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 unsuccessful 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 pre-operative and intra-operative ultrasound

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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 successful and failed version both reached 100%. The overall accuracy was 82.5% for 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 prediction 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 (ACOG, 2020; Impey LWM, 2017). Considering the increased risk of adverse perinatal outcomes, vaginal breech delivery remains rare in most countries (Bresson et al., 2023; Impey LWM, 2017). 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 (de Castro et al., 2020; Impey LWM, 2017; 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 <2500 g, are associated with a failed version (ACOG, 2020; Kishkovich et al., 2023). Meanwhile, evidence is contradictory about the impact of other factors in predicting a successful ECV. For example, Londero and colleagues found that high pre-pregnancy body mass index (BMI) and high BMI at delivery are associated with an increased risk of failure (Londero et al., 2023), while another study suggested that maternal obesity does not impair the success rate (Svensson et al., 2021). Since the ECV procedure involves the surgeon 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 surgeon's 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 nor 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 (Kasera et al., 2024; Plotka et al., 2023; 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, 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 of demographic characteristics and comprehensive preoperative ultrasonic assessment.

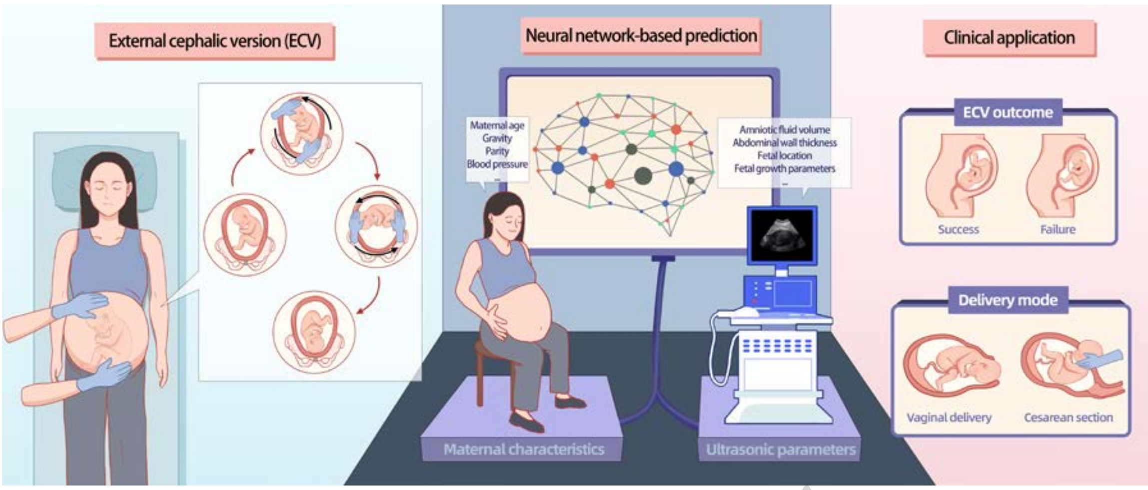

Fig. 1 Schematic of the neural network approach for predicting external cephalic version (ECV) outcome and mode of delivery based on demographic characteristics and preoperative ultrasonic assessment. For pregnant women who were candidates for ECV, data on the demographic characteristics were extracted 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.

2 Methods

2.1 Study population

This retrospective cohort study enrolled women with singleton pregnancies who underwent an ECV for breech presentation at a single, tertiary, university-affiliated hospital between January 2016 and September 2023. This study was approved by the Institutional Review Board of the Tenth Affiliated Hospital, Southern Medical University (KYKT2024-010).

The inclusion criteria for the participants were as follows: (1) women with singleton pregnancy $\geqslant$ 36 gestational weeks; (2) breech presentation; (3) patients willing to undergo an ECV procedure; (4) the umbilical cord wrapped no more than two times around the fetal neck. Specifically, women with > two loops were excluded according to our institutional protocol on the basis of evidence that a cord entanglement of $\geqslant$ 3 loops is associated with a higher risk of fetal distress (Schreiber et al., 2019).

The exclusion criteria were as follows: (1) suspected or confirmed placental abruption, placenta previa, active labor, premature rupture of membranes, fetal distress, major fetal anomalies, uterine rupture, abnormal fetal Doppler on ultrasound, and antepartum hemorrhage within the past seven days; (2) presence of other factors necessitating a caesarean section irrespective of the fetal presentation; (3) patients with a scarred uterine, including those with a history of cesarean section, myomectomy, uterine perforation, and other uterine surgery; (4) cases with incomplete data.

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; (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 o'clock, 9 o'clock 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 quadrant, 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 $>$ 5 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 % CI 0.86–0.96), and the agreement with the clock-face method was excellent (κ = 0.88; 95 % CI 0.80-0.95).

2.3 ECV procedure

Candidates for ECV were admitted to the hospital on the day of the procedure. Eligibility for ECV was re-examined, including taking general and obstetrical history, physical examination, and ultrasound evaluation. Cardiotocography was performed to evaluate fetal well-being and uterine contraction. If contraction was detected by cardiotocography or physical examination, tocolysis was used 30 min before the procedure.

Bedside ultrasound was employed to monitor fetal heart rate and fetal position throughout the ECV procedure. As described in the study by Rodgers et al. (2017), ECV was performed as follows: The obstetrician applied firm pressure to the fetal buttocks through the patient's abdomen. The fetal breech was lifted out of the pelvis and displaced laterally. Then, constant and firm pressure was placed on the fetal hip and head until the fetus was rotated to a cephalic position. The obstetrician usually initiated with the attempt of a forward roll. In the event when this failed, a subsequent attempt was made with a backward roll. When the rotation was difficult, the obstetrician instructed the woman to perform abdominal breathing slowly and attempted to rotate the fetus again with the rise and fall of the maternal abdomen. In most cases, the procedure was terminated after three unsuccessful attempts. Additional attempts were undertaken if the obstetrician considered that there was a reasonable chance of success, for which the patient's agreement was also required. In line with previous studies (Isakov et al., 2019; Kuppens et al., 2017) and our practical experience, the ECV attempt was terminated under any one of the following conditions: (1) the fetus was successfully inverted to a cephalic position; (2) 30 min of fetal manipulation had elapsed (doing one attempt and then waiting for few mins before reattempting, instead of continuous manipulation); (3) the patient asked to stop the procedure due to pain or any other reason; (4) vaginal bleeding, premature rupture of membranes, or significant abdominal pain were observed, or bedside ultrasonography revealed non-reversible fetal bradycardia, prolapse of the umbilical cord, or placental abnormalities; (5) the obstetrician decided that continuing the procedure would be of no benefit. Specifically, all ECV procedures at our center were performed by Director Zhongjun Li's team, with every operator being experienced (having performed a minimum of 20 ECVs).

To confirm the success of ECV, an ultrasound scan was performed after the procedure. Cardiotocography was also conducted to evaluate fetal heart rate. If the patient remained stable, she 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 extracted from the hospital's electronic patient record system. The collected data included: (1) Maternal characteristics at the time of ECV procedure, such as age, gravidity, parity, gestational weeks, weight, BMI, blood pressure, fundal height and abdominal circumference, engagement of the fetal presentation; (2) Preoperative ultrasonic parameters such as placental location, morphological abnormality of the umbilical cord and placenta, umbilical artery blood flow spectrum, amniotic fluid volume, amniotic fluid index, fetal presentation, cord around the neck, as well as biparietal diameter, head circumference, abdominal circumference, and femur length of the fetus. The thickness of the women's abdominal wall and the detailed fetal position were also included as stated above; (3) Information about the ECV procedure, such as time from ultrasound to ECV procedure, tocolytic therapy, number of ECV attempts, forward or backward rolls, success/failure of the procedure, reason to stop the procedure; (4) Complications, such as 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); (5) Mode of delivery (if appliable).

2.5 Statistical analysis of comparisons between groups

Comparisons of the patient characteristics between two groups were performed using SPSS Version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables conforming to a normal distribution were expressed as mean ± 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 n (%) 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 ratios (OR) and 95% confidence intervals. A p-value < 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 1,024, 512 and 256 neurons, respectively, and an output layer with 2 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 layer, 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 our hospital. Among them, ECV was successful in 279 cases and unsuccessful in 99 cases, with an overall success rate of 73.8% (279/378). Among the 378 procedures, two complications (0.40%) 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 unsuccessful 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 abdominal circumference, engagement of fetal presentation, and the presence of uterine adhesions or septate uterus. The detailed patient characteristics were shown in Fig. 2 and Table 1.

Table 1 Maternal characteristics of the study population

Maternal characteristics	Overall (*n*=378)	Successful ECV (*n*=279)	Unsuccessful ECV (*n*=99)	*Z*, *t* or X^2	*P*-value
Maternal age (year)	29.00 [27.00, 33.00]	30.00 [27.00, 33.00]	29.00 [25.00, 32.50]	15588	0.057
Gravidity	2.00 [1.00, 3.00]	2.00 [1.00, 3.00]	2.00 [1.00, 3.00]	15715.5	0.034
Parity	1.00 [0.00, 1.00]	1.00 [0.00, 1.00]	0.00 [0.00, 1.00]	17148	<0.001
Nulliparous				14.95	<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)	65.50 [60.00, 70.95]	65.00 [60.00, 70.00]	67.00 [60.80, 72.95]	12235.5	0.092
BMI on ECV day (kg/m^2)	25.90 ± 3.06	25.87 ± 3.01	25.99 ± 3.21	-0.314	0.754
Systolic pressure (mmHg)	114.50 [108.00, 121.00]	113.00 [107.00, 120.00]	117.00 [109.00, 123.50]	11650.5	0.021
Diastolic pressure (mmHg)	73.00 [69.00, 78.00]	73.00 [69.00, 78.00]	73.00 [70.00, 78.00]	12972.5	0.369
Uterus height (cm)	33.00 [32.00, 34.00]	33.00 [32.00, 34.00]	33.00 [32.00, 35.00]	13429	0.679
Abdomen circumference (cm)	97.00 [93.00, 100.00]	97.00 [92.00, 100.00]	96.00 [93.00, 100.00]	13723.5	0.926
Engagement of fetal presentation				0.49	0.482
Yes	365 (96.56%)	271 (97.13%)	94 (94.95%)		
No	13 (3.44%)	8 (2.87%)	5 (5.05%)		
Intrauterine adhesions					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 ± SD and non-normally distributed data as median [25th percentile, 75th percentile]. BMI, body mass index; ECV, external cephalic version.

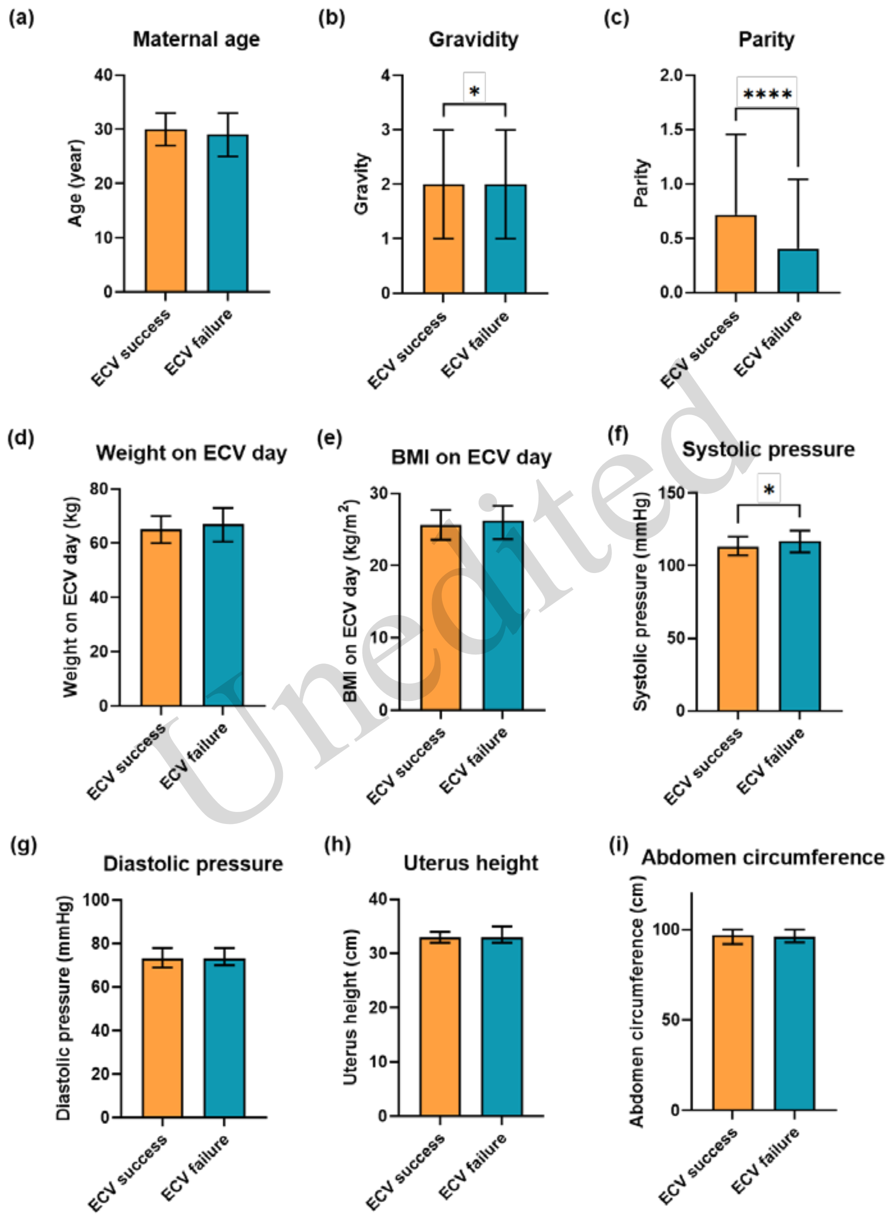

Fig. 2 Demographic characteristics of the participants with successful and failed ECV. Comparison of (a) maternal age, (b) gravidity, (c) parity, (d) weight on ECV day, (e) BMI on ECV day, (f) systolic pressure, (g) diastolic pressure, (h) uterus height and (i) maternal abdomen circumference between two groups (ECV success, *n*=279; ECV failure, *n*=99). Normally distributed values are expressed as mean ± SD and non-normally distributed data as median [25th - 75th percentile]. ECV, external cephalic version; BMI, body mass index. Significant difference at * *P*<0.05 and ** *P*<0.0001.**

3.2 Comprehensive ultrasonic assessment before ECV

Each patient eligible for ECV underwent a preoperative ultrasound assessment to thoroughly assess the fetal size, fetal position, placental location, amniotic fluid volume, and maternal abdominal wall thickness. The ultrasound measurement parameters for the two groups were detailed in Fig. 3 and Table 2. Specifically, the AFI in the successful group was significantly higher than that in the unsuccessful group, although no between-group differences were demonstrated in AFV. The maternal abdominal wall thickness at the 3 o'clock, 6 o'clock, and 9 o'clock directions in the unsuccessful group were significantly greater than 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; Lopez-Perez et al., 2020; Sium et al., 2023; Svensson et al., 2021) 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.

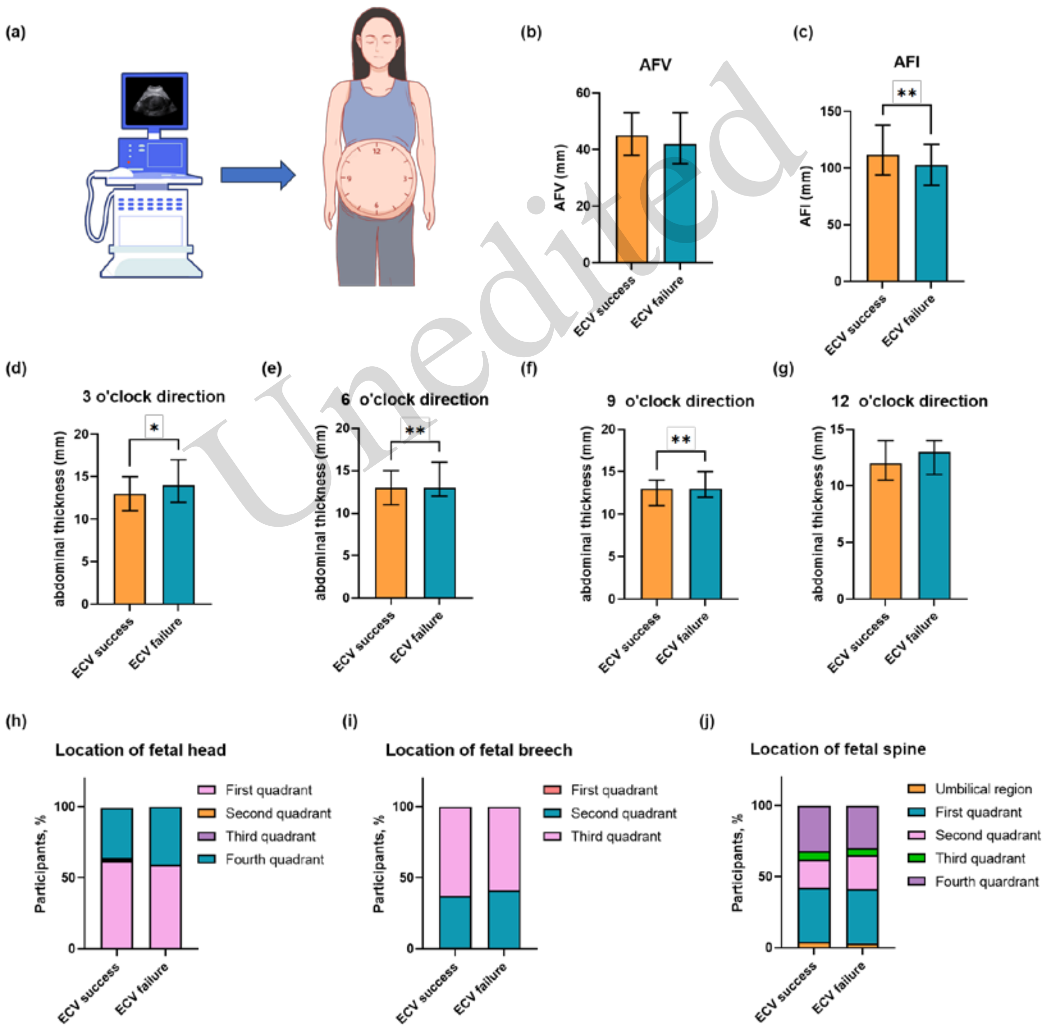

Fig. 3 Preoperative ultrasonic assessment with successful and failed ECV (ECV success, *n*=279; ECV failure, *n*=99). (a) The directions on the maternal abdomen were represented according to the clock method. (b) - (c). Comparison of AFV and AFI between the two groups. (d) - (g). Measurement of the thickness 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. Normally distributed values are expressed as mean ± SD and non-normally distributed data as median [25th - 75th percentile]. ECV, external cephalic version; AFV, amniotic fluid volume; AFI, amniotic fluid index. Significant difference at * *P*<0.05 and ** *P*<0.01.

Table 2 Ultrasonic characteristics of the study population

Ultrasonic characteristics	Overall (*n*=378)	Successful ECV (*n*=279)	Unsuccessful ECV (*n*=99)	*Z*, *t* or X^2	*P*-value
Fetal growth parameters					
BPD (mm)	91.00 [89.00, 93.00]	92.00 [89.00, 94.00]	91.00 [88.50, 93.00]	15213.5	0.132
HC (mm)	332.19 ± 9.85	332.32 ± 9.60	331.81 ± 10.58	0.44	0.658
AC (mm)	326.70 ± 12.09	326.99 ± 11.86	325.88 ± 12.73	0.79	0.431
FL (mm)	70.00 [68.00, 71.00]	70.00 [68.00, 71.00]	70.00 [68.00, 71.00]	13063.5	0.419
Placenta location				0.02	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 (97.31%)	275 (98.57%)	94 (94.95%)		
Yes	22 (2.91%)	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)	45.00 [37.00, 53.00]	45.00 [38.00, 53.00]	42.00 [35.00, 53.00]	15136.5	0.156
AFI (mm)	110.00 [92.00, 134.75]	112.00 [94.00, 137.50]	103.00 [85.50, 120.50]	16786	0.001
Thickness of maternal abdominal wall (mm)					
3 o'clock direction	13.00 [11.33, 15.48]	13.00 [11.00, 15.00]	14.00 [12.00, 17.00]	11464	0.012
6 o'clock direction	13.00 [11.00, 15.00]	13.00 [11.00, 15.00]	13.00 [12.00, 16.00]	11286.5	0.007
9 o'clock direction	13.00 [11.00, 15.00]	13.00 [11.00, 14.00]	13.00 [12.00, 15.00]	10986.5	0.002
12 o'clock direction	12.65 [11.00, 14.00]	12.00 [10.50, 14.00]	13.00 [11.00, 14.00]	12900.5	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%)		
Forth 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%)		
Forth quadrant	120 (31.75%)	90 (32.26%)	30 (30.30%)		
Days from preoperative ultra-sound to ECV	1.00 [1.00, 3.00]	1.00 [1.00, 3.00]	1.00 [1.00, 2.00]	15122.5	0.141

Normally distributed data are expressed as mean ± SD and non-normally distributed data as median [25th percentile, 75th percentile]. BPD, biparietal diameter; HC, head circumference; AC, abdominal circumference; FL, femur length; AFV, amniotic fluid volume; AFI, amniotic fluid index; ECV, external cephalic version.

3.3 Comparison of ECV procedure between groups

The ECV conditions for the two groups were detailed in Fig. 4 and Table 3. The AFI indicated by intraoperative 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 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 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 (see detailed results in Table S1). 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 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 3 Patient characteristics associated with ECV procedure

ECV details	Overall (n=378)	Successful ECV (n=279)	Unsuccessful ECV (n=99)	*Z* or X^2	*P*-value
Gestational weeks on ECV day					0.803
36-36+6 weeks	78 (20.63%)	58 (20.79%)	20 (20.20%)		
37-37+6 weeks	182 (48.15%)	138 (49.46%)	44 (44.44%)		
38-38+6 weeks	87 (23.02%)	60 (21.51%)	27 (27.27%)		
39-39+6 weeks	24 (6.35%)	18 (6.45%)	6 (6.06%)		
≥40 weeks	7 (1.85%)	5 (1.79%)	2 (2.02%)		
AFV on ECV day (mm)	41.00 [35.00, 50.00]	42.00 [35.00, 50.00]	40.00 [35.00, 47.50]	14924.5	0.233
AFI on ECV day (mm)	105.00 [88.00, 128.00]	108.00 [89.00, 130.00]	100.00 [84.50, 119.50]	16290.5	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				15.53	<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				58.101	<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*				168.81	<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%)		

Normally distributed data are expressed as mean ± SD and non-normally distributed data as median [25th percentile, 75th percentile]. AFV, amniotic fluid volume; AFI, amniotic fluid index; ECV, external cephalic version. *Number of ECV attempts in the same session.

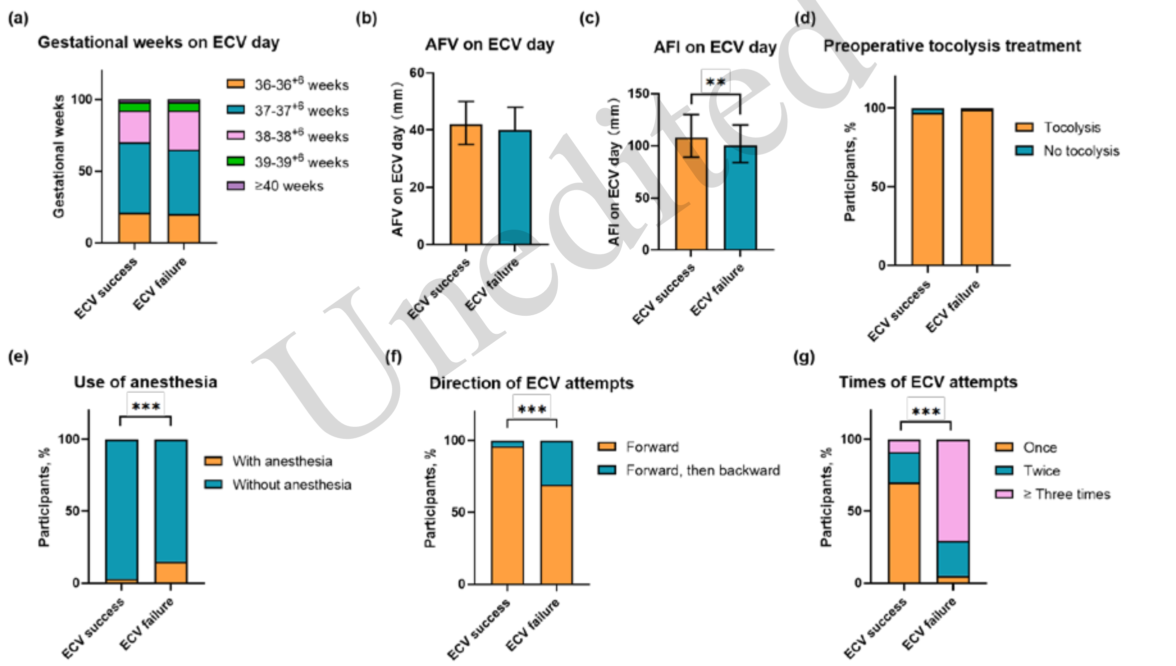

Fig. 4 Patient characteristics associated with the ECV procedure. Comparison of (a) gestational weeks on ECV day, (b) AFV on ECV day, (c) AFI on ECV day, (d) preoperative tocolysis treatment, (e) use of anethesia, (f) direction of ECV attempts and (i) times of ECV attempts between two groups (ECV success, *n*=279; ECV failure, *n*=99). Normally distributed values are expressed as mean ± SD and non-normally distributed data as median [25th - 75th percentile]. ECV, external cephalic version; AFV, amniotic fluid volume; AFI, amniotic fluid index. Significant difference at ** *P*<0.01 and *** *P*<0.001.

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 unsuccessful 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 distributions. 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, 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 improves, reaching 100% and 82.5%, respectively. Meanwhile, the training loss reaches 0.055 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%, demonstrating great performance. Fig. 5B shows that the neural network achieved a prediction accuracy probability 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, as shown in 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 prediction probabilities of different outcomes, as shown in Fig. 5E, are more informative than simply providing success and failure results. The final accuracy distribution of the algorithm was 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.

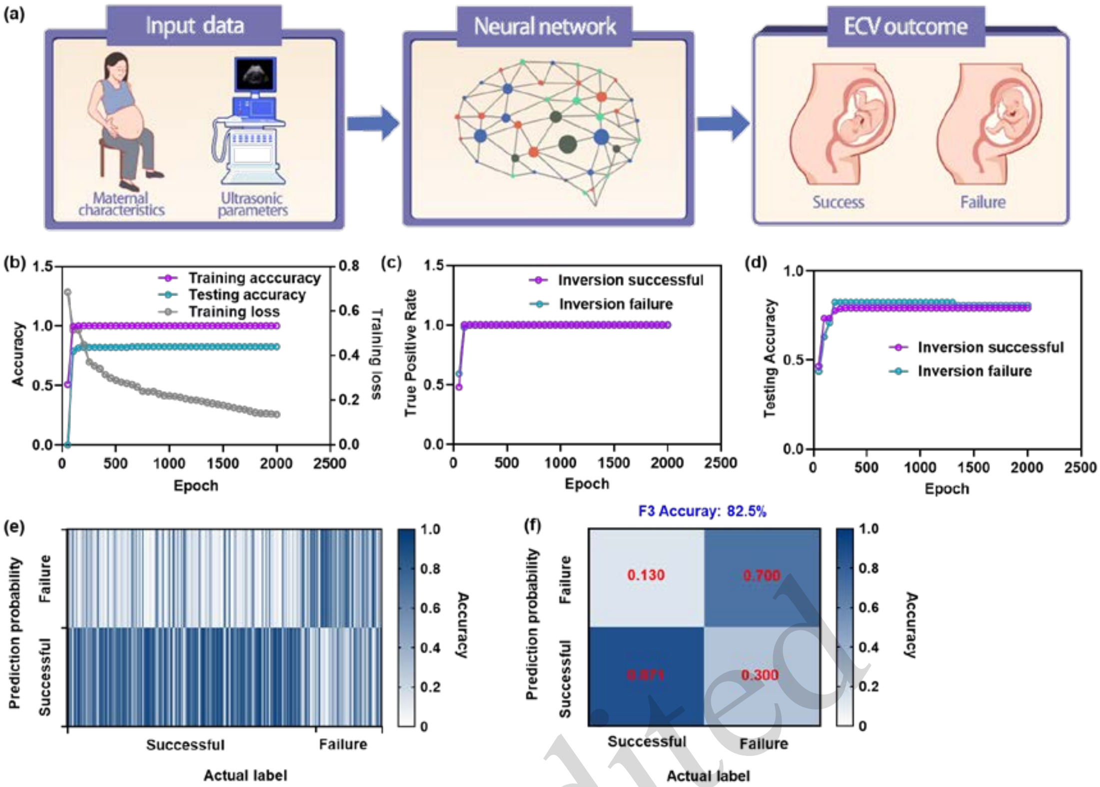

Fig. 5 Performance characterization of the prediction of external cephalic version (ECV) procedure outcome based on the neural network algorithm. (a) Prediction of ECV outcomes by neural network algorithm. (b) Training set accuracy, testing set accuracy, and training loss of the neural network algorithm. (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.

3.5 Prediction of delivery mode after ECV based on neural networks

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 was illustrated in Fig. 6A. With an increase in the number of iterations, both the training set accuracy and testing set accuracy improved, reaching 100% and 78.8%, respectively. Furthermore, the training loss reached 0.055 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, as depicted in Fig. 6B. After 2000 iterations, the true positive rates for the vaginal delivery and cesarean section samples both reached 100%, exhibiting excellent performance. As shown in Fig. 6A, the neural network achieved a predictive 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 samples in the testing set, as shown in 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, as shown in 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, thus it provides important guidance for obstetricians and pregnant women in decision making.

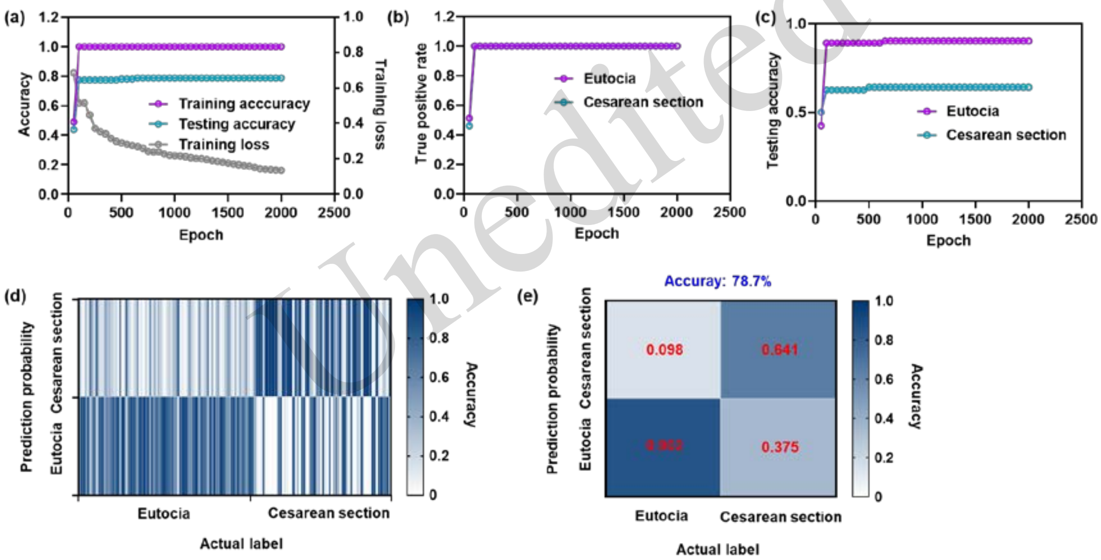

Fig. 6 Performance prediction of preferred delivery mode based on the neural network algorithm. (a) Training set accuracy, testing set accuracy, and training loss of the neural network algorithm. (b) True positive rates of the vaginal delivery and cesarean section sample sets in the neural network training set. (c) Identification accuracy of vaginal delivery samples 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.

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 (ACOG, 2020; Impey LWM, 2017). 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; Lopez-Perez et al., 2020; Olson Koutrouvelis, 2019). Therefore, the precise prediction of ECV outcomes is critical in the decision-making process.

In this study, we compared the demographic characteristics, pre-operative 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 pre-operative 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 (Londero et al., 2023; Svensson et al., 2021) 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 (Boujenah et al., 2017; Magro-Malosso et al., 2016). 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 manoeuvers and restrict fetal rotation, thereby increasing the risk of ECV failure. The thickness of the maternal abdominal wall was assessed by pre-operative 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, existing 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 ($\geqslant$ 20 procedures) were chosen to participate in this study.

Thus far, several studies have been dedicated to the prediction of ECV outcomes. Velzel and colleagues 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 (Velzel et al., 2015). In 2019, Isakov and colleagues 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 (Isakov et al., 2019). Later, in 2021, a prediction model constructed was based on BMI, parity, placental location, and fetal malpresentation, with the area under the receiver operating characteristic (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 version both reached 100%, demonstrating excellent performance. The overall accuracy was 82.5% for predicting ECV outcomes. Instead of outputting the predicted outcome alone, this algorithm output exact prediction 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 predictive 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, maternal comorbidities, etc., 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. Firstly, 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. Secondly, as the study was conducted in a single center, this to some extent influenced the application of the results to general populations. Thirdly, 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 have formulated a prediction model that employs a neural network algorithm to estimate the success or failure of ECV. This model has 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 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 author on reasonable request.

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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 read and approved the final manuscript and, therefore, had 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 conflict of interest.

All procedures followed were in accordance with the ethical principles of the Declaration of Helsinki and received approval from the Institutional Review Board of the Tenth Affiliated Hospital, Southern Medical University (KYKT2024-010). Written consent was waived for the retrospective nature.

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Supplementary information

Table S1 Results of binary logistic regression model

Factors	B	Standard Error	Wald	Degrees of Freedom	Significance	Odds Ratio (OR), Exp(B)	95% Confidence Interval for Exp(B)	
							upper limit	lower limit
Gravidity	-0.223	0.137	2.632	1	0.105	0.8	0.612	1.047
Parity	0.947	0.302	9.826	1	0.002	2.577	1.426	4.658
Systolic pressure	-0.026	0.015	3.116	1	0.078	0.974	0.947	1.003
Myoma	-2.152	0.88	5.981	1	0.014	0.116	0.021	0.652
AFI	0.015	0.007	4.23	1	0.040	1.015	1.001	1.029
Thickness of maternal abdominal wall at 3 o'clock	-0.057	0.045	1.641	1	0.200	0.944	0.865	1.031
Thickness of maternal abdominal wall at 6 o'clock	-0.028	0.063	0.2	1	0.654	0.972	0.86	1.099
Thickness of maternal abdominal wall at 9 o'clock	-0.011	0.05	0.052	1	0.819	0.989	0.897	1.09
AFI on ECV day	0	0.007	0.001	1	0.977	1	0.987	1.014
use of anesthesia	-1.806	0.471	14.72	1	0.000	0.164	0.065	0.413

ECV, external cephalic version; AFI, amniotic fluid index.

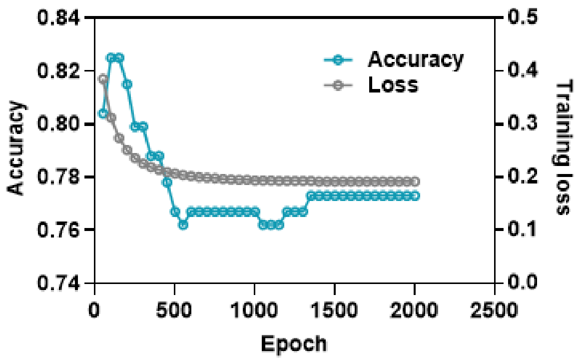

Fig. S1 Predictive accuracy of a logistic regression model for external cephalic version (ECV).

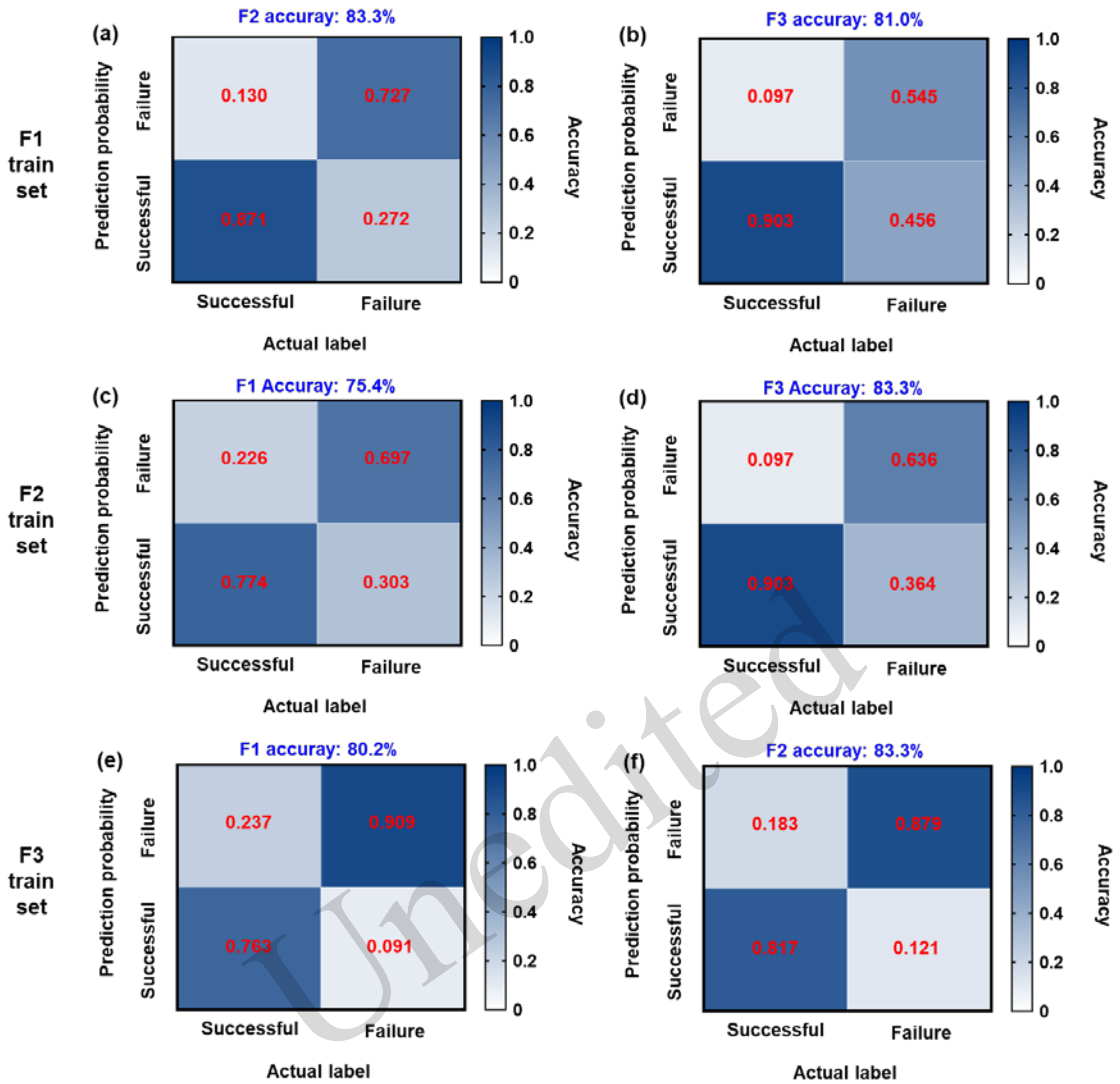

Fig. S2 3-fold cross-validation of the neural network algorithm for the prediction of external cephalic version (ECV). (a) Prediction accuracy when F1 is the training set and F2 is the test set. (b) Prediction accuracy when F1 is the training set and F3 is the test set. (c) Prediction accuracy when F2 is the training set and F1 is the test set. (d) Prediction accuracy when F2 is the training set and F3 is the test set. (e) Prediction accuracy when F3 is the training set and F1 is the test set. (f) Prediction accuracy when F3 is the training set and F2 is the test set.

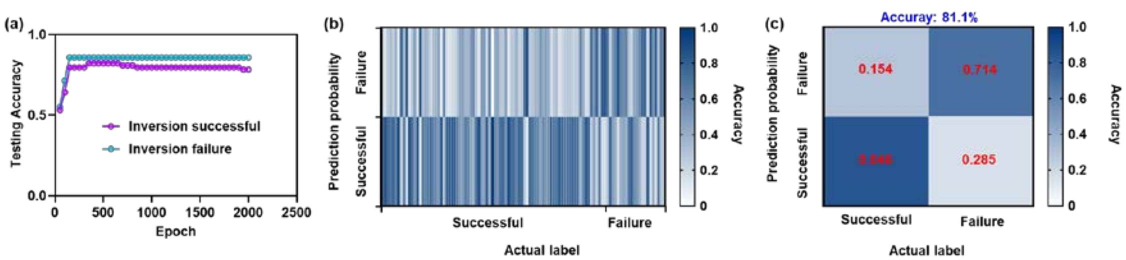

Fig. S3 External data verification performance of external cephalic version (ECV) prediction program based on neural network algorithms. A. The recognition accuracy of successful and failed ECV samples in the external data set. B. The predicted probability distribution output by the neural network algorithm. C. Recognition accuracy of the neural network after 2000 iterations.

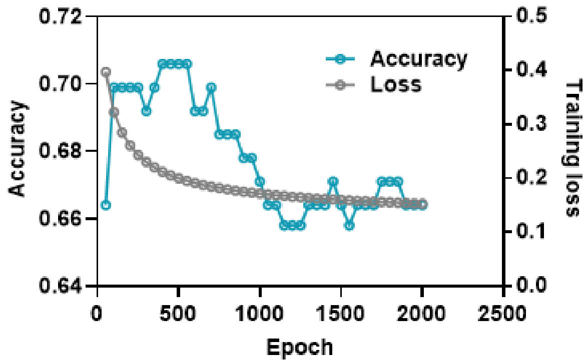

Fig. S4 Predictive accuracy of a logistic regression model for preferred delivery mode.

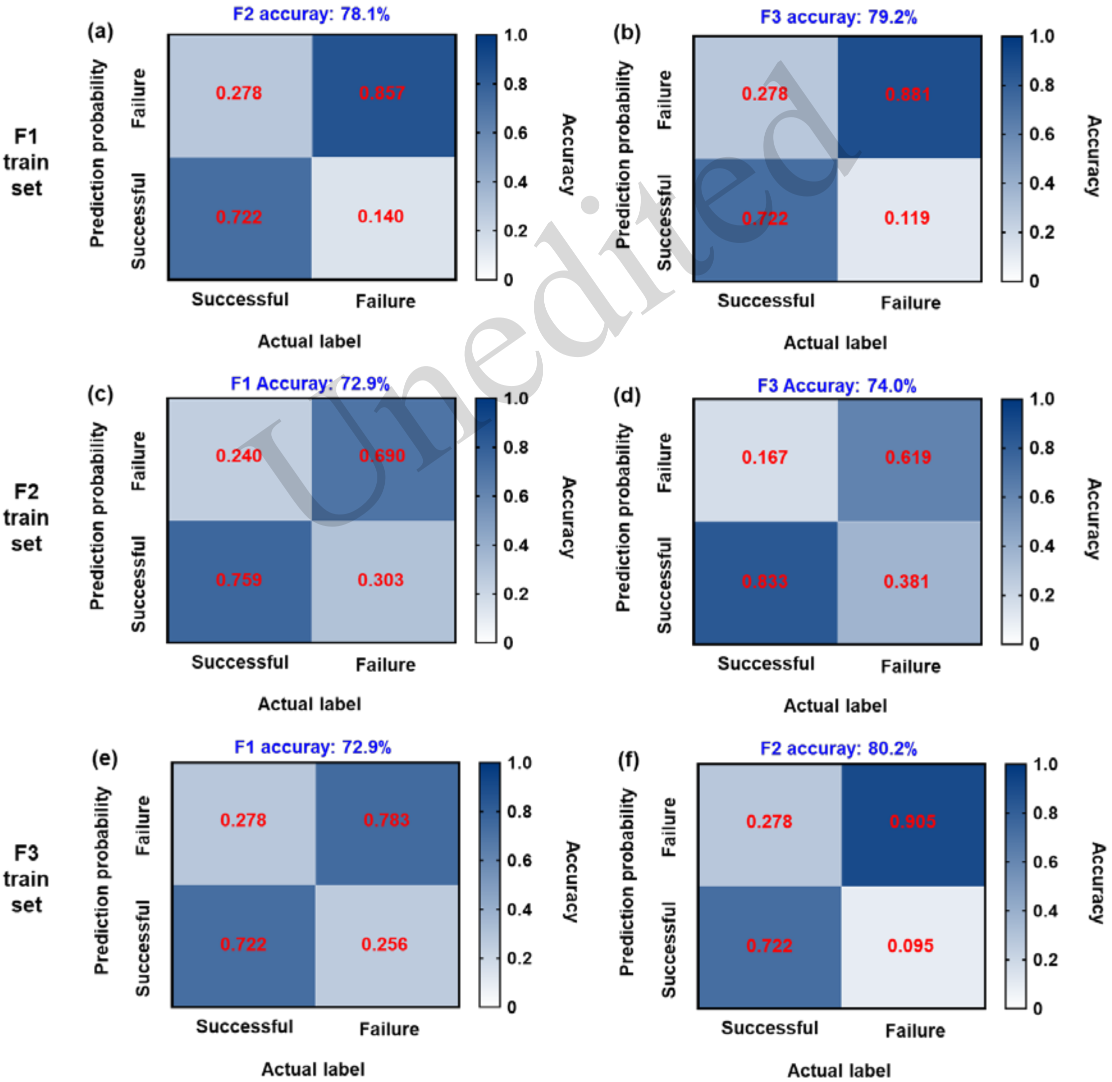

Fig. S5 3-fold cross-validation of the neural network algorithm for the prediction of delivery mode. (a) Prediction accuracy when F1 is the training set and F2 is the test set. (b) Prediction accuracy when F1 is the training set and F3 is the test set. (c) Prediction accuracy when F2 is the training set and F1 is the test

set. (d) Prediction accuracy when F2 is the training set and F3 is the test set. (e) Prediction accuracy when F3 is the training set and F1 is the test set. (f) Prediction accuracy when F3 is the training set and F2 is the test set.

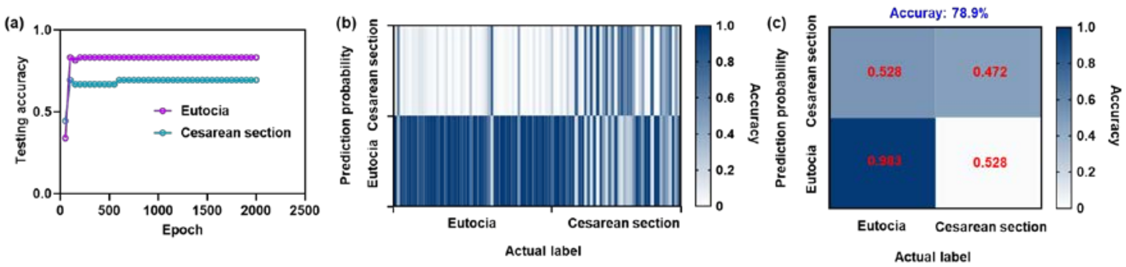

Fig. S6 External data verification performance of delivery mode prediction program based on neural network algorithms. A. Identification accuracy of vaginal delivery samples and cesarean section samples in the external data set. B. Predicted probability distribution output by the neural network algorithm. C. Recognition accuracy of the neural network after 2000 iterations.