INTRODUCTION

Annually, around 1 million neonates worldwide die because of birth asphyxia [1]. According to the World Health Organization guideline on basic newborn resuscitation, although around one-fourth of neonatal mortality is due to birth asphyxia, effective cardiopulmonary resuscitation (CPR) at the moment of childbirth can prevent a large proportion approximately 30% of these deaths [2,3]. Most neonates enter from intrauterine to extrauterine life with no special assistance. However, less than 1% of all neonates [4] and around 0.1% of term neonates require advanced CPR at the moment of birth [5,6]. These statistics are much higher for preterm
infants; 6%–7% of preterm neonates (gestational age [GA] <32 weeks) [7] and around 6%–10% of very low birth weight and extremely low birth weight infants require advanced CPR, i.e., chest compression with or without injecting epinephrine [8]. Many studies have been performed on CPR consequences, and mortality, neurological morbidity, neurodevelopmental impairment, lower motor scores, and retinopathy of prematurity (ROP) are more prevalent among preterm infants who have received CPR [7,9,10]. Thus, timely identification and rapid CPR of neonates in the delivery room can reduce neonatal mortality and morbidity [8].

Currently, at-birth CPR is suggested for neonates with asystole, profound bradycardia (heart rate <60 per minutes), and pulseless electrical activity despite effective ventilation. Absence of heart beat or other vital signs, which is recorded as zero APGAR (Appearance, Pulse, Grimace, Activity, Respiration), can also be used as a guideline for decision-making on beginning CPR [9]. Different studies have shown that the severity scoring systems have many limitations, and systems based on Machine Learning (ML) have better performance in prediction [11,12]. Accordingly, considering the importance of at-birth CPR, use of ML-based systems can be useful for anticipating the need for neonatal CPR. Application of ML algorithms in medicine, especially in neonatal medicine, has shown that these techniques have suitable performance in prediction and diagnosis.

Nevertheless, only a few studies have dealt with CPR in neonates, and most of these have a small set of samples and risk factors because of the challenges in data collection [13-17]. The aim of most studies is to identify the risk factors affecting the need for at-birth CPR [13,14,18-20]. Further, most studies have dealt with neonatal CPR in the Neonatal intensive care unit (NICU), although few of them have addressed at-birth CPR, due to examine at birth CPR, only antepartum factors should be considered. To the best of our knowledge, this is the first study on predicting the need for at-birth CPR in neonates using ML algorithms and considering a comprehensive set of maternal and prenatal risk factors. Accordingly, our aim is to design an ML-based clinical decision support system (CDSS) to predict the need for at-birth CPR in neonates based on maternal and fetal factors.

**MATERIALS AND METHODS**

This retrospective study was conducted based on maternal, prenatal, and fetal data, with the aim of predicting the need for at-birth general/basic/advanced CPR in neonates. To develop the prediction model, ML algorithms were used. Also, the models were evaluated to examine the performance and determine the best model. Details related to the data, setting, method of development, and evaluation of the prediction models are presented in this section. All participants’ parents provided written consent before loading the data into the registry.

**Data Source**

The data were obtained through a neonatal registry system in Valiasr Hospital affiliated to Tehran University of Medical Sciences (TUMS) includes the information related to all neonates hospitalized in the NICU of Valiasr Hospital that has a grade of B3. The data related to the mother and fetus are entered into the registry by the person in charge. In this retrospective study, the data available in this registry were retrieved anonymously from March 2016 to March 2020. Consent forms were filled out by the father or mother of the infant before entering the data into the registry. Participant data were considered confidential, and no extra cost was imposed on our participants. The study was approved by the TUMS institutional review board (approval ID: IR.TUMS.VCR.REC.1398.591).

**Identification of Neonatal CPR Risk Factors**

Risk factors are identified according to the sixth edition of the *Textbook of neonatal resuscitation* [21] and the International Liaison Committee on Resuscitation (ILCOR) guidelines [22]. Three neonatologists were asked to review the list of risk factors and add any factors not listed. Infertility information, sex, and delivery order of any appropriate infant in multiple gestation were added. According to experts’ opinions, some variables (such as fetal problems and maternal chronic disease) were divided into smaller and more specialized subclasses. However, several identified risk factors were not recorded in the neonatal registry of Valiasr Hospital and were excluded. Figure 1 shows the process of risk factor identification.

**KEY MESSAGES**

- In the delivery room, timely neonatal cardiopulmonary resuscitation (CPR) could significantly reduce mortality and other neurological disabilities.
- Use of Machine Learning-based systems for predicting the need for at-birth CPR can be useful.
**Inclusion and Exclusion Criteria**

All neonates hospitalized in the NICU from March 2016 to March 2020 were included in this study. Post-delivery data such as APGAR score, height, and weight of the neonate were excluded.

**Definition**

In this study, delivery room CPR and CPR immediately after birth were examined. CPR refers to any activity performed to simulate the cardiorespiratory activity of neonates who met the conditions of CPR according to the American Academy of Pediatrics (AAP) guidelines [23,24]. These activities can be categorized into two groups: basic CPR (use of oxygen mask, nasal continuous positive airway pressure (CPAP), and positive pressure ventilation (PPV)) and advanced CPR (basic CPR plus epinephrine injection, chest compression, and intubation) [25]. In this study, basic, advanced, and general CPR were considered separately. The neonatal CPR protocol used in Iran is the newest version of the neonatal resuscitation program (NRP) developed by the AAP and the American Heart Association in 2020 [26]. Currently, the Ministry of Health is in charge of issuing NRP certificates. In our NICU, CPR procedures are performed by neonatologists, pediatric residents (second-year residents onwards), or neonatology fellows with NRP certification.

Steroid administration is considered the use of any type of fluorinated corticosteroid. Chorioamnionitis is defined by a maternal inflammatory response with neutrophilic infiltration of the chorionic plate or membranes with or without fetal inflammatory response [27]. Prenatal care adequacy is defined on the basis of the Kotelchuck Index [28]. Levels of “inadequate” and “intermediate” are considered as “no” outcomes, and “adequate” and “adequate plus” levels as “yes” results in the dataset used in this study.

**Data Extraction and Preprocessing**

After removing all identifiers, the data were extracted from the registry as a .sav file and classified into one of six groups: (1) Gestational risk factors: prenatal care, chorioamnionitis, steroid administration, and magnesium sulfate administration; (2) Maternal risk factors: age, hypertension (chronic, gestational, eclampsia), diabetes (chronic, gestational), addiction, human immunodeficiency virus (HIV), chronic disease history, history of abortion (less than 20 weeks), and intrauterine fetal death; (3) Female infertility: use of assisted reproductive techniques (ART), type of ART; (4) Accreta status: decollement/placenta abruption, vasa previa, previa, placenta accreta; (5) Fetal data: gender, GA, rank, and number of infants; intrauterine growth restriction; congenital problems diagnosed before birth; fetal hydrops; (6) Delivery risk factors: mode of delivery, prelabor rupture of membranes (PRoM), duration of PRoM, presentation, cord status, thick meconium, amniotic fluid status, and fetal heart rate during delivery.

The outcome variable is whether CPR is performed for a baby in the delivery room. The general, basic, and advanced resuscitation levels are considered separately as outcomes. The data set contained approximately 7% missing values, which were imputed by the multiple imputation method.
Prediction Model Construction
When a study is associated with a large number of interdependent factors and there is a need to categorize records into two classes, one of the simplest and most effective methods is the binary classifier [29]. Therefore, to develop the prediction model for the need for at-birth general/basic/advanced CPR, ML algorithms of J48, multilayer perceptron, support vector machine (SVM), Naïve Bayesian (NB) and random forest were used. All algorithms were performed with the original data set. Next, Feature Selection (FS) techniques were used to determine the importance of each attribute in predicting type of CPR. As a result, only relevant attributes were involved in the data mining process, which improved predictive accuracy and reduced processing time. For this purpose, filter FS algorithms including relief and correlation-based feature selection (CFS) and wrapper methods using classifiers SVM, J48, and NB were used (Table 1). These methods consider feature dependencies as well as predictive ability of attributes. As a result, feature subsets with less inter-correlation but high correlation to the outcome are preferred [30-33]. Then, the risk factors were organized based on the total importance resulting from implementing the five FS algorithms. Based on the ordered list of variables, various data subsets were created, and ML algorithms were implemented on both the original data set and these data subsets.

Statistical Analysis and Performance Measurements
For continuous data, mean, range, and standard deviation were reported, while frequency and percentage were reported for discrete data. To investigate the distribution of variables in the two groups (neonates receiving CPR vs. those not receiving CPR), independent samples t-test, chi-square, Fisher exact, and Mann-Whitney tests were used. The significance levels for all tests were set at P<0.05. All statistical analyses were performed using IBM SPSS ver. 20.0 (IBM Corp., Armonk, NY, USA). After analyzing the role of risk factors in predicting the outcome and developing the prediction models for need for at-birth general/basic/advanced CPR, the performance of the developed models was evaluated based on accuracy, precision, sensitivity, specificity, and F-measure criteria as well as the 10-fold cross validation method. The role of variables was analyzed using the FS algorithms in WEKA software. Development and assessment of models were performed using R v3.4.1 (R Foundation, Vienna, Austria).

Clinical Decision Support System Design
After selecting the best algorithm for predicting the need for delivery room CPR in neonates, the system user interface was designed based on the best prediction model for the need for at-birth CPR in Visual Studio platform 2015.

RESULTS
A total of 3,882 infants with an average birth weight of 2,500.81 g (standard deviation [SD], 889.107 g; range, 400–5,250 g) was included in the study according to the inclusion/exclusion criteria (Figure 2). Of these, 2,011 (51.8%) received delivery room CPR. Overall, 1,909 infants (49.18%) received basic CPR, and 510 (13.14%) received advanced CPR. The frequency of

Table 1. Characteristics of FS methods

| Type of FS method | Evaluation algorithm | Weka class name | Parameters tuning |
|-------------------|----------------------|-----------------|------------------|
| Filter            | Attribute evaluation using relief | ReliefFAttributeEval |                  |
|                   | Correlation-based feature selection evaluation | CfsSubsetEval |                  |
| Wrapper           | Subset evaluation by using a user-specified classifier and separate held-out test set | ClassifierSubsetEval | Classifier=SVM  |
|                   | Subset evaluation by using a user-specified classifier and internal cross-validation | WrapperSubsetEval-weka.classifiers.trees.J48 | Classifier=J48  |
|                   | Subset evaluation by using a user-specified classifier and internal cross-validation | WrapperSubsetEval-weka.classifiers.bayes.NaiveBayes | Classifier=NB   |

FS: feature selection; SVM: support vector machine; NB: Naïve Bayesian.
CPR types was as follows: nasal CPAP (n=1,120, p=28.8%), PPV (n=891, p=22.9%), oxygen mask (n=723, p=18.6%), intubation (n=494, p=12.7%), chest compression (n=86, p=2.2%), and epi-nephrine injection (n=68, p=1.7%). Data are shown in Table 2.

To develop a prediction model for need for at-birth general/basic/advanced CPR, ML algorithms were used. The results obtained from applying these algorithms to the original data set are shown in Figure 3. Based on all performance criteria, the SVM method demonstrated the best performance for predicting the need for at-birth general and basic CPR (Figure 3A and B). The J48 method demonstrated comparable results. As in Figure 3C, the performance of the J48 technique was better than that of the other models in predicting advanced CPR. However, the NB method had the highest specificity.

In the next step of simulation, FS algorithms were employed. For this, the two filter FS algorithms of relief and CFS were implemented with the three wrapper methods of SVM, J48, and NB. Then, for each risk factor, the total importance resulting from implementing the five FS algorithms was calculated. The rank resulting from the FS algorithms as well as the average rank for each attribute in predicting the types of CPR are presented in Table 3. The average rank was calculated using the following relation, where \( r_i \) represents the rank of variable in the \( i \)th feature selection algorithm.

Average rank: \( \frac{r_1 + r_2 + \ldots + r_5}{5} \)

According to Table 3, GA is the most important risk factor for predicting all types of CPR. Also, the average ranks of "maternal kidney disease," "thyroid disorders," and "decollement/placenta abruption" were lowest in predicting general, basic, and advanced CPR, respectively. For each type of resuscitation, the variables were sorted based on average rank, and then 20 feature subsets were created, including 1, 2, ..., 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, and 60 important variables, respectively. In other words, the first group included the most important feature, the second one included the two most important features and so on. According to these subsets, 20 data subsets were created, and ML algorithms were implemented on these data subsets. Each time, one type of CPR was considered as the outcome. Figures 4 and 5 reveal the results of the ML algorithms with the 20 data subsets obtained from FS.

According to Figures 4 and 5, J48 using the four first important variables with an accuracy of 90.89% and an F-measure of 90.9% produced the best results. GA, delivery type, presentation, and maternal addiction were the most important features in general CPR prediction. J48 also achieved the best results in predicting basic CPR on the basis of the 10 most significant variables: GA, delivery type, prenatal care, decollement, addiction, amniotic fluid, other chronic diseases, macrosomia, infant rank, and fetal hydrops. To predict the need for advanced CPR, J48 achieved the best accuracy of 90.97% using the six most important variables: GA, infertility, gestational diabetes, kidney diseases, HIV, and PRoM. However, according to F-measure, the NB method with the three variables of GA, infertility, and gestational diabetes had the best performance. Given that only 510 infants received advanced resuscitation, the data subsets were unbalanced. Therefore, the SVM method can categorize all items in the majority group (non-CPR), and the value of the F-measure could not be calculated (Figure 5C).

The best results of every algorithm are shown in Table 4. Comparing the results shown in Figure 3 and Table 4, we found that use of the FS algorithms in general CPR prediction caused 4.88% increased accuracy and 5.12% increased F-measure on average. Further, the use of the FS method in basic and advanced CPR prediction models increased mean accuracy by 3.05% and 3.34%, respectively, and mean F-measure by 1.49% and 1.26%.

Graphical user interface of the proposed CDSS for CPR prediction was designed in Visual Studio 2015, based on the three best models which were developed on the basis of J48 (Figure 6). After entering the data, all three prediction models (general/basic/advanced CPR prediction models) were executed, and the final output was calculated by OR combination of the output of each model.

**DISCUSSION**

This paper dealt with a prediction system for the need for neonatal CPR immediately after birth in the delivery room. To achieve a system with proper performance, various ML algorithms were compared with different sets of risk factors to identify the best system and the most effective factors for predicting type of CPR. According to the obtained results, to predict the need for at-birth CPR in general, SVM using all risk factors reached an accuracy of 88.43% and an F-measure of 88.4%, while J48 using the first four most important variables reached an accuracy of 90.89% and an F-measure of 90.9%. For basic CPR prediction, the highest accuracy and F-measure were achieved for the SVM model at 87.64% and 87.4%, respectively. After applying the FS methods and selecting the 10 most important features, the best fit model was J48, with an accuracy of 88.92% and an F-measure of 88.9%. Among the
Table 2. Descriptive statistics of risk factors

| Variable                              | Total (n=3,882) | CPR (n=2,011) | Non-CPR (n=1,871) | P-value (CPR vs. non-CPR group) |
|---------------------------------------|-----------------|---------------|-------------------|---------------------------------|
| **Gestational risk factor**           |                 |               |                   |                                 |
| Prenatal care                         | 3,426 (88.25)   | 1,837         | 1,589             | <0.001                          |
| Chorioamnionitis                      | 71 (1.83)       | 37            | 34                | 0.958                           |
| Steroid administration                | 933 (24.03)     | 647           | 286               | <0.001                          |
| Magnesium sulfate administration      | 333 (8.58)      | 238           | 95                | <0.001                          |
| **Maternal risk factor**              |                 |               |                   |                                 |
| Hypertension                          | 184 (4.74)      | 113           | 71                | 0.008                           |
| Gestational hypertension              | 654 (16.85)     | 379           | 275               | 0.001                           |
| Diabetes                              | 105 (2.71)      | 53            | 52                | 0.783                           |
| Gestational diabetes                  | 600 (15.46)     | 317           | 283               | 0.583                           |
| Mother addiction                      | 63 (1.62)       | 22            | 41                | 0.007                           |
| Mother HIV                            | 28 (0.72)       | 14            | 14                | 0.848                           |
| Cardiac disease                       | 304 (7.83)      | 142           | 162               | 0.064                           |
| Blood disease                         | 187 (4.82)      | 98            | 89                | 0.866                           |
| Kidney disease                        | 63 (1.62)       | 33            | 30                | 0.926                           |
| Thyroid disorders                     |                 |               |                   | 0.274                           |
| Hyperthyroidism                       | 15 (0.39)       | 8             | 7                 |                                 |
| Hypothyroidism                        | 694 (17.88)     | 344           | 350               |                                 |
| Thyroidectomy                         | 2 (0.05)        | 0             | 2                 |                                 |
| Respiratory disease                   | 28 (0.72)       | 15            | 13                | 0.851                           |
| Mental disease                        | 21 (0.54)       | 11            | 10                | 0.958                           |
| Infectious disease                    | 16 (0.41)       | 8             | 8                 | 0.885                           |
| Brain diseases                        | 62 (1.6)        | 37            | 25                | 0.211                           |
| Cancer disease                        | 33 (0.85)       | 19            | 14                | 0.505                           |
| Skin disease                          | 7 (0.18)        | 3             | 4                 | 0.635                           |
| Liver disease                         | 63 (1.62)       | 32            | 31                | 0.872                           |
| Autoimmune disease                    | 64 (1.65)       | 32            | 32                | 0.771                           |
| Uterus disease                        | 41 (1.06)       | 23            | 18                | 0.580                           |
| Digestive disease                     | 34 (0.88)       | 15            | 19                | 0.368                           |
| Eye disease                           | 4 (0.10)        | 2             | 2                 | 0.942                           |
| Other chronic disease                 | 12 (0.31)       | 9             | 3                 | 0.107                           |
| **Pre-eclampsia**                     |                 |               |                   | 0.192                           |
| Eclampsia                             | 8 (0.21)        | 4             | 4                 |                                 |
| Preeclampsia                          | 198 (5.10)      | 115           | 83                |                                 |
| Abortion history                      | 17 (0.44)       | 9             | 8                 | 0.925                           |
| Intrauterine fetal death Infertility  | 10 (0.26)       | 3             | 7                 | 0.167                           |
| Female infertility                    | 214 (5.51)      | 146           | 68                | <0.001                          |
| ART                                   | 144 (3.71)      | 94            | 50                | 0.001                           |
| Drug                                  | 26 (0.67)       | 23            | 3                 | <0.001                          |
| IUI                                   | 18 (0.46)       | 9             | 9                 |                                 |
| IVF                                   | 100 (2.58)      | 62            | 38                |                                 |
| **Accreta status**                    |                 |               |                   |                                 |
| Decollement/placenta abruption        | 41 (1.06)       | 28            | 13                | 0.034                           |
| Vasa previa                           | 1 (0.03)        | 1             | 0                 | 0.335                           |
| Previa                                | 113 (2.91)      | 62            | 51                | 0.508                           |
| Placenta accreta                      | 163 (4.2)       | 94            | 69                | 0.126                           |
| **Fetal data**                        |                 |               |                   |                                 |
| Number of infants                     |                 |               |                   | <0.001                          |
| 1                                     | 3,407 (87.76)   | 1,678         | 1,729             |                                 |
| 2                                     | 419 (10.79)     | 293           | 126               |                                 |
| 3                                     | 55 (1.42)       | 39            | 16                |                                 |
| 4                                     | 1 (0.03)        | 1             | 0                 |                                 |
| Sex                                   |                 |               |                   | 0.396                           |
| Female                                | 1,730 (44.57)   | 881           | 849               |                                 |

(Continued to the next page)
Table 2. Continued

| Variable                                      | Total (n=3,882) | CPR (n=2,011) | Non-CPR (n=1,871) | P-value (CPR vs. non-CPR group) |
|-----------------------------------------------|-----------------|---------------|-------------------|---------------------------------|
| Male                                          | 2,146 (55.28)   | 1,128         | 1,018             | <0.001                          |
| Ambiguous genitalia                          | 6 (0.15)        | 2             | 4                 |                                 |
| Rank of infant                                |                 |               |                   |                                 |
| 1                                             | 3,628 (93.46)   | 1,838         | 1,790             |                                 |
| 2                                             | 235 (6.05)      | 160           | 75                |                                 |
| 3                                             | 19 (0.49)       | 13            | 6                 |                                 |
| IUGR                                          | 223 (5.75)      | 134           | 89                | 0.011                           |
| Tumor                                         | 14 (0.36)       | 8             | 6                 | 0.689                           |
| Genetic problems/anomaly                      | 18 (0.46)       | 13            | 5                 | 0.082                           |
| Macrosomia                                    | 19 (0.49)       | 3             | 16                | 0.002                           |
| Cardiac problem                               | 31 (0.8)        | 16            | 15                | 0.983                           |
| Surgery (defect of the abdominal)             | 54* (1.39)      | 24            | 30                | 0.276                           |
| Blood problem                                 | 4 (0.10)        | 2             | 2                 | 0.942                           |
| Pulmonary problem                             | 12 (0.31)       | 9             | 3                 | 0.107                           |
| Brain problem                                 | 25 (0.64)       | 13            | 12                | 0.984                           |
| Fetal hydrops                                 | 12 (0.31)       | 10            | 2                 | 0.029                           |
| Other problem (fetus)                         | 6 (0.15)        | 3             | 3                 | 0.930                           |
| Delivery risk factor                          |                 |               |                   |                                 |
| Delivery type                                 |                 |               |                   | <0.001                          |
| Cesarean                                      | 3,617 (93.17)   | 1,923         | 1,694             |                                 |
| Vaginal                                       | 265 (6.83)      | 88            | 177               |                                 |
| PROm                                          | 549 (14.14)     | 304           | 245               | 0.071                           |
| Presentation                                  |                 |               |                   | 0.073                           |
| Breech                                       | 106 (2.73)      | 42            | 64                |                                 |
| Transverse                                    | 6 (0.15)        | 2             | 4                 |                                 |
| Hand                                          | 1 (0.03)        | 1             | 0                 |                                 |
| Normal                                        | 3,769 (97.09)   | 1,966         | 1,803             |                                 |
| Cord                                          |                 |               |                   | 0.240                           |
| Absent Doppler                                | 27 (0.69)       | 18            | 9                 |                                 |
| Cord prolapse                                 | 4 (0.10)        | 3             | 1                 |                                 |
| Reverse                                       | 1 (0.03)        | 1             | 0                 |                                 |
| No                                            | 3,850 (99.18)   | 1,989         | 1,861             |                                 |
| Thick meconium                                | 24 (0.62)       | 16            | 8                 | 0.144                           |
| Amniotic fluid                                |                 |               |                   | 0.041                           |
| Oligohydramnios                               | 43 (1.11)       | 18            | 25                |                                 |
| Polyhydramnios                                | 26 (0.67)       | 8             | 18                |                                 |
| Normal                                        | 3,813 (98.22)   | 1,985         | 1,828             |                                 |
| Fetal heart condition                         |                 |               |                   | 0.395                           |
| Arrhythmia                                    | 1 (0.03)        | 0             | 1                 |                                 |
| BPP                                           | 2 (0.05)        | 1             | 1                 |                                 |
| Bradycardia                                   | 6 (0.15)        | 5             | 1                 |                                 |
| Tachycardia                                   | 10 (0.26)       | 5             | 5                 |                                 |
| Decreased FHR                                 | 269 (6.93)      | 148           | 121               |                                 |
| Fetal distress                                | 8 (0.21)        | 6             | 2                 |                                 |
| Sinusoidal                                    | 1 (0.03)        | 1             | 0                 |                                 |
| PVC                                           | 1 (0.03)        | 1             | 0                 |                                 |
| No                                            | 3,584 (92.31)   | 1,844         | 1,740             |                                 |

Continuous risk factor

| Variable                                      | Total (n=3,882) | CPR (n=2,011) | Non-CPR (n=1,871) | P-value (CPR vs. non-CPR group) |
|-----------------------------------------------|-----------------|---------------|-------------------|---------------------------------|
| Maternal age (yr)                             | 30.89±5.9       | 30.85±3.81    | 30.94±3.68        | 0.474                           |
| Gestational age (day)                         | 247.1±25.17     | 237.19±26.35  | 257.85±18.38      | <0.001                          |
| PROm (hr)                                     | 0.0 (0.0)       | 0.0 (0.0)     | 0.0 (0.0)         | <0.001                          |

Values are presented as number (%), mean±standard deviation (range), or median (interquartile range).

CPR: cardiopulmonary resuscitation; HIV: human immunodeficiency virus; ART: assisted reproductive technique; IUI: intrauterine insemination; IVF: in vitro fertilization; IUGR: intrauterine growth restriction; PROm: prelabor rupture of membranes; BPP: biophysical profile; FHR: fetal heart rate; PVC: premature ventricular contraction.

*Including colonic atresia, diaphragmatic hernia, duodenal atresia, esophageal atresia, gastrochisis, internal hernia, intestinal atresia, jejunal atresia, omphalocele.
Figure 3. Performance metrics of Machine Learning algorithms for original dataset. (A) At-birth cardiopulmonary resuscitation (CPR) prediction in general, (B) at-birth basic CPR prediction, (C) at-birth advanced CPR prediction. MLP: multilayer perceptron; SVM: support vector machine; RF: random forest; NB: Naïve Bayesian.
Table 3. Rank of attributes based on five feature selection methods

| No. | Variable name          | General CPR | Basic CPR | Advanced CPR |
|-----|------------------------|-------------|-----------|--------------|
|     |                        | Relief      | CFS       | Wrapper (SVM)| Wrapper (J48)| Averaged rank | Relief | CFS       | Wrapper (SVM)| Wrapper (J48)| Averaged rank | Relief | CFS       | Wrapper (SVM)| Wrapper (J48)| Averaged rank |
| 1   | Abortion               | 30          | 43        | 48          | 13          | 10           | 288    | 48          | 48          | 50          | 36          | 19           | 402    | 55          | 45          | 53          | 17           | 11          | 362       |
| 2   | Addiction              | 12          | 12        | 7           | 14          | 19           | 128    | 10          | 16          | 26          | 17          | 20           | 178    | 27          | 53          | 2           | 15           | 24          | 242       |
| 3   | Amniotic fluid        | 17          | 10        | 8           | 42          | 27           | 208    | 15          | 11          | 47          | 18           | 3            | 18.8   | 30          | 24          | 38          | 31           | 31          | 308       |
| 4   | ART name               | 23          | 22        | 49          | 50          | 47           | 382    | 16          | 30          | 13          | 44           | 34           | 27.4   | 18          | 23          | 4           | 55           | 52          | 304       |
| 5   | ART use                | 37          | 59        | 16          | 56          | 30           | 396    | 33          | 59          | 10          | 56           | 26           | 36.8   | 17          | 56          | 6           | 56           | 42          | 354       |
| 6   | Autoimmune             | 60          | 55        | 51          | 35          | 29           | 46    | 59          | 52          | 58          | 40           | 23           | 46.4   | 38          | 39          | 39          | 32           | 48           | 39.4      |
| 7   | Blood diseases        | 18          | 47        | 38          | 36          | 34           | 346    | 57          | 46          | 53          | 19           | 29           | 408    | 23          | 37          | 5           | 8            | 54           | 25.4      |
| 8   | Blood problems        | 43          | 37        | 45          | 22          | 22           | 318    | 46          | 26          | 39          | 26           | 11           | 236    | 48          | 14          | 46          | 16           | 20           | 28.8      |
| 9   | Brain diseases        | 56          | 33        | 12          | 9           | 43           | 306    | 20          | 51          | 49          | 24           | 32           | 35.2   | 28          | 46          | 11          | 28           | 34           | 29.4      |
| 10  | Brain problem         | 46          | 42        | 56          | 23          | 40           | 414    | 42          | 28          | 42          | 7            | 33           | 30.4   | 43          | 26          | 42          | 47           | 36          | 38.8      |
| 11  | Cancer                 | 35          | 38        | 23          | 38          | 49           | 366    | 34          | 41          | 29          | 37           | 53           | 38.8   | 33          | 17          | 30          | 3            | 25           | 21.6      |
| 12  | Cardiac diseases      | 14          | 24        | 11          | 52          | 51           | 304    | 17          | 23          | 25          | 43           | 41           | 29.8   | 4           | 7           | 7            | 53           | 49           | 240       |
| 13  | Cardiac problems      | 36          | 54        | 52          | 24          | 37           | 406    | 35          | 47          | 41          | 28           | 44           | 39    | 41          | 50          | 36          | 30           | 17           | 34.8      |
| 14  | Chorioamnionitis      | 15          | 58        | 53          | 27          | 26           | 35.8  | 12          | 45          | 28          | 9            | 17           | 22.2   | 29          | 10          | 24          | 24           | 35           | 24.4      |
| 15  | Cord                   | 39          | 19        | 28          | 51          | 16           | 306    | 32          | 14          | 18          | 51           | 24           | 27.8   | 35          | 6           | 47          | 37           | 29           | 30.8      |
| 16  | Decollement/placenta  | 27          | 11        | 31          | 4           | 14           | 17.4  | 28          | 21          | 17          | 4            | 14           | 16.8   | 45          | 42          | 60          | 44           | 45           | 47.2      |
| 17  | Delivery type          | 5           | 4         | 4           | 2           | 2            | 3.4    | 3           | 4           | 12          | 2            | 2            | 4.6    | 10          | 44          | 58          | 27           | 51           | 380       |
| 18  | Diabetes               | 55          | 56        | 57          | 15          | 18           | 402    | 18          | 50          | 51          | 16           | 42           | 35.4   | 22          | 51          | 29          | 5            | 53           | 320       |
| 19  | Digestive diseases    | 38          | 41        | 24          | 29          | 33           | 33    | 29          | 36          | 45          | 15           | 30           | 31    | 54          | 43          | 51          | 20           | 19           | 37.4      |
| 20  | Pre-eclampsia         | 54          | 29        | 42          | 16          | 58           | 39.8  | 54          | 34          | 19          | 35           | 57           | 39.8   | 12          | 8           | 50          | 19           | 56           | 280       |
| 21  | Eye diseases          | 33          | 32        | 37          | 12          | 7            | 242    | 38          | 38          | 44          | 21           | 8            | 29.8   | 53          | 16          | 48          | 11           | 6            | 26.8      |
| 22  | FHR                   | 44          | 8         | 54          | 54          | 54           | 428    | 44          | 10          | 23          | 50           | 36           | 32.6   | 11          | 12          | 44          | 29           | 33           | 25.8      |
| 23  | GA                    | 1           | 1         | 1           | 1           | 1            | 1     | 1           | 1           | 1           | 1            | 1             | 1.1    | 1           | 1           | 19          | 1           | 1            | 1.1         | 4.6       |
| 24  | Gestational diabetes  | 7           | 51        | 18          | 44          | 56           | 352    | 7           | 58          | 59          | 32           | 48           | 408    | 2           | 5           | 28          | 35           | 28           | 19.6      |
| 25  | Genetic problems/     | 26          | 36        | 33          | 11          | 25           | 262    | 24          | 20          | 20          | 27           | 35           | 25.2   | 36          | 47          | 34          | 34           | 13           | 32.8      |

(Continued to the next page)
Table 3. Continued

| No. | Variable name                     | General CPR | Basic CPR | Advanced CPR |
|-----|-----------------------------------|-------------|-----------|--------------|
|     |                                  | Relief      | CFS       | Wrapper (SVM) | Wrapper (J48) | Averaged rank | Relief | CFS | Wrapper (SVM) | Wrapper (J48) | Averaged rank | Relief | CFS | Wrapper (SVM) | Wrapper (J48) | Averaged rank |
| 36  | Kidney diseases                   | 52          | 50        | 58          | 39          | 59          | 50        | 498  | 40  | 54          | 56          | 41          | 28          | 438  | 37  | 35          | 8           | 12          | 12          | 208  |
| 37  | Liver diseases                    | 45          | 46        | 59          | 32          | 17          | 39        | 393  | 27  | 33          | 43          | 39          | 25          | 334  | 44  | 29          | 32          | 32          | 40          | 354  |
| 38  | Macrosomia                        | 22          | 18        | 9           | 3           | 24          | 152       | 15   | 19  | 13          | 32          | 3           | 31          | 196  | 39  | 21          | 33          | 4           | 18          | 230  |
| 39  | Magnesium sulfate                 | 3           | 5         | 60          | 55          | 46          | 338       | 21   | 21  | 5           | 4           | 55          | 56          | 282  | 11  | 60          | 33          | 53          | 38          | 39   |
| 40  | Maternal age                      | 21          | 60        | 22          | 53          | 22          | 356       | 11   | 60  | 33          | 53          | 38          | 39          | 282  | 13  | 57          | 56          | 9           | 30          | 330  |
| 41  | Mental diseases                   | 57          | 52        | 43          | 8           | 29          | 378       | 56   | 43  | 40          | 6           | 18          | 326         | 326  | 60  | 32          | 12          | 40          | 3           | 294  |
| 42  | Other chronic diseases (mother)   | 29          | 23        | 32          | 5           | 6           | 19        | 31   | 19  | 24          | 8           | 13          | 19          | 292  | 49  | 19          | 57          | 6           | 15          | 292  |
| 43  | Other problems (fetus)            | 49          | 48        | 47          | 34          | 11          | 378       | 51   | 57  | 46          | 31          | 9           | 388         | 388  | 57  | 25          | 46          | 18          | 10          | 310  |
| 44  | Placenta accreta                  | 51          | 31        | 26          | 28          | 36          | 344       | 58   | 29  | 15          | 30          | 47          | 358         | 358  | 14  | 54          | 49          | 46          | 57          | 440  |
| 45  | Prenatal care                     | 6           | 6         | 3           | 47          | 39          | 202       | 4    | 8   | 8           | 11          | 45          | 152         | 152  | 3   | 15          | 23          | 43          | 46          | 260  |
| 46  | Presentation                      | 10          | 7         | 6           | 17          | 8           | 96        | 6    | 9   | 52          | 42          | 4           | 226         | 226  | 20  | 9           | 41          | 25          | 41          | 272  |
| 47  | Previa                            | 25          | 53        | 39          | 45          | 32          | 388       | 26   | 56  | 31          | 46          | 50          | 418         | 418  | 24  | 41          | 54          | 48          | 50          | 434  |
| 48  | PfoM (hr)                         | 24          | 57        | 20          | 49          | 52          | 404       | 23   | 55  | 14          | 45          | 54          | 382         | 382  | 5   | 55          | 17          | 7           | 23          | 214  |
| 49  | PfoM (hr)                         | 50          | 9         | 30          | 60          | 44          | 386       | 45   | 7   | 16          | 60          | 40          | 336         | 336  | 52  | 60          | 16          | 54          | 4           | 372  |
| 50  | Pulmonary problems                | 34          | 26        | 35          | 31          | 35          | 322       | 39   | 27  | 22          | 29          | 43          | 32          | 32   | 42  | 40          | 43          | 42          | 26          | 386  |
| 51  | Respiratory diseases              | 42          | 44        | 41          | 21          | 41          | 378       | 52   | 44  | 48          | 23          | 39          | 412         | 412  | 40  | 20          | 14          | 36          | 14          | 248  |
| 52  | Sex                               | 4           | 28        | 46          | 43          | 55          | 352       | 8    | 31  | 60          | 33          | 59          | 382         | 382  | 6   | 30          | 20          | 39          | 43          | 276  |
| 53  | Skin diseases                     | 53          | 49        | 36          | 25          | 3           | 332       | 53   | 53  | 35          | 34          | 6           | 362         | 362  | 59  | 48          | 31          | 10          | 5           | 306  |
| 54  | Steroids administration           | 2           | 2         | 2           | 46          | 60          | 224       | 2    | 2   | 2           | 52          | 55          | 226         | 226  | 8   | 13          | 27          | 57          | 55          | 320  |
| 55  | Surgery                           | 28          | 34        | 13          | 18          | 23          | 232       | 30   | 32  | 38          | 5           | 7           | 224         | 224  | 32  | 4           | 37          | 51          | 39          | 326  |
| 56  | Thick meconium                    | 31          | 25        | 29          | 37          | 21          | 286       | 37   | 40  | 34          | 14          | 16          | 282         | 282  | 47  | 36          | 40          | 46          | 27          | 390  |
| 57  | Thyroid disorders                 | 19          | 20        | 55          | 48          | 53          | 39        | 60   | 18  | 54          | 49          | 60          | 482         | 482  | 9   | 18          | 13          | 50          | 59          | 298  |
| 58  | Tumors                            | 40          | 44        | 44          | 26          | 13          | 326       | 41   | 39  | 55          | 22          | 15          | 344         | 344  | 46  | 34          | 35          | 49          | 16          | 360  |
| 59  | Uterus diseases                   | 59          | 39        | 34          | 33          | 42          | 414       | 43   | 42  | 30          | 25          | 52          | 384         | 384  | 31  | 49          | 52          | 22          | 22          | 352  |
| 60  | Vasa previa                       | 41          | 27        | 27          | 7           | 4           | 212       | 47   | 25  | 36          | 12          | 5           | 25          | 25   | 51  | 27          | 59          | 38          | 9           | 368  |

CPR: cardiopulmonary resuscitation; CFS: correlation-based feature selection; SVM: support vector machine; NB: Naive Bayesian; ART: assisted reproductive techniques; FHR: fetal heart rate; GA: gestational age; HIV: human immunodeficiency virus; IUFD: intrauterine fetal death; IUGR: intrauterine growth restriction; PRoM: prelabor rupture of membranes.
Figure 4. Accuracy of Machine Learning algorithms for 20 feature subsets. (A) At-birth cardiopulmonary resuscitation (CPR) prediction in general, (B) at-birth basic CPR prediction, (C) at-birth advanced CPR prediction. MLP: multilayer perceptron; SVM: support vector machine; RF: random forest; NB: Naive Bayesian.
Figure 5. F-measure of Machine Learning algorithms for 20 feature subsets. (A) At-birth cardiopulmonary resuscitation (CPR) prediction in general, (B) at-birth basic CPR prediction, (C) at-birth advanced CPR prediction. MLP: multilayer perceptron; SVM: support vector machine; RF: random forest; NB: Naïve Bayesian.
ML algorithms, the best model to predict advanced CPR was J48, with an accuracy of 90.15% and an F-measure of 87.5%. According to the experiment performed on the six most important features, J48 had the highest accuracy of 90.89%, while NB using the three most significant features achieved the best performance with an F-measure of 88.9%.

Feature ranking was performed using five FS algorithms, and the most effective risk factors were identified for the general/basic/advanced CPR prediction. Among all variables, only GA was significant in all types of CPR prediction models. Delivery type, presentation, and addiction are other important factors in general CPR prediction. Also, the most significant risk factors of basic CPR prediction were GA, delivery type, prenatal care, placental abruption, mother’s addiction, amniotic fluid status, maternal chronic disease history, macrosomia, rank of infant, and fetal hydrops. Moreover, GA, infertility, gestational diabetes, history of kidney disease, HIV, and PRoM were the most important risk factors for predicting the need for ad-
vanced CPR.

According to the sixth edition of the Textbook of neonatal resuscitation [21] and the ILCOR guidelines [22], the risk factors of GA, delivery type, presentation, macrosomia, prenatal care, PRoM, history of kidney disease, multiple gestation, fetal hydrops, amniotic fluid status, diabetes, placental abruption, and maternal chronic disease history all can contribute to an increased need for at-birth CPR in neonates. In a study by Afjeh et al. [18], risk factors affecting CPR in neonates were examined, whereby placental abruption, multiple gestation, delivery type, and infertility were identified as the risk factors that contribute to increasing the need for delivery room CPR. Also, a study by Jiang et al. found that diabetes, hypertension, and delivery type affect the need for CPR in neonates [19].

In our study, HIV was identified as an effective risk factor in predicting advanced CPR. To the best of our knowledge, the association between maternal HIV infection and need for neonatal CPR has not previously been reported. However, many previous studies have shown that maternal HIV infection is associated with small for gestational age, preterm birth, low birth weight, and stillbirth [34-37]. Our results revealed that macrosomia is one of the most important risk factors for predicting the need for basic resuscitation. However, while association between macrosomia and CPR was not found in the literature, previous studies showed that macrosomia is associated with shoulder dystocia, perinatal asphyxia, diabetes or gestational diabetes, and prolonged labor [38,39], factors that all play vital roles in increasing the need for at-birth resuscitation risk.

The prevalence of mortality, neurodevelopmental impairment, respiratory support at 28 days, days to full oral feeds, and length of stay are very high among neonates who have undergone at-birth CPR [9,40]. Even the National Institute of Child Health and Developmental Neonatal Research reported that CPR in the delivery room is a prognostic factor for morbidity and later complications up to 18 months of age [41]. Thus, the healthcare system should be able to better predict which neonates require CPR before delivery, so that the neonatal resuscitation team is present in time [42]. Previous studies have shown that antenatal transfer of high-risk mothers reduces pre-discharge neonatal mortality [43,44]. Thus, predicting the need for at-birth CPR can be very effective, as it increases the preparation of the neonatal resuscitation team and provides the possibility of consultation with the family before delivery [42]. Therefore, according to the results obtained from this study, use of the proposed system for predicting the need for at-birth CPR in neonates will greatly reduce the adverse outcomes in childbirth with more preparation time for the CPR team.

In addition, coordination between the CPR team and obstetricians can lead to reduced adverse events in the delivery room and improve overall care [42]. A study by Draper et al. [45] examined intrapartum deaths in the UK and found that around 25% of mortalities were due to lack of suitable communication between the multidisciplinary team members during delivery. Thus, the proposed system can be used as an infant pre-resuscitation guide to ensure coordination between the CPR team and obstetricians.

Despite the importance of CPR prediction, very few studies have dealt with neonatal CPR, most of which have addressed CPR in the NICU [13-16], which have small numbers of samples and few risk factors because of challenges in data collection [13-17]. However, in this study, in addition to considering a sample of suitable size, attempts were made to capture all fetal and maternal risk factors mentioned in credible guidelines, which also had demonstrated their importance in previous studies.

The main limitation of this study, like most previous studies, was that the data related to only one center were examined. Thus, it is suggested to conduct studies with a more diverse sample extracted from multiple centers with different grades of NICU. Comparison of the results can be useful in identifying significant risk factors affecting the need for CPR and its prediction. Also, the included population was all neonates hospitalized in the NICU, which is a very selective high-risk group of neonates who had a very high incidence of resuscitation. This limited the generalizability of this dataset to the usual situation in the delivery room.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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