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Acid-Base and Electrolyte Teaching Case

Assessing Acid-Base Status: Physiologic Versus Physicochemical Approach

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The physiologic approach has long been used in assessing acid-base status. This approach considers acids as hydrogen ion donors and bases as hydrogen ion acceptors and the acid-base status of the organism as reflecting the interaction of net hydrogen ion balance with body buffers. In the physiologic approach, the carbonic acid/bicarbonate buffer pair is used for assessing acid-base status and blood pH is determined by carbonic acid (ie, $Paco_2$) and serum bicarbonate levels. More recently, the physicochemical approach was introduced, which has gained popularity, particularly among intensivists and anesthesiologists. This approach posits that the acid-base status of body fluids is determined by changes in the dissociation of water that are driven by the interplay of 3 independent variables: the sum of strong (fully dissociated) cation concentrations minus the sum of strong anion concentrations (strong ion difference); the total concentration of weak acids; and $Paco_2$. These 3 independent variables mechanistically determine both hydrogen ion concentration and bicarbonate concentration of body fluids, which are considered as dependent variables. Our experience indicates that the average practitioner is familiar with only one of these approaches and knows very little, if any, about the other approach. In the present Acid-Base and Electrolyte Teaching Case, we attempt to bridge this knowledge gap by contrasting the physiologic and physicochemical approaches to assessing acid-base status. We first outline the essential features, advantages, and limitations of each of the 2 approaches and then apply each approach to the same patient presentation. We conclude with our view about the optimal approach.
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INDEX WORDS: Stewart approach; base excess; acid-base disorders; anion gap; physiologic approach; physicochemical approach; acid-base status; diagnosis.

Note from the editors: This article is part of a series of invited case discussions highlighting the diagnosis and treatment of acid-base and electrolyte disorders.

INTRODUCTION

Successful management of acid-base disorders depends on accurate diagnosis. In turn, accurate diagnosis requires a 2-tiered process: reliable determination of acid-base variables in blood and sound interpretation of the data to assess the patient's acid-base status; and careful synthesis of the clinical information and additional testing, as appropriate, to identify the cause(s) of the prevailing acid-base disorder(s).[1]

Early in the 20th century, Henderson, Van Slyke, and coworkers pioneered the classic approach to assessing acid-base disorders, which we call the physiologic approach.[2-5] Starting in the late 1950s, Astrup, Siggaard-Andersen, and coworkers developed a variation of the physiologic approach, the base-excess approach,[6-9] which in our opinion offered no advantages but rather introduced several shortcomings.[10] Finally, in 1978, Stewart proposed a fundamentally different framework that was further developed by his followers, which we call the physicochemical approach.[11-15] The latter approach has gained popularity, particularly among intensivists and anesthesiologists.

In our experience, most physicians use a single approach to assess acid-base status and know very little, if any, about the other approaches. This situation undermines communication among caregivers and can adversely affect patient care, especially because all approaches are frequently practiced within an institution. We attempt to bridge this knowledge gap by contrasting the physiologic and physicochemical approaches to assessing acid-base status. The essential features, advantages, and limitations of each of the 2

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approaches are first described, highlighting differences with substantial diagnostic and therapeutic implications. We then apply each approach to the same patient presentation and conclude with our view about which is the optimal approach.

CASE REPORT

Clinical History and Initial Laboratory Data

A 21-year-old man with type 1 diabetes mellitus and a 3-day history of an upper respiratory infection and poor oral intake was brought to the emergency department. On admission, he was obtunded and had severe hyperpnea. Physical examination showed supine blood pressure of 92/40 mm Hg, temperature of 38.2°C, respirations of 22 breaths/min, clear lungs, and decreased skin turgor.

Serum laboratory data on arrival were as follows: sodium, 127 mEq/L; potassium, 6.0 mEq/L; chloride, 94 mEq/L; total carbon dioxide, 5 mEq/L; urea nitrogen, 60 mg/dL; creatinine, 3.2 mg/dL (corresponding to estimated glomerular filtration rate of 26 mL/min/1.73 m^2 calculated by CKD-EPI [Chronic Kidney Disease Epidemiology Collaboration] creatinine equation); glucose, 340 mg/dL; albumin, 2.0 g/dL; and inorganic phosphate, 3.4 mg/dL. Arterial blood gas evaluation (on 2 L/min of oxygen) showed pH 7.15; $Paco_2$, 12 mm Hg; Pao_2, 96 mm Hg; and calculated bicarbonate concentration, 4 mEq/L.

Additional Investigations

Blood ketones (Acetest) were positive (1:4 dilution). Urine ketones were 3+. Serum lactate level was 1.9 mEq/L. Cultures of blood and bronchial secretions showed no growth.

Diagnosis

The patient's acid-base status at presentation was assessed as follows: physiologic approach, high anion gap (AG) metabolic acidosis; and physicochemical approach, strong ion gap (SIG) acidosis, hypoalbuminemic alkalosis, and respiratory alkalosis.

Clinical Follow-up

The patient was treated with insulin, intravenous fluids, and levofloxacin. Alkali was not administered. Four days following admission, the patient was discharged home.

DISCUSSION

Box 1 summarizes the essential features of the physiologic approach. This approach embraces the concept of Brønsted[16] and Lowry[17] of acids as hydrogen ion donors and bases as hydrogen ion acceptors. It views the acid-base status of the organism as originating from the interaction of net hydrogen ion balance (ie, influx minus efflux) with the available body buffers.[3,4,18-20] This concept allows simplification of a complex biological system and enables easy but rigorous assessment of the body's acid-base status. Based on the isohydric principle, measurement of the 2 components of a single buffer system, the carbonic acid/bicarbonate pair, incorporates the contribution of the nonbicarbonate buffers and allows evaluation of acid-base status.[1,3,4] Blood pH is calculated from the Henderson equation, $[H^+] = 24 \times Paco_2/[HCO_3^-]$, which considers carbonic acid (ie, $Paco_2$, the respiratory component) and serum bicarbonate levels (the metabolic component; Table 1).

Box 1. Physiologic Approach

1. Acids are H^+ donors ($AH \rightarrow A^- + H^+$) and bases are H^+ acceptors ($A^- + H^+ \rightarrow AH$).
2. Acid-base status is determined by the interaction of net H^+ balance (influx minus efflux) with the available body buffers (weak acid/conjugate base pairs).
3. Changes in $[H^+]$ are minimized by body buffers (acting like bases to added acid and like acids to added base).
4. Measurement of the 2 components of a single buffer pair incorporates the contribution of all other buffers and allows assessment of acid-base status (isohydric principle).
5. The H_2CO_3/HCO_3^- buffer pair is used for assessment of acid-base status by applying the Henderson equation: $[H^+] = 24 \times PaCO_2/[HCO_3^-]$
6. Four cardinal acid-base disorders are recognized and expressed as primary changes in serum $[HCO_3^-]$ (metabolic disorders) or $Paco_2$ (respiratory disorders).
7. Empirical observations have quantitated the secondary responses to primary changes in serum $[HCO_3^-]$ or $Paco_2$.
8. Serum AG ($AG = [Na^+] - ([Cl^-] + [HCO_3^-])$ complements the assessment of serum $[HCO_3^-]$ (metabolic component).
9. Changes in patient's serum AG (ΔAG) are estimated by comparing calculated serum AG to the average reference value of the laboratory. The latter value must be adjusted for the patient's serum albumin concentration (subtracting or adding 2.5 mEq/L for each 1 g/dL of serum albumin below or above the average reference value of 4 g/dL, respectively).
10. An elevated ΔAG, particularly if >5 mEq/L, points to the presence of high AG metabolic acidosis. Examination of the relationship between ΔAG and $\Delta[HCO_3^-]$ (Δ/Δ) estimates the degree to which retention of fixed acids is responsible for the $\Delta[HCO_3^-]$ and assists in the identification of coexisting acid-base disorders.

Abbreviations and definitions: AG, anion gap; $[Cl^-]$, chloride concentration; $[H^+]$, hydrogen ion concentration; H_2CO_3, carbonic acid; $[HCO_3^-]$, bicarbonate concentration; $[Na^+]$, sodium concentration.

The carbonic acid/bicarbonate pair is used on account of its abundance and physiologic importance and because both compounds are homeostatically regulated.[1,5] The standard blood gas analyzer measures pH and Pco_2, from which serum bicarbonate concentration is calculated. Verification of the derived serum bicarbonate concentration is provided by comparing its level with the measured total carbon dioxide concentration in venous blood. Notably, a majority of acid-base disorders are initially tracked by practitioners based on abnormal venous total carbon dioxide concentrations.

Four cardinal acid-base disorders are recognized by the physiologic approach (Table 2).[1,21-23] Metabolic disorders are expressed as primary changes in serum bicarbonate concentrations, whereas respiratory disorders are expressed as primary changes in $Paco_2$. Each primary