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ORIGINAL PAPER / OBSTETRICS

Use of the expanded Apgar score for the assessment of intraventricular and intraparenchymal haemorrhage risk in neonates

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ABSTRACT

Objectives: Preterm birth is a key factor contributing to haemorrhage incidence in neonates. This study focused on defining relevant parameters for the assessment of intraventricular and intraparenchymal haemorrhage risks in neonates.

Material and methods: Chi-square automatic interaction detection was used to analyse the Apgar score (AS), the Apgar max score, and the course of resuscitation documented according to the expanded AS in 696 infants born between 2009 and 2011 in the Neonatal and Intensive Care Department of the Medical University of Warsaw.

Results: Gestational age was the most relevant discriminating variable for the prediction of intraventricular III degree and intraparenchymal haemorrhage incidences. Infants born before the 31st week of pregnancy made up 80% of the intraventricular or intraparenchymal haemorrhage cases. Additionally, a fraction of inspired oxygen > 0.8 at ten minutes after birth was a better discriminating variable in the youngest neonates than an Apgar max score ≤ 5, identifying 31.6% and 20.6% of infants with intraventricular and intraparenchymal haemorrhage, respectively.

Conclusions: Consideration of the oxygen concentration supplied during resuscitation significantly improves the prognosis of intraventricular and intraparenchymal haemorrhages in preemies compared to the use of the classical AS.

Key words: algorithm; Apgar score; CHIAD; IPH; IVH

INTRODUCTION

In 1952, in response to a student who asked her how to estimate the health status of a newborn immediately after birth, Virginia Apgar wrote down five points on a piece of tissue paper. A year later, the Apgar score (AS) was made public, and two years later it was officially published. In 2015, the American Academy of Paediatrics (AAP) and the American College of Obstetricians and Gynaecologists (ACOG) accepted the AS as a reliable and convenient measure of an infant's health status and the reaction to resuscitation, if needed [1, 2].

The AS was never intended to serve as a prognostic tool, and according to the AAP and the ACOG guidelines, it should not be used to predict individual neonatal mortality or neurologic outcome. However, the correlation between the AS and a newborn's further development became of great interest in clinical practice [1–5]. A low AS in the fifth minute after birth has been linked to abnormal development later in life [6, 7]. Numerous studies also indicate an impact of the procedures performed immediately after birth on the incidence of retinopathy of prematurity (ROP), bronchopulmonary dysplasia (BPD), and intraventricular or intraparenchymal haemorrhage (IVH/IPH), particularly in preemies [8–10]. In fact, the immaturity of preemies is the main cause of IVH III and IPH [11, 12]. IVH III and IPH substantially contribute to further complications and neonatal mortality. They are also key causes of developmental disorders of motor, cognitive, and behavioural functions in schoolchildren [12].

Since an infant's condition and further development often depends on medical interventions used to support postnatal transition, a description of these procedures is an important component of an alternative scoring system — the extended Apgar score. The extended AS rates the same five signs as the original AS (heart rate, skin colour, muscle tone, reflex irritability, and respiratory function) but extends the observations and scoring to 10, 15, and 20 minutes after birth (if the 5-minute AS is < 7) [13]. Additionally, the expanded AS allows the resuscitative procedures performed immediately after birth to be recorded, including continuous positive airway pressure, oxygen supplementation bag and mask ventilation, intubation and ventilation, chest compressions, and surfactant and/or epinephrine administration [13].

Objectives

In the present study, using the expanded AS, we investigated if the interventions performed in the labour ward can reliably predict the incidence of early complications in infancy. In particular, we focussed on the incidence of IVH III and IPH in neonates, as they have the highest clinical impact.

MATERIAL AND METHODS

Our single-centre study was based on the medical documentation of 696 infants born between 2009 and 2011 in the Neonatal and Intensive Care Department Medical University of Warsaw, which was sufficient to perform statistical analyses. This group comprised 276 infants (147 boys and 129 girls) born between the 23rd and 31st week of gestational age (GA), 190 infants (100 boys and 90 girls) born between the 32nd and 36th week of GA, and 230 infants (119 boys and 111 girls) born after the 37th week of GA. The study included neonates that required resuscitation in the first minutes after birth (ventilation using a mask ventilator, intubation, oxygen concentration used, cardiac massage, and epinephrine use) and with an AS ≤ 7 in the first minute after birth. The exclusion criteria included an AS > 7, the presence of significant congenital disorders, and a lack of resuscitation interventions. The youngest group ($\leq 31^{st}$ week GA) studied in detail consisted of 109 infants born by vaginal birth and 167 by caesarean section, with an average duration of pregnancy of 27.8 weeks.

The following analysed parameters were used as inputs for the chi-square automatic interaction detection (CHAID) algorithm: i) the AS at 1, 3, 5, 10, and 15 minutes after birth; ii) the maximum value from the AS measured at 1, 3, 5, and 10 minutes after birth (AS max); and iii) the course of resuscitation documented according to the expanded AS (ventilation using a mask ventilator, intubation, oxygen concentration used, cardiac massage, and epinephrine use).

Statistical analysis

The CHAID algorithm, which assures high specificity and sensitivity of the analysis and statistically significant division of the nodes, was used for data analysis (SPSS 15.0). Data were compared using Pearson’s chi-square test with p set at 0.05 (Bonferroni adjusted for multiple comparisons) and a cut-off selected automatically for all the parameters. The algorithm starts with the discretisation of the continuous variables. Next, the variable that best discriminates between decision classes is chosen based on the results of the chi-square test. In this way, the whole set of observations (*i.e.*, root node) is split into subsets (*i.e.*, internal nodes) that are as homogeneous as possible (regarding decision classes), with the branches extending from the root to the nodes describing the rules of division. The internal nodes are then further divided based on the results of the chi-square test. The division continues until nodes containing only one decision class (*i.e.*, leaf nodes) are obtained, the desired depth of the tree is reached, or when the outcome of the next division does not significantly change the structure of the decision classes. Optionally, the decision tree can be trimmed. The branches (rules of division) that do not significantly influence the accuracy to distinguish between decision classes regarding preceding nodes can be shortened.

The branches linking the nodes, going from the top (root) to the bottom (leaves) of the tree, create decision rules in the form of implications: if A and if B and if… and if Z, then the ratio of the decision class (*e.g.*, incidence of IVH) equals X. We aimed to define the relevant parameters affecting IVH III/IPH incidence and to assess the risk of IVH III/IPH based on medical findings and their interactions. Therefore, the classes of our binary variable, namely the presence or lack of IVH III/IPH, were marked as 1 or 0, respectively.

RESULTS

To evaluate the relationship between IVH III/IPH incidence and gestational age, we first prepared a frequency plot (Fig. 1). IVH III cases were observed most frequently in the youngest neonates. Because 80% of IVH III/IPH cases were observed in the infants born before the 31^{st} week of GA, only these neonates were chosen for further analysis.

Artificial intelligence algorithms are currently the tool of choice in medical diagnostics and in decision-making systems. We used one of these modern statistical tools — a CHAID decision tree — to create a clear knowledge system based on decision rules. Next, we constructed a CHAID decision tree. Based on the CHAID algorithm, the expanded AS and a fraction of inspired oxygen (FiO_2) > 0.8 at 10 minutes after birth were chosen as variables with the highest discriminating power. By using these parameters in the analysis, we identified 12 infants with IVH III/IPH in a group of 38 neonates (31.6%) (Fig. 2). When we used the classical AS and an AS max ≤ 5, we identified 13 neonates with IVH III/IPH in a group of 63 infants (20.6%) (Fig. 3).

These results indicate a higher discriminative power of the FiO_2 at 10 minutes after birth (based on the expanded AS) than the AS max. In the key leaf node, the discriminative power of the expanded AS to identify infants with IVH III/IPH was 10% higher than that of the AS max. Additionally, using the expanded AS resulted in a more specific (*i.e.*, smaller) subgroup of neonates (38 vs 63), in which a similar number of IVH III/IPH cases was identified (12 vs 13).

The above analysis was conducted on the group of youngest infants (≤ 31 weeks GA), who experienced IVH III/IPH the most often. In this group, an $FiO_2 > 0.8$ at 10 minutes after birth was a discriminating parameter. Therefore, we decided to investigate this parameter further. We analysed the whole group of infants and added the GA as a new parameter to our decision tree. In this way, the tree reached a depth of two. In the node of ≤ 26 weeks of GA, a new division was generated, creating two subgroups based on the FiO_2 at 10 minutes after birth as a decision parameter: ≤ 0.3 and > 0.3. An $FiO_2 > 0.3$ was a discriminating value in this analysis and identified 29.1% of the group as having experienced IVH III/IPH (Fig. 4). Lastly, using an $FiO_2 \geq 21\%$ as a reference point, we analysed the concentration of oxygen that was given to the infants with IVH III/IPH (Fig. 5). An $FiO_2 > 80\%$ resulted in the highest IVH III/IPH incidence. An $FiO_2 > 30\%$ identified IVH III/IPH cases less precisely, but it included a larger group of infants. Therefore, even though we suggest the FiO_2 as a powerful discriminative parameter, a direct correlation between the oxygen concentration and IVH III/IPH incidence should be evaluated carefully and might require further analysis of, for example, the partial pressures of carbon dioxide (pCO_2) and oxygen (pO_2).

DISCUSSION

The objective evaluation of an infant's health status is important not only for the care the newborn requires but also for scientific research. The need for an unambiguous and comparable record of such an assessment led to the invention of a clear numerical scale. Virginia Apgar was the first to propose a measure of an infant's health status that is quantitative, and therefore applicable in medical research.

To assess the health status of infants born prematurely and those requiring medical interventions, Rudiger et al. [13, 14] suggested a modification of the AS (the specified AS). The modification aimed to relate the AS to the GA, but it was independent of the requirements to achieve the scor. Hence, an infant born full-term or prematurely, who has no problems adapting to extrauterine life or who reacts favourably to resuscitation or other interventions, obtains the maximum specified AS.

The rapid progress observed in the field of neonatology in the last decades, the expanding knowledge base, and technological developments have resulted in increased survival of newborns. This has led to a significantly greater number of medical procedures undertaken immediately after birth. These procedures and their outputs should not be omitted in the health assessment of newborns [13, 15, 16]. Our results confirm the link between the interventions undertaken immediately after birth and the health status later in life. In 2006, the AAP Committee on Foetuses and Newborns and the ACOG Committee on Obstetric Practice proposed an expanded AS to account for these interventions and their effects [2, 16]. This scale contains, along with the classical AS, a listed course of resuscitation procedures. In use since 2008 in the Neonatal and Intensive Care Department of the Medical University of Warsaw, the expanded AS has significantly improved the precision of the documentation of the resuscitation procedures. It has also decreased the subjectivity of the health status evaluation of newborns. Therefore, this score was used in our study.

Further developments in the health assessment of newborns include the combined AS developed by Rudiger and Aguar [14], which merges the specified and expanded AS and assigns numeric values to the descriptive components of the expanded AS. Dalili et al. [17] compared the four types of AS and concluded that only a low score according to the combined AS predicts the incidence of IVH and its neurological complications in infants with perinatal hypoxia. A low combined AS at 5 minutes after birth has been independently linked to IVH incidence. However, it does not indicate the severity of IVH. These results agree with the ACOG and AAP, our results, and other published studies showing the low prognostic value of the classic AS on prospective neurological status or unfavourable health prognosis [18–23].

Our study was based on decision trees, which have several advantages over other decision algorithms. Their simple structure allows for an easy interpretation of the results. They enable the assessment of the importance of the variables and attributes and do not require assumptions regarding the specific distribution of the variables. The missing data do not cause problems in the analysis, and the classification based on decision trees is characterised by high accuracy. Additionally, the possibility of modelling dependencies of nonlinear phenomena and of analysing various sets of variables (nominal, ordinal, and continuous) allows for greater precision and detail in the description of the infants' health status and the undertaken interventions. The decision tree algorithm suited our study goals and setup because we required i) a simple data representation structure, ii) the possibility to analyse various sets of variables (nominal, ordinal, and continuous) with non-normal distribution, and iii) a high-accuracy classification system.

Our CHAID-based analysis shows the importance of the concentration of the oxygen supplied after birth in the prognosis of IVH III/IPH incidence in premature infants. In score-only-based systems this information is lost. The combined AS only considers the presence or absence of oxygen supply. In our analysis, we defined the thresholds for the selection of the groups of newborns for whom the health status prognosis can be made. Nevertheless, this is only a preliminary study that focuses on the prognosis of IVH III and IPH incidence based on an infant's health status after birth. The GA and the birth body weight are the most important risk factors for complications such as IVH, ROP, and BPD. Although these diseases have complex pathogenesis, the states of blood supply and oxygenation of cells and tissues are the key influencing factors [24, 25].

CONCLUSIONS

The concentration of oxygen used during resuscitation is an important factor in the prognosis of IVH III and IPH incidence. In follow-up studies, we plan to define the elements of the expanded AS that facilitate predictions of other early complications in preemies, like ROP and BPD. This information will not only improve the assessment of a newborn's health status but also allow doctors in labour wards to choose the most appropriate and effective interventions.

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Conflict of interests

The authors declare no conflict of interest.

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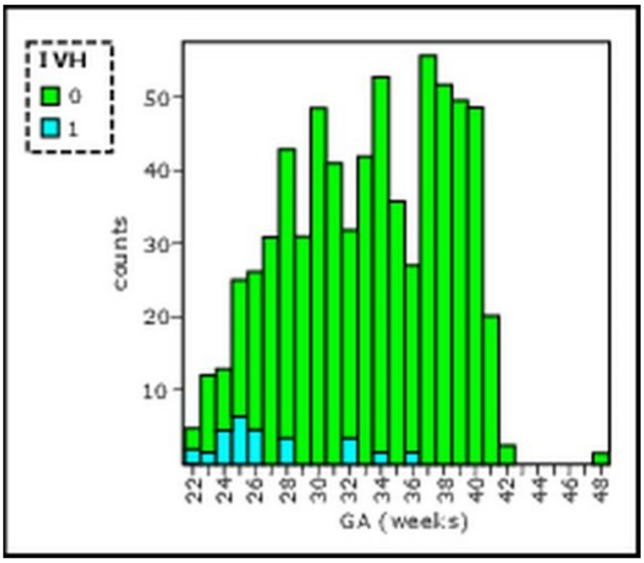

Figure 1. Intraventricular or intraparenchymal haemorrhage (IVH III/IPH) frequency distribution by pregnancy week; The frequency of IVH III/IPH is shown in relation to gestational age (in weeks). For every gestational week, the number of infants with (1, blue) or without (0, red) IVH III/IPH is shown. n = 696

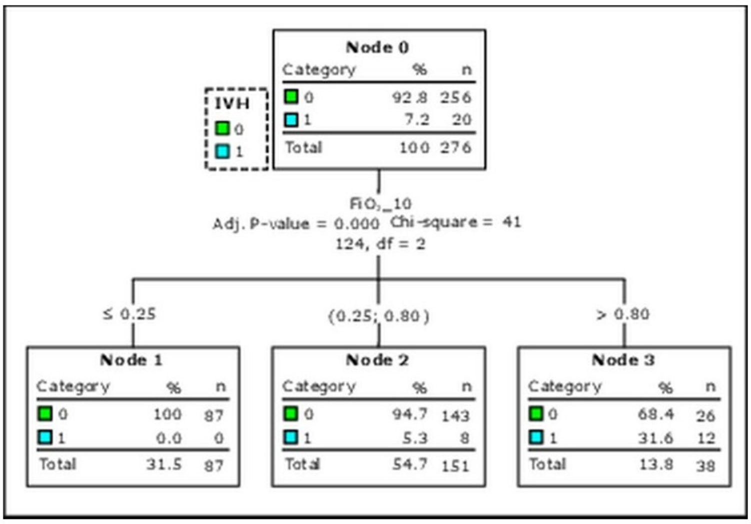

Figure 2. The decision tree based on the expanded Apgar score (fraction of inspired oxygen 10 minutes after birth) for infants ≤ 31st week of gestational age (GA); The group consisting of the youngest infants (≤ 31st week of GA) was split into three subgroups based on the fraction of inspired oxygen (FiO_2) at 10 minutes after birth: ≤ 0.25, 0.25–0.8, and > 0.8. The decision classes referring to the presence or lack of IVH III/IPH were marked as 1 or 0, respectively. n = 276; Pearson's chi-square test with P inset at 0.05 (Bonferroni adjusted for multiple comparisons) was used to assess statistical significance

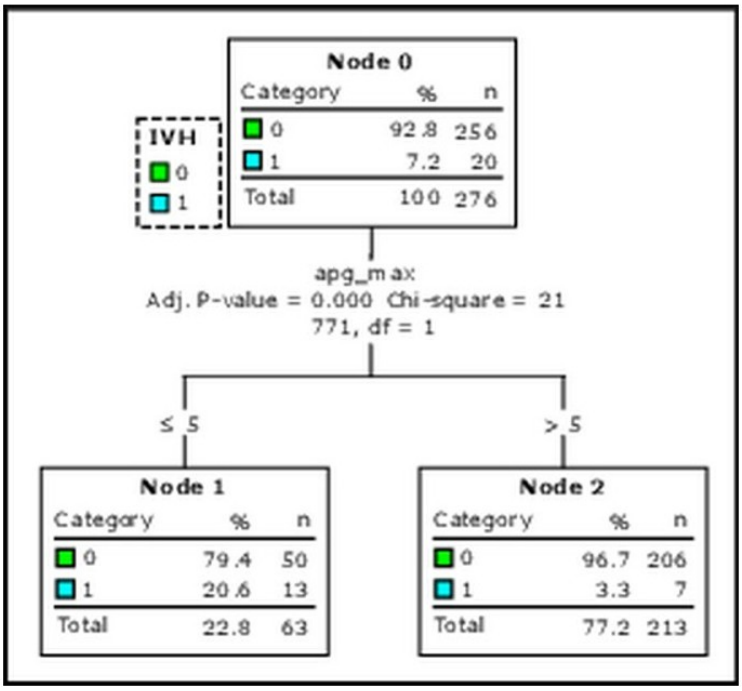

Figure 3. The decision tree based on Apgar max score; The group consisting of the youngest infants (≤ 31st week of GA) was split into two groups based on the Apgar max score (apg_max): ≤ 5 and > 5. The decision classes referring to the presence or lack of IVH III/IPH were marked as 1 or 0, respectively. n = 276; Pearson's chi-square test with p inset at 0.05 (Bonferroni adjusted for multiple comparisons) was used to assess statistical significance

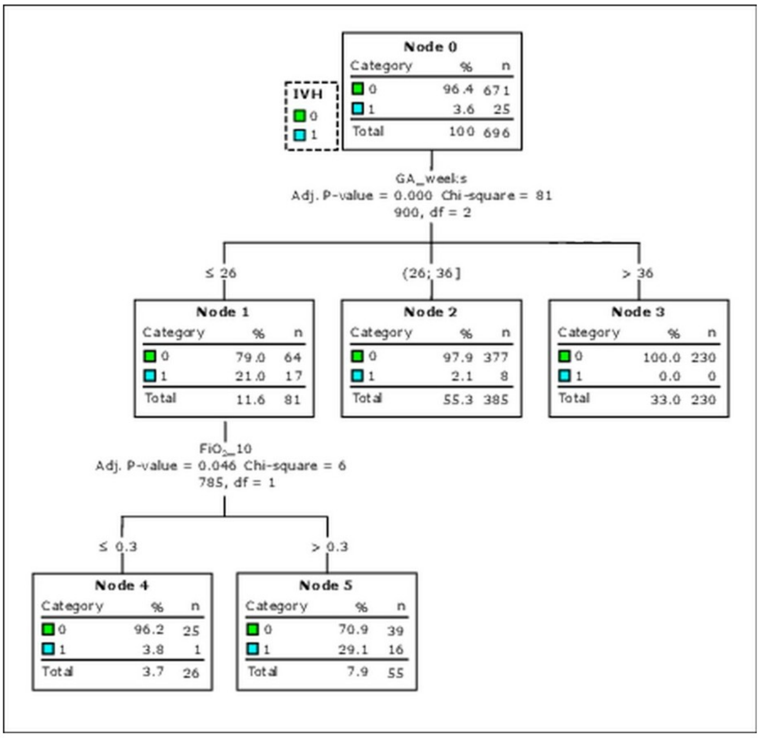

Figure 4. The decision tree relating IVH III/IPH incidence to the gestational age (GA) and the fraction of inspired oxygen (FiO_2) ten minutes after birth; The study group (n = 696) in the root node was split into three subgroups based on GA: ≤ 26th, 26th–36th, and > 36th week of GA. The node ≤ 26th week of GA was further divided into subgroups according to the FiO_2 ten minutes after birth: ≤ 0.3 and > 0.3. The decision classes referring to the presence or lack of IVH III/IPH were marked as 1 or 0, respectively. Pearson's chi-square test with p inset at 0.05 (Bonferroni adjusted for multiple comparisons) was used to assess statistical significance

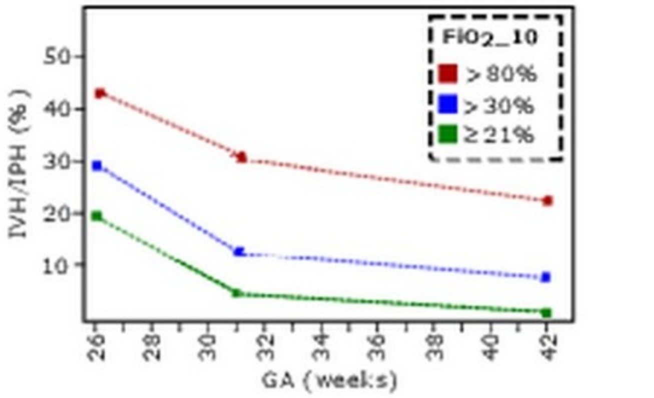

Figure 5. Effect of the fraction of inspired oxygen (FiO_2) ten minutes after birth on IVH III/IPH incidence according to gestational age (GA); The percentages (%) of cumulative IVH III/IPH incidence depending on the FiO_2 ten minutes after birth were plotted against GA: > 80% (marked in red), > 30% (marked in blue), and ≥ 21% (marked in green). Squares indicate data points: GA ≤ 26, GA ≤ 31, and GA ≤ 42. The dashed lines represent estimations of the values. FiO_2 > 80% shows the highest penetration of IVH III/IPH incidence. FiO_2 > 30% identifies IVH III/IPH incidences less precisely but includes a larger group of infants. FiO_2 ≥ 21% was used as a reference point