]	13.0 [12.0, 16.0]	0.007
9 o'clock direction	13.0 [11.0, 15.0]	13.0 [11.0, 14.0]	13.0 [12.0, 15.0]	0.002
12 o'clock direction	12.6 [11.0, 14.0]	12.0 [10.5, 14.0]	13.0 [11.0, 14.0]	0.328
Location of fetal head				0.644
First quadrant	236 (62.43%)	178 (63.80%)	58 (58.59%)	
Second quadrant	1 (0.26%)	1 (0.36%)	0 (0.00%)	
Third quadrant	1 (0.26%)	1 (0.36%)	0 (0.00%)	
Fourth quadrant	140 (37.04%)	99 (35.48%)	41 (41.41%)	
Location of fetal breech				0.472
First quadrant	3 (0.79%)	3 (1.08%)	0 (0.00%)	
Second quadrant	141 (37.30%)	100 (35.84%)	41 (41.41%)	
Third quadrant	234 (61.90%)	176 (63.08%)	58 (58.59%)	
Location of fetal spine				0.827
Umbilical region	15 (3.97%)	12 (4.30%)	3 (3.03%)	
First quadrant	146 (38.62%)	109 (39.07%)	37 (37.37%)	
Second quadrant	76 (20.11%)	52 (18.64%)	24 (24.24%)	
Third quadrant	21 (5.56%)	16 (5.73%)	5 (5.05%)	
Fourth quadrant	120 (31.75%)	90 (32.26%)	30 (30.30%)	
Days from preoperative ultrasound to ECV (d)	1 [1, 3]	1 [1, 3]	1 [1, 2]	0.141

Normally distributed data are expressed as mean±standard deviation (SD), whereas non-normally distributed data are expressed as median [25th percentile, 75th percentile]. Categorical variables were described as number (percentage). BPD: biparietal diameter; HC: head circumference; AC: abdominal circumference; FL: femur length; AFV: amniotic fluid volume; AFI: amniotic fluid index; ECV: external cephalic version.

gravidity, parity, concomitant uterine fibroids, AFI, abdominal wall thickness at the 3, 6, and 9 o'clock positions, AFI on ECV day, and administration of anesthesia—were entered into a binary logistic

regression model. The direction and times of ECV attempts were not included in the multivariate analysis because they represent intra-procedural variables that cannot be assessed prior to the intervention. The final

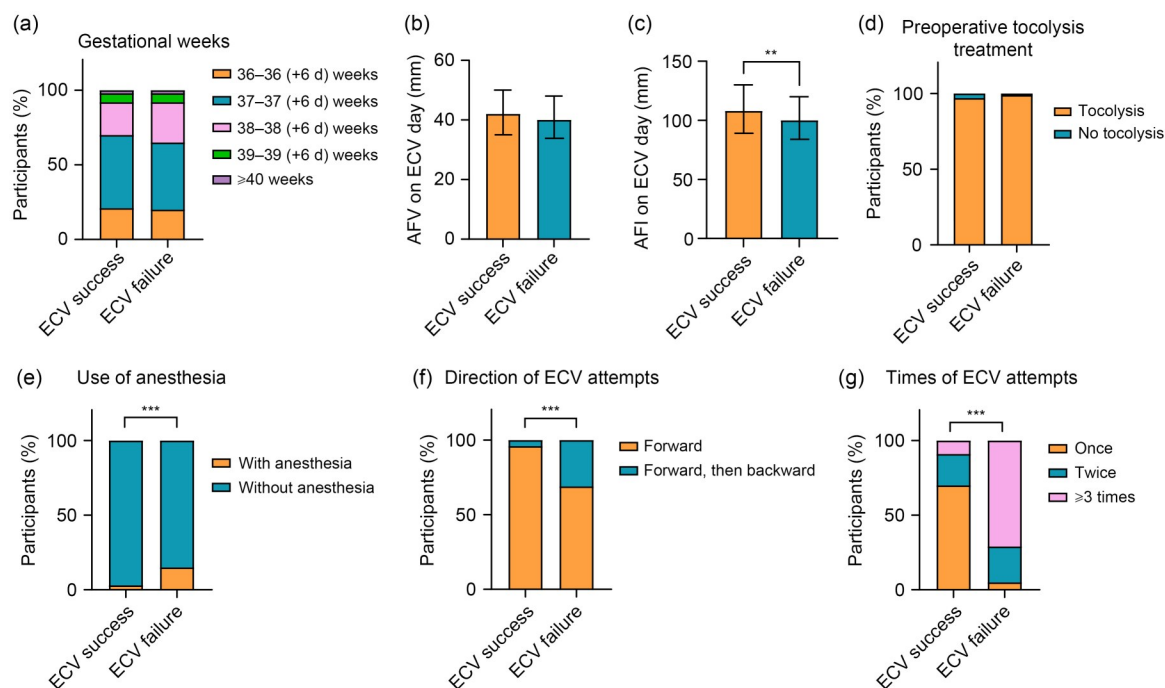


Fig. 4 Patients' characteristics associated with the external cephalic version (ECV) procedure. Comparison of gestational weeks on ECV day (a), amniotic fluid volume (AFV) on ECV day (b), amniotic fluid index (AFI) on ECV day (c), preoperative tocolysis treatment (d), use of anesthesia (e), direction of ECV attempts (f), and times of ECV attempts (g) between two groups (ECV success, $n=279$; ECV failure, $n=99$). AFV and AFI on ECV day were both non-normally distributed data and presented as median [25th–75th percentile]. Significant difference at ** $P<0.01$ and *** $P<0.001$.

Table 3 Patients' characteristics associated with external cephalic version procedure

ECV details	Overall ($n=378$)	Successful ECV ($n=279$)	Failed ECV ($n=99$)	P -value
Gestational weeks on ECV day				0.803
36–36 (+6 d)	78 (20.63%)	58 (20.79%)	20 (20.20%)	
37–37 (+6 d)	182 (48.15%)	138 (49.46%)	44 (44.44%)	
38–38 (+6 d)	87 (23.02%)	60 (21.51%)	27 (27.27%)	
39–39 (+6 d)	24 (6.35%)	18 (6.45%)	6 (6.06%)	
≥40	7 (1.85%)	5 (1.79%)	2 (2.02%)	
AFV on ECV day (mm)	41 [35, 50]	42 [35, 50]	40 [35, 48]	0.233
AFI on ECV day (mm)	105 [88, 128]	108 [89, 130]	100 [84, 120]	0.008
Preoperative tocolysis treatment				0.456
No	9 (2.38%)	8 (2.87%)	1 (1.01%)	
Yes	369 (97.62%)	271 (97.13%)	98 (98.99%)	
Use of anesthesia				<0.001
No	354 (93.65%)	270 (96.77%)	84 (84.85%)	
Yes	24 (6.35%)	9 (3.23%)	15 (15.15%)	
Direction of ECV attempts				<0.001
Forward	337 (89.15%)	269 (96.42%)	68 (68.69%)	
Forward, then backward	41 (10.85%)	10 (3.58%)	31 (31.31%)	
Times of ECV attempts [#]				<0.001
Once	199 (52.65%)	194 (69.53%)	5 (5.05%)	
Twice	84 (22.22%)	60 (21.51%)	24 (24.24%)	
Three times or more	95 (25.13%)	25 (8.96%)	70 (70.71%)	

Non-normally distributed data are expressed as median [25th percentile, 75th percentile] and categorical variables were described as number (percentage). [#] Number of ECV attempts in the same session. ECV: external cephalic version; AFV: amniotic fluid volume; AFI: amniotic fluid index.

model revealed that parity ($P=0.002$; OR=2.577; 95% CI, 1.426–4.658), presence of uterine fibroids ($P=0.014$; OR=0.116; 95% CI, 0.021–0.652), AFI ($P=0.040$; OR=1.015; 95% CI, 1.001–1.029), and use of anesthesia ($P<0.001$; OR=0.164; 95% CI, 0.065–0.413) were independent determinants of ECV success (Table S1).

3.4 Prediction of success rate of ECV based on neural network

By applying pressure to the maternal abdomen in the ECV procedure, the fetus can be turned from a non-cephalic presentation to a head-down position, thereby increasing the chance of vaginal delivery. However, there is a failure rate associated with this strategy, which can lead to emotional and economic losses. Through an analysis of various parameters between successful and failed ECV samples, we have observed specific differences between the two groups.

By analyzing these parameters in advance, it is hoped that the outcome of the ECV procedure can be better predicted. Obstetricians and patients can refer to the predictive results to determine whether to proceed with the procedure, thereby avoiding unnecessary emotional and economic losses as well as risks of adverse obstetrical outcomes.

Manual parameter analysis only enables a rough estimation of ECV success, while the low efficiency and poor quantifiability of this approach underscore the need for more objective decision aids. Neural network algorithms can classify samples and output the probability distribution. Thus, a neural network algorithm was constructed to predict the success rate of the ECV procedure using a total of 37 parameters, including maternal characteristics, ultrasonographic parameters, and procedural details (complications not included) (Fig. 5a). A total of 378 samples were involved in the analysis, with 279 successful and 99 failed samples,

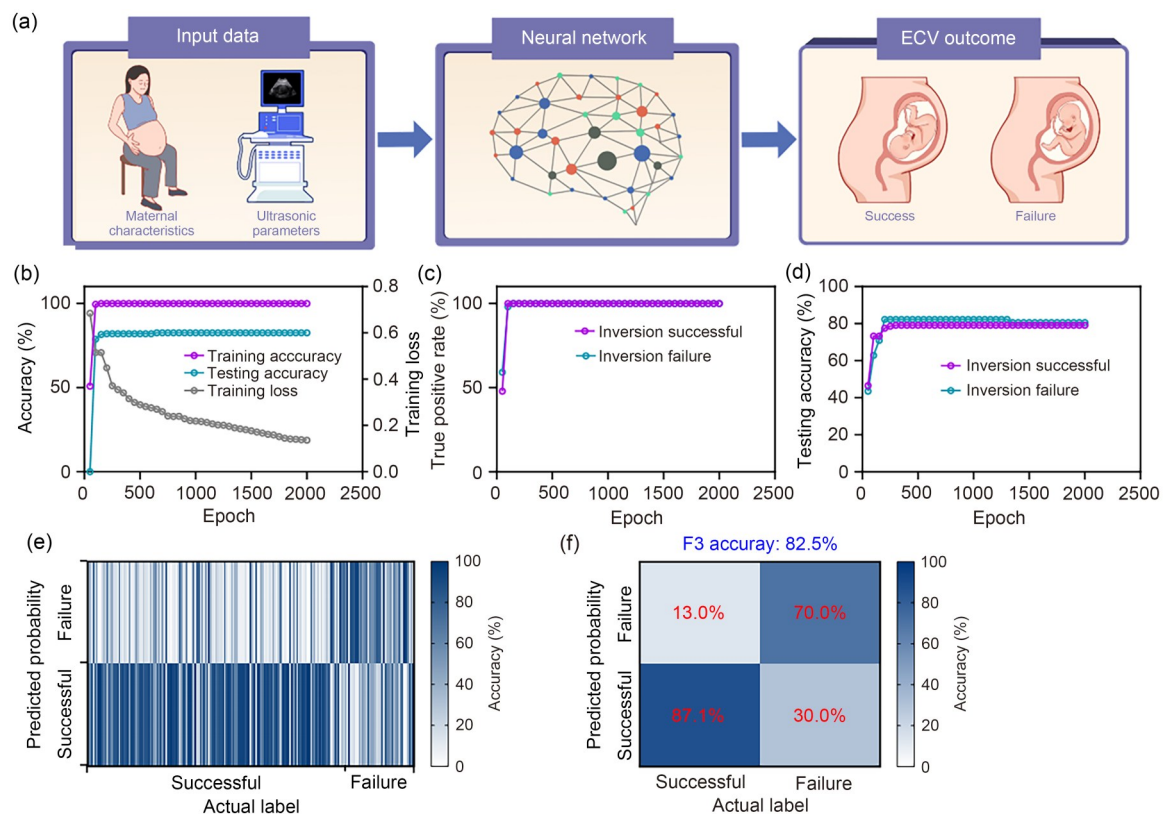


Fig. 5 Performance characterization of the prediction of external cephalic version (ECV) procedure outcome based on the neural network algorithm. (a) Prediction of ECV outcomes by neural network algorithm. (b) Training set accuracy, testing set accuracy, and training loss of the neural network algorithm. (c) True positive rates for successful and failed versions in the training set of the neural network. (d) Recognition accuracy of successful and failed ECV samples in the testing set. (e) Predicted probability distribution output by the neural network algorithm. (f) Recognition accuracy of the neural network after 2000 iterations.

and the samples were divided into training and testing sets in a 1:1 ratio. Fig. 5b shows the relationship between the accuracy of the training set, the accuracy of the testing set, and the training loss with the same number of iterations (with an interval of 50). The figure illustrates that as the number of iterations increases, both the accuracy of the training set and the accuracy of the testing set markedly improve, reaching 100.0% and 82.5%, respectively. Meanwhile, the training loss reaches 0.136 after 2000 iterations, demonstrating favorable training effectiveness. To further characterize the effects of training we evaluated the true positive rates of successful and failed version samples in the training set, as shown in Fig. 5c. After 2000 iterations, the true positive rates for successful and failed samples both reached 100.0%, demonstrating great performance. Fig. 5b shows that the neural network achieved a prediction accuracy of 82.5% for predicting ECV outcomes. To further analyze the performance of the algorithm, we examined the recognition accuracy of successful and failed ECV samples in the testing set (Fig. 5d). With an increasing number of iterations, the recognition accuracy of failed ECV testing samples decreases. This is because the training samples were mainly optimized for overall recognition accuracy, leading to a potential decrease in prediction accuracy for some sample sets. Finally, the recognition accuracy rates for successful and failed ECV attained 87.1% and 70.0%, respectively. It is also worth noting that the algorithm output predicted probabilities of different outcomes (Fig. 5e), are more informative than simply providing success and failure results. The final accuracy distribution of the algorithm is shown in Fig. 5f, with a total accuracy of 82.5% after 2000 iterations. Logistic regression was further employed for ECV prediction, as depicted in Fig. S1. The results demonstrate that logistic regression exhibits limitations in modeling nonlinear relationships and automated feature learning, consequently yielding lower accuracy (77.3%) and reduced stability compared to neural network algorithms. Moreover, to ensure generalizability, a 3-fold cross-validation was performed, where the dataset was partitioned into three equal subsets. For each iteration, two subsets served as the training set and the remaining subset as the validation set. As illustrated in Fig. S2, the six combinations achieved a mean accuracy of 81.1%, comparable to the accuracy of 82.5%, demonstrating the stability of the

algorithm. Additionally, an external validation set comprising 106 samples (78 successful ECV cases and 28 failed cases) was employed to assess the algorithm's performance. The results demonstrated 81.1% accuracy on this external set, providing preliminary evidence of the algorithm's generalizability, as shown in Fig. S3. In summary, the neural network algorithm constructed in this article can predict ECV outcomes with a high accuracy, potentially providing a valuable reference for patients to reduce emotional and economic damage as well as resource consumption.

3.5 Prediction of delivery mode after ECV based on neural network

For pregnant women who have successfully turned to a cephalic presentation through an ECV, a vaginal delivery may not necessarily be a viable option in the end. Therefore, effectively predicting the probability of a vaginal delivery after a successful ECV is also an important aspect. To objectively and accurately predict the mode of delivery, neural network algorithms can identify patterns from patient characteristics prior to the ECV procedure. Herein, we combined 38 parameters of pregnant women to automatically predict the delivery mode using a neural network algorithm.

A total of 291 samples with recorded modes of delivery, including 164 vaginal delivery samples and 127 cesarean section samples, were included in this model. These were allocated into training and testing sets in a 1:1 ratio. The relationship between the training set accuracy, testing set accuracy, and training loss with the number of iterations (in intervals of 50) for the neural network is illustrated in Fig. 6a. With an increase in the number of iterations, both the training set accuracy and testing set accuracy improved, reaching 100.0% and 78.8%, respectively. Furthermore, the training loss reached 0.136 after 2000 iterations, indicating favorable training results. We also evaluated the true positive rates of the vaginal delivery and cesarean section samples in the training set (Fig. 6b). After 2000 iterations, the true positive rates for the vaginal delivery and cesarean section samples both reached 100.0%, exhibiting excellent performance. As shown in Fig. 6a, the neural network achieved a prediction accuracy of 78.8% for the mode of delivery. To further analyze the performance of the neural network, we conducted an analysis of the identification accuracy of the vaginal delivery and cesarean section

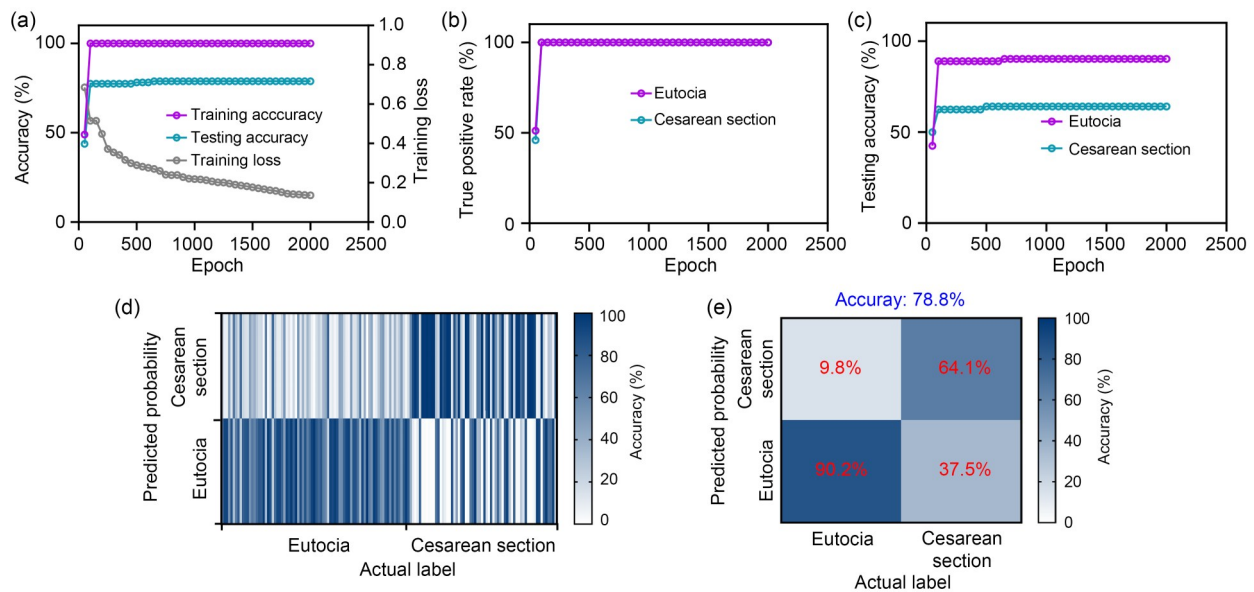


Fig. 6 Performance prediction of preferred delivery mode based on the neural network algorithm. (a) Training set accuracy, testing set accuracy, and training loss of the neural network algorithm. (b) True positive rates of the vaginal delivery and cesarean section sample sets in the neural network training set. (c) Identification accuracy of vaginal delivery and cesarean section samples in the testing set. (d) Predicted probability distribution output by the neural network algorithm. (e) Recognition accuracy of the neural network after 2000 iterations.

samples in the testing set (Fig. 6c). With an increasing number of iterations, the identification accuracy of both the vaginal delivery and cesarean section samples clearly improved. After 2000 iterations, their identification accuracies reached 90.2% and 64.1%, respectively, indicating that the prediction of vaginal delivery by the neural network is more informative for patients. Fig. 6d illustrates the probability distribution of the testing sample predictions by the neural network after 2000 iterations, which provides more valuable references than simply outputting the delivery results. The accuracy distribution is displayed in Fig. 6e, with an overall accuracy of 78.8% after 2000 iterations. Similarly, logistic regression was applied to predict the delivery mode, achieving only 66.4% accuracy (Fig. S4). This result underscores the superior performance of the neural network approach. The 3-fold cross-validation yielded a mean accuracy of 76.2%, closely aligned with the accuracy of 78.8%, confirming the robust stability of the predictive algorithm (Fig. S5). Moreover, an external validation set comprising 95 samples (59 vaginal delivery samples and 36 cesarean section samples) was employed to assess the algorithm's performance. The results showed that on this external set, the accuracy rate was 78.9%, which underscores the generalization ability of the algorithm (Fig. S6). In conclusion, the neural network

algorithm constructed in this study could effectively predict the mode of delivery and demonstrates a relatively high prediction accuracy, and thus it provides important guidance for obstetricians and pregnant women in decision-making.

4 Discussion

The ECV procedure is an important option in the management of breech presentation. Currently, cesarean section is the most common mode of delivery for pregnant women with breech presentation (Olson Koutrouvelis, 2019). For these women willing to opt for vaginal delivery, ECV is recommended by several guidelines (Impey et al., 2017; American College of Obstetricians and Gynecologists, 2020). However, the attempt of an ECV is associated with possible failure, more medical costs, as well as risks of maternal and fetal complications, although these risks are rather limited (Kuppens et al., 2017; Olson Koutrouvelis, 2019; López-Pérez et al., 2020). Therefore, the precise prediction of ECV outcomes is critical in the decision-making process.

In this study, we compared the demographic characteristics, preoperative ultrasonic parameters, and ECV procedure details between patients who had

successful ECV and those with failed attempts. Univariate analysis showed that gravidity, parity, systolic blood pressure, AFI indicated by preoperative and intra-operative ultrasound, and the presence of uterine fibroids were positively associated with successful ECV attempts, while thicker maternal abdominal walls and the use of anesthesia were correlated with ECV failure. Multivariate analysis revealed that parity, uterine fibroids, AFI, and the use of anesthesia were independent determinants of ECV outcomes. Subsequently, we developed a novel system using neural network approaches to predict the ECV outcome and mode of delivery for patients undergoing ECV attempts. When predicting a successful version, this algorithm achieved a total accuracy of 82.5%, showing favorable prediction performance. The neural network algorithm also demonstrated a relatively high prediction accuracy (overall accuracy of 78.8%) for the prediction of the mode of delivery in the internal validation cohort. We further employed an external validation set to assess the algorithm's performance and achieved an accuracy of 78.9%, demonstrating the discriminative performance of this model.

The overall success rate of ECV was 73.8% (279/378) in our cohort, which is relatively high considering that previously reported rates range from 35% to 86% (Isakov et al., 2019). In our center, a team of ECV specialists composed of experienced and skilled obstetricians was established in 2016, and a number of ECV procedures have been conducted since then. During the ECV procedure, the obstetricians rotated the fetus while coordinating with the patients' abdominal breathing, which may increase the success rate of ECV. In terms of influencing factors, our results suggest that participants with multiparity (Svensson et al., 2021; Londero et al., 2023) and higher AFI (Levin et al., 2019; Svensson et al., 2021) were more likely to achieve a successful external version, consistent with previous reports, which have suggested that anesthesia improves the success rate of ECV (Magro-Malosso et al., 2016; Boujenah et al., 2017). In the present study, however, anesthesia was associated with ECV failure. This apparent discrepancy may be explained by the divergent indications for anesthesia: while the literature reflects protocols in which anesthesia was offered to all patients—thereby enhancing overall success—we selectively provided anesthesia only to women who explicitly requested it. These women were frequently highly anxious and might demonstrate

reduced cooperation during the procedure, factors that may independently compromise the likelihood of successful version. The presence of uterine fibroids may impede the operator's manipulative maneuvers and restrict fetal rotation, thereby increasing the risk of ECV failure. The thickness of the maternal abdominal wall was assessed by preoperative ultrasound, and this parameter may influence the difficulty of ECV manipulation. Although we hypothesized that greater thickness would correlate with a higher risk of ECV failure, multivariable analysis demonstrated that abdominal wall thickness is not an independent predictor of ECV outcome. Moreover, the literature has confirmed that operator experience significantly influences the success rate of ECV (Hakem et al., 2021). To eliminate this confounding factor, only operators with substantial ECV experience (≥ 20 procedures) were chosen to participate in this study.

Thus far, several studies have been dedicated to the prediction of ECV outcomes. Velzel et al. (2015) summarized the prediction models published before 2015, and concluded that the most important variables for predicting successful ECV were parity, placental location, breech engagement, and palpable fetal head. Isakov et al. (2019) evaluated the correlation of variables and ECV success utilizing a multivariate logistic regression and a decision tree, achieving a prediction accuracy of 91.9% (86.5%–97.3%) in internal validation. Later, in 2021, a prediction model was constructed based on BMI, parity, placental location, and fetal malpresentation, with the area under the receiver operating characteristic curve (AUROC) of 0.667 (0.634–0.701) (Dahl et al., 2021). This model was subsequently externally validated, displaying a similar AUROC of 0.70 (0.65–0.75) (Kishkovich et al., 2023). However, these models were established by conventional multivariable logistic regression modeling, which may be limited by its linearity assumption, lack of inherent ability to capture complex nonlinear relationships, and potential for overfitting with high-dimensional data when compared to neural network approaches (Renganathan, 2019). The induction of neural network algorithms has greatly improved the diagnostic and predictive performance of models in a number of clinical scenarios (Issaiy et al., 2023). However, the application of neural network-based model in the management of ECV has rarely been reported.

To our knowledge, this is the first study to establish a prediction model for ECV outcomes using a neural network algorithm. The proposed algorithm achieved favorable training effects, and by increasing the number of iterations, the true positive rates for successful and failed versions both reached 100.0%, demonstrating excellent performance. The overall accuracy was 82.5% for predicting ECV outcomes. Instead of outputting the predicted outcome alone, this algorithm outputs exact predicted probabilities of the probable outcomes according to the individualized conditions, which is more informative and helpful in clinical practice. An external validation was also employed to confirm the algorithm's performance.

Since a successful ECV does not guarantee a vaginal birth (Levin et al., 2020), we also attempted to predict the mode of delivery for patients undergoing ECV. This neural network-based model showed favorable training results and achieved a prediction accuracy of 78.8% for ECV outcomes after 2000 iterations. Compared to the model predicting ECV outcome, this model was slightly less accurate. This might be because the mode of delivery can be influenced by a number of other variables, such as maternal pelvis, psychological factors, and maternal comorbidities, which were not included in the current algorithm. Despite this issue, the accuracy was acceptable, so this model can potentially assist in clinical decision-making for women eligible for ECV.

Despite the benefits of the proposed model, we acknowledge several limitations of this study. First, it consisted of participants from a retrospective cohort, which inevitably introduced bias and thereby affected the reliability of the results. Although the prediction model has undergone external validation, its performance also requires further validation by future studies. Second, as the study was conducted in a single center, this to some extent influenced the application of the results to general populations. Third, in the prediction of delivery mode, other factors that may be important in deciding the mode of delivery, such as pelvic conditions, cervical maturity, maternal complications, and comorbidities, were not included, which to some extent reduces the accuracy of prediction.

As aforementioned, this study utilized a neural network algorithm to construct prediction models for ECV outcomes and the mode of delivery based on the clinical data and ultrasonic characteristics of pregnant women with breech presentation. As such, the results

may assist obstetricians in making individualized assessments based on clinical characteristics and probable outcomes, and may also help candidates for ECV to make decisions that better fit their personal wishes and interests.

5 Conclusions

In this study, we formulated a prediction model that employs a neural network algorithm to estimate the success or failure of ECV. This model demonstrated commendable performance metrics. Subsequently, we devised a neural network-based predictive model to predict the mode of delivery. Its accuracy was satisfactory, although it exhibited a modest decrement in accuracy compared to ECV outcome prediction. Importantly, instead of merely providing a predicted outcome, these models furnish precise probabilistic estimates of the potential outcomes, which is informative and can be instrumental in augmenting the utility of these models in clinical practice. For women eligible for ECV, the application of such a model can be of high value in clinical decision-making processes.

Data availability statement

The dataset used or analyzed during the current study is available from the corresponding authors upon reasonable request.

Acknowledgments

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Author contributions

Zhongjun LI, Ning HU, and Suran HUANG conceived and designed the study. Yuting XIANG, Wanhua WU, and Haixia LIN performed data collection and preparation. Yuting XIANG drafted the manuscript and Hao WANG substantially revised it. Wenjian YANG, Haote HAN, and Hao WANG performed statistical analysis. Yuting XIANG and Hao WANG prepared the figures. All authors have read and approved the final manuscript, and therefore, have full access to all the data in the study and take responsibility for the integrity and security of the data.

Compliance with ethics guidelines

Yuting XIANG, Wenjian YANG, Haote HAN, Haixia LIN, Wanhua WU, Suran HUANG, Hao WANG, Ning HU, and Zhongjun LI declare that they have no conflicts of interest.

All procedures followed were in accordance with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards, and received approval from the Institutional Review Board of the Tenth Affiliated Hospital, Southern Medical University (No. KYKT2024-010). Written consent was waived for the retrospective nature.

Declaration on the use of generative AI tools

No generative AI tools were used in the preparation of this manuscript.

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Supplementary information

Table S1; Figs. S1–S6