

Integral Homeostasis Index in a Decision Support System for the Assessment and Prediction of the Clinical Condition of Children with Severe Mechanical Trauma

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Abstract. Objective: Daily assessment of the acid-base balance (ABB) in blood is one of the important elements of multi-parameter patient monitoring at intensive care units (ICUs). The present work aims to determine the effectiveness and validity of the integral homeostasis index IHx calculated from ABB blood test data for the assessment and prognosis of children with critical traumatic conditions. Methods: 345 patients were studied. IHx was calculated and the data were subjected to statistical evaluation. An Arden-Syntax-based clinical decision support (CDS) platform was used. One purpose of the study was to incorporate the platform into the ICU IT landscape of the hospital, and the second purpose was to develop a CDS module for the calculation of IHx and present the results in real time to the attending physician. Results: Integral homeostasis index IHx calculations as well as their prompt assessment permit better and more rapid treatment of children with severe traumatic injury.

Keywords. Severe mechanical trauma in children, Acid-Base Balance (ABB), Clinical Decision Support (CDS), Machine learning classification, Arden Syntax, CDS software.

1. Introduction

The treatment of patients with severe mechanical trauma still remains an acute and complex clinical problem. The rate of lethal outcomes is high, and a significant number of survivors remain in a state of severe disability [1].

Acid-base balance (ABB) blood tests are a commonly used standard procedure in the treatment of these patients at intensive care units (ICUs). The daily assessment of ABB in blood, which is performed two or more times a day, is an important part of multi-

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parameter patient monitoring. ABB analyses, along with estimations of electrolyte and metabolic indicators, permit an objective assessment of the patient's condition. However, the use of these laboratory analyses for the development of a single integrated indicator of a patient's condition and its dynamics is practically unknown.

In an earlier study based on machine learning algorithms, we developed a mathematical classification model for the prediction of clinical outcomes. Several learning techniques were tested, including artificial neural networks, support vector machines, and principal component analyses. One of the latter was finally selected as a classification algorithm [2].

Based on this model, we obtained a linear regression function that permitted the calculation of an integral index with a conditional scale; this was referred to as the integral homeostasis index IHx. The conditional scale ranges from +10 to -10 points: positive IHx scores signify a favorable outcome while negative scores indicate an unfavorable outcome. The absolute IHx value describes the level of affinity to favorable or unfavorable outcomes.

Since August 2015, IHx is routinely used as part of the laboratory monitoring of patients at the children's trauma ICU in our hospital, and is integrated into and recorded in the ICU's computerized information system.

The aim of the present study is to further verify IHx as an assessment and prognostic index of the clinical condition of children who have experienced severe mechanical trauma.

2. Material and Methods

2.1. Patient study

Three hundred and forty-five patients with severe mechanical trauma, who were admitted to the hospital's ICU from August 2015 to March 2018 were studied. Their mean age was 9 ± 6 years (range, 1 month to 18 years); 218 were boys (63.2%) and 127 (36.8%) girls. Due to their critical clinical condition, all patients required multi-parameter monitoring. The mean duration of their stay at the ICU was 10 ± 4 days. All patients underwent routine ABB testing, including the automatic calculation of IHx two or more times a day. Radiometer CopenhagenABL-500 (Denmark) was used for ABB gas analysis. A total of 7,322 ABB tests were performed.

Based on the duration of the ICU stay (more than 5 days) and the severity of traumatic injury (an injury severity score [3] in excess of 16), we identified 32 patients for detailed comparative analysis. These patients were divided into two subgroups according to the Glasgow outcome scale [4]: the first subgroup consisted of 21 patients with a positive outcome, and the second subgroup consisted of 11 patients with a negative outcome (deep disability, vegetative state, or death).

We also developed a procedure for clinical expert evaluation of IHx. Doctors were asked to mark a checkbox if their professional opinion regarding the clinical condition of a patient at each ABB test corresponded to the IHx value and its dynamics. These evaluations were performed for 1,414 of 7,322 ABB tests.

By means of statistical analysis, the data were checked for compliance with the normal distribution law. Means, variances, coefficient of variation, and angles of regression linear trends were calculated. The data were compared using Student's t-test and Fisher's F-test. The level of significance was set to $p < 0.05$.

2.2. IHx calculation based on Arden Syntax and clinical decision support

One of the main aspects of clinical informatics research at our ICU is the development and implementation of a comprehensive clinical decision support (CDS) system to support the treatment of children with severe mechanical trauma, including traumatic brain injury (TBI). The knowledge required for the CDS is written in Arden Syntax, a medical knowledge representation and processing language which is part of the HL7 International's standardization work [5]. Currently the CDS system at the ICU includes monitoring the cerebral autoregulation of the injured brain, protocols of step therapy for cerebral hypertension, and protocols for the implementation of various scales for assessing the severity of a patient's clinical condition. One element of this CDS system is monitoring laboratory parameters along with the automated interpretation of test results, as well as the calculation and graphic representation of IHx and its dynamics.

Technically the ICU's CDS is developed on the basis of the commercial software ArdenSuite [6, 7]. It has a modular architecture and is part of the hospital's overall IT landscape, including the hospital information system (HIS), laboratory information system (LIS), imaging tools (PACS), and patient monitoring equipment. All communication between the hospital's information sources is conducted in accordance with HL7 protocols.

3. Results and Discussion

Based on 1,414 expert evaluations of 1,374 cases, a positive correlation of more than 97% was obtained. The value of this result may be doubted because less than 20% of all ABB tests were used for the expert evaluation. Nevertheless, the value does indicate the validity of IHx.

Statistical comparison of subgroups of the 32 patients selected for in-depth analysis is shown in Table 1. The subgroup with a favorable outcome had a significantly higher mean IHx value and a lower statistical variance compared to the subgroup with an unfavorable outcome.

Table 1. IHx statistical summary of patients who were subjected to an in-depth comparative analysis. The asterisk * indicates a statistically significant difference.

Group	Number	Mean	Variance
Subgroup 1: favorable outcome	21	2.20	3.04
Subgroup 2: unfavorable outcome	11	-3.94*	5.05*

Further discriminant analysis [8] yielded two classification equations (one for each subgroup):

$$\bullet \text{ For subgroup 1(class 1): } = 0.58 * \text{mean IHx} + 0.19 * \text{variance} - 1.48 \quad (1)$$

$$\bullet \text{ For subgroup 2(class 2): } = -1.08 * \text{mean IHx} + 0.55 * \text{variance} - 6.51 \quad (2)$$

The maximum value returned by these functions defines the prognostic class. The prognostic matrix obtained on the basis of this classifier is shown in Table 2. All of the 21 patients with a favorable outcome were classified correctly. Of those with an

unfavorable outcome, only one of 11 was classified incorrectly. Thus, the overall accuracy of classification was about 97 %.

Table 2. Matrix of classification errors.

Outcome	Correct classification (in %)	Favorable outcome	Unfavorable outcome
Subgroup 1: favorable outcome	100	21	0
Subgroup 2: unfavorable outcome	90.91	1	10
Total	96.88	22	10

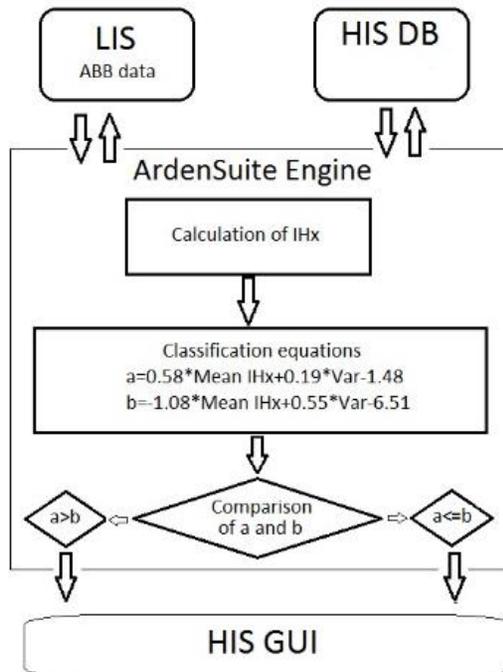


Figure 1. The IHx decision support algorithm implemented in Arden Syntax. LIS stands for the laboratory information system, HIS DB for the hospital's information system database, and HIS GUI for the hospital information system graphical user interface.

3.1. Clinical case

Patient F., a 12-year-old girl, was admitted in coma after a traffic accident. She had heavy TBI and combined trauma. An intracranial pressure (ICP) sensor was implanted immediately; her ICP had increased to 31. The patient underwent step therapy. On the fourth day a bifrontal cerebral decompression was performed. Her clinical condition remained very critical. A systemic inflammation became apparent on the sixth day. The first two sessions of hyperbaric oxygen therapy (HBO) were performed on the tenth and eleventh day, after which her clinical condition started to improve. Two further sessions of HBO were performed. The result was more than favorable: the girl survived and was

subsequently discharged from the hospital. The dynamics of IHx in Figure 2 show the positive development of the patient's clinical condition.

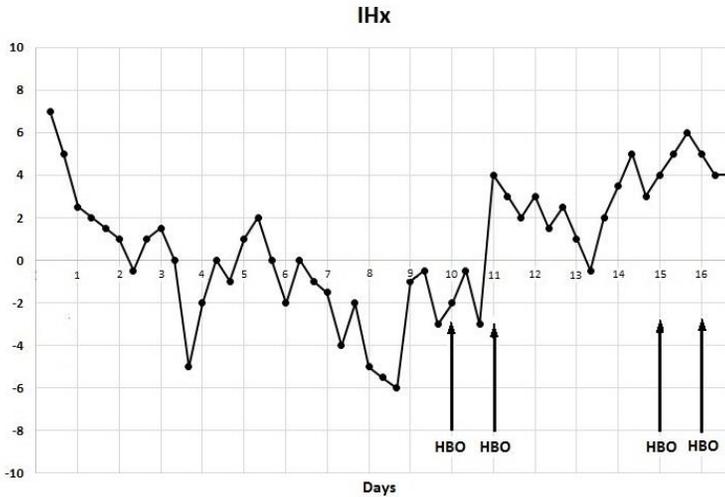


Figure 2. Effect of hyperbaric oxygen therapy (HBO); IHx – integral homeostasis index.

4. Conclusion

The technique used in the study confirms the high validity (about 97% of the classifications were correct) of the integrated homeostasis index (IHx) for the assessment and prognosis of children with severe mechanical trauma. A flexible and scalable CDS solution based on Arden Syntax was created for the ICU. It now forms an integral part of the overall IT landscape at our children's hospital.

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