

Clinical Utility of Stewart's Method in Diagnosis and Management of Acid-Base Disorders

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For the past 5 decades, a bicarbonate-based approach has been the dominant method used for the diagnosis and treatment of acid-base disorders. This approach, however, has been criticized by some as (1) qualitative and not quantitative in nature and (2) incapable of detecting important diagnoses. Stewart, using principals of electroneutrality and conservation of mass, developed a "new" approach to the diagnosis and management of these disorders. The proponents of Stewart's approach believe that it not only offers a mechanistic explanation for the disorders but also provides the tool to make a more accurate diagnosis. Although Stewart's approach has been largely ignored by nephrologists and renal physiologists, it is increasingly used by anesthesiologists and intensivists. This review discusses the clinical utility of Stewart's method compared with the traditional bicarbonate-based approach. Although Stewart's method proposes a different, however not new, approach, it does not improve our ability to diagnose more accurately or manage these disorders. Stewart's method also does not provide the tool to prognosticate any better than the traditional method.

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Peter Stewart, a biochemist at Brown University, published his seminal work on acid-base disorders in an article in 1978 and as a book in 1981 (1,2). Using fundamental biochemical and mathematical concepts, Stewart challenged the traditional bicarbonate-based method of diagnosing and treating acid-base disorders and proposed an approach based primarily on charge differences between strong cations and anions. This approach, however, did not attract much attention until the early 1990s, when it was simplified by several investigators to allow its use in clinical setting (3–6). This was followed by publication of a number of studies comparing the utility of the traditional and Stewart's approaches as a diagnostic and prognostic tool. It is interesting that until recently, Stewart's method has been largely ignored by nephrologists and renal physiologists, with only a rare article appearing in renal journals (7,8). This, however, should change as Stewart's method is increasingly used in clinical settings where nephrologists work side by side with intensivists and anesthesiologists who routinely use this method. Nephrologists should be familiar with Stewart's contribution to our understanding of acid-base disorders and its utility in clinical setting.

A recent article discussed the mathematical and biochemical basis of Stewart's method in detail and challenged the basic concept that Stewart has created a new paradigm (8), a paradigm that is compared by some to Copernicus's discovering that Earth rotates around the sun and not *vice versa* (9)! In

addition, it challenges the claim that Stewart's approach provides a mechanistic explanation for acid-base disorders (8). This review will not deal with this issue, and readers who are interested in a more in-depth understanding of the biochemical and mathematical basis of Stewart's method are referred to this (8) as well as other reviews (3,4,6,7). This review focuses primarily on the clinical utility of Stewart's method, assessing its strengths and weaknesses as a diagnostic and prognostic tool. To do so, a brief history of key events leading to the development of the present approach to acid-base disturbances is in order. Table 1 summarizes the definition of key terms as well as abbreviations used in this article.

Historical Review of Approach to Clinical Acid-Base Disorders

The modern era of acid-base began in 1910 with Lapworth's suggestion that hydrogen was the "universal acid" (10). This was extended by the work of Lowry in Cambridge (11) and Brønsted in Copenhagen (12), who defined an acid as a substance that is capable of donating hydrogen to and base as one capable of accepting hydrogen from a solution. This definition helped explain the natural avidity of acid and base and the role of weak acids and their salt in creation of buffer systems. Henderson (13) was first to recognize the unique role that bicarbonate-carbonic acid buffer system plays in stabilizing the acid-base equilibrium in body fluid. This led to the development of the Henderson-Hasselbalch formula:

$$\text{pH} = \text{pK} + \log \frac{[\text{HCO}_3^-]}{\text{SXPCO}_2}$$

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Table 1. Definitions and abbreviations^a

AG = ([Na ⁺] + [K ⁺]) - ([Cl ⁻] + [HCO ₃ ⁻]) (normal range 14 to 16) or: AG = [Na ⁺] - ([Cl ⁻] + [HCO ₃ ⁻]) (normal range 8 to 12)
AGc = observed AG + 2.5 × ([normal albumin] - [observed albumin]) = observed AG + 2.5 × (4.4 - [observed albumin]), where albumin concentration is in g/dl
A ⁻ = Primarily albumin and phosphate (in plasma) as well as hemoglobin (in whole blood)
A _{TOT} = Total A ⁻ and its weak acid ([A ⁻] + [HA])
Buffer base = ([Na ⁺] + [K ⁺] + [Ca ²⁺] + [Mg ²⁺]) - ([Cl ⁻] + [HCO ₃ ⁻] + [A ⁻])
BE or BD = Amount of acid or alkali that must be added to 1 L of whole blood to restore pH to 7.40 at Pco ₂ of 40
SBE or SBD = BE or BD corrected for hemoglobin and size of interstitial fluid compartment; this can be calculated by dividing BE by 3 or calculating BE using hemoglobin of 5 g/dl
BEua = BE corrected for changes in free water, chloride, albumin, and Pco ₂ (used as a surrogate for SIG)
SID = ([Na ⁺] + [K ⁺] + [Ca ²⁺] + [Mg ²⁺]) - ([Cl ⁻] + [HCO ₃ ⁻] + [A ⁻])
SIDa = ([Na ⁺] + [K ⁺] + [Ca ²⁺] + [Mg ²⁺]) - ([Cl ⁻])
SIDe = [HCO ₃ ⁻] + [A ⁻] = 12.2 × Pco ₂ /(10 ^{-pH}) + [albumin in g/L] × (0.123 × pH - 0.631) + [PO ₄ ⁻ in mmol/L] × (0.309 × pH - 0.469).
SIG = SIDa - SIDe

^aAll units are in mEq/L, unless otherwise indicated. A⁻, nonbicarbonate buffers; AG, anion gap; AGc, AG corrected for albumin; A_{TOT}, total weak acids; BD, base deficit; BE, base excess; BEua, BE contributed by unmeasured anions; SBD, standard base deficit; SBE, standard base excess; SID, strong ion difference; SIDa, apparent strong ion difference; SIDe, effective strong ion difference; SIG, strong ion gap.

which became the foundation for future advances in this field. The clinical application of this formula was greatly advanced by Hasselbalch's invention of an electrode capable of measuring H ion concentration in body fluids (14).

Beginning in the second decade of the 20th century, Van Slyke and Peters as well as other investigators helped to develop the bicarbonate-based approach to acid-base disorders (15). This approach was slightly modified by other investigators through the introduction of base excess (BE) and base deficit (BD) to quantify changes in bicarbonate concentration secondary to metabolic disorders (16,17). The use of BE and BD was criticized, however, because it represented measurements done on whole blood and did not accurately represent the whole-body behavior. This could lead to erroneous diagnosis, especially in patients with chronic respiratory acidosis, for whom the compensatory elevation in bicarbonate could be misdiagnosed as primary metabolic alkalosis (18). This criticism resulted in what was termed the "great transatlantic debate" between Copenhagen and Boston schools and the introduction of standard BE (SBE) and standard BD (SBD) to account for whole-body response to alterations in Pco₂ (19). Interesting, whereas BD and BE are used clinically by intensivists and anesthesiologists, they are rarely used by nephrologists and renal physiologists. In this article, the term traditional approach is used to encompass both the original bicarbonate-base approach and its modification using BE and BD.

The traditional approach is based on the centrality of H ion concentration and its dependence on the concentration of whole-body buffers as represented by bicarbonate and carbonic acid. Several investigators including Peters and Van Slyke, although accepting Henderson-Hasselbalch's formula, believed that a "more complete description of the acid-base balance should include concentration of all of the anions and cations"

(20). In the late 1940s, Singer and Hasting presented their acid-base nomogram and introduced the concept of buffer base (BB) as the difference between all of the cations (termed total base) and anions (termed total fixed acid) (16). On the basis of this terminology, cations such as sodium, potassium, and calcium are considered to be base and anions such as chloride and phosphate to be acid. This concept, discarded by basic chemists decades before, was challenged by several investigators and was finally abandoned by clinical chemists (21,22). During the next 2 decades, the traditional approach gained greater strength through the publication of many well-designed studies that defined the clinical and biochemical parameters that are critical to the diagnosis and management of acid-base disorders. These parameters became the foundations of our approach to clinical acid-base disorders for the past 4 decades (23).

Stewart's Approach to Acid-Base Disorders

As indicated, the traditional approach has been criticized as (1) descriptive rather than mechanistic in nature and (2) limited in scope and therefore unable to make complete diagnosis in patients with complex disorders. In contrast, proponents of Stewart's approach believe it to be mechanistic in nature and comprehensive in scope, able to detect important hidden disorders (6,24). The fundamental underpinning of Stewart's approach is the concept of independent and dependent variables in acid-base homeostasis. According to Stewart, "Independent variables in any system are those which can be directly altered from outside the system without affecting each other" and "...dependent variables in a system can be thought of as internal to the system. Their values represent the system's reaction to the externally imposed values of the independent variables."

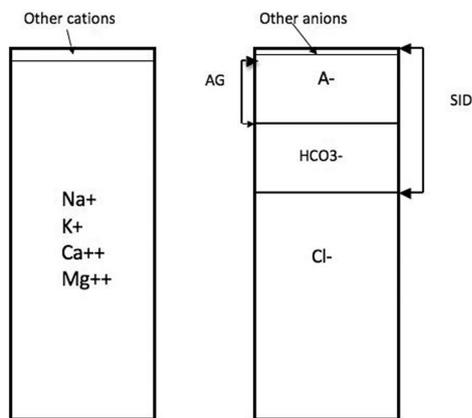


Figure 1. Relationship between SID, anion gap (AG), and bicarbonate in normal individuals.

(1). Using principals of conservation of mass, electrical neutrality, and dissociation constant of partially dissociated weak electrolytes, Stewart derived the following fourth-order polynomial formula for H concentration in a fluid compartment containing bicarbonate and CO₂:

$$\begin{aligned}
 & [H^+]^4 + [H^+]^3(K_a[SID]) \\
 &= [H^+]^2\{K_a ([SID] - [A_{TOT}]) - (K_1 \times S \times P_{CO_2} + K_w)\} \\
 &- [H^+] (K_a(K_1 \times S \times P_{CO_2} + K_w) + K_a \times K_3 \times K_1 \times S \\
 &\quad \times P_{CO_2} = 0(1,2)
 \end{aligned}$$

where strong ion difference (SID) is the difference between strong cations and anions in solution:

$$\begin{aligned}
 SID &= [Na^+] + [K^+] + [Ca^{2+}] + [Mg^{2+}] \\
 &- (Cl^- + lactate + other strong ions)
 \end{aligned}$$

and A_{TOT} reflects the concentration of total weak acid in solution:

$$[A_{TOT}] = [HA] + [A^-]$$

On the basis of Stewart's definition, H⁺ and bicarbonate are dependent variables whose concentrations are determined by the three independent variables, namely SID, P_{CO₂}, and A_{TOT}. Although the mathematical basis of Stewart's formula has not been challenged, this alone does not prove causality, which must be proved through empirical observations (8).

In Stewart's approach, similar to the traditional approach, respiratory disorders are those that are due to a primary alterations in P_{CO₂}. Metabolic disorders, however, are due to primary alterations in SID or A_{TOT} and not bicarbonate. By the law of electroneutrality:

$$\begin{aligned}
 & ([Na^+] + [K^+] + [Ca^{2+}] + [Mg^{2+}]) - ([Cl^-] \\
 &+ [lactate + other strong anions]) - ([HCO_3^-] + [A^-]) = 0.
 \end{aligned}$$

This formula can be rearranged as follows:

$$\begin{aligned}
 & [Na^+] + [K^+] + [Ca^{2+}] + [Mg^{2+}] \\
 & - (Cl^- + lactate + other strong ions) = [HCO_3^-] + [A^-]
 \end{aligned}$$

Therefore,

$$\begin{aligned}
 SID &= [Na^+] + [K^+] + [Ca^{2+}] + [Mg^{2+}] \\
 & - (Cl + lactate + other strong ions) = [HCO_3^-] + [A^-].
 \end{aligned}$$

Under normal conditions, concentration of lactate and other strong ions is very low and can be ignored. The formula could therefore be simplified to

$$\begin{aligned}
 SID &= [Na^+] + [K^+] + [Ca^{2+}] + [Mg^{2+}] \\
 & - (Cl^-) = [HCO_3^-] + [A^-]
 \end{aligned}$$

SID therefore can be calculated as the difference between fully dissociated cations and anions or sum of bicarbonate and A⁻ where A⁻ represents total charges contributed by all nonbicarbonate buffers, primarily albumin, phosphate, and, in whole blood, hemoglobin (Figure 1). SID is therefore the same as buffer base concept introduced by Singer and Hasting more than 5 decades ago (16).

When an abnormal anion is present, a gap will appear between SID calculated by the difference between strong ions (the so-called "apparent SID") and calculated by the addition of bicarbonate and nonbicarbonate buffers (so called "effective SID"; Figure 2). This difference, named strong ion gap (SIG), is a marker for the presence of an abnormal anion (25).

Anion gap (AG) is also calculated on the basis of the principal of electroneutrality as shown as follows:

$$\begin{aligned}
 ([total\ cations] - [total\ anions]) &= ([measured\ cations] \\
 &+ [unmeasured\ cations]) - ([measured\ anions] \\
 &+ [unmeasured\ anions]) = 0.
 \end{aligned}$$

This can be rearranged as:

$$\begin{aligned}
 ([measured\ cations] - [measured\ anions]) \\
 = ([unmeasured\ anions - unmeasured\ cations]) = AG.
 \end{aligned}$$

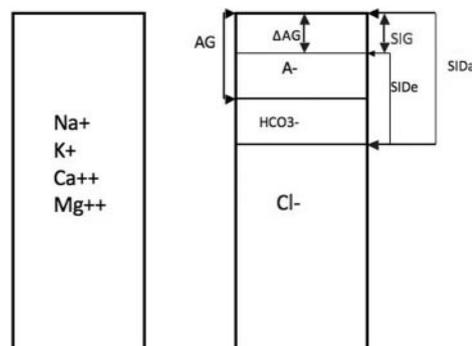


Figure 2. Relationship between strong ion gap (SIG) and ΔAG.

In normal state, plasma unmeasured anions reflect charges contributed by the nonbicarbonate anions (A^-), primarily albumin and phosphate. The unmeasured cations are primarily made up of calcium, magnesium, and, depending on the formula used, potassium. ΔAG , the difference between the abnormal and normal (or baseline) AG, represents the amount of abnormal anion(s) present in plasma. SIG, as pointed out already, also represents the amount of abnormal anion(s) present in plasma and is expected to be mathematically equal to ΔAG (Figure 2). Moviat *et al.* (26) in studying 50 consecutive patients with metabolic acidosis (defined as $BD > 5$ mM) documented a tight correlation between SIG and ΔAG corrected for albumin and lactate ($r = 0.9344$; Figure 3). This relationship could have been even stronger if ΔAG were calculated in a more precise manner by using actual baseline values for AG in each patient rather than the mean value of 12 (27). It should be clear from this discussion that specific components of Stewart's formulas, such as SID and SIG, are conceptually and mathematically closely related to specific components of traditional formulas such as bicarbonate, AG, and ΔAG . To help the reader become familiar with the application of commonly used formulas, the appendix summarizes the basic data and pertinent calculations on a patient evaluated by both methods.

Clinical Application of Stewart's approach

Classification of Acid-Base Disorders

One important goal of any method used to analyze acid-base disorders is to develop a clinically useful classification. The traditional approach, using a robust body of empirical observations, has developed a classification that contains six primary disorders: Metabolic acidosis, metabolic alkalosis, acute and chronic respiratory acidosis, and acute and chronic respiratory alkalosis. Metabolic acidosis can further be classified as anion gap or hyperchloremic acidosis. In addition, by using compensatory formulas as well as ΔAG , the traditional approach is capable of diagnosing complex acid-base disorders (28). In Stewart's approach, classification of acid-base disorders is based on changes in the three "independ-

ent" variables (Table 2) (29). Respiratory disorders, as in the traditional approach, are due to a change in PCO_2 , whereas metabolic disorders are due to alterations in either SID or A_{TOT} . SID is decreased in metabolic acidosis and increased in metabolic alkalosis. By calculating SIG, one can further classify metabolic acidosis. In hyperchloremic metabolic acidosis, both effective and apparent SID decrease equally, as the increase in chloride is counterbalanced by an equal decrease in the bicarbonate concentration. SIG therefore remains at or near 0. In AG metabolic acidosis, apparent SID does not change (as chloride concentration is unchanged), but effective SID decreases (as a result of a decrease in bicarbonate concentration) and SIG therefore becomes positive (29). One major departure from the traditional approach is classification of acid-base disorders as a result of alteration in A_{TOT} . A_{TOT} , representing all nonbicarbonate buffers pairs ($HA + A^-$), is made up of charges contributed primarily by serum proteins (mainly albumin) with phosphate and other buffers playing a minor role. On the basis of this classification, an increase in serum protein would result in metabolic acidosis and a decrease, metabolic alkalosis (see next section) (29,30).

Clinical Utility of Stewart's Approach in Diagnosing Acid-Base Disorders

In addition to proposed disorders as a result of alterations in A_{TOT} , the major practical difference between Stewart's and the traditional approach is the use of SID and SIG instead of bicarbonate and AG in the diagnosis of metabolic disorders. As pointed out already, these four variables all are interrelated, but the question remains: "Does Stewart's method uncover disorders that are not diagnosed by the use of the traditional method?" In a study of 152 intensive care unit (ICU) patients, 96% of whom had severe hypoalbuminemia (serum albumin concentration below the mean by 3 SD), Stewart's method uncovered underlying metabolic acidosis in 20 patients with normal BE and 22 patients with normal bicarbonate (29). The authors believe that the normal BE or bicarbonate was due to the presence of a counterbalancing hypoalbuminemic alkalosis. It is important to note, however, that in these patients, use of AG corrected for hypoalbuminemia also leads to the correct diagnosis of mixed metabolic acidosis and alkalosis (29). In a prospective observational study of 935 ICU patients, Stewart's method detected metabolic disorders in 131 (14%) patients with normal bicarbonate and BE, whereas the traditional method made a similar diagnosis in 108 (13%) patients. Stewart's method, however, failed to make an important acid-base diagnosis in 27 (3%) patients compared with the traditional method using corrected AG (31). In another study, 2152 complete sets of laboratory tests in 427 trauma patients were analyzed by the two methods. There was 28% disagreement between the two methods when corrected AG was not used (32). This is similar to the finding in another report in a pediatric population, in which base excess as a result of unmeasured anion was used as a surrogate for SIG (33). In summary, if corrected AG is used, then the traditional method performs at

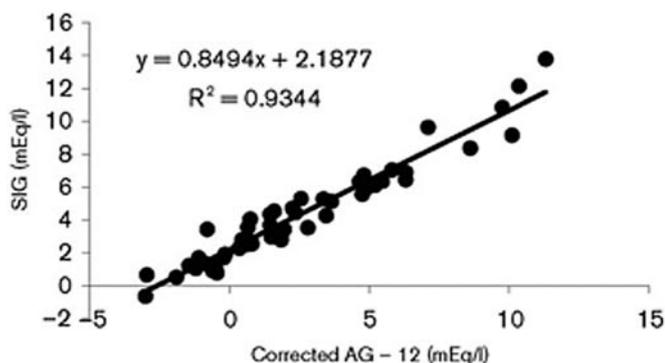


Figure 3. Relationship between ΔAG and SIG. AG was corrected for albumin and lactate. SIG was also calculated correcting apparent SID for lactate. Reprinted from reference (26), with permission.

Table 2. Classification of primary acid-base disturbances^a

Parameter	Acidosis	Alkalosis
Respiratory	↑ Pco ₂	↓ Pco ₂
Nonrespiratory (metabolic)		
abnormal SID		
water excess/deficit	↓ SID, ↓ [Na]	↑ SID, ↑ [Na]
imbalance of strong anions		
chloride excess/ deficit	↓ SID, ↑ [Cl]	↑ SID, ↓ [Cl]
unidentified anion excess	↓ SID, ↑ [XA]	
nonvolatile weak acids		
serum albumin	↑ [Alb]	↓ [Alb]
inorganic phosphate	↑ [Pi]	↓ [Pi]

^aFor further discussion, refer to text and to reference (29). [Alb], albumin concentration; [Pi], inorganic phosphate concentration; XA, concentration of unidentified strong anion.

least as well as Stewart's approach in uncovering a hidden metabolic disorder.

The role of hypoalbuminemia in the development of acid-base disorders deserves a comment. One report presents eight ICU patients with near-normal renal function and elevated serum bicarbonate concentration (mean 31.3 ± 1.6 mM) but normal concentration of sodium, chloride, and appropriately low AG. Although other causes of metabolic alkalosis were not ruled out, it was assumed that this disorder was due to a decrease in total weak acid secondary to hypoalbuminemia (33). In contrast, in another study, among 935 ICU patients, only one patient was thought to have hypoalbuminemic alkalosis (31). In an *in vitro* experiment, a decrease in serum albumin from 4.7 to 2.8 g%, while maintaining constant Pco₂, resulted in an increase in serum bicarbonate from 23.9 to 29.6 mM, whereas an increase in serum albumin to 6.6 resulted in a drop in serum bicarbonate to 19.2 mM (34). This study has been criticized for the use of whole blood rather than plasma and addition of diluting fluid with high bicarbonate content. In addition, the observed changes could be explained by the alteration in ionic strength resulting in a change in Gibbs-Donnan equilibrium and solubility as well as dissociation constant of CO₂ (8). This *in vitro* observation is also not supported by the clinical observation that patients with nephrotic syndrome and similar degree of hypoalbuminemia have normal serum bicarbonate concentration (35).

Prognostic Value of Stewart's Method Compared with the Traditional Method

The main goal of any proposed acid-base approach is to help clinicians make accurate diagnostic and therapeutic decisions. In this respect, as discussed, Stewart's method has not been shown to be superior to the traditional method. Many studies, however, have attempted to evaluate the ability of specific components of formulas used in either Stewart's or the traditional method in predicting meaningful clinical outcomes such as mortality (32,33,36–40). These studies, all performed on patients who were admitted to the ICU, are summarized in Table 3. As this summary shows,

these studies include very different patient populations, study designs, and statistical methods and are therefore difficult to compare or combine. In addition, because most variables of interest are interconnected, these studies are able to use only univariate and not multivariate analysis. Despite these limitations, certain general conclusions can be derived:

1. Clinical assessment such as APACHE II, injury severity index (ISI), and pediatric index mortality (PIM) are as powerful as the laboratory assessments in predicting clinical outcomes (32,36,39),
2. Correction of AG for albumin significantly increases its predictive power (38,41,42),
3. Correction of AG for albumin and SIG, on average, performed equally well in predicting mortality (32,39,40),
4. In two studies, both in trauma patients, receiver operator characteristic curve for SIG and AG achieved clinically useful levels (38,40). In other studies, reported receiver operator characteristic were too low to be of clinical use.
5. In no study was SIG compared with ΔAG.
6. No studies compared the utility of Stewart's method with traditional method in diagnosing and/or managing respiratory disorders.

In general, these types of studies using either the traditional or Stewart's approach, although interesting, are of questionable clinical utility in treating these severely ill and complex patients. The outcome in such patients will depend on multiple independent clinical and laboratory variables, which may or may not include acid-base parameters. We should also recognize the limitation of standard arterial blood gas analysis in informing us about buffering by the bicarbonate system at the tissue level. As pointed out by Gowrishankar *et al.* (42), this limitation is partly due to the fact that arterial Pco₂, although setting the lower limit for capillary Pco₂, does not accurately reflect the tissue buffering by bicarbonate system, which is better reflected by venous Pco₂.

Table 3. Summary of studies comparing the prognostic power of the traditional and Stewart's approach^a

Author/Year (ref)	Study Design	Patient Population	Clinical and Laboratory Measurements	End Point(s)	Results	Comments
Balasubramany <i>et al.</i> (33), 1999	Retrospective pediatric ICU	n = 255 patients with simultaneous acid-base parameters	BE, AG, BEua, ^b Lactate	In-hospital mortality	BEua (ROC 0.79) performed better than AG (0.64), and lactate level (0.63), BE (0.53)	BEua is used instead of SIG AGc not reported
Rocktaeschel <i>et al.</i> (36), 2003	Retrospective adult ICU	n = 300 patients with simultaneous acid-base parameters	BE, AG, AGc, BEua, ^b lactate, APACHE II	Lactate level and in-hospital mortality	BE, BEua, AG good predictor of lactate >5 but not mortality ROC BEua 0.64, AGc 0.67, BD 0.59, and AG 0.66 APACHE II best predictor of mortality	BEua used instead of SIG
Hatherill <i>et al.</i> (37), 2003	Prospective observational pediatric ICU	n = 46 children with shock	BE, AG, SIG, Lactate, PIM	ICU mortality	Only ROC for lactate (0.83) and PIM (0.71) are significant	Overall mortality in this cohort 35%
Kaplan and Kellum (38), 2004	Retrospective observational surgical ICU	n = 282 vascular trauma patients	BD, AG, SID, SIG, ISI, lactate	28-d mortality	pH, BD, lactate, AG, SID, SIG predict survival; SIG, AG with ROC 0.99	Single measurement in emergency department; AGc not reported
Martin <i>et al.</i> (32), 2005	Retrospective surgical ICU	n = 2152, laboratory tests in 427 trauma patients	BD, AG, AGc, SIDa, SIDA, SIG, BEua, ISI	Lactate level and mortality	AGc and SIG best predicted lactate level ROC for AGc 0.68 and BEua 0.70 best predicted mortality	In univariate, age and ISI and most acid-base parameters predictor of mortality
Gunnerson <i>et al.</i> (39), 2008	Retrospective observational medical and surgical ICU	n = 851 suspected lactic acidosis; other tests done within 4 h	SID, SIG, lactate, BE, AGc, age	In hospital mortality	In logistic regression analysis, lactate and SIG as well as age and serum phosphate predicted mortality; good correlation between SIG and AGc	AGc for albumin as well as lactate
Kaplan <i>et al.</i> (40), 2008	Prospective surgical ICU	n = 78 consecutive patients with major trauma	SBE, AG, AGc, SIG, lactate	28-d mortality	ROC for SIG 0.959 greater than for AGc of 0.86	28-d mortality 33%

^aICU, intensive care unit; ISI, injury severity score; PIM, pediatric index mortality; ROC, receiver operator characteristic curve.

^bBEua is base excess corrected for water content as well as chloride, albumin, and Pco₂ and reflects changes in BE as a result of presence of abnormal anion. This correlates closely with SIG. For details of the calculation, please refer to reference (33).

Conclusions

Stewart, by creating an alternative view of acid-base universe and developing its own vocabulary and formulas, has challenged the traditional approach. This has led to the development of a new classification of acid-base disorders. This approach, however, is not a paradigm shift, as claimed by its proponents, but a variation on the widely known and controversial model using ionic charge differences to analyze acid-base disorders. In addition, the key components of the Stewart's formulas are closely related to the key components of the traditional formulas. Clinically, the traditional approach is intuitive in nature and is supported by a large body of robust empirical observations. The traditional approach should be abandoned only if proponents of Stewart's approach could provide clear empirical observations supporting its superiority as a clinical tool in diagnosing and treating patients with acid-base disorders.

Disclosures

None.

Appendix. Data from a patient who developed urosepsis resulting in lactic acidosis and acute kidney injury^a

Parameter	1	2
Na	136	136
K	4.5	4.5
Cl	106	108
HCO ³	24	15
Ca	3.3	3.3
P (mmol/L)	1.0	2.0
Mg	1.6	1.6
Albumin (g/dl)	4.4	2.0
Lactate	1.0	6.0
pH	7.40	7.33
Pco ₂ (mmHg)	40	30
AG	6	13
AGc	6	19
ΔAG	0	13
SIDa	39	37
SIDe	38	24
SIG	1	13

^aColumn 1 represents the baseline data, and column 2 represents data obtained on admission to the ICU with fever and hypotension. The formulas used in calculating AG, AGc, SIDa, SIDe, and SIG are shown in Table 1. AG is calculated as Na – (Cl + HCO₃). Note the effect of hypoalbuminemia on AG and ΔAG as well as the relationship between ΔAG and SIG. All values are in mEq/L except as indicated.

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Correction

Erratum for: Clinical Utility of Stewart's Method in Diagnosis and Management of Acid-Base Disorders. *Clin J Am Soc Nephrol* 4: 1267–1274, 2009.

The equation on page 1269 is shown as:

$$\begin{aligned}
 & [H^+]^4 + [H^+]^3 K_a [SID] \\
 & = [H^+]^2 \{ K_a ([SID]) - [A_{TOT}] - (K_1 \times S \times P_{CO_2} + K_w) \} \\
 & - [H^+] (K_a (K_1 \times S \times P_{CO_2} + K_w) + K_a \times K_3 \times K_1 \times S \\
 & \qquad \qquad \qquad \times P_{CO_2} = 0(1,2)
 \end{aligned}$$

The correct equation should instead show a plus sign before $[H^+]^2$, rather than an equals sign. The correct equation is:

$$\begin{aligned}
 & [H^+]^4 + [H^+]^3 K_a [SID] \\
 & + [H^+]^2 \{ K_a ([SID]) - [A_{TOT}] - (K_1 \times S \times P_{CO_2} + K_w) \} \\
 & - [H^+] (K_a (K_1 \times S \times P_{CO_2} + K_w) + K_a \times K_3 \times K_1 \times S \\
 & \qquad \qquad \qquad \times P_{CO_2} = 0(1,2)
 \end{aligned}$$