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Health effects of energy drinks, facts and myths – literature review

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Abstract

Energy drinks are carbonated or non-carbonated beverages containing stimulants designed to improve energy and concentration. These drinks are gaining popularity, specifically among teenagers and young adults. However, despite their easy availability on store shelves, there is growing concern about the safety and health effects of consuming energy drinks in particular. Energy drinks appear to have the greatest impact on the cardiovascular system, leading to increased blood pressure and increased heart rate, and on the mental state of consumers, in the long term causing increased levels of anxiety. The paper also addresses the effects of energy drinks on the nervous and gastrointestinal systems. Despite many studies, the health effects of energy drinks have still not been fully investigated, so there is a need for further research on the subject and for age-appropriate regulation of consumers and their education.

Keywords: energy drinks, toxicity, adolescent, health effects

1. Introduction

Energy drinks are carbonated or non-carbonated beverages that contain stimulants designed to improve energy and concentration. The main ingredients that energy drinks contain are caffeine, taurine, simple sugars, inositol, B vitamins, flavorings and preservatives and acidity regulators [1]. These drinks are gaining popularity, especially among teenagers and young adults. This is because the effects of energy drinks are advertised as increasing concentration, improving focus and boosting energy, allowing people to work longer and more effectively both physically and mentally, [2] an alluring effect for young people whose pace of life is increasing day by day. However, despite their widespread recognition and easy availability on store shelves, there is growing concern about the safety and impact of energy drink consumption, especially in the context of health, and particularly in the teenage age group. According to a report by Poland's National Institute of Public Health PZH, energy drinks were consumed by 64.3% of teenagers and 72.6% of teenage girls. The prevalence of energy drink consumption among Polish adults (18 to 64 years old) was 51.5% for men and 35.1% for women, respectively. [3] Similar results were obtained in the US, where a study was conducted on a group of college students, which showed that one in two students consumed an energy drink at least once a month to improve concentration and fight fatigue. [4] Polish experts have recognized the problem of the growing popularity of energy drinks among young people and their potentially negative impact on teenagers' health. Following the voice of the experts, the Polish Government banned the sale of energy drinks to people under the age of 18, which came into effect on January 1, 2024, was introduced by the Law on Amendments to the Law on Public Health dated August 17, 2023. [5] Our review will analyze scientific studies and meta-analyses examining the harmful effects of energy drinks on human body systems

such as the cardiovascular system, nervous system, digestive system and consumers' mental state.

2. Material and methods

A review of the literature available in the National Library of Medicine database at <https://pubmed.ncbi.nlm.nih.gov> and in Google Scholar was conducted. The following keywords were used when searching for articles: energy drink, toxicity, adolescent, health effects. Thirty-three scientific studies and meta-analyses were analyzed. Data from the mentioned studies were used to formulate conclusions.

3. Ingredients

3.1. Caffeine

Caffeine is an organic chemical compound from the alkaloid group, which is a natural stimulant present in plants such as coffee, tea and cocoa beans. Caffeine's effects on the human body are due to its effects on the nervous system, particularly on adenosine receptors. [6] After caffeine is ingested, it is absorbed almost completely, reaching most of the body's tissues. It is metabolized in the liver and then excreted by the kidneys in the form of metabolites. [7] Daily caffeine intake should be no more than 400-450mg/day, and in the case of children, no more than 2.5mg/kg body weight per day. [8] Caffeine triggers a number of actions in the human body, including reducing feelings of fatigue and drowsiness, by increasing the release of neurotransmitters, improving mood, increasing concentration. Caffeine also affects the cardiovascular system by increasing heart rate, resulting in increased blood flow. The most common symptoms of caffeine overdose are severe psychomotor agitation, tachycardia, arrhythmia, increased diuresis and nausea. [9] The caffeine content of the most popular energy drinks on the market ranges from 30 to 40 mg per 100 ml of drink, while 250 ml, 330 ml and 500 ml drinks are available on the market. [10]

3.2. Taurine

Taurine is a sulfur amino acid, but is not used for protein synthesis. It is responsible for maintaining the body's electrolyte balance, the normal development of the nervous system, is involved in stabilizing cell membranes, and exhibits antioxidant properties. [11] It is estimated that the daily requirement for taurine is between 40 and 400mg. [12] It is suspected that the presence of taurine in energy drinks may enhance such effects of caffeine as increased concentration or faster reaction time to motor stimulus. [13]

3.3. Guarana

Guarana is a plant native to the Amazon. Its seeds are a natural source of caffeine; the caffeine content of guarana seeds is much higher than that of coffee beans. In addition, the seeds are a source of theophylline and theobromine, which have similar stimulating effects to caffeine. Energy drink manufacturers often add it to their products to enhance the effects of caffeine. [14]

3.4. Carnitine

Carnitine is a chemical compound that resembles an amino acid in structure and plays an important role in fat metabolism. It occurs naturally in foods of animal origin. It is a key factor in transporting fatty acids to the mitochondria, where their oxidation and energy production takes place.

3.5. B vitamins

B vitamins are a collection of eight water-soluble vitamins that play key roles in many of the body's metabolic processes. B vitamins include thiamin, riboflavin, niacin, pantothenic acid, pyridoxine, biotin, folic acid, cyanocobalamin. These are important substances involved in cellular metabolism, and play roles as coenzymes in energy processes, which can enhance the effects of other energy drink ingredients. The content of B vitamins in energy drinks ranges from 20% up to 143% of their daily requirement in 100 ml of such a drink. [10] As we mentioned earlier, drinks available on the market are offered in volumes of at least 250 ml, which means that consumers of energy drinks exceed the recommended daily intake of B vitamins several times over.

3.6. Carbohydrates

The average carbohydrate content of an energy drink ranges from 5 grams to 11 grams per 100 ml of drink. [10] The high intake of simple sugars consumed in energy drinks may be a factor in the development of obesity and insulin resistance. In addition, a study has been conducted showing that most energy drinks on the market are highly acidic, which, combined with high carbohydrate content, can lead to dental enamel erosion. [15]

4. Impact on health

The increased prevalence and growing popularity of energy drinks has made them a regular part of many young people's diets. With the growing popularity of these drinks, questions about the potential side effects of their consumption have also multiplied. The following section will analyze scientific studies and meta-analyses examining the harmful effects of energy drinks on human body systems, such as the cardiovascular system, nervous system, digestive system and the mental state of consumers.

4.1. Cardiovascular system

The main ingredient in energy drinks is caffeine, and it is caffeine's action that has the greatest effect on the cardiovascular system. Its mechanisms of action are further enhanced by the guarana contained in these drinks, which also contains caffeine, as well as theophylline and theobromine. Caffeine has mainly inotropic and chronotropic effects on the heart. At low caffeine intake, this is due to the increased release of the catecholamines epinephrine and norepinephrine, which is caused by caffeine's antagonizing effect on adenosine receptors at presynaptic junctions. At higher concentrations, caffeine can directly increase calcium uptake by increasing cAMP concentrations through phosphodiesterase inhibition. Steinke et al. conducted a study on 15 healthy young adults, showing that after daily consumption of 500 ml of an energy drink over a 7-day period, their heart rate increased by an average of 5-7 beats per minute and their systolic blood pressure by 10 mmHg from baseline. [16] Similar conclusions were reached by Elitok et al. who in their study conducted a trial on 50 young adults aged 25 ± 2.3 years. The subjects, 2 hours after consuming 335 ml of an energy drink, were subjected to an ECG and measurements of heart rate and blood pressure. The subjects showed an increase in heart rate by an average of 6 beats per minute, an increase in SBP by 9 mmHg and DBP by 3.3 mmHg. [17] The researchers also attempted to assess the effect of energy drink consumption on the subjects' electrocardiographic findings. Ammar et al. conducted a trial on 10 young healthy adults, aiming to assess electrocardiographic values such as PR, QRS, QT, QTc and RR intervals, as well as the dispersion of QT and QTc intervals, after they consumed a beverage containing 400 mg of caffeine. They showed that moderate caffeine consumption by healthy young adults did not affect PR, QRS, QT, QTc and RR intervals, or the dispersion of QT and QTc intervals. Like previous researchers, they demonstrated that the consumption of a caffeinated beverage determines an increase in heart rate and an increase in systolic and diastolic blood pressure. [18] Interesting conclusions were

reached by Sutherland et al. who conducted a study to determine the clinico-electrophysiological effects of a moderate dose of caffeine by comparing heart rate and rhythm, incidence and prevalence of ventricular arrhythmias, and Q-T intervals in two groups during a 24-hour period without caffeine consumption and the subsequent 24 hours when caffeine was consumed at a dose of 1 mg/kg body weight during intervals of half-lives during wakefulness. Group 1 consisted of 18 clinically healthy subjects, group 2 of 18 subjects with frequent ventricular episodes of premature ventricular contractions (PVCs) and no (n = 16) or little (n = 2) heart disease. The study found a slight increase in heart rate in healthy subjects, and showed no significant difference in Q-Tc intervals compared to when no caffeine was consumed and when caffeine was consumed. Individuals suffering from frequent premature ventricular contractions (PVCs) showed an increased frequency of these events after consuming caffeine, suggesting a possible effect of caffeine on the occurrence of ventricular arrhythmias. This suggests caution in the use of energy drinks in individuals who struggle with premature ventricular contractions. [19]

4.2. Nervous system

Caffeine, which is the main ingredient in energy drinks, shows a number of effects on the nervous system. Caffeine acts as a stimulant, affecting the central nervous system. It blocks adenosine receptors, leading to increased release of neurotransmitters such as dopamine and norepinephrine. This, in turn, can lead to arousal, improved mood and increased alertness. Caffeine consumption at doses below 500 mg has benefits such as increased alertness, speed of thought and speech, and reduced feelings of fatigue and shorter sleep. However, at higher doses, adverse effects such as restlessness, anxiety, insomnia, tremors and, in cases of acute toxicity, even seizures that do not respond to antiepileptic drugs can occur. [20] The relationship between caffeine contained in energy drinks and the onset of an epileptic condition is still the subject of much research and has not been thoroughly clarified. There are many clinical case reports suggesting a link between a large dose of caffeine and the triggering of an epileptic seizure. Van Koert et al. undertook an analysis of the PubMed database to find studies evaluating the effects of caffeine on susceptibility to epileptic seizures, epilepsy and drug interactions in both humans and animal models. In animal studies, caffeine was found to reduce the efficacy of some antiepileptic drugs, with the drug's inhibitory effect being greatest with topiramate. [21] Costatino et al. undertook an analysis of 22 clinical cases reported in PubMed that involved the neurological effects of energy drink overdose. Among these cases were various events such as clonic seizures (6 cases), psychotic episodes (9 cases),

manifestations of retinopathy (2 cases), stroke (1 case), subarachnoid hemorrhage due to aneurysm (1 case), agitation and anxiety (1 case), Roland's epilepsy (1 case), and hyperosmotic syndrome with diabetic ketoacidosis (1 case). Half of the patients who experienced the effects of energy drink overdose had chronic diseases such as schizophrenia, migraine, obesity, hypertension. [22]

4.3. Mental health

Like other body systems, energy drinks can affect the consumer's mental sphere in the long term. A number of studies have been conducted showing the relationship between energy drink consumption and consumer well-being. Walther et al. conducted a study whose purpose was to analyze the relationship between energy drink consumption and subjects' ratings of well-being. At the conclusion of the study, results indicated that a higher percentage of subjects reporting well-being occurred in those who consumed an energy drink once a week or not at all. Those who consumed energy drinks twice a week or more reported worse well-being compared to the first group. A drawback of the study was that the subjects consumed alcohol along with the energy drinks, making it difficult to assess the impact of just the energy drink on mental well-being. However, the results of the study suggest that excessive consumption of energy drinks has a negative impact on well-being. [23] Trapp et al. conducted the study on 1,069 young Australian residents with a mean age of 20 ± 3 years. The study group included 502 men and 567 women. The study was designed to examine the effects of energy drink consumption on psychological well-being. The study found a positive relationship between the presence of anxiety and energy drink consumption in a large sample of subjects. After taking into account potential factors influencing the outcome of the trial, the researchers concluded that energy drink consumption of at least 100 ml per day was significantly associated with feelings of anxiety, which, however, was only the case for men. [24] Azagba et al. conducted a study on a group of Canadian adolescents, aiming to investigate the prevalence and extent of energy drink consumption among adolescents and to determine whether more frequent consumption of energy drinks is associated with mood swings. A total of 8210 Canadian teenagers were studied. Nearly two-thirds of survey respondents (62%) reported consuming energy drinks at least once in the previous year, with about 20% admitting to consuming them at least once a month. It was noted that depressive episodes and lowered mood among those who consumed energy drinks were significantly higher compared to those who did not consume energy drinks. The association of energy drinks with other potentially negative health outcomes suggests that consumption of these

products may be a predictor of other activities that can negatively impact adolescent development, health and well-being. [25] Richard and Smith attempted to investigate the relationship between caffeine and stress, anxiety and depression among British teenagers. They collected questionnaires from 2307 adolescents between the ages of 11 and 17, where the mean age was 13.6 ± 1.49 . The researchers showed that the subjects' increased stress levels were directly related to total weekly caffeine intake (this did not change even after other factors such as diet, demographics and lifestyle were taken into account), but failed to observe a direct relationship with caffeine from energy drinks. Low caffeine intake from energy drinks (0.100-133 mg/week) was associated with higher stress levels in subjects. Increased weekly caffeine intake did not, although no such association was found for high intake (≥ 133 mg/week). The situation is similar when it comes to correlations of weekly caffeine intake and the occurrence and level of anxiety. Total caffeine intake per week was positively related to anxiety levels. The researchers observed an association of low caffeine intake (0.100-133 mg/week) from energy drinks was associated with high levels of generalized anxiety; no such association was found for high intake (≥ 133 mg/week). The researchers also noted positive correlations between caffeine consumption and the tendency to develop depression. However, they did not see significant data when it came to caffeine from energy drinks. [26]

4.4. Gastrointestinal system

Energy drinks can also affect gastrointestinal function. The authors report cases of acute hepatitis and acute pancreatitis resulting from an overdose of energy drinks. Ingestion of excessive amounts of vitamin B3 (niacin) contained in beverages in large doses is associated with hepatotoxicity. Hepatotoxicity manifests itself as mild elevations of liver enzymes (ALT/AST), hepatic steatosis, hepatic necrosis and, in rare cases, liver failure. According to the literature, the lowest known dose of vitamin B3 capable of causing hepatotoxicity is 1 g per day. [27] Randhawa et al. described the case of a 29-year-old man who presented to the emergency department with nausea, vomiting and severe epigastric pain. Laboratory determination of pancreatic enzyme lipase yielded a level of 3122 U/L, well above the normal in a healthy person. The patient's clinical picture and laboratory results were clearly indicative of acute pancreatitis. [28] The patient admitted that before developing symptoms, he had been consuming 5 to 6 energy drinks per day for a long time. Other laboratory tests that could indicate the cause of acute pancreatitis were normal, and the patient also denied alcohol consumption. After conservative treatment, the patient's condition improved. Failure to find a

typical cause of acute pancreatitis strongly suggests the influence of energy drink abuse on the development of acute pancreatitis in this patient. The authors also searched PubMed, Medline, and the ISI Web of Sciences database, and from this, 5 cases of acute pancreatitis were described where the suggested etiology was chronic energy drink abuse. [29] The data available in the literature is not sufficient to conclusively assess the effect of energy drinks on the incidence of pancreatitis; however, there are cases where the etiology of the disease strongly suggests energy drink abuse. However, further research is needed in this direction.

5. Energy drinks and alcohol

Combining an energy drink with alcohol is becoming increasingly popular. The combination is a tempting proposition for young people and is increasingly offered at least in bars. Peacock et al. conducted a survey of 403 young Australian adults in an effort to understand their motivations for consuming alcohol and energy drinks simultaneously. Respondents, given the opportunity to choose several answers, mostly answered that they like the flavor combination of alcohol with an energy drink (69% of them), and to be able to stay longer at a social gathering (54% of respondents). A smaller proportion of respondents answered that they consume alcohol together with energy drinks to be able to drink more alcohol (32% of respondents), or to reduce the occurrence of a hangover (6% of respondents). [30] A similar study was conducted by Bonar et al. who surveyed 439 teenagers between the ages of 14 and 20. Among them, 158 of the subjects had combined alcohol consumption with energy drinks within the previous year. 39.2% of them did so to mask the taste of alcohol, 35.8% because they like the combination, 32.3% to stay stimulated, and 7.6% to neutralize the effects of alcohol. [33] Reis et al. conducted a study on rats and found that the combination of these alcohol and energy drinks resulted in an increase in the lipid peroxidation parameter malondialdehyde (MDA), a marker of liver damage. The MDA parameter was significantly higher with the combination of energy drinks and alcohol compared to that of energy drinks alone, ethanol alone or a control sample. [31]

6. Summary

There have been quite a few works on the effects of energy drinks on consumer health. In our review of the literature on the subject, we found a number of works indicating the negative consequences of consuming large quantities of energy drinks. Included in the range of these consequences are cardiovascular disorders such as an increase in the frequency of ventricular arrhythmias after consuming energy drinks in subjects struggling with premature ventricular

beats, and an increase in mean arterial pressure in subjects without chronic illness. The effects of the drinks on the nervous system, gastrointestinal tract and the impact on the subjects' psychological well-being were also addressed. A number of works have shown that chronic consumption of energy drinks negatively affects the subjects' well-being, increasing their anxiety and anxiety levels, while occasional consumption of these drinks in small doses did not cause such complications. As a result of the immense popularity that energy drinks have gained, it seems that they have settled permanently into the landscape of store shelves and are an integral part of the daily diet of a large number of people. As such, it is important to adhere to intake standards for products contained in beverages such as caffeine and taurine. The European Food Safety Authority (EFSA) has set recommended standards for daily caffeine intake, which is 400 mg per day for adults, and standards for a single dose of caffeine contained in the beverage consumed which should not exceed 200 mg of caffeine. EFSA has not established a safe dose of caffeine in energy drinks for children, while suggesting that children and adolescents should not consume energy drinks. [32] Most beverages on the market meet the single-dose caffeine standard, with caffeine content ranging from 50 mg - 150 mg, depending on the manufacturer. In conclusion, the results presented in the paper suggest that energy drinks, due to the ingredients they contain, can lead to a number of adverse health effects, so an important role in controlling access to energy drinks for children and adolescents should rest with local governments that choose to impose restrictions on access to energy drinks for children and adolescents. [5] Further research and monitoring of energy drink consumption is recommended to better understand and define the potential health risks associated with their consumption.

7. Disclosure

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