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Acid Base Balance and Its Influence on Sperm Quality and Count: A Narrative Review

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Abstract

Male infertility is a major reproductive-health concern in which abnormalities in sperm concentration, total sperm number, motility, morphology, and sperm DNA integrity may contribute to reduced reproductive potential. Spermatogenesis is a complex and highly regulated process requiring coordinated endocrine signaling, adequate energy metabolism, appropriate testicular temperature, nutritional support, and maintenance of a stable biochemical microenvironment. Acid-base homeostasis is fundamental to cellular physiology because hydrogen-ion concentration influences protein structure, enzyme activity, membrane transport, mitochondrial function, and metabolic reactions. However, the relationship between systemic acid-base status and male fertility require careful interpretation. In healthy individuals, arterial blood pH is maintained within a narrow physiological range, approximately 7.35-7.45, through integrated chemical buffering, respiratory regulation, and renal mechanisms. Consequently, ordinary dietary differences in acid-producing or alkalizing foods do not generally produce clinically meaningful changes in systemic blood pH.

Clinically significant acid-base disturbances may occur in severe systemic disorders, including advanced kidney disease and major metabolic illnesses. Such disorders may coexist with impaired reproductive function, but the available evidence suggests that reproductive impairment is more likely to reflect a complex interaction among oxidative stress, inflammation, mitochondrial dysfunction, endocrine abnormalities, vascular dysfunction, and impaired metabolism rather than a direct effect of altered blood pH alone. Seminal-fluid pH represents a separate physiological parameter and may provide information regarding the male reproductive tract and accessory-gland function. Dietary quality and lifestyle factors may also influence semen quality through effects on metabolic health, antioxidant status, inflammation, and nutritional adequacy rather than through direct systemic alkalinization. This review summarizes the physiological basis of acid-base regulation, potential mechanisms linking systemic metabolic disturbances with sperm dysfunction, the distinction between blood and seminal pH, and the clinical implications for evaluation of male infertility.

Keywords: Acid Base Balance; Male Infertility; Sperm Quality; Sperm Count; Semen pH

Introduction

Male reproductive function depends on the coordinated regulation of spermatogenesis, steroidogenesis, sperm maturation, and transport through the male reproductive tract. Semen quality is conventionally evaluated using parameters including sperm concentration, total sperm number, motility, morphology, and other laboratory characteristics according to standardized procedures. The sixth edition of the World Health Organization (WHO) Laboratory Manual for the Examination and Processing of Human Semen provides internationally standardized procedures for semen examination and remains an important reference for clinical and research laboratories. [1,2] Cellular processes involved in spermatogenesis require a tightly regulated biochemical environment. Hydrogen-ion concentration and acid-base balance influence enzymatic reactions, protein conformation, membrane transport, cellular signaling, and mitochondrial metabolism. These observations have led to interest in whether systemic acid-base disturbances could influence sperm production and function. However, it is important to distinguish physiological acid-base regulation from the popular concept of "body acidity." Human arterial pH is maintained within a very narrow range through the interaction of chemical buffers,

pulmonary carbon-dioxide elimination, and renal regulation of hydrogen ions and bicarbonate. [3-5] Therefore, dietary consumption of foods commonly described as "acidic" or "alkaline" does not normally cause substantial changes in arterial blood pH in healthy individuals. The objective of this narrative review is to examine the potential relationship between acid-base balance and male reproductive function while distinguishing established physiological mechanisms from hypotheses that require further investigation.

Physiological Regulation of Acid-Base Homeostasis

Acid base homeostasis is essential for maintaining normal cellular function. The major physiological systems involved include chemical buffer systems, respiratory regulation, and renal control. The bicarbonate-carbonic acid system provides an important extracellular buffer. The lungs regulate carbon dioxide elimination, whereas the kidneys contribute to long-term acid-base control through hydrogen-ion secretion, bicarbonate reabsorption, and generation of new bicarbonate. [3-5] These mechanisms work together to prevent clinically significant changes in arterial pH. The normal physiological range of arterial blood pH is approximately 7.35-7.45. Small deviations may occur transiently, but substantial persistent deviations indicate clinically important disturbances requiring evaluation. Acidosis and alkalosis may result from respiratory or metabolic abnormalities, including impaired ventilation, excessive carbon-dioxide retention, gastrointestinal bicarbonate loss, renal dysfunction, or disturbances in organic-acid metabolism. [3,4] This physiological regulation has an important implication for discussions of male fertility. A diet that contains a relatively high proportion of acid-producing foods does not necessarily cause systemic acidosis. Similarly, consumption of fruits and vegetables does not meaningfully "alkalize the blood" in a healthy person. The biological effects of dietary patterns on reproductive health should therefore be interpreted primarily through nutritional, metabolic, inflammatory, and antioxidant mechanisms rather than presumed changes in systemic blood pH.

Spermatogenesis and the Importance of Cellular Homeostasis

Spermatogenesis involves the proliferation and differentiation of germ cells within the seminiferous epithelium. Sertoli cells provide structural, metabolic, and nutritional support to developing germ cells, while Leydig cells produce testosterone under the regulation of the hypothalamic-pituitary-gonadal axis. The process requires substantial energy and depends on appropriate mitochondrial function, redox balance, protein synthesis, membrane integrity, and intracellular signaling. Consequently, conditions that disturb cellular metabolism may adversely affect sperm production and function. Although acid-base balance is fundamental to cellular physiology, direct evidence that small systemic pH variations independently determine sperm count is currently insufficient. Severe systemic metabolic disturbances may influence reproductive function, but such effects are likely to occur through several interacting pathways rather than through hydrogen-ion concentration alone.

Potential Relationship Between Metabolic Disturbances and Sperm Quality

Oxidative stress

Oxidative stress is one of the most extensively investigated mechanisms underlying impaired male reproductive function. Spermatozoa contain abundant polyunsaturated fatty acids and have relatively limited cytoplasmic antioxidant defenses. Excessive production of reactive oxygen species (ROS) may therefore produce lipid peroxidation, mitochondrial dysfunction, protein oxidation, impaired sperm motility, and DNA damage. [6-9] Oxidative stress may provide an important mechanistic link between systemic metabolic disease and impaired semen quality. However, this relationship should not be interpreted as evidence that ordinary dietary acid load causes sperm oxidative damage through systemic acidosis. Rather, oxidative stress is more plausibly associated with broader metabolic and inflammatory abnormalities.

Mitochondrial dysfunction

Mitochondria are central to sperm energy production and motility. Mitochondrial dysfunction can increase ROS generation and reduce cellular energy availability. Because sperm motility is highly dependent on efficient energy metabolism, disturbances in mitochondrial function may contribute to reduced progressive motility and impaired sperm function. [7-9] Severe systemic illness and metabolic disturbances can affect mitochondrial activity in multiple tissues. Whether clinically significant systemic acid-base abnormalities independently alter sperm mitochondrial function remains an important area for future research.

Endocrine mechanisms

Normal spermatogenesis depends on the hypothalamic-pituitary-gonadal axis. Gonadotropin-releasing hormone stimulates pituitary secretion of luteinizing hormone and follicle-stimulating hormone. Luteinizing hormone stimulates Leydig-cell testosterone production, whereas follicle-stimulating hormone acts primarily through Sertoli cells to support germ-cell development. Chronic systemic disease may disturb this endocrine system. Obesity, diabetes, chronic kidney disease, and other metabolic conditions may be associated with altered testosterone concentrations and reproductive dysfunction. Such abnormalities should, however, be evaluated directly rather than attributed automatically to acid-base imbalance.

Inflammation and metabolic dysfunction

Chronic inflammation and metabolic dysfunction may influence reproductive function through oxidative stress,

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endothelial dysfunction, altered hormone signaling, and changes in testicular cellular activity. Obesity and metabolic syndrome, for example, may create a systemic environment characterized by inflammation, oxidative stress, insulin resistance, and hormonal disturbance. Therefore, when reproductive dysfunction occurs in individuals with major metabolic abnormalities, acid-base disturbance should generally be considered one possible component of a broader physiological disturbance rather than the primary cause.

Systemic Blood pH Versus Seminal Plasma pH

A major conceptual distinction is required between systemic arterial blood pH and seminal-fluid pH. Systemic blood pH is tightly regulated by the lungs, kidneys, and buffer systems. In contrast, seminal fluid represents a specialized reproductive-tract environment influenced by secretions from the prostate, seminal vesicles, and other accessory reproductive structures. Seminal pH can therefore provide information about the local reproductive tract. Abnormal semen pH may occur in association with infection, inflammation, obstruction, or altered accessory-gland secretions. Semen pH should consequently be interpreted together with the clinical history, physical examination, and other semen parameters rather than as a surrogate marker of systemic blood pH. [1,2] Thus, an abnormal seminal pH should not automatically be interpreted as evidence of systemic acidosis or alkalosis.

Dietary Acid Load and Male Reproductive Health

Dietary patterns have attracted considerable interest in relation to male reproductive health. Diets rich in fruits, vegetables, whole grains, legumes, nuts, and other nutrient-dense foods provide antioxidants, vitamins, minerals, fiber, and bioactive compounds that may support metabolic and reproductive health. Conversely, dietary patterns characterized by high consumption of ultra-processed foods, processed meats, refined carbohydrates, and excessive energy intake may be associated with poorer metabolic health. Recent evidence suggests that healthier dietary patterns, including Mediterranean-style dietary patterns, may be associated with more favorable semen parameters in some populations.[10,11] A 2025 systematic review and meta-analysis specifically evaluated adherence to the Mediterranean diet in relation to semen quality and medically assisted reproductive outcomes, highlighting growing interest in dietary quality as a potentially modifiable factor in male reproductive health.[11] Nevertheless, these findings should not be interpreted as evidence that dietary "alkalization" directly increases sperm count. The potential benefits of a healthy dietary pattern are more plausibly explained by improved nutrient intake, antioxidant availability, metabolic health, reduced inflammation, and better overall physiological function.

Lifestyle Factors and Sperm Quality

Lifestyle factors may have substantially greater practical importance for male reproductive health than minor differences in dietary acid load.

Potentially modifiable factors include:

- ✓ obesity and excessive adiposity;
- ✓ tobacco exposure;
- ✓ excessive alcohol consumption;
- ✓ physical inactivity;
- ✓ poor dietary quality;
- ✓ inadequate sleep;
- ✓ uncontrolled diabetes and other metabolic diseases;
- ✓ exposure to environmental pollutants;
- ✓ excessive heat exposure; and
- ✓ certain medications and recreational substances.

These factors may affect reproductive function through oxidative stress, inflammation, endocrine disruption, mitochondrial dysfunction, vascular abnormalities, and direct effects on testicular cells. [6-9] Accordingly, a comprehensive approach to male reproductive health should focus on overall metabolic and lifestyle health rather than attempting to manipulate systemic blood pH through dietary "alkalization."

Chronic Kidney Disease and Acid-Base Disturbances

Chronic kidney disease provides an important clinical example of the interaction between systemic metabolism, acid-base physiology, and reproductive health. The kidneys have a central role in maintaining acid-base balance through hydrogen-ion excretion and bicarbonate regulation. [4,5] Advanced kidney disease may be accompanied by metabolic acidosis, endocrine abnormalities, inflammation, oxidative stress, anemia, nutritional abnormalities, and vascular dysfunction. These abnormalities may collectively contribute to impaired reproductive function. The 2024 KDIGO Clinical Practice Guideline emphasizes the systemic nature of chronic kidney disease and its associated metabolic complications.[12] Importantly, reproductive abnormalities observed in chronic kidney disease should not be attributed to metabolic acidosis alone. The underlying renal disease and its multiple systemic consequences may be more important determinants.

Clinical Evaluation of Male Infertility

The evaluation of male infertility should be systematic and evidence-based. Semen analysis remains a fundamental component of laboratory assessment and should be performed according to standardized procedures. [1,2]

Important semen parameters include:

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- ✓ sperm concentration;
- ✓ total sperm number;
- ✓ total and progressive motility;
- ✓ sperm morphology;
- ✓ semen volume;
- ✓ semen pH; and
- ✓ other clinically indicated laboratory parameters.

When clinically indicated, additional evaluation may include reproductive hormone testing, assessment of metabolic disorders, investigation for genital-tract infection or inflammation, evaluation of varicocele, genetic testing in selected patients, and assessment of sperm DNA integrity. Routine blood acid-base testing should not be considered a standard fertility investigation in otherwise healthy individuals. Acid-base assessment is more appropriately performed when there is a clinical indication of an underlying metabolic, renal, respiratory, or systemic disorder.

Current Evidence and Knowledge Gaps

The available literature supports a strong biological rationale for maintaining normal acid-base homeostasis but provides limited evidence that small variations in systemic blood pH independently determine sperm count or semen quality.

Several research questions remain unresolved.

First, prospective studies are needed to determine whether clinically meaningful acid-base abnormalities are independently associated with sperm concentration, motility, morphology, or DNA integrity. Second, future studies should simultaneously evaluate arterial or venous acid-base parameters, renal function, metabolic markers, reproductive hormones, oxidative-stress biomarkers, mitochondrial function, and semen parameters. Third, important confounders should be controlled, including age, body mass index, smoking, alcohol consumption, diabetes, kidney disease, medication exposure, physical activity, diet, environmental exposures, and socioeconomic factors. Fourth, research should distinguish between clinically significant metabolic acidosis or alkalosis and normal variation associated with dietary patterns. This distinction is essential because these conditions have fundamentally different physiological meanings.

Clinical and Preventive Implications

Current evidence does not support the use of dietary "alkalization" as an established treatment for low sperm count or male infertility.

A more evidence-based preventive strategy should include:

- ✓ maintaining a healthy body weight;
- ✓ consuming a balanced, nutrient-dense diet rich in fruits and vegetables;
- ✓ obtaining adequate protein, micronutrients, and essential fatty acids;
- ✓ undertaking regular physical activity;
- ✓ avoiding tobacco and recreational drug exposure;
- ✓ limiting excessive alcohol consumption;
- ✓ maintaining adequate sleep;
- ✓ managing diabetes and other chronic metabolic conditions;
- ✓ avoiding unnecessary exposure to excessive testicular heat; and
- ✓ seeking appropriate medical evaluation when infertility is suspected.

Longitudinal studies would be particularly valuable because spermatogenesis is a dynamic process and may respond to changes in systemic health over time. It would also be useful to investigate whether severe metabolic acidosis, chronic kidney disease, diabetes, or other systemic disorders produce measurable alterations in the testicular microenvironment and sperm epigenome.

Conclusion

Acid-base homeostasis is fundamental to human physiology and is essential for normal enzymatic activity, protein structure, membrane transport, cellular metabolism, and mitochondrial function. However, systemic arterial pH is tightly regulated, and ordinary dietary differences in acid-producing or alkalizing foods do not generally produce substantial changes in blood pH in healthy individuals. The current evidence therefore supports a predominantly indirect relationship between systemic acid-base disturbances and male reproductive health. Severe metabolic disorders may coexist with impaired sperm production or function, but oxidative stress, mitochondrial dysfunction, inflammation, endocrine abnormalities, vascular dysfunction, nutritional disturbances, and the underlying systemic disease are likely to contribute substantially to these reproductive effects. Seminal-fluid pH should be considered separately from systemic blood pH because it reflects the specialized biochemical environment of the male reproductive tract and may provide information concerning accessory-gland function and reproductive-tract pathology.

Consequently, the proposition that "body acidity" directly causes low sperm count should be interpreted cautiously. Current evidence does not establish minor dietary acid load or ordinary variation in dietary pH as an independent cause of male infertility. A more scientifically appropriate model considers acid-base balance as one component of a broader metabolic and cellular environment. Future prospective and mechanistic studies are needed to determine whether clinically significant acid-base abnormalities independently affect spermatogenesis and sperm function. Until such evidence becomes available, clinical

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management should emphasize standardized semen analysis, identification of established causes of male-factor infertility, optimization of metabolic and lifestyle health, and appropriate treatment of underlying systemic disease.

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