Acid-base alterations in heatstroke

A. Bouchama
E. B. De Vol

Abstract  Objective: To analyze the acid-base balance during heatstroke.
Design: Retrospective study.
Setting: Heatstroke Center, Makkah, Saudi Arabia.
Patients: Hundred nine consecutive heatstroke patients (mean age 55 ± 12 years) with rectal temperature from 40 to 43.4°C following exposure to hot weather.
Intervention: Arterial blood gases collected prospectively and analyzed using 95% confidence limits established by controlled experimental studies. Severity of heatstroke on admission assessed by Simplified Acute Physiology Score and Organ System Failure score.
Results: Metabolic acidosis was the predominant acid-base change followed by respiratory alkalosis (81 and 55% of the patients, respectively). The prevalence of metabolic acidosis (but not respiratory alkalosis) was significantly associated with the degree of hyperthermia: 63, 95 and 100% at 41, 42 and 43°C, respectively (p < 0.0001). Patients with metabolic acidosis had a large anion gap (24 ± 5). Arterial partial pressure of oxygen (PaO₂), systemic blood pressure and Organ System Failure score were similar with or without metabolic acidosis. Although the acute physiology score was higher in patients with, than without, metabolic acidosis (15.7 ± 3.7 vs 9.8 ± 4.4, p < 0.001), there was no significant difference in neurologic morbidity and mortality (7.9 vs 1.1%, 5.6 vs 0%, p = 0.776 and 0.581, respectively).
Conclusion: We conclude that metabolic acidosis is the predominant response in heatstroke.

Key words  Metabolic acidosis · Respiratory alkalosis · Heat · Heatstroke

Introduction

It has long been established that exposure to heat results in respiratory alkalosis in humans [1, 2], but the effect of extreme hyperthermia on acid-base equilbrium is not well understood. Human volunteers’ intolerance of high temperature limits their exposure to less than 1 h with only a moderate increase in body temperature [3], so that the time-course of acid-base changes has not been comprehensively delineated. Studies on animals suggest that the acid-base response to heat stress is dynamic and progresses in a predictable pattern. Rats [4], oxen [5] and dogs [6] passively exposed to heat develop respiratory alkalosis; metabolic acidosis ensues when a threshold body temperature (which varies according to species) is reached, and if the exposure is prolonged the metabolic acidosis predominates. Furthermore, heatstroke syndrome induces concomitant multi-organ system injury, namely cardiorespiratory, renal, hepatic and neurologic, that may culminate in death. Thus it seems that not only the peak and duration of elevated core temperature, but also organ system dysfunction determine the acid-base response.
Classic heatstroke, a state characterized by elevated core temperature in healthy subjects after prolonged exposure to a hot and humid environment, offers an opportunity to study the changes in acid-base balance over a broad range of elevated body temperature. Only two small series have been reported and they give conflicting results [7, 8]. In one study [8], metabolic acidosis was the predominant disorder at presentation. In the other study [7], respiratory alkalosis was predominant, metabolic acidosis was unusual and associated with high neurologic morbidity and mortality. In neither study were acid-base changes classified according to the 95% confidence limits established by controlled experimental studies [9, 10] and no attempt was made to identify those patients with metabolic acidosis masked by the presence of concomitant respiratory alkalosis. Further, most of the patients had underlying disease, or were on medication that may have interfered with their acid-base regulation [7, 8].

The present investigation was undertaken to: (1) study the acid-base status in a large series of patients with elevated core temperature secondary to exposure to a high ambient temperature; (2) examine the relationship between heatstroke and the acid-base changes; (3) analyze the clinical and metabolic consequences of heatstroke-related acid-base alterations.

**Materials and methods**

**Methods**

The study was retrospective but based on a prospectively collected database. Part of this database was published previously [11]. One hundred and nine patients admitted to the Heatstroke Center in Makka during three consecutive annual pilgrimages, had a diagnosis of heatstroke based on rectal temperature over 40°C, neurologic signs (convulsions, coma and/or delirium) and history of exposure to hot weather. All were entered into the study.

Blood pressure, pulse and respiratory rates were recorded immediately on admission. Temperature was recorded continuously from a thermistor probe placed in the rectum. Neurologic status was assessed by the Glasgow Coma Score and index of severity of illness was calculated using the Simplified Acute Physiology Score (SAPS) [12] and the acute Organ System Failure score (OSF) [13]. Blood samples were taken immediately, before parental treatment or cooling was started. Fifty-eight patients (53%) received oxygen via nasal prongs or facemask and the remainder (47%) breathed in room air. Arterial blood was drawn anaerobically, packed in ice and sent immediately to the laboratory for blood gas analysis using an ABL III (Radiometer, Copenhagen). Blood gas values were measured at 37°C and corrected to the patient’s actual temperature [14].

Acid-base changes were classified according to the 95% confidence limits constructed for acute and chronic hypocapnia in anesthetized patients passively hyperventilated during minor surgical procedures [9] and in normal healthy volunteers subjected to altitude-induced hypobaric hypoxia [10], respectively. Simple acute or chronic respiratory alkalosis was assumed to be present if the changes in PaCO₂ and pH or hydrogen ion activity (H⁺) estimated from pH as \( H^+ = 10^{-\text{pH}} \) were within the corresponding 95% confidence limits. Metabolic acidosis was assumed if the changes in PaCO₂ and pH were above the upper border of the 95% confidence limits. The metabolic acidosis was further interpreted as mixed with respiratory alkalosis if the pH was between 7.36 and 7.42 or simple if the pH was less than 7.36 (Fig. 1). Plasma electrolytes were measured on an auto-analyzer. Anion gap was calculated according to the formula \( \text{Na}^+ - (\text{HCO}_3^- + \text{Cl}^-) \).

The patients were cooled using the principle of dissipation of heat by evaporation, as reported previously [15]. Cooling time was recorded as the time from arrival in the cooling unit to the first measured temperature of 39.4°C. Neurologic morbidity was considered to be present if the Glasgow Coma Score was less than 15 at 24 h after completion of cooling. Mortality was recorded at hospital discharge. Long-term follow-up after hospital discharge was not available.

This study was approved by the Research Advisory Council of King Faisal Specialist Hospital and waived the need for informed consent.

**Statistical analysis**

The data were analyzed using SAS version 6.12 (SAS Institute, Cary, N.C.). The values are expressed as means ± SD or as median (25th–75th percentile). ANOVA and Fisher’s exact test were used to compare variables between different groups of patients according to acid-base status. When a statistically significant difference was observed by ANOVA, Duncan’s multiple comparisons method was used. Furthermore, Bonferroni correction was used to adjust for the large number of statistical comparisons.

The confidence limits for acute respiratory alkalosis were derived from data derived from Arbus et al. [9]; those for chronic respiratory alkalosis were derived by digitizing the points from the

![Fig. 1 Ninety-five percent confidence limits for acute (dashed line) and chronic (continuous line) respiratory alkalosis [9, 10]. Horizontal and vertical lines indicate a pH (or H⁺) of 7.36 units and PaCO₂ of 42 mmHg, respectively. Arterial blood pH (or H⁺) and PaCO₂ of each patient are superimposed on the 95% confidence limits. Simple respiratory alkalosis (solid circle), normal acid base (empty black circle), mixed respiratory alkalosis and metabolic acidosis (empty diamond), simple metabolic acidosis (solid diamond), mixed respiratory and metabolic acidosis (empty square) and metabolic alkalosis (empty gray circle)](image-url)