

Understanding Acid Base Disorders



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KEYWORDS

- Acid base • Hydrogen • Stewart • Henderson–Hasselbalch • pH • Base excess
- Strong ion difference

KEY POINTS

- There are currently 3 methods to assess acid base balance in the clinical setting, the Henderson–Hasselbalch equation, the standard base excess, and the Stewart approach, all of which are approximations to represent physiologic behavior of aqueous solutions.
- All 3 methods provide the means to arrive at similar conclusions in daily clinical practice, because they are all fundamentally based on equilibrium equations.
- The Stewart approach conceived aqueous solutions as systems, and thus, attempted to explain the behavior of pH by including every possible mechanism (ie, the Henderson–Hasselbalch's proposed evaluation of the $\text{HCO}_3\text{--pCO}_2$ base pair).
- These methods should be conceived as complementary, and not substitutive.

INTRODUCTION

Although most ion concentrations exist naturally in the millimolar range in people, the concentration of the hydrogen ion is regulated within a narrow margin at the nanomolar range, between 16 and 160 nmol/L, with a physiologic value approaching 40 nmol/L in human whole blood.¹ Such rigorous regulation is not by chance, as hydrogen is a highly reactive ion that can interact with hydrogen bonds, proteins, and enzymes, and can alter protein structure and function,² compromising thereby biochemical processes and even cell survival. It is not surprising then that the correct assessment of acid–base balance and the adequate management of its alterations are of major importance in clinical medicine.

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Before 1923, acids and bases were conceived as anions and cations, respectively. Although Humphrey Davy had already observed and reported the association of acidity with the presence of hydrogen ions in the early 19th century, it was not until the seminal work by Arrhenius, Brønsted and Lowry, and Lewis, that clarity was brought to the field with the establishment of the hydrogen ion as the centerpiece of acid base analysis, and the concept that what determines acidity of a solution is the chemical potential of hydrogen ions. This paradigm shift also established the modern definitions of acids and bases as substances able to release, or accept hydrogen ions at a given pH, respectively,³ and of buffer pairs as weak acids that enter in equilibrium with their complementing weak bases, also at a given pH.³

Relative consensus was achieved in terms of the effect of partial pressure of carbon dioxide (P_{CO_2}), as an independent variable, on the concentration of hydrogen ions in solution by virtue of the following chemical reaction,



where CO_2 denotes carbon dioxide, H_2O water, H_2CO_3 carbonic acid, H^+ hydrogen ion, and HCO_3^- bicarbonate.

There are currently 3 widely recognized approaches to assess changes in acid–base status, which essentially differ in their method to quantify the nonrespiratory (or metabolic) component:

1. The traditional Henderson–Hasselbalch approach, also called the physiologic approach, which uses the relationship between HCO_3^- and P_{CO_2}
2. The standard base excess (SBE) approach based on the Van Slyke equation
3. The quantitative or Stewart approach, which uses the strong ion difference (SID) and the total weak acids (A_{Tot})

In essence, all methods to quantify acid base disorders are simply increasingly accurate (and more complex) approximations to the estimation of the equilibrium of carbonate and noncarbonate buffers,^{4–6} and as shall be seen, all methods are readily compatible with each other when assessed from a multicompartment modeling standpoint.⁷ Despite this apparent interchangeability, and the potential benefit of conceiving these methods as complementary rather than mutually exclusive, intense discussions rage on between advocates and detractors of each of these models. Indeed, the controversy raised by Stewart’s relatively novel postulates is reminiscent of the intense discussions between advocates of the bicarbonate-based approximations (conceptually centered on the Henderson-Hasselbalch approach and geographically located mainly in Boston) and the supporters of the SBE approach (led essentially by Siggaard-Andersen from Copenhagen, Denmark), which was immortalized by Bunker in his famous editorial entitled the “Great trans-Atlantic acid–base debate”.⁸

This article explores the origins of the current concepts framing the existing methods to analyze acid base balance, to demonstrate that despite having differences, these approaches can all be used to improve the understanding of acid–base derangements in the clinical setting. The unification of concepts will also provide clarity to the debate and provide the clinician with the necessary tools to better assess these alterations at the bedside.

THE CONCEPT OF EQUILIBRIUM AND THE EVOLUTION OF THE ANALYSIS OF ACID–BASE PHYSIOLOGY

Every method to qualitatively or quantitatively describe the chemical transactions associated with significant changes in hydrogen ion concentration in biological fluids

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