Energy Drinks and Health Risks Across Organ Systems: Clinical and Public Health Implications

Giorgio Maria Orazi*

Università Cattolica del Sacro Cuore, Rome, Italy

Received: 4 April 2026

Accepted: 9 November 2026

*Corresponding author: giorgiomaria.orazi01@icatt.it

DOI 10.5001/omj.2029.35

Abstract

Energy drinks remain widely consumed, particularly among adolescents and young adults, despite growing concern regarding their safety profile. These beverages typically contain caffeine in combination with sugar, taurine, guarana, ginseng, vitamins, and other additives, with substantial variability across products and incomplete transparency for some ingredients. This narrative review examines the available evidence on the health risks associated with energy drink consumption across major organ systems and discusses the broader public health implications of their widespread use. The literature indicates that the strongest and most consistent signals concern acute cardiovascular effects, especially increases in blood pressure and, in some studies, alterations in ventricular repolarization; sleep disruption, including reduced sleep duration and poorer sleep quality; and neuropsychiatric and behavioral correlates, such as anxiety, stress, depressive symptoms, and selected risk-related behaviors. Evidence also supports concern regarding high-risk patterns of use involving alcohol and other substances, particularly in college-age and emergency care populations. Additional findings suggest possible acute metabolic effects on glucose-insulin homeostasis, whereas renal, hepatic, and gastrointestinal complications are described mainly in case-based literature. Oral health studies further indicate erosive potential on dental enamel under experimental conditions. Children, adolescents, and young adults appear especially vulnerable because of high exposure, aggressive marketing, and frequent consumption in risky behavioral contexts. Overall, energy drinks should not be regarded as risk-free lifestyle beverages, particularly in vulnerable individuals and in high-risk patterns of use. Greater clinical awareness, stronger risk communication, and more rigorous prospective research are needed to clarify long-term outcomes, vulnerable subgroups, and the impact of regulatory strategies.

Keywords: Energy Drinks; Caffeine; Adolescent; Young Adult; Cardiovascular Diseases; Sleep; Alcohol Drinking; Public Health

Introduction

Energy drink (ED) consumption has emerged as a significant public health issue, and these beverages have become increasingly normalized, particularly among adolescents and young adults.[1,3] Since the introduction of Red Bull in Austria in 1987 and in the United States in 1997, the market has grown rapidly; by 2006, approximately 500 new brands had been launched worldwide.[1] Between 2004 and 2009, sales of energy drinks in the United States increased by 240%.[2] These products are typically formulated to enhance mental alertness and physical stimulation and commonly contain caffeine, taurine, sugar, herbal extracts such as guarana and ginseng, and B vitamins.[2-4]

A major concern is the marked heterogeneity of these products, which differ substantially in caffeine content, serving size, sugar load, and overall formulation.[1] While a standard 12-ounce caffeinated soda typically contains between 35 mg and 54 mg of caffeine, the caffeine content in EDs can range from a modest 50 mg to as much as 505 mg per serving.[1,2] Despite this variability, aggressive marketing strategies continue to target young adults and adolescents, often highlighting claims of improved performance, focus, and stamina.[2,3] This is particularly concerning given that approximately one-third of adolescents aged 12 to 17 years and about half of college students report consuming EDs regularly.[2]

The clinical implications of ED consumption are extensive and involve multiple organ systems, including the cardiovascular, neuropsychiatric, gastrointestinal, renal, endocrine, and behavioral domains.[3] In a systematic review and meta-analysis of 32 studies involving 96,549 individuals, Nadeem et al. reported that the most frequent adverse events in pediatric populations were insomnia (35.4%), stress (35.4%), and depressive mood (23.1%).[2] In adults, the most common effects were jitteriness or restlessness (29.8%), insomnia (24.7%), and gastrointestinal upset (21.6%).[2] Furthermore, mixing EDs with alcohol has been shown to significantly reduce perceived sedation while increasing stimulatory effects, potentially masking symptoms of intoxication.[2]

More severe adverse events have also been documented, ranging from tachycardia and anxiety to rare life-threatening events such as ventricular fibrillation, seizures, stroke, and sudden cardiac death.[4] The absence of consistent regulatory oversight and the lack of transparent labeling regarding potential adverse effects may further amplify these risks.[1,3] The aim of this review is to critically examine the health risks associated with energy drink consumption across major organ systems and to discuss their broader public health implications, with particular attention to vulnerable populations and patterns of co-consumption with alcohol.[1-4] The main clinical and public health domains potentially affected by energy drink consumption are summarized in Figure 1.[5-57]

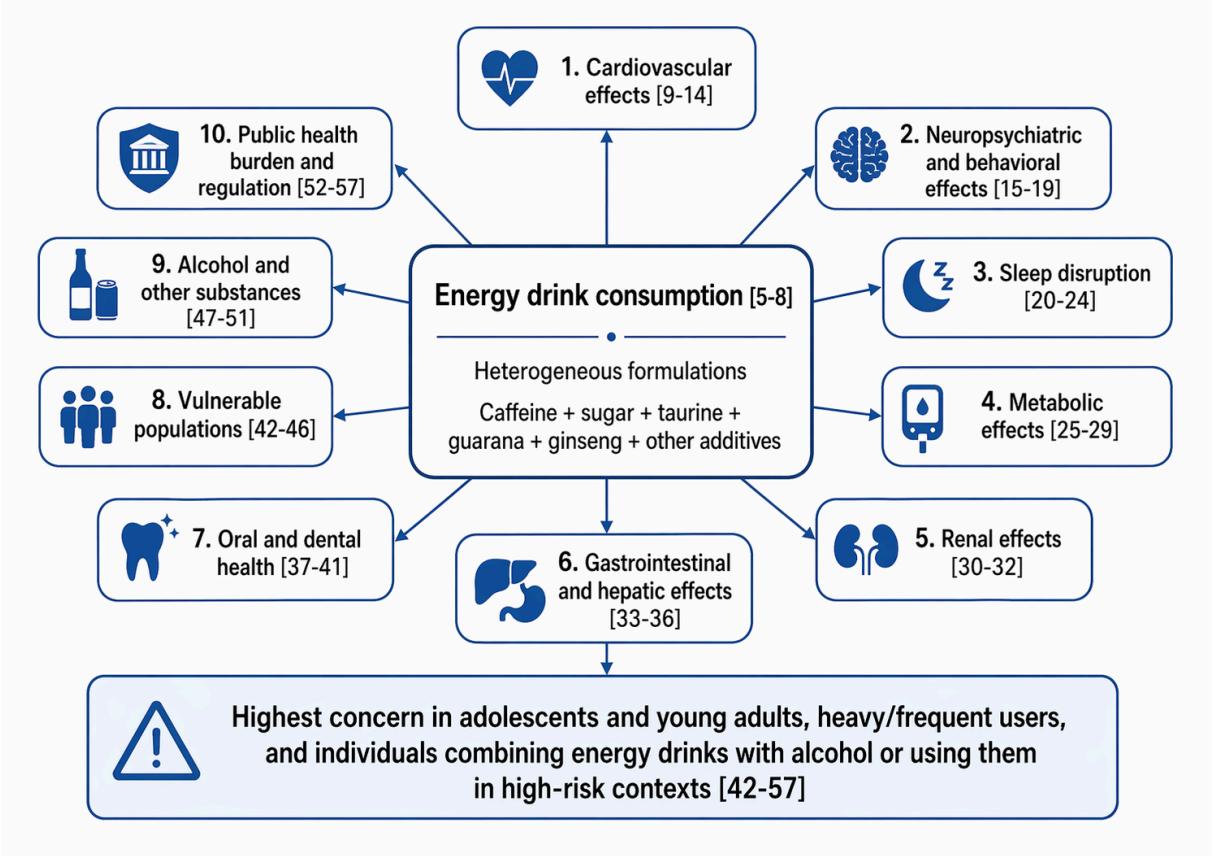


Figure 1: Overview of health risks associated with energy drink consumption across organ systems and public health domains.[5-57]

At the center, energy drink consumption is characterized by heterogeneous formulations typically involving caffeine with additional ingredients such as sugar, taurine, guarana, ginseng, glucuronolactone, and vitamins.[5-8] Surrounding domains include cardiovascular effects,[9-14] neuropsychiatric and behavioral correlates,[15-19] sleep disruption,[20-24] metabolic effects,[25-29] renal effects,[30-32] gastrointestinal and hepatic effects,[33-36] oral and dental effects,[37-41] vulnerable populations,[42-46] co-use with alcohol and other substances,[47-51] and broader public health implications including prevalence, healthcare utilization, marketing exposure, and regulatory concerns.[52-57]

Methods

This narrative review was based on a focused search of the PubMed database to identify literature addressing energy drink consumption and adverse health effects. Searches used the phrase “energy drink” alone and in iterative combinations with domain-specific terms corresponding to the predefined scope of the review, including caffeine, cardiovascular effects, arrhythmia, neuropsychiatric effects, sleep, metabolic effects, renal injury, gastrointestinal effects, hepatic effects, oral health, adolescents, alcohol, and public health. The search was intentionally iterative rather than based on a single prespecified Boolean string, consistent with the narrative design and the broad range of clinical, behavioral, and public health outcomes considered. The final literature search was performed on April 23, 2026.

To improve completeness, the reference lists of relevant articles were also examined to identify additional PubMed-indexed studies of interest. Only articles published in English were considered. Priority was given to human studies, including observational studies and clinical trials. Case reports and case series were retained when they described rare or severe adverse events for which higher-level clinical evidence was limited, whereas in vitro studies were considered in domains such as oral health when they provided relevant mechanistic or biological-plausibility evidence.

Selected review articles, surveillance reports, and policy-oriented publications were used when useful to contextualize the topic, identify additional primary studies, or address population-level and regulatory implications.

Study selection followed a staged, relevance-based process appropriate to a narrative review. Records identified through the focused searches were assessed at title and abstract level for potential relevance, and potentially pertinent publications were subsequently evaluated in full text. Studies were retained when they provided direct evidence on adverse health effects, clinically relevant mechanisms of harm, vulnerable populations, high-risk patterns of consumption, healthcare utilization, marketing exposure, or regulatory and public health implications. Publications focused solely on performance outcomes without relevant safety information, duplicate reports, and articles without a meaningful connection to the predefined review domains were not prioritized. Because this was not designed as a systematic review, study-flow counts were not prospectively maintained, duplicate screening was not performed, and a PRISMA-style flow diagram was not generated. The selected literature was then organized into the predefined thematic sections of the review.

Given the narrative objective of the review and the marked heterogeneity of the included evidence, no formal meta-analysis or standardized risk-of-bias/quality-assessment instrument was applied. This decision reflected the aim of providing a broad clinical and public health synthesis rather than a pooled quantitative effect estimate, as well as the inclusion of evidence ranging from randomized and experimental human studies to observational studies, case reports, in vitro investigations, surveillance data, and policy literature. Nevertheless, the evidence was critically appraised according to study design, sample size, directness of exposure and outcome assessment, consistency with other findings, potential for confounding, characterization of dose and co-exposures, and clinical applicability. Conclusions were weighted accordingly, with greater inferential weight given to controlled human and prospective evidence than to isolated case-based or in vitro findings. The absence of a formal quality score is acknowledged as a methodological limitation.

Composition and Mechanisms of Potential Harm

Energy drinks (EDs) are a heterogeneous group of beverages marketed to improve energy, focus, and alertness.[1,3,4] Their formulations vary substantially across brands and typically involve a combination of caffeine, taurine, sugars, B vitamins, glucuronolactone, and herbal extracts such as guaraná and ginseng.[5-8]

Heterogeneity and Ingredient Profile

The complexity of these formulations is illustrated by a label-based analysis of 75 products (55 EDs and 20 energy shots) in the United States, which found a mean of 18.2 ± 5.7 ingredients per product.[5] In this study, caffeine was present in 100% of formulations, while vitamin B6, B3, and B12 were found in approximately 67-72% of products.[5] Notably, 15 of these formulations used proprietary blends with undisclosed ingredient amounts, and many contained B-vitamin levels significantly exceeding recommended daily values.[5] Sugar was present in 45.3% of the formulations, whereas herbal extracts such as ginseng and guaraná were found in 30.7% and 25.3%, respectively.[5]

Caffeine: The Principal Active Constituent

Caffeine is the only ingredient consistently characterized across most products.[5,6] Mean caffeine content has been reported at 174.4 ± 81.1 mg per serving, with values ranging from 45 mg to 400 mg.[5] Other reports suggest that a typical 235 mL ED provides between 40 and 250 mg of caffeine,[6] although concentrations can reach up to 505 mg in some high-potency formulations.[1] The lack of disclosure of exact quantities in certain brands remains a significant clinical challenge.[7]

Taurine and Other Additives

Taurine is among the most frequent non-caffeine ingredients and is typically found in doses of 750-1000 mg per serving in popular brands such as Red Bull, Monster, and Rockstar.[6,7] However, quantitative disclosure is inconsistent, and taurine is frequently listed without a declared amount.[5] Other recurring constituents include glucuronolactone and amino acids, although their exact concentrations are often not transparent.[6,7]

Functional Synergy and Evidence of Performance

Current evidence identifies caffeine as the primary driver of the stimulatory effects associated with EDs.[6,8] Systematic evaluations have found an overwhelming lack of evidence that components other than caffeine, with the minor exception of glucose and guaraná, contribute meaningfully to physical or cognitive performance enhancement.[6] This is supported by experimental data: a double-blind crossover study by Peacock et al. demonstrated that 80 mg of caffeine facilitated reaction time, whereas 1000 mg of taurine showed no independent performance benefit.[8] Furthermore, the co-administration of taurine appeared to attenuate the facilitative effect of caffeine in stimulus degradation tasks.[8]

Mechanistic Plausibility of Harm

The biological risk of EDs is primarily mediated through excessive sympathetic activation. High caffeine doses increase catecholamine release, leading to positive inotropic and chronotropic effects on the heart.[3,4] This mechanism may be further exacerbated by high sugar content, averaging 25-30 g per 250 mL, which contributes to acute glycemic spikes and metabolic strain.[1,3] Additionally, the acidic pH of these beverages, ranging from 1.5 to 3.3, is a documented factor in dental enamel erosion.[4] Therefore, caffeine remains the best-defined active constituent, whereas the contributions of taurine and other additives should be interpreted with caution because their independent effects remain insufficiently established.[5-8] The main ingredients commonly found in energy drinks and their proposed mechanisms relevant to harm are summarized in Table 1.[5-8]

Table 1: Main ingredients of energy drinks and proposed mechanisms of harm.[5-8]

Ingredient	Typical role in energy drinks	Proposed mechanism(s) relevant to harm	Main concerns relevant to this review
Caffeine[5-8]	Principal psychoactive stimulant	Adenosine receptor antagonism; increased alertness and wakefulness; sympathetic stimulation[6-8]	Acute increases in blood pressure and heart rate, possible contribution to repolarization changes in some settings, anxiety, jitteriness, sleep disruption, and high-dose toxicity[6-8]
Taurine[5-8]	Common non-caffeine additive	Putative neuromodulatory and metabolic effects; possible interaction with caffeine[7,8]	Independent clinical contribution remains uncertain; possible interaction with caffeine may complicate interpretation of adverse effects[7,8]
Sugar[5-7]	Common caloric component in many formulations	Rapid carbohydrate load; glycemic and insulinemic stimulation[5,6]	Acute glucose-insulin excursions, potential contribution to obesity/metabolic risk, and oral health concerns when combined with acidic beverages[5,6]
Guarana[5-7]	Herbal additive frequently included in “energy blends”	Additional source of caffeine and other methylxanthines[6,7]	May increase total stimulant burden beyond declared caffeine content; labeling transparency may be limited[6,7]
Ginseng[5-7]	Herbal additive in some products	Claimed stimulant or performance-related effect[6,7]	Independent role in routine energy drink toxicity is unclear; potential interactions remain insufficiently characterized[6,7]
Glucuronolactone[5-7]	Common additive in commercial formulations	Proposed metabolic or “performance” support[6,7]	Clinical relevance remains uncertain; difficult to isolate from combined ingredient effects[6,7]
B-group vitamins[5-7]	Frequently present, sometimes in high amounts	Marketed as supporting energy metabolism[5,6]	Functional stimulant role is unclear; high quantities may contribute little to acute desired effects yet reinforce a “health halo” around products[5,6]

Other proprietary blend components[5-7]	Variable by brand	Product-specific and often incompletely disclosed[5,6]	Heterogeneity of formulations limits comparability across studies and complicates dose-response interpretation[5-7]

Cardiovascular Effects

Cardiovascular effects are among the most consistently reported acute adverse findings associated with energy drink consumption.[9-14] Across controlled studies, the most reproducible signal is a transient increase in blood pressure, whereas heart-rate and electrocardiographic changes are less uniform and appear more dependent on dose, product formulation, and host susceptibility.[9-14] This distinction is important because controlled physiological changes provide stronger evidence of an acute effect than temporally associated arrhythmic events reported in susceptible individuals, which remain clinically concerning but do not by themselves establish causality.[11-14]

Hemodynamic Parameters

In an early prospective study of 15 healthy adults, Steinke et al. found that, after consumption of 500 mL of a commercially available ED, the maximum mean SBP and HR occurred at 4 hours, whereas the maximum mean diastolic blood pressure (DBP) occurred at 2 hours.[9] Within 4 hours of consumption, SBP increased by 7.9% on day 1 and 9.6% on day 7, while HR increased by 7.8% on day 1 and 11.0% on day 7.[9] Similarly, Elitok et al. reported in 50 healthy subjects that single low-dose Red Bull (355 mL) consumption did not acutely alter PR, QRS, QT, QTc, or Tp-e intervals, although HR and mean BP increased 1-2 hours post-ingestion.[10]

Ventricular Repolarization and High-Volume Intake

Recent randomized crossover trials suggest that high-volume consumption significantly affects cardiac repolarization.[11,12] Fletcher et al. demonstrated that, after 946 mL of an ED, the baseline-adjusted corrected QT (QTc) interval was significantly higher compared with a caffeine-matched control at 2 hours, and SBP remained elevated even at 6 hours.[11] In a larger trial (n=34), Shah et al. found that 32 oz of EDs significantly prolonged the QTc interval compared with placebo, with a maximum change in Bazett-corrected QT interval of +17.9 ± 13.9 ms for one brand and +19.6 ± 15.8 ms for another, versus +11.9 ± 11.1 ms for placebo.[12]

Pediatric and Vulnerable Populations

Evidence in younger populations suggests that acute rhythm-related effects may occur even in the absence of structural heart disease. Mandilaras et al. conducted a randomized trial in 26 healthy children and adolescents and found that ED consumption significantly increased the number of supraventricular extrasystoles compared with placebo.[13] Although malignant ventricular arrhythmias were not observed, this finding highlights the sensitivity of the pediatric electrical conduction system.[13]

Furthermore, case-based data raise concern regarding EDs as potential triggers in susceptible individuals. A retrospective review from a genetic heart rhythm clinic identified 7 of 144 sudden cardiac arrest survivors (5%) who had consumed an ED in close temporal proximity to their event.[14] Diagnoses among these patients included long QT syndrome, catecholaminergic polymorphic ventricular tachycardia, and idiopathic ventricular fibrillation.[14] While these findings do not establish direct causality, they support clinical caution in individuals with underlying arrhythmogenic disorders.[14]

Neuropsychiatric and Behavioral Effects

The literature on neuropsychiatric and behavioral effects of energy drinks is driven predominantly by observational studies and systematic syntheses of psychosocial correlates, particularly in adolescents and young adults.[15-19] Across this body of evidence, the most consistent signals concern anxiety, stress, depressive symptoms, suicidality, and selected behavioral correlates, whereas stronger causal inferences remain limited by the predominance of cross-sectional designs.[15-19]

In children and adolescents, the available evidence suggests that energy drink use clusters with a range of unfavorable psychological and behavioral features.[15,19] In their systematic review of 104 original articles on psychosocial correlates of energy drink consumption in subjects aged 0-18 years, Marinoni et al. reported positive associations with sensation seeking, irritability or anger, and suicide ideation, planning, or attempts; they also noted that lower grades, low parental monitoring, and negative peer influences were associated with a higher likelihood of energy drink consumption.[19] The same review emphasized that these findings were based mostly on cross-sectional studies.[19]

Population-based studies from Korea have further linked energy drink intake with mood symptoms, stress-related outcomes, and suicidality in adolescents.[15,18] In a nationally representative sample of 68,043 Korean adolescents, Park et al. found that energy drink intake was significantly associated with sleep dissatisfaction, severe stress, depressive mood, suicidal ideation, suicide planning, and suicide attempts, with stronger associations among more frequent users.[15] In that study, the associations were particularly prominent in adolescents who also frequently consumed junk food.[15] Likewise, Kim et al., analyzing more than 53,000 Korean adolescents, found that increasing weekly energy drink consumption was associated with depressive mood and suicide ideation in both boys and girls, with the strongest associations observed among those consuming energy drinks three or more times per week.[18] Both studies, however, were cross-sectional and therefore cannot establish temporal direction or causality.[15,18]

Evidence in young adults also points toward anxiety- and stress-related correlates, particularly in males.[16,17] In a population-based cohort of Australian young adults, Trapp et al. reported that energy drink consumption was significantly associated with anxiety, but not depression or stress, after adjustment for sociodemographic and lifestyle factors, and that this association was observed only in males.[16] Extending this work longitudinally in the same cohort, Kaur et al. found that participants who changed from being non-users to energy drink users showed an average increase in stress scores over 2 years, and that among males, this change in use was associated with increases in depression, anxiety, and stress scores.[17] The authors concluded that energy drink consumption may be a possible marker for mental health symptoms in young male adults.[17]

Mechanistically, these studies discuss a plausible contribution of stimulant ingredients, especially caffeine, to adverse neurobehavioral outcomes, but the human literature remains largely associative.[16-18] Kaur et al. noted that caffeine at higher doses may produce restlessness, nervousness, anxiety, insomnia, tremors, seizures, psychosis, depression, hallucinations, and anxiety, while also pointing to guarana and other ingredients as potentially relevant contributors.[17] Kim et al. similarly discussed caffeine as the main ingredient in energy drinks and linked excessive intake to sleep disturbance, stress-related responses, and emotional instability in adolescents.[18] These interpretations are biologically plausible, but the cited epidemiologic studies do not prove that energy drinks directly caused the reported psychiatric outcomes.[17,18]

Overall, the current literature supports a consistent association between energy drink consumption and adverse neuropsychiatric and behavioral correlates, especially anxiety, stress, depressive mood, suicidality, and selected behavioral traits in adolescents and young adults.[15-19] At the same time, the evidence base remains dominated by cross-sectional data, so these findings should be interpreted as signals of risk and clinical relevance rather than as definitive proof of causation.[15,18,19]

Sleep and Circadian Disruption

Sleep-related outcomes represent one of the most consistent non-cardiovascular domains associated with energy drink consumption in adolescents and young adults.[20-24] Across the available studies, the evidence concerns primarily sleep duration, sleep quality, and sleep satisfaction, whereas direct circadian measures have been investigated much less frequently.[20-24]

Among college students, Lohsoonthorn et al. reported in 2,854 Thai students that the prevalence of poor sleep quality was 48.1% and that stimulant use was positively associated with poor sleep quality (OR 1.50; 95% CI 1.28-1.77).[20] In another cross-sectional study of 919 college students from the United Arab Emirates, Faris et al. found that 41% regularly consumed energy drinks and reported a significant inverse relationship between energy drink consumption and sleep quality or patterns ($r = -0.10$, $P < 0.05$).[21] These findings support an association between energy drink use and poorer sleep in university populations, although the cross-sectional design of both studies does not allow conclusions about directionality.[20,21]

Similar findings have been observed in school-aged populations. In a cross-sectional study of 1,611 students aged 10 to 18 years in the United Arab Emirates, Almulla and Faris found that energy drink consumers were less likely to meet recommended sleep duration than non-consumers (37% vs 62%, $P < .001$).[22] In that study, energy drink consumption was also associated with male sex, older age, higher energy-dense fast food consumption, and longer screen time.[22]

More recent adolescent data are directionally consistent. In a population-based cross-sectional study of 1,287 adolescents aged 15 to 19 years in Belgrade, Tomanic et al. found that regular energy drink intake, defined as weekly or more frequent use, was an independent risk factor negatively associated with sufficient sleep (≥8 h) in both sexes.[23] In the same study, the authors concluded that energy drink intake was negatively associated with sufficient sleep in both boys and girls.[23]

Findings from a much larger Korean adolescent sample further reinforce the association between poor sleep and energy drink use. Using data from 50,455 adolescents, Kim et al. reported that sleeping less than 5 h was strongly associated with energy drink consumption (OR 2.36; 95% CI 2.14-2.60), and that lower sleep satisfaction was also associated with consumption (OR 1.12; 95% CI 1.03-1.21).[24] In sensitivity analyses, adolescents with shorter sleep

duration and poor sleep satisfaction were more likely to report higher amounts of energy drink consumption, including at least once-daily use.[24]

Taken together, the current literature supports a consistent association between energy drink use and shorter sleep duration, poorer sleep quality, or lower sleep satisfaction in both adolescents and young adults.[20-24] However, because the evidence base is composed predominantly of cross-sectional studies, these findings should be interpreted as robust associations rather than proof that energy drinks directly cause sleep disturbance or circadian dysregulation.[20-24]

Metabolic and Endocrine Effects

Compared with the cardiovascular and sleep literature, the evidence on metabolic and endocrine effects of energy drinks is more heterogeneous, but several studies suggest that these beverages may acutely affect glucose handling, insulin responses, and selected cardiometabolic markers.[25-29] The strongest data concern short-term alterations in glucoregulation after experimental exposure, whereas evidence linking habitual intake to metabolic syndrome or adiposity is less consistent.[25-29]

In a randomized controlled crossover trial in 38 healthy young adults, Basrai et al. found that a single high-volume intake of a commercial energy drink caused not only acute cardiovascular changes but also metabolic alterations.[25] All study products induced a decrease in serum glucose and an increase in insulin concentrations after 1 hour, with a corresponding elevation in HOMA-IR; however, the energy drink condition was associated with a greater increase in insulin resistance indices than the comparison products.[25] The authors concluded that a single high-volume intake of energy drink produced adverse changes in insulin sensitivity in young healthy individuals and that these effects could not be easily attributed to caffeine, taurine, or glucuronolactone alone.[25]

Pediatric and adolescent experimental data point in the same direction. In a double-blind randomized crossover study, Shearer et al. showed that a caffeine-containing energy shot (5 mg/kg) given before an oral glucose tolerance test in adolescents resulted in a 25% increase in glucose area under the curve and a 26% increase in insulin area under the curve compared with the decaffeinated control beverage.[28] The authors interpreted these findings as evidence of acute impaired glucoregulation characterized by hyperinsulinemia after a glucose challenge.[28] In a more recent clinical study in 71 adolescents, Naveh et al. found that blood glucose levels were significantly higher at 15 and 30 minutes after energy drink consumption than after a carbohydrate- and volume-matched non-caffeinated soft drink, and insulin concentrations at 45 minutes were also significantly higher in the energy drink group.[29] In that study, the glycemic pattern was particularly marked in heavy energy drink consumers, and the amount of caffeine consumed per kilogram was positively correlated with glucose and insulin responses.[29]

Evidence from people with diabetes also suggests that energy drinks may have clinically relevant glycemic consequences. In a double-blind randomized comparison in 16 adults with type 1 diabetes, Olateju et al. found that consumption of Red Bull and a carbohydrate-containing control drink produced an early sustained rise in blood glucose, but the rise was augmented by Red Bull.[27] The authors concluded that energy drinks can represent a significant carbohydrate load for people with diabetes and may require appropriate insulin adjustment; they also noted that the caffeine-containing energy drinks caused a rise in systolic blood pressure.[27]

By contrast, longer-term observational evidence relating energy drink intake to broader metabolic syndrome phenotypes is less convincing. In a prospective investigation of young adults from the Raine Study, Trapp et al. found positive but non-significant cross-sectional associations between frequent energy drink intake and both body mass index and the likelihood of metabolic syndrome at ages 20 and 22 years, with no associations in prospective analyses over 2 years.[26] After adjustment, some cross-sectional associations were observed with lower HDL-cholesterol and higher fasting triglycerides at age 20, but these were not supported by prospective findings, and the authors explicitly concluded that no significant associations existed between energy drink intake frequency and BMI, metabolic syndrome, or its individual components over the 2-year follow-up.[26]

Overall, the available literature suggests that energy drinks can acutely worsen glucoregulatory responses, particularly by increasing post-consumption glucose and insulin excursions, while the evidence for longer-term associations with obesity, metabolic syndrome, or chronic dysmetabolism remains limited and inconsistent.[25-29] Accordingly, the metabolic signal in the current literature appears strongest for acute impairment of glucose-insulin homeostasis, whereas broader endocrine or cardiometabolic consequences require further longitudinal study.[25,26,28,29]

Renal and Hydroelectrolytic Effects

The evidence linking energy drink consumption to renal and hydroelectrolytic disturbances is limited and is derived mainly from case reports rather than controlled clinical studies.[30-32] Accordingly, this section should be interpreted as describing clinically relevant signals of potential harm rather than a well-established causal pathway.[30-32]

A severe adolescent case was reported by Schöffl et al., who described a 17-year-old boy with acute renal failure after consuming 3 L of energy drink together with 1 L of vodka, corresponding to 4600 mg of taurine and 780 mg of caffeine mixed with 380 g of alcohol.[30] The patient developed a creatinine rise from 1.0 mg/dL at admission to 6.9 mg/dL, required hemodialysis, and urine sediment revealed acute tubular necrosis; renal function subsequently returned to normal.[30] Because the exposure involved concurrent alcohol intake and very high volumes, the case supports a possible nephrotoxic risk in extreme patterns of co-consumption, but it does not allow isolation of the specific contribution of energy drinks alone.[30]

A second case, reported by Greene et al., described a 40-year-old man with serum creatinine rising from a baseline of 0.9 mg/dL to 5.5 mg/dL after a 2- to 3-week period of ingesting 100 to 120 oz of Red Bull daily.[31] Renal dysfunction improved rapidly after discontinuation of the energy drink, with serum creatinine falling to 1.1 mg/dL within 2 days and remaining normal at 10 months of follow-up.[31] The authors considered the relationship between Red Bull ingestion and acute kidney injury to be probable on the Naranjo scale, while also acknowledging that the mechanism of injury was not defined.[31]

Additional support comes from the case described by Al Yacoub et al., in which a 62-year-old woman who had consumed five to six 16-ounce cans of a sugar-free energy drink daily over several weeks developed acute kidney injury together with acute hepatitis.[32] Renal and hepatic function improved with supportive care and discontinuation of energy drinks.[32] Importantly, the authors noted that energy drinks differ from sports drinks, contain high levels of carbohydrates and caffeine, and that caffeine may promote diuresis and natriuresis rather than hydration, which may be relevant in vulnerable patients attempting to maintain oral intake primarily through these beverages.[32]

Taken together, the available literature suggests that excessive energy drink consumption may be associated with acute kidney injury in selected circumstances, particularly when intake is very high or combined with other stressors such as alcohol or poor oral intake.[30-32] However, the current evidence base is too limited to define incidence, dose thresholds, or a specific mechanism of renal injury.[30-32] Therefore, renal and hydroelectrolytic effects should be presented in this review as rare but clinically important case-based events rather than as firmly established outcomes of routine consumption.[30-32]

Gastrointestinal and Hepatic Effects

The evidence on gastrointestinal and hepatic effects of energy drinks is concentrated mainly on rare cases of clinically apparent liver injury, whereas isolated gastrointestinal toxicity is less well characterized in the available literature for this section.[33-36] In the reported hepatic cases, gastrointestinal symptoms such as abdominal pain, nausea, vomiting, anorexia, and jaundice are common presenting features, but the dominant clinical concern is acute hepatocellular injury rather than primary gastrointestinal disease.[33-36]

One of the earliest reported cases was described by Vivekanandarajah et al., who reported a previously healthy 22-year-old woman presenting with epigastric pain, nausea, vomiting, and jaundice after consuming approximately 10 cans of an energy drink daily for 2 weeks.[33] Her liver tests became markedly abnormal, with AST 7709 U/L, ALT 7533 U/L, and INR 1.6, while viral serologies and toxicology screening were negative; she improved with supportive care and follow-up liver enzymes normalized.[33] The authors considered the development of acute hepatitis most likely related to excessive energy drink ingestion and speculated that niacin was the most likely culprit ingredient.[33]

A second case was reported by Harb et al. in a 50-year-old man who had consumed 4-5 energy drinks daily for 3 weeks before presenting with malaise, anorexia, abdominal pain, nausea, vomiting, dark urine, jaundice, and marked transaminitis.[34] Liver biopsy showed severe acute hepatitis with bridging necrosis and marked cholestasis, and the patient improved after withdrawal of the energy drink and supportive care.[34] However, this case also had important diagnostic complexity because the patient was found to have chronic hepatitis C infection, and therefore the attribution to energy drinks, although considered likely by the authors, is not completely unambiguous.[34,36]

A more severe presentation was described by Huang et al., who reported a 36-year-old man with right upper quadrant pain, jaundice, and fatigue after consuming 3 sugar-free energy drinks daily for 1 year, in the setting of weekend binge alcohol use.[35] His liver function progressively deteriorated, and he ultimately required orthotopic liver transplantation; pathology demonstrated massive hepatocellular necrosis with inflammatory infiltrates consistent with drug-induced liver injury.[35] The authors raised the possibility that niacin may have contributed, but also acknowledged that cumulative exposure and the patient's alcohol use may have increased susceptibility to injury.[35]

The broader synthesis provided by LiverTox is more cautious than the individual case reports.[36] LiverTox notes that excess energy drink consumption has been linked to several instances of clinically apparent acute liver injury, sometimes severe enough to require urgent transplantation, but also emphasizes that many reports are incompletely documented, some are not fully convincing, and the responsible component remains unclear.[36] Importantly, LiverTox states that caffeine itself has not been convincingly linked to hepatic injury and is therefore unlikely to be the direct hepatotoxic agent, whereas other constituents present in energy drinks may be involved.[36]

Taken together, the available literature suggests that severe hepatic injury related to excessive energy drink consumption is possible but rare, and that current evidence is based predominantly on isolated case reports rather than controlled studies.[33-36] The signal appears strongest for acute hepatocellular injury occurring after high-volume or prolonged consumption, often with potential confounding factors, while the specific contribution of niacin, other additives, or ingredient interactions remains uncertain.[33-36] Thus, gastrointestinal and hepatic effects should be presented in this review as uncommon but clinically important hepatotoxic events with accompanying gastrointestinal symptoms rather than as routine consequences of standard consumption.[33-36]

Oral and Dental Health

The available literature suggests that energy drinks may adversely affect oral health primarily through their erosive potential on dental enamel.[37-41] However, most of the evidence in this field derives from in vitro models, which are useful for identifying physicochemical risk but do not fully reproduce the protective effects of saliva, oral clearance, drinking behavior, and pellicle formation in vivo.[37-40]

One recurring finding is that energy drinks are acidic beverages with characteristics compatible with enamel demineralization.[37-40] In the in vitro study by Silva et al., the energy drinks tested had pH values ranging from 2.36 to 3.41, and all examined energy drinks were erosive to tooth enamel under the study conditions.[37] Among the tested beverages, TNT Energy Drink® showed the greatest percentage loss of surface microhardness, surface loss, lesion depth, and mineral loss, followed by Red Bull® and Monster Energy®.[37]

Earlier in vitro work also supports the erosive potential of high-energy drinks. Kitchens and Owens evaluated multiple beverages and found that Coca-Cola Classic, Gatorade, and Red Bull showed the highest post-treatment surface roughness measurements, and that Coca-Cola Classic, Diet Coke, Gatorade, and Red Bull all had significantly higher post-treatment roughness than coffee, bottled water, and tap water.[38] In that study, fluoride varnish was not a significant protective factor, whereas beverage type and exposure time significantly influenced enamel roughness.[38]

Similarly, Ehlen et al. reported that energy drinks had greater titratable acidity than regular sodas and diet sodas, and that enamel lesion depths after beverage exposure were greatest for Gatorade®, followed by Red Bull® and Coke®.[39] The authors concluded that beverages popular in the United States can produce dental erosion.[39] Notably, lesion depth in that study was not associated simply with pH or titratable acidity alone, suggesting that erosive potential is influenced by more than a single chemical parameter.[39]

The potential of beverages to dissolve enamel has also been described in earlier laboratory work. Von Fraunhofer and Rogers emphasized that soft drinks and other low-pH beverages may subject enamel to acid dissolution and erosion, and framed erosion as an important consequence of frequent beverage exposure, especially in younger individuals with high intake patterns.[40] Their work supports the broader concept that acidic beverage consumption can contribute to irreversible loss of dental hard tissue.[40]

More recent work has extended this concern to beverages commonly consumed by younger adults. Pierce et al., in an in vitro study of beverages commonly consumed by millennials, evaluated acidity, fluoride content, and enamel-softening effects and included energy and sports drinks among the tested beverage categories.[41] This further supports the relevance of beverage acidity and composition in relation to enamel softening, although the study was not limited exclusively to energy drinks.[41]

Taken together, the available evidence indicates that energy drinks have demonstrable erosive potential on dental enamel under experimental conditions and therefore represent a plausible oral health risk, particularly with frequent exposure.[37-41] At the same time, because the evidence is largely laboratory-based, this section should be presented as evidence of biological plausibility and enamel erosion risk rather than definitive proof of clinically significant dental damage in all routine consumers.[37-40]

Vulnerable Populations: Children, Adolescents, and Young Adults

Children, adolescents, and young adults represent the population groups in which energy drink exposure appears to be most concentrated and most concerning.[42-46] Seifert et al. reported that, according to self-report surveys, energy drinks are consumed by 30% to 50% of adolescents and young adults and also noted that half of the energy drink market consists of children, adolescents, and young adults.[42] In U.S. national data, Vercammen et al. found that the prevalence of energy drink consumption increased significantly from 2003 to 2016 among both adolescents and young adults, and that total caffeine intake was substantially higher among energy drink consumers than non-consumers in both groups.[43]

Among minors, adolescents appear to be a particularly high-exposure subgroup. In the review by Li et al., data from the European Food Safety Authority indicated that the highest prevalence of energy drink consumption was reported in adolescents (68%), followed by adults (30%) and children (18%).[45] The same review reported that among underage consumers, high chronic consumption was estimated at 12% for adolescents and 16% for children, and high acute

consumption at 12%.[45] In a large school-based longitudinal study of 6902 German adolescents aged 9-19 years, Galimov et al. found that lifetime energy drink use was reported by 61.7% of participants and past 30-day use by 21.4%.[46]

The reasons these age groups are vulnerable are not limited to prevalence alone. Seifert et al. emphasized that safe levels of energy drink consumption have not been established for most children, adolescents, and young adults, and highlighted concern that youth-directed marketing and adolescent risk-taking tendencies may increase overdose potential.[42] De Sanctis et al. similarly noted that young adults and adolescents are especially attracted to energy drinks because of effective product marketing, peer influence, and limited knowledge of potential harmful effects.[44] In the German adolescent cohort, Galimov et al. showed that both lifetime and recent use were positively associated with male sex, older age, drug use, poor dietary habits, higher body mass index, sensation seeking, worse school performance, and more frequent advertising exposure; initiation over 12 months was also predicted by male sex, sensation seeking, more frequent advertising exposure, and curiosity about trying energy drinks, while better school performance was protective.[46]

Children and adolescents may also be vulnerable because adverse events in minors appear to cluster in specific clinical contexts. Seifert et al. noted that serious adverse effects have been reported especially in children, adolescents, and young adults with seizures, diabetes, cardiac abnormalities, or mood and behavioral disorders, or in those taking certain medications.[42] Li et al., in their review of 18 reported cases of adverse health events in minors, found that 45% involved the cardiovascular system, 33% the neuropsychological system, and 22% other organ systems; additionally, 33% of cases involved extra trigger factors and 44% occurred in the presence of preexisting health conditions.[45] Both reviews therefore support the view that vulnerability is heightened not only by age, but also by underlying disease and contextual cofactors.[42,45]

Young adults remain a relevant vulnerable group even beyond adolescence. De Sanctis et al. reported that in a survey of college students in the United States, 51% had consumed at least one energy drink in the previous month, most often for insufficient sleep, to increase energy, or to combine with alcohol while partying.[44] Vercammen et al. further showed that among U.S. young adults, the prevalence of energy drink consumption increased from 0.5% to 5.5% between 2003 and 2016, and per capita energy drink consumption also increased significantly in this age group.[43] These findings suggest that the transition from adolescence to young adulthood is marked not by declining exposure, but often by continued or increasing use in settings that may promote heavier intake and co-consumption behaviors.[43,44]

Taken together, the available literature indicates that children, adolescents, and young adults should be regarded as vulnerable populations with respect to energy drink consumption, albeit for partially different reasons.[42-46] In children and adolescents, concern centers on developing physiology, high market exposure, lack of established safe intake thresholds, and the interaction with preexisting conditions or trigger factors.[42,45] In adolescents and young adults, vulnerability is further reinforced by behavioral and social correlates including marketing exposure, sensation seeking, substance use, poor sleep, and academic or lifestyle factors that may facilitate repeated consumption.[43,44,46]

Alcohol and Other Substances

Concurrent use of energy drinks with alcohol represents one of the most clinically relevant consumption patterns described in adolescents and young adults.[47-51] In a web-based survey of college students, O'Brien et al. found that 24% of past 30-day drinkers reported consuming alcohol mixed with energy drinks in the previous 30 days.[47] In an emergency department sample of youth aged 14-20 years who reported past-year alcohol use, Bonar et al. found that 36% had consumed alcohol and energy drinks in the same beverage or on the same occasion, whereas 23% had used both on separate occasions and 41% reported alcohol use without energy drinks.[51]

Across observational studies, combined alcohol and energy drink use is consistently associated with heavier drinking patterns and a greater burden of alcohol-related consequences.[47,49,51] O'Brien et al. reported that college students consuming alcohol mixed with energy drinks had more heavy episodic drinking days on average than those not consuming such combinations (6.4 vs 3.4 days) and almost twice as many episodes of weekly drunkenness (1.4 vs 0.73 days/week).[47] They also had a higher prevalence of several alcohol-related consequences, including being taken advantage of sexually, taking advantage of another sexually, riding with an intoxicated driver, being physically hurt or injured, and requiring medical treatment.[47] Similarly, Bonar et al. found that combined users had the highest rates of alcohol severity and other risk behaviors, including drug use, sexual risk behaviors, and driving after drinking.[51]

The motivations for this pattern of use appear to be partly hedonic and partly functional.[47,51] In the youth emergency department sample described by Bonar et al., the most common reasons for combining alcohol and energy drinks were hiding the flavor of alcohol (39%) and liking the taste (36%).[51] The most commonly reported consequences were feeling jittery (71%) and trouble sleeping (46%).[51] More broadly, O'Brien et al. noted that alcohol mixed with energy drinks has been promoted on college campuses through student-oriented marketing and branded drink culture, which likely contributes to its popularity among younger consumers.[47]

Energy drink use is also associated with broader substance-related risk beyond alcohol alone.[49,50] In a longitudinal study of college students, Arria et al. found that energy drink users had heavier alcohol consumption patterns and were

more likely to have used other drugs, both concurrently and at the preceding assessment.[50] In regression analyses, Year 2 energy drink use was significantly associated with Year 3 nonmedical use of prescription stimulants and prescription analgesics, even after accounting for demographics, prior drug use, and other factors.[50] In a separate study of fourth-year college students, the same group found that high-frequency energy drink users had significantly greater risk for alcohol dependence than both non-users and low-frequency users, even after adjusting for demographics, typical alcohol consumption, fraternity or sorority involvement, depressive symptoms, parental history of alcohol or drug problems, and childhood conduct problems.[49]

At the same time, the causal interpretation of these associations remains unsettled.[48] Howland and Rohsenow emphasized that hypotheses about the risk of alcohol mixed with energy drinks include reduced sensation of intoxication, impaired judgment regarding risky behaviors, and the possibility of increased alcohol consumption.[48] However, they also noted that many cross-sectional studies comparing users of alcohol mixed with energy drinks with non-users may be confounded by underlying personality traits such as impulsivity and sensation seeking, and that within-participant studies have often been less consistent in linking this pattern of use itself to risky behavior.[48] Thus, the current literature supports a strong and clinically important association between energy drinks, heavy alcohol involvement, and selected other substance-related risks, but it does not yet establish that energy drinks are the sole or direct cause of these outcomes.[47-51]

Taken together, the evidence indicates that alcohol-related use patterns are central to the public health relevance of energy drinks in youth and young adults.[47-51] The signal is strongest for heavier drinking, alcohol-related harms, and co-occurring substance use, especially in college and emergency department populations.[47,49-51] Accordingly, this section is best framed not simply as a question of beverage preference, but as part of a broader cluster of risky consumption behaviors in which energy drinks may function as a marker, amplifier, or facilitator of harm.[48-51]

Public Health Burden, Healthcare Utilization, and Regulation

From a public health perspective, the relevance of energy drink consumption derives not only from individual adverse events, but also from the combination of high population exposure, youth-oriented marketing, and increasing healthcare contacts related to use.[52-57] In the most comprehensive recent synthesis identified for this section, Aonso-Diego et al. included 192 studies comprising 196 distinct samples and more than 1.1 million participants worldwide, and estimated a pooled prevalence of 54.7% for lifetime use, 43.4% for past-12-month use, 32.3% for past-30-day use, 21.6% for past-7-day use, and 8.82% for daily use.[52] Their subgroup analyses showed that energy drink use was particularly high among adolescents and young adults.[52]

These prevalence data are complemented by evidence of substantial acute healthcare utilization. In the national report by Mattson, based on Drug Abuse Warning Network estimates, the number of emergency department visits involving energy drinks in the United States doubled from 10,068 in 2007 to 20,783 in 2011.[53] In 2011, 58% of these visits involved energy drinks alone, whereas 42% involved other drugs.[53] The same report noted that, although the greatest number of visits occurred among patients aged 18 to 39 years, the largest relative increase was observed among patients aged 40 years or older, whose visits increased by 279% between 2007 and 2011.[53]

Emergency care data at the patient level also suggest that adverse effects are not rare among consumers presenting to acute care settings. In a cross-sectional study of 1,298 emergency department patients with prior energy drink consumption, Nordt et al. found that 33.5% reported at least one adverse effect.[54] The most commonly reported reactions were feeling shaky or jittery, insomnia, palpitations, gastrointestinal upset, headache, and chest pain, and seizures were reported in a small number of patients.[54] Although this was not a population-based estimate, it supports the view that energy drink-related symptoms are clinically relevant in emergency medicine settings.[54]

A major part of the public health burden also concerns the way these products are marketed. Harris and Munsell emphasized that energy drink sales have continued to grow while marketing has often been directed toward youth under the age of 18 years.[55] They described a market environment characterized by high caffeine content, incomplete labeling of some ingredients, large container sizes, and extensive advertising expenditures, including television, internet, social media, and sports-linked promotion.[55] In the Canadian study by Hammond and Reid, 83% of respondents aged 12-24 years reported ever seeing energy drink advertising through at least one channel; common sources included television (60%), posters or signs in stores (49%), and online exposure (44%).[56] Across experimental conditions, most respondents thought the ads targeted people their age or younger, and sport-themed advertisements were more likely to be perceived as promoting energy drink use during sports.[56]

These findings have direct regulatory implications. Harris and Munsell noted that health experts and physician groups have raised concerns about youth exposure, while policymakers have discussed restrictions on sales and marketing to reduce harm.[55] Hammond and Reid further argued that the high reach of advertising among young people and the perception that these ads promote energy drink use during sports are problematic in light of Canadian rules stating that such products should not be promoted to children or marketed in ways that imply sport performance benefits.[56] In a broader editorial perspective, Budney and Emond argued that the increasing addition of caffeine to

consumer products, performance-oriented promotion, and targeting of youth require more urgent attention from both research and regulatory communities.[57] They emphasized concerns about widespread caffeine use among minors, the growing popularity of energy drinks among adolescents, and the need for action while evidence continues to accumulate.[57]

Recent evidence on sugar-sweetened beverages (SSBs) provides broader cardiometabolic and population-level context for sugar-containing energy drinks, but it should not be interpreted as energy drink-specific evidence. In a 2025 Burden of Proof meta-regression, Haile et al. found that SSB intake was associated with at least an 8% average increase in type 2 diabetes risk and a 2% increase in ischemic heart disease risk; both associations received two-star ratings, reflecting relatively weak relationships or inconsistency in the underlying evidence.[58] In a Global Burden of Disease 2021 analysis, Alves-Costa et al. defined SSB exposure to include carbonated beverages, sodas, energy drinks, and fruit drinks and reported an attributable burden of cardiovascular disease, diabetes, kidney disease, and other noncommunicable diseases, together with a projected 9.54% increase in global SSB exposure by 2050.[59] These findings strengthen the public health rationale for limiting high-sugar beverage exposure, while the aggregate SSB definitions in both studies prevent attribution of the reported chronic-disease burden specifically to energy drinks.

Taken together, the available literature supports framing energy drinks as a public health issue rather than merely an individual lifestyle choice.[52-59] The energy drink-specific burden is sustained by high worldwide prevalence, concentration of use in adolescents and young adults, measurable emergency department utilization, and aggressive marketing practices that reach young audiences through multiple channels.[52,53,55,56] Broader SSB evidence adds cardiometabolic and population-level context for sugar-containing formulations but does not isolate the contribution of energy drinks from other sweetened beverages.[58,59] At the same time, the regulatory response remains heterogeneous, and the current evidence supports stronger attention to labeling, youth-oriented promotion, and risk communication, especially for vulnerable populations.[55-57] Vulnerable populations, high-risk patterns of use, and their main clinical and public health implications are summarized in Table 2.[42-57]

Table 2: Vulnerable populations, high-risk patterns of use, and public health implications.[42-57]

Population or pattern	Why vulnerable	Main concerns	Clinical/public health implication
Children and adolescents[42,44,45]	High exposure, developing physiology, limited established safe caffeine thresholds[42,45]	Cardiovascular, neuropsychiatric, sleep-related, behavioral, and dental concerns[42,44,45]	Routine counseling and prevention messaging should discourage use in minors[42,45,55,57]
Young adults/college students[43,44,47-50]	Frequent use in settings of sleep restriction, social drinking, and performance pressure[43,44,47]	Heavy drinking, risky behavior, sleep loss, stimulant overuse[43,47-50]	Screening should include context of use, not just frequency[47-50]
Individuals with preexisting cardiac vulnerability[13,14,42,45]	Possible heightened susceptibility to stimulant-related hemodynamic and rhythm effects[13,14,45]	Palpitations, repolarization changes, arrhythmia triggering in susceptible individuals[13,14,42,45]	Greater caution and explicit clinical questioning are warranted[13,14,42,45]
Individuals with psychiatric or sleep vulnerability[15-24,42]	Caffeine and associated use patterns may worsen existing symptoms[15-24]	Anxiety, stress, poor sleep, mood-related symptoms[15-24]	Energy drink use should be assessed when evaluating sleep or mental health complaints[15-24,42]

Users combining energy drinks with alcohol[47-51]	Caffeine may reduce perceived intoxication without removing impairment[47-49]	Heavier drinking, alcohol-related harms, risky driving, sexual risk[47-51]	High-priority target for counseling, campus prevention, and emergency-care intervention[47,48,51]
Heavy/frequent users[49,52]	Greater cumulative stimulant exposure and more likely co-use behaviors[49,52]	Higher burden of symptoms, dependence-like patterns, substance-related risk[49,52]	Frequency and dose should be assessed explicitly in clinical settings[49]
Use during strenuous exercise or dehydration-prone settings[55,56]	Marketing may normalize use in sport contexts despite physiological concerns[55,56]	Hemodynamic stress, sleep disruption, dehydration-related concerns[55,56]	Risk communication should directly address sport-related misuse[55,56]
Youth exposed to intensive marketing[55-57]	Advertising may normalize consumption and frame products as performance-enhancing[55,56]	Early initiation, misperception of safety, sport-linked use[55,56]	Supports clearer labeling and restrictions on youth-directed promotion[55-57]

Discussion

For clarity, the main adverse outcomes reviewed across organ systems and their evidentiary basis are synthesized in Table 3.[9-59] Overall, the strongest signals concern acute cardiovascular changes, sleep disruption, neuropsychiatric and behavioral correlates, vulnerability of adolescents and young adults, and high-risk patterns of use involving alcohol and other substances.[9-24,42-57] These findings acquire additional public health relevance because energy drink exposure is widespread, especially among younger age groups, while recent SSB analyses provide broader cardiometabolic context for sugar-containing formulations.[42,43,46,52-59]

Table 3: Main adverse effects associated with energy drink consumption by organ system.[9-59]

Organ system/domain	**Main reported effects**	**Predominant type of evidence**	**Overall interpretation**
Cardiovascular[9-14]	Increased blood pressure, increased heart rate, repolarization changes, supraventricular extrasystoles, concern in susceptible patients	Randomized crossover trials, experimental studies, selected case-based data[9-14]	One of the strongest sections of the literature; acute cardiovascular effects are consistently supported[9-14]
Neuropsychiatric and behavioral[15-19]	Anxiety, stress, depressive symptoms, suicidal ideation, sensation seeking, behavioral risk correlates	Cross-sectional studies, longitudinal observational studies, systematic review[15-19]	Consistent associations, but causality remains difficult to establish[15-19]

Sleep and circadian disruption[20-24]	Shorter sleep duration, poorer sleep quality, lower sleep satisfaction	Mainly cross-sectional studies in adolescents and young adults[20-24]	Strong and repeated association across populations[20-24]
Metabolic and endocrine[25-29]	Acute increases in glucose and insulin responses, impaired glucoregulation; inconsistent long-term links with metabolic syndrome	Experimental studies and limited prospective observational data[25-29]	Acute metabolic effects are supported better than chronic metabolic outcomes[25-29]
Renal and hydroelectrolytic[30-32]	Acute kidney injury, possible dehydration-related or cofactor-related renal stress	Case reports[30-32]	Rare but clinically important; evidence remains limited[30-32]
Gastrointestinal and hepatic[33-36]	Nausea, vomiting, abdominal pain, acute hepatitis, severe liver injury in rare cases	Case reports and hepatotoxicity reviews[33-36]	Severe events appear possible but uncommon; causality is often difficult to isolate[33-36]
Oral and dental[37-41]	Enamel softening, demineralization, erosion	In vitro studies[37-41]	Clear erosive potential under experimental conditions; real-world clinical burden likely depends on exposure pattern[37-41]
Alcohol and other substances[47-51]	Heavier drinking, alcohol-related harms, alcohol dependence, nonmedical prescription drug use, illicit drug use	Observational studies and emergency department data[47-51]	Major high-risk behavioral domain, especially relevant in youth and college populations[47-51]
Public health[52-59]	Emergency department visits, youth-targeted marketing exposure, regulatory concerns, and broader SSB-related cardiometabolic/NCD burden context	Surveillance reports, prevalence meta-analysis, marketing studies, policy/editorial literature, and contextual SSB meta-regression/GBD analyses[52-59]	Strong public health relevance due to widespread exposure and measurable healthcare utilization; SSB evidence is contextual and not specific to energy drinks[52-59]

The findings of the present review are broadly concordant with previous major syntheses while differing in emphasis and scope. Nadeem et al.[2] systematically quantified reported adverse events and highlighted insomnia, jitteriness/restlessness, gastrointestinal symptoms, and risks associated with co-consumption of energy drinks and alcohol. Other broad reviews, including Kaur et al.[3] and Costantino et al.[4], have emphasized the multisystem and public health dimensions of energy drink consumption. The present review builds on these earlier contributions by integrating evidence through April 2026 and by explicitly comparing evidentiary strength across organ systems, separating controlled acute physiological findings from observational associations, case-based safety signals, and in vitro evidence. It also places organ-specific findings within a framework that includes sleep, behavioral co-use, vulnerable populations, healthcare utilization, marketing, and regulation. Because the present work is narrative rather than systematic, it is intended to complement rather than replace systematic effect estimates such as those provided by Nadeem et al.[2]

Across domains, the hierarchy of evidence becomes clearer when study design is considered together with consistency of findings. Cardiovascular effects are supported by controlled trials showing repeated acute increases in blood pressure, with repolarization changes observed mainly after high-volume exposure.[9-13] Sleep-related findings are highly consistent across large adolescent and young-adult samples, but their predominantly cross-sectional design limits inference about directionality.[20-24] Neuropsychiatric findings are also recurrent, yet they are more vulnerable to residual confounding and to shared behavioral traits such as sensation seeking, poor sleep, or substance use.[15-19]

Evidence is less definitive for chronic metabolic, renal, hepatic, and oral outcomes. Experimental metabolic studies support acute perturbation of glucose-insulin homeostasis, whereas prospective evidence for chronic metabolic syndrome remains inconsistent.[25-29] Renal and hepatic signals derive mainly from case reports involving very high intake or important co-exposures, and oral-health evidence is largely based on in vitro enamel models.[30-41] Consequently, the clinical severity of a reported event should not be conflated with certainty of association: rare dramatic cases may be important safety signals while providing weaker causal evidence than reproducible effects demonstrated in controlled studies.[25-41]

An important interpretive issue is whether the observed harms are specific to energy drinks as a product class or are driven primarily by caffeine exposure, often amplified by sugar load, co-ingredients, rapid consumption, and high-risk behavioral contexts.[5-8,47,55] The current literature suggests that caffeine is the best-defined active constituent and likely explains a substantial proportion of the acute cardiovascular, sleep-related, and neurobehavioral effects.[5-8,9-24] However, energy drinks may differ from other caffeinated beverages because they are frequently consumed in large volumes, often contain incompletely transparent multi-ingredient formulations, are heavily marketed to younger populations, and are commonly used in association with alcohol, sleep restriction, and high-risk social settings.[5-8,47,55,56] Accordingly, the risk profile of energy drinks should be interpreted not only in pharmacologic terms, but also in relation to formulation, dose, and context of use.[5-8,47-57]

A recurrent theme across the review is that context matters. Children, adolescents, and young adults appear especially vulnerable not only because of higher exposure, but also because consumption often occurs in settings of sleep restriction, academic or social pressure, sport-related identity, sensation seeking, or co-use with alcohol and other substances.[42-46] The alcohol-related literature is particularly relevant because the association of energy drink use with heavier drinking, alcohol dependence, sexual risk, driving after drinking, and broader substance involvement indicates that the problem extends beyond caffeine physiology alone and intersects with patterns of risky behavior.[47-51] At the population level, high prevalence, emergency department utilization, youth-oriented marketing, and regulatory uncertainty amplify these individual-level concerns, while recent SSB evidence provides additional chronic-disease context for sugar-containing products without establishing energy drink-specific attribution.[52-59] Clinically, this supports asking not only whether patients consume energy drinks, but also how much, how often, in what context, and whether use occurs with alcohol, drugs, intense exercise, or preexisting medical vulnerabilities.[42,45,47-59]

Overall, a graded interpretation is more appropriate than a uniform statement of harm. Controlled human data provide the strongest support for acute cardiovascular and glucoregulatory effects; repeated observational data support concern regarding sleep, neuropsychiatric, behavioral, and substance-use correlates; and case-based or in vitro evidence identifies plausible but less certain renal, hepatic, and dental risks.[9-41,47-51] The newer SSB literature further supports a broader cardiometabolic and population-health rationale for limiting high-sugar beverage exposure, while not permitting energy drink-specific attribution.[58,59] Thus, the risk profile of energy drinks is best understood as dependent on dose, formulation, co-exposures, pattern of use, and host susceptibility.[5-8,30-59]

Limitations

This review has several limitations that should be acknowledged. First, it is a narrative review based on a focused literature search rather than a full systematic review with duplicate screening, a PRISMA-style study-flow process, formal risk-of-bias assessment, and quantitative synthesis of all eligible studies. A single standardized quality tool was not applied because the review intentionally integrated highly heterogeneous evidence types, from randomized crossover trials to observational studies, case reports, in vitro experiments, surveillance reports, and policy literature. Although the evidence was appraised according to design, directness, consistency, confounding, exposure characterization, and clinical applicability, the absence of formal quality scoring and duplicate selection reduces reproducibility and means that study inclusion inevitably involved a degree of author judgment and thematic prioritization.

Second, much of the literature reviewed is observational, and a large proportion of studies in key sections, particularly those dealing with neuropsychiatric outcomes, sleep, youth behaviors, alcohol use, and marketing exposure, are cross-sectional.[15-24,46-57] As a result, directionality cannot be firmly established, and some observed relationships may reflect reverse causation or shared underlying traits rather than a direct effect of energy drink exposure itself. This is especially relevant in domains such as sensation seeking, depressive symptoms, substance use, poor sleep, and school performance, where energy drink use may function partly as a marker of broader behavioral vulnerability.[15-19,46-51]

Third, the quality and type of evidence vary substantially across organ systems. Some sections, such as cardiovascular effects, are supported by randomized crossover trials and controlled experimental studies,[11-13] whereas others rely mainly on case reports or in vitro models.[30-41] Therefore, the strength of inference is not comparable across all sections of the review. In particular, renal and hepatic complications may be severe but are supported mainly by isolated clinical cases, while oral effects are supported largely by laboratory evidence of enamel erosion rather than longitudinal clinical outcomes.[30-41]

Fourth, energy drinks are a heterogeneous product class. Formulations differ widely across brands and servings, with variability in caffeine content, sugar load, taurine, guarana, glucuronolactone, vitamins, and proprietary blends.[5-8,55] In many products, exact ingredient quantities are incompletely disclosed, making it difficult to determine whether reported adverse outcomes are driven mainly by caffeine, by synergistic effects among ingredients, by sugar load, or by contextual factors such as rapid consumption, concurrent alcohol use, or physical exertion.[5-8,47,55] This heterogeneity limits comparability across studies and complicates attempts to define safe thresholds or product-specific risks.

Finally, this review used PubMed as its primary bibliographic database and was restricted to English-language publications, so relevant evidence indexed elsewhere or published in other languages may have been missed. The field itself also remains limited by relatively scarce long-term prospective data, inconsistent definitions of exposure, and frequent aggregation of occasional use, regular use, heavy intake, and combined use with alcohol or other substances under broad labels of "energy drink consumption".[25,26,47-52] These limitations, together with the narrative selection process, mean that the present work should be interpreted as a critical clinical and public health synthesis of the available evidence rather than as an exhaustive systematic estimate or a definitive causal map of all outcomes associated with energy drinks.[25-59]

Conclusion

Energy drinks should not be regarded as risk-free beverages, particularly in vulnerable individuals and in high-risk patterns of use. The overall literature reviewed here indicates that their use is associated with a clinically and publicly relevant spectrum of risks, with the strongest and most consistent signals involving acute cardiovascular effects, sleep disruption, neuropsychiatric and behavioral correlates, vulnerability in adolescents and young adults, and high-risk patterns of co-use with alcohol and other substances.

At the same time, the evidence is not uniform across all outcomes. Some harms are supported by controlled human data, whereas others remain grounded mainly in case reports or experimental models. This difference in evidentiary strength should encourage a balanced interpretation that is neither alarmist nor dismissive, but appropriately cautious.

From a clinical perspective, energy drink use deserves routine attention during history taking, particularly in younger patients, in individuals with preexisting cardiovascular or neuropsychiatric vulnerability, and in those reporting alcohol use, stimulant use, palpitations, sleep problems, or recurrent unexplained symptoms. From a public health perspective, the combination of high prevalence, youth-oriented marketing, incomplete product transparency, and measurable healthcare utilization justifies greater preventive attention.

Future research should move beyond cross-sectional association and focus on prospective designs, standardized exposure definitions, and better characterization of dose, formulation, and co-exposures. More work is also needed on under-studied populations, including minors, patients with preexisting medical conditions, and frequent users combining energy drinks with alcohol, drugs, or intensive physical activity. Finally, regulatory and policy research should evaluate whether clearer labeling, youth marketing restrictions, container-size limits, and educational interventions can reduce harm in real-world settings.

Disclosure

The author declared no conflicts of interest. No funding was received for this study. Ethical approval was not applicable because this study is a narrative review of previously published literature and did not involve direct research on human participants or animals.

Use of Artificial Intelligence

During the preparation of this manuscript, the author used ChatGPT (OpenAI) to support English-language editing and improvements in the presentation of the manuscript. All AI-assisted modifications were critically reviewed by the author, who retains full responsibility for the scientific content, accuracy, and integrity of the work.

References

1. Reissig CJ, Strain EC, Griffiths RR. Caffeinated energy drinks--a growing problem. Drug Alcohol Depend. 2009;99(1-3):1-10.

2. Nadeem IM, Shanmugaraj A, Sakha S, et al. Energy drinks and their adverse health effects: a systematic review and meta-analysis. Sports Health. 2021;13(3):265-277.

3. Kaur A, Yousuf H, Ramgobin-Marshall D, et al. Energy drink consumption: a rising public health issue. Rev Cardiovasc Med. 2022;23(3):83.

4. Costantino A, Maiese A, Lazzari J, et al. The dark side of energy drinks: a comprehensive review of their impact on the human body. Nutrients. 2023;15(18):3922.

5. Jagim AR, Harty PS, Barakat C, et al. Prevalence and amounts of common ingredients found in energy drinks and shots. Nutrients. 2022;14(2):314.

6. McLellan TM, Lieberman HR. Do energy drinks contain active components other than caffeine? Nutr Rev. 2012;70(12):730-744.

7. Curran CP, Marczinski CA. Taurine, caffeine, and energy drinks: reviewing the risks to the adolescent brain. Birth Defects Res. 2017;109(20):1640-1648.

8. Peacock A, Martin FH, Carr A. Energy drink ingredients. Contribution of caffeine and taurine to performance outcomes. Appetite. 2013;64(1):1-4.

9. Steinke L, Lanfear DE, Dhanapal V, Kalus JS. Effect of “energy drink” consumption on hemodynamic and electrocardiographic parameters in healthy young adults. Ann Pharmacother. 2009;43(4):596-602.

10. Elitok A, Oz F, Panc C, et al. Acute effects of Red Bull energy drink on ventricular repolarization in healthy young volunteers: a prospective study. Anatol J Cardiol. 2015;15(11):919-922.

11. Fletcher EA, Lacey CS, Aaron M, et al. Randomized controlled trial of high-volume energy drink versus caffeine consumption on ECG and hemodynamic parameters. J Am Heart Assoc. 2017;6(5):e004448.

12. Shah SA, Szeto AH, Farewell R, et al. Impact of high volume energy drink consumption on electrocardiographic and blood pressure parameters: a randomized trial. J Am Heart Assoc. 2019;8(11):e011318.

13. Mandilaras G, Li P, Dalla-Pozza R, Haas NA, Oberhoffer FS. Energy drinks and their acute effects on heart rhythm and electrocardiographic time intervals in healthy children and teenagers: a randomized trial. Cells. 2022;11(3):498.

14. Martinez KA, Bains S, Neves R, et al. Sudden cardiac arrest occurring in temporal proximity to consumption of energy drinks. Heart Rhythm. 2024;21(7):1083-1088.

15. Park S, Lee Y, Lee JH. Association between energy drink intake, sleep, stress, and suicidality in Korean adolescents: energy drink use in isolation or in combination with junk food consumption. Nutr J. 2016;15(1):87.

16. Trapp GSA, Allen KL, O’Sullivan T, et al. Energy drink consumption is associated with anxiety in Australian young adult males. Depress Anxiety. 2014;31(5):420-428.

17. Kaur S, Christian H, Cooper MN, et al. Consumption of energy drinks is associated with depression, anxiety, and stress in young adult males: evidence from a longitudinal cohort study. Depress Anxiety. 2020;37(11):1089-1098.

18. Kim H, Park J, Lee S, et al. Association between energy drink consumption, depression and suicide ideation in Korean adolescents. Int J Soc Psychiatry. 2020;66(4):335-343.

19. Marinoni M, Parpinel M, Gasparini A, et al. Psychological and socio-educational correlates of energy drink consumption in children and adolescents: a systematic review. Eur J Pediatr. 2022;181(3):889-901.

20. Lohsoonthorn V, Khidir H, Casillas G, et al. Sleep quality and sleep patterns in relation to consumption of energy drinks, caffeinated beverages, and other stimulants among Thai college students. Sleep Breath. 2013;17(3):1017-1028.

21. Faris MAIE, Jahrami H, Al-Hilali MM, et al. Energy drink consumption is associated with reduced sleep quality among college students: a cross-sectional study. Nutr Diet. 2017;74:268-274.

22. Almulla AA, Faris ME. Energy drinks consumption is associated with reduced sleep duration and increased energy-dense fast foods consumption among school students: a cross-sectional study. Asia Pac J Public Health. 2020;32(5):266-273.

23. Tomanic M, Paunovic K, Lackovic M, et al. Energy drinks and sleep among adolescents. Nutrients. 2022;14(18):3813.

24. Kim DH, Kim B, Lee SG, Kim TH. Poor sleep is associated with energy drinks consumption among Korean adolescents. Public Health Nutr. 2023;26(12):3256-3265.

25. Basrai M, Schweinlin A, Menzel J, et al. Energy drinks induce acute cardiovascular and metabolic changes pointing to potential risks for young adults: a randomized controlled trial. J Nutr. 2019;149(3):441-450.

26. Trapp G, Hurworth M, Jacoby P, et al. Energy drink intake and metabolic syndrome: a prospective investigation in young adults. Nutr Metab Cardiovasc Dis. 2020;30:1679-1684.

27. Olateju T, Begley J, Green DJ, Kerr D. Physiological and glycemic responses following acute ingestion of a popular functional drink in patients with type 1 diabetes. Can J Diabetes. 2015;39(1):78-82.

28. Shearer J, Reimer RA, Hittel DS, et al. Caffeine-containing energy shots cause acute impaired glucoregulation in adolescents. Nutrients. 2020;12(12):3850.

29. Naveh G, Mansour B, Bader M, et al. Physiological impacts of energy drink consumption: a clinical analysis in adolescents. Nutrients. 2024;16(14):2328.

30. Schoffl I, Kothmann JF, Schoffl V, Rupprecht HD, Rupprecht T. "Vodka energy": too much for the adolescent nephron? Pediatrics. 2011;128(1):e227-e231.

31. Greene E, Oman K, Lefler M. Energy drink-induced acute kidney injury. Ann Pharmacother. 2014;48(10):1366-1370.

32. Al Yacoub R, Luczkiewicz D, Kerr C. Acute kidney injury and hepatitis associated with energy drink consumption: a case report. J Med Case Rep. 2020;14(1):23.

33. Vivekanandarajah A, Ni S, Waked A. Acute hepatitis in a woman following excessive ingestion of an energy drink: a case report. J Med Case Rep. 2011;5(1):227.

34. Harb JN, Taylor ZA, Khullar V, Sattari M. Rare cause of acute hepatitis: a common energy drink. BMJ Case Rep. 2016;2016:bcr2016216612.

35. Huang B, Kunkel D, El Kabany M. Acute liver failure following one year of daily consumption of a sugar-free energy drink. ACG Case Rep J. 2014;1(4):214-216.

36. National Institute of Diabetes and Digestive and Kidney Diseases. Energy drinks. In: LiverTox: Clinical and Research Information on Drug-Induced Liver Injury [Internet]. Bethesda, MD: National Institute of Diabetes and Digestive and Kidney Diseases; 2012-. Updated 2020 Jun 20.

37. Silva JGVC, Martins JPG, Sousa EBG, et al. Influence of energy drinks on enamel erosion: in vitro study using different assessment techniques. J Clin Exp Dent. 2021;13(11):e1076-e1082.

38. Kitchens M, Owens BM. Effect of carbonated beverages, coffee, sports and high energy drinks, and bottled water on the in vitro erosion characteristics of dental enamel. J Clin Pediatr Dent. 2007;31(3):153-159.

39. Ehlen LA, Marshall TA, Qian F, Wefel JS, Warren JJ. Acidic beverages increase the risk of in vitro tooth erosion. Nutr Res. 2008;28(5):299-303.

40. von Fraunhofer JA, Rogers MM. Dissolution of dental enamel in soft drinks. Gen Dent. 2004;52(4):308-312.

41. Pierce S, Amini A, Tantbirojn D, Versluis A, Dehghan M, Almoazen H. Millennial drinks: acidity, fluoride content, and enamel softening. Gen Dent. 2023;71(4).

42. Seifert SM, Schaechter JL, Hershorin ER, Lipshultz SE. Health effects of energy drinks on children, adolescents, and young adults. Pediatrics. 2011;127(3):511-528.

43. Vercammen KA, Koma JW, Bleich SN. Trends in energy drink consumption among U.S. adolescents and adults, 2003-2016. Am J Prev Med. 2019;56(6):827-833.

44. de Sanctis V, Soliman N, Soliman AT, et al. Caffeinated energy drink consumption among adolescents and potential health consequences associated with their use: a significant public health hazard. Acta Biomed. 2017;88(2):222-231.

45. Li P, Haas NA, Dalla-Pozza R, Jakob A, Oberhoffer FS, Mandilaras G. Energy drinks and adverse health events in children and adolescents: a literature review. Nutrients. 2023;15(11):2537.

46. Galimov A, Hanewinkel R, Hansen J, Unger JB, Sussman S, Morgenstern M. Energy drink consumption among German adolescents: prevalence, correlates, and predictors of initiation. Appetite. 2019;139:172-179.

47. O'Brien MC, McCoy TP, Rhodes SD, Wagoner A, Wolfson M. Caffeinated cocktails: energy drink consumption, high-risk drinking, and alcohol-related consequences among college students. Acad Emerg Med. 2008;15(5):453-460.

48. Howland J, Rohsenow DJ. Risks of energy drinks mixed with alcohol. JAMA. 2013;309(3):245-246.

49. Arria AM, Caldeira KM, Kasperski SJ, Vincent KB, Griffiths RR, O'Grady KE. Energy drink consumption and increased risk for alcohol dependence. Alcohol Clin Exp Res. 2011;35(2):365-375.

50. Arria AM, Caldeira KM, Kasperski SJ, et al. Increased alcohol consumption, nonmedical prescription drug use, and illicit drug use are associated with energy drink consumption among college students. J Addict Med. 2010;4(2):74-80.

51. Bonar EE, Cunningham RM, Polshkova S, Chermack ST, Blow FC, Walton MA. Alcohol and energy drink use among adolescents seeking emergency department care. Addict Behav. 2015;43:11-17.

52. Aonso-Diego G, Krotter A, Garcia-Perez A. Prevalence of energy drink consumption world-wide: a systematic review and meta-analysis. Addiction. 2024;119(3):438-463.

53. Mattson ME. Update on emergency department visits involving energy drinks: a continuing public health concern. In: The CBHSQ Report. Rockville, MD: Substance Abuse and Mental Health Services Administration; 2013 Jan 10.

54. Nordt SP, Vilke GM, Clark RF, et al. Energy drink use and adverse effects among emergency department patients. J Community Health. 2012;37:976-981.

55. Harris JL, Munsell CR. Energy drinks and adolescents: what's the harm? Nutr Rev. 2015;73(4):247-257.

56. Hammond D, Reid JL. Exposure and perceptions of marketing for caffeinated energy drinks among young Canadians. Public Health Nutr. 2018;21(3):535-542.

57. Budney AJ, Emond JA. Caffeine addiction? Caffeine for youth? Time to act! Addiction. 2014;109(11):1771-1772.

58. Haile D, Harding KL, McLaughlin SA, et al. Health effects associated with consumption of processed meat, sugar-sweetened beverages and trans fatty acids: a Burden of Proof study. Nat Med. 2025;31:2244-2254.

59. Alves-Costa S, Nascimento GG, de Souza BF, Hugo FN, Leite FRM, Ribeiro CCC. Global, regional, and national burden of high sugar-sweetened beverages consumption, 1990-2021, with projections up to 2050: a systematic analysis for the Global Burden of Disease Study 2021. Am J Clin Nutr. 2025;122(5):1413-1422.