REVIEW ARTICLE

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Medical and forensic aspects of energy drinks and caffeine shots

Medyczno-sądowe aspekty napojów energetycznych i szotów kofeinowych

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Abstract

Introduction and Objective. The number of users of energy drinks and caffeine shots worldwide is very high and varies depending on the age group. In many countries, legislative measures have been taken to restrict access to these products for minors. The main ingredient in energy boosters is caffeine which is responsible for the stimulating properties of these products. Other substances, such as guarana, taurine, vitamins, and simple sugars, are also included in their composition. The aim of the study is to investigate the impact of these products on the body, and their medical and forensic aspects.

Review Methods. A literature review was conducted using PubMed, Medline, Google Scholar, and information from legal documents and product labels available on the market.

Brief description of the state of knowledge. The use of high-caffeine products is associated with a negative impact on various systems in the human body, with cardiovascular issues being the most commonly observed. Based on available literature, it can be speculated that children are most vulnerable to the harmful effects of these substances. Another concern related to energy drinks and caffeine shots is their interaction with many medications and other substances. There have been cases reported of overdosing on energy drinks, suicide attempts, and deaths, as a result. In medico-legal diagnostics, toxicological examinations regarding caffeine levels in the blood and appropriate differential diagnostics are crucial.

Summary. The consumption of energy drinks and caffeine shots may pose a threat to health. Further analyses of the broad impact of these products on the human body, with special consideration for children, are needed.

Key words

toxicity, caffeine, energy drinks, taurine, forensic

Streszczenie

Wprowadzenie i cel pracy. Liczba konsumentów napojów energetycznych i szotów kofeinowych na świecie jest bardzo wysoka i różni się w zależności do grupy wiekowej. W wielu krajach podjęto działania legislacyjne mające na celu ograniczone osobom niepełnoletnim dostępu do tych produktów. Głównym składnikiem napojów energetycznych i szotów kofeinowych jest kofeina, która ma odpowiadać za pobudzające właściwości tych produktów. W ich skład wchodzą również inne substancje, takie jak guarana, tauryna, witaminy i cukry proste. Celem pracy była ocena wpływu tych napojów na organizm i przedstawienie ich aspektów medyczno-sądowych.

Metody przeglądu. Przegląd piśmiennictwa został wykonany z wykorzystaniem internetowych baz danych PubMed, Medline oraz Google Schoolar, posłużono się również informacjami z aktów prawnych i etykiet produktów dostępnych na rynku.

Opis stanu wiedzy. Stosowanie produktów o wysokiej zawartości kofeiny wpływa negatywnie na wiele układów w organizmie człowieka. Najczęściej obserwuje się dolegliwości ze strony układu sercowo-naczyniowego. Na podstawie dostępnej literatury można przypuszczać, że najbardziej narażone na szkodliwe działanie tych substancji są dzieci. Kolejnym zagrożeniem związanym z napojami energetycznymi i szotami kofeinowymi są ich interakcje z licznymi lekami i używkami. Istnieją przypadki przedawkowania napojów energetycznych, prób samobójczych oraz zgonów z tego powodu. W diagnostyce medyczno-sądowej ważne jest badanie toksykologiczne mierzące stężenie kofeiny we krwi oraz odpowiednia diagnostyka różnicowa.

Podsumowanie. Konsumpcja napojów energetycznych i szotów kofeinowych może stanowić zagrożenie dla zdrowia. Potrzebne są dalsze analizy szeroko pojętego wpływu napojów energetycznych na ludzki organizm ze szczególnym uwzględnieniem dzieci.

Słowa kluczowe

kofeina, medycyna sądowa, napoje energetyczne, toksyczność, tauryna

INTRODUCTION AND OBJECTIVE

Energy boosters are popular products characterized by a high caffeine content. Some consider them as enhancers of cognitive abilities such as concentration and memory, while

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others view them as a potential source of health risks. They constitute a significant element of contemporary consumer culture, generating both interest and controversy. Initially designed for athletes, they have gained the most popularity among students and young adults [1].

Energy drinks entered the market over 80 years ago and have been gaining increasing popularity year by year. The history of energy drinks dates back to the mid-20th century when the first attempts were made to create a non-alcoholic, stimulant beverage enriched with vitamins, serving as an alternative to the carbonated drinks with high sugar content available at that time. The pioneering product in this category was Dr. Enuf®, which debuted in the USA in 1949 [2]. The beverage quickly gained consumer recognition, initiating its mass production that continues to this day. Another product from the same category, Lipovitan®, considered a precursor to the famous Red Bull, was created in 1962 in Japan. It gained popularity, thus initiating a trend in the Asian market. Red Bull®, introduced in 1987 in Austria, played a key role in popularizing energy drinks through its unconventional marketing, and currently maintains a leading position in the global market [3].

Producers of energy drinks strive to keep up with consumers and their evolving needs, as well as contemporary trends [3]. There is continuous development in this industry, with producers regularly introducing new products to the market that differ in composition, flavour, as well as unique colouring or labels designed to attract specific consumers. Currently, producers are offering increasingly innovative solutions, such as caffeine shots, 'sugar-free' drinks, or beverages enriched with natural ingredients, aligning with the current trend of promoting a healthy lifestyle [4]. Due to intense competition in the energy drink market, manufacturers place significant emphasis on marketing, often utilizing viral marketing strategies. Energy drinks are frequently advertised as effective tools for instant energy boost and improved concentration. The images of well-known athletes, actors or musicians, are increasingly used to enhance the attractiveness of advertisements [3].

In general, since the debut of energy drinks on the market, their popularity has consistently grown. In the USA, from 2003 to 2016, there was an increase in the consumption of these products among youths, young adults, and middle-aged adults. However, in recent years, there has been slower growth or even a decline in consumption among the youth and young adult demographic [1]. In Europe, however, there is a growing trend, and according to a survey conducted in 2012 in 16 European Union (EU) member countries, 18% of children, 68% of adolescents, and 30% of adults consumed an energy drink at least once a year [5]. Eurostat, the Statistical Office of the European Union, presented the results of a study focused on the frequency of consumption of beverages classified as soft drinks in 2019, which included energy drinks. In the EU, every 10th person consumes such a product at least once a day, with Belgium standing out significantly, where every 5th citizen consumed these products that often. Countries with a high percentage of citizens consuming energy drinks daily include Malta, Germany, Hungary, and Bulgaria. On the other hand, the highest number of people who declared that they do not consume such products or consume them only occasionally, reside in Finland, Estonia, Lithuania, Italy, and Latvia [6]. Analysis of the frequency of energy drink consumption in Poland shows that in the age group of 30–44 years, such products are the most popular. In addition to age, differences in the frequency of consumption of such products are also observed depending on education and financial situation. People with lower than secondary education, and those with very good or good financial status prevail [7]. The meta-analysis conducted by Alonso-Diego G. et al. revealed that globally, over half of the participants had consumed energy drinks at some point in their lives. Significant differences were observed based on age groups and continents [8].

The energy drinks available on the market vary significantly in terms of their composition (Tab. 1), [2]. The caffeine content in selected products available on the market is presented in Figure 1. Other commonly used ingredients in these products include, among others, taurine, guarana, as well as vitamin A, B-group vitamins, electrolytes, methylxanthines, ginseng, yerba mate, maltodextrin, inositol, carnitine, creatine, glucuronolactone, and ginkgo biloba [9,10]. Simple sugars are also part of these products (Fig. 2). These drinks often contain additional flavourings, sweeteners, colourings and preservatives, aimed at creating a product with a distinctive taste and appearance. Their highly complex composition can pose challenges in assessing their impact on the body, raising concerns about safety.

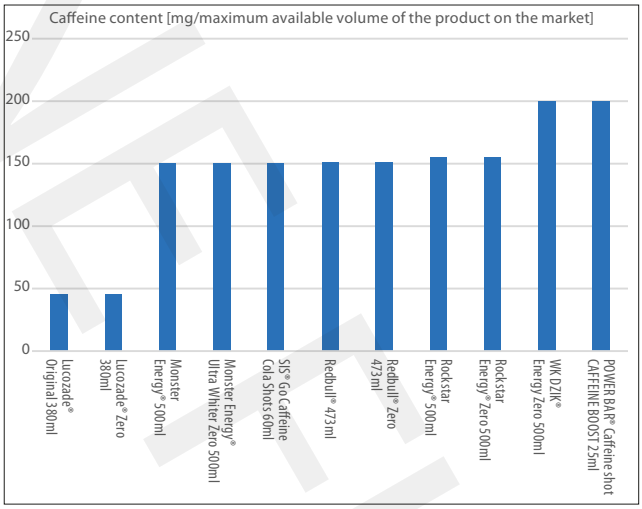

Diagram 1. The diagram illustrates the caffeine content in the largest available volume of the product on the market [103]

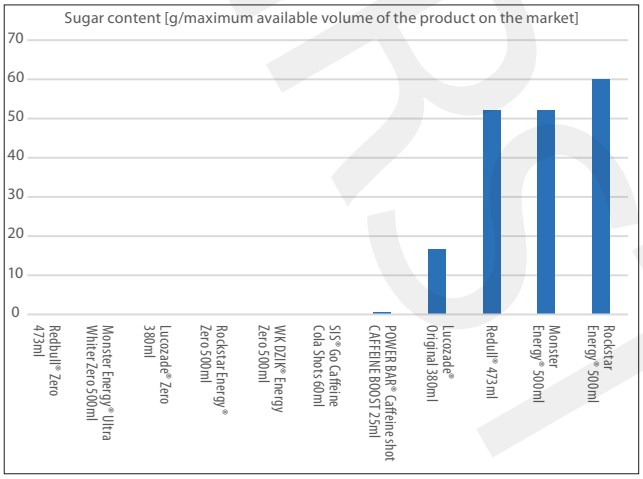

Diagram 2. The diagram illustrates the sugar content in the largest available volume of the product on the market [103]

Table 1. Selected substances found in energy drinks and caffeine shots, volumes of these products available on the market [103]

	Redbull®	Redbull® Zero	Monster Energy®	Monster Energy® ultra whiter zero	Lucozade® Original	Lucozade® Zero	Rockstar Energy®	Rockstar Energy® Zero	WK DZIK® Energy Zero	POWER BAR® Caffeine shot CAFFEINE BOOST	SIS® Go Caffeine Cola Shots
caffeine (mg/100ml)	32	32	30	30	12	12	31	31	40	800	250
carbohydrates without sugars. (g/100ml)	0	0	1	0,88	4,4	0	0	0,7	0	2,2	0
sugars (g/100ml)	11	0	11	0	4,5	0,1	12	0	0,5	2,5	0
riboflavin (B2) (mg/100ml)	-	-	0,7	-	-	-	-	-	0,56	-	0,77
niacin (B3) (mg/100ml)	8	8	8,5	8,6	1.2	1.2	3,2	3,2	6,4	-	-
pantothenic acid (B5) (g)	2	2	-	4,2	-	-	-	-	-	-	-
vitamin B6 (mg/100ml)	2	2	0,8	0,8	-	-	0,28	0,28	0,56	-	-
folic acid B9 (µg/100ml)	-	-	-	-	-	-	-	-	-	-	111
cobalamin B12 (µg/100ml)	2	2	2,5	2,4	-	-	0,5	-	1	-	1,4
taurine (%)	0,4	0,4	0,4	0,4	-	-	0,4	0,02	0,4	-	-
sweeteners	-	sucralose, acesulfame K, steviol glycosides	-	sucralose, acesulfame K	aspartame, acesulfam K	aspartame, acesulfam K	-	sucralose, acesulfame K, erythritol	sucralose, acesulfame K,	sucralose, acesulfame K, cyclamates, saccharin	sucralose, acesulfame K, steviol glycosides
preservatives	-	-	sorbic acid, benzoic acid	sorbic acid, benzoic acid	potassium sorbate	potassium sorbate	-	-	potassium sorbate, sodium benzoate	potassium sorbate	potassium sorbate, sodium benzoate
acidity regulators	sodium carbonate, magnesium carbonate	sodium carbonate, magnesium carbonate	sodium citrate	sodium citrate	sodium citrate	Sodium gluconate	sodium citrate	sodium citrate, potassium phosphate	sodium citrate	citric acid	citric acid, malic acid
colorants	caramel, riboflavin	caramel, riboflavin	anthocyanins	anthocyanins	orange yellow S, ponceau 4R	present, no specific data	caramel, riboflavin	caramel, riboflavin	caramel	-	-
flavors	present, no specific data	xanthan, thaumatin	present, no specific data	present, no specific data	present, no specific data	present, no specific data	present, no specific data	present, no specific data	present, no specific data	present, no specific data	present, no specific data
ginseng root extract(%)	-	-	0,08	0,08	-	-	-	0,0025	0,08	-	-
guarana	-	-	-	present	-	-	-	-	present	present	-
inositol	-	-	present	present	-	-	present	present	present	-	-
L-winian L-karnityny (%)	-	-	0,04	0,015	-	-	-	-	0,04	-	-
kcal/100ml	46	9	2,2	47	37	1,7	51	3	3	24	14
Available volumes (ml) and caffeine content in the entire product (g)	250ml- 80g, 473ml- 151,36g	250ml- 80g, 473ml- 151,36g	500ml- 150mg	500ml- 150mg,	380ml- 45,6mg	380ml- 45,6mg	250ml- 77,5mg, 500ml- 155mg	250ml- 77,5mg, 500ml- 155mg	500ml-200mg	25ml-200mg	60ml-150mg

Legal regulations concerning energy drinks constitute a significant area within global health policies. In many countries, there are specific regulations aimed at controlling the production, sale, and advertising of these beverages. Due to their relatively short presence on the market and the growing trend in popularity, discussions about their legal status are ongoing. Colombia stands out as a precursor in this regard, where, in 2009, the sale of energy drinks to children under the age of 14 was prohibited [11]. In accordance with EU regulations, products containing more than 150mg/l of caffeine should include a warning on the label about high caffeine content, and that the beverage is not recommended for children and pregnantwomen [12]. Some EU member states have tightened regulations on energy drinks. In 2014, Lithuania became the first to prohibit the sale of products containing over 150mg of caffeine per litre to minors [13]. In Poland, starting from 1 January 2024, the sale of products with the same caffeine concentration as in Lithuania, and with the addition of taurine, is prohibited in educational institutions and vending machines to individuals under 18 years of age [14]. Also, in Uzbekistan, the sale of such products to individuals under 18 years of age is prohibited. Additionally, according to Article 221, advertising products containing more than 150mg/l of caffeine is prohibited between the hours of 0700–2200 [15]. Meanwhile, in the United Kingdom, there are plans to introduce age restrictions, but currently many supermarkets do not sell energy drinks to individuals under 16 years of age [16,17].

The aim of this study is to analyze the impact of consuming energy drinks and caffeine boosters on the human body, with particular emphasis on forensic aspects.

REVIEW METHODS

For the literature review, searches were conducted using the databases PubMed, Medline and Google Scholar. Publications in various languages were selected. Information was also obtained from legal documents regarding energy drinks available on government websites, as well as from the labels of products currently available on the market.

STATE OF KNOWLEDGE

Impact on health. Energy drinks and caffeine shots are popular due to their stimulating properties and ability to enhance concentration. Because of the presence of numerous substances in their composition, these products exhibit complex effects impacting various systems in the human body. Evaluating the impact of energy boosters on the body should consider the synergistic action of all contained substances, rather than focusing solely on individual ingredients.

Research results on the effects of energy drinks on the cardiovascular system are highly divergent, and based on available literature, it is challenging to unequivocally state which parameters undergo changes after their consumption. M. Basrai et al. recorded the highest increase in blood pressure one hour after consumption, with the parameter subsequently returning to normal. In the same studies, prolongation of QTc (electrocardiogram results?) and an increase in heart rate were also observed [18]. Other authors have also observed an increase in blood pressure and heart rate [19]. On the other hand, research conducted by Hajsadeghi et al. suggests that energy drinks do not have a significant impact on increasing blood pressure, but lead to a decrease in heart rate and changes in the morphology of the ECG ST-T segment [20]. Analysis of the results of another study did not allow for a clear assessment of the impact of energy drinks on blood pressure, but an increase in heart rate and a shortening of the QT interval were observed [21]. It is suggested that the decrease in heart rate may be a compensatory mechanism for the increase in blood pressure, or may result from the action of taurine [22]. From the above data, it appears that energy drinks either have no impact or can elevate blood pressure, induce a decrease or acceleration in heart rate, and may influence the electrical activity of the heart.

Energy drinks contain numerous substances that affect the nervous system. The main ingredients are caffeine, guarana, taurine, and B-group vitamins. There are many publications on individual components found in energy drinks, but there is limited data on the direct impact of these beverages on the nervous system. Caffeine acts by blocking adenosine receptors, increasing neuronal activity, and stimulating the release of neurotransmitters, such as norepinephrine and dopamine. This results in improved concentration, alertness, and cognitive processes [23].

Guarana operates through a similar mechanism to caffeine, primarily due to its content of guaranine, which is structurally similar to caffeine [24]. The presence of caffeine and guarana in most energy drinks explains the occurrence of neurological symptoms, such as headaches, dizziness, tremors, unclear speech, difficulty walking, reduced coordination, visual disturbances, and seizures [25]. Taurine is a non-proteinogenic amino sulfonic acid responsible for improving cognitive abilities, and exhibits antioxidant properties. This may explain its protective effect on nerve cells. It is also involved in regulatory processes related to ion transport, influencing the maintenance of the membrane potential of nerve cells [26,27]. Vitamins from the B-group, also present in energy drinks, are substances that affect the nervous system. It has been proven that the use of supplements with a high content of these vitamins reduces markers of oxidative stress in neurons and in the blood. However, such results were achieved using a preparation with concentrations of B3 ten times higher, B5 seven times higher, B6 2.5 times higher, and B12 three times higher than in energy drinks. Additionally, the supplement contained substances not found in most energy drinks, such as folic acid, biotin, or thiamine [28,29].

Energy drinks also influence metabolism. The first aspect is the presence of large amounts of simple sugars in standard versions of these beverages (Fig. 2). A randomized controlled trial left no doubt that there is a correlation between the consumption of energy drinks and an increased risk of developing metabolic diseases, such as obesity, insulin resistance, and diabetes [18]. Interestingly, 'sugar-free' versions, sweetened with artificial sweeteners, may also contribute to the development of metabolic disorders. A study conducted on mice demonstrated that there is a risk of metabolic syndrome associated with sugar-free counterparts to the same or even lesser extent than with sugar-sweetened beverages [30]. Caffeine, by stimulating 5'-Adenosine monophosphate-activated protein kinase (AMPK), affects insulin-independent glucose transport in skeletal muscle [31]. From the available publications on the

effects of caffeine, it appears that long-term intake of this substance may contribute to a reduction in insulin sensitivity [32]. Another substance found in energy drinks that has a significant impact on metabolism is taurine, responsible for maintaining glucose homeostasis. The mechanism of its action in this regard has not been fully understood, but it likely influences insulin secretion, for example, by increasing insulin gene expression. It has also been suggested that taurine may improve lipid profiles, and may also have a preventive effect in the development of atherosclerosis in diabetic patients [33,34]. The increase in blood glucose levels as a result of consuming energy drinks is due to the predominance of hyperglycaemic substances (mainly sugars) over substances with hypoglycaemic effects (such as taurine).

In the literature, cases of toxic effects on the liver, kidneys and pancreas have been described, where a correlation with the consumption of energy drinks was noted, along with changes in laboratory markers indicating damage to these organs [35–37]. On the other hand, a study conducted on 22 elite male soccer players, showed that in individuals subjected to intense physical exertion, energy drinks may accelerate the regeneration of muscles and the liver [38]. There is a lack of broader studies that would allow for an assessment of whether the impact of these products is statistically significant.

Caffeine shots have a similar composition to energy drinks, but individual substances occur in different proportions, resulting in different effects on the body. These products allow for the intake of caffeine in a more concentrated form, where the content of caffeine in relation to other substances, such as sugars, is much higher (Fig. 2). This explains the predominance of effects strictly associated with caffeine, such as stimulation, improved concentration, and increased blood pressure [9].

Impact on minors. The epidemiological data described in the Introduction indicate that the paediatric population comprises a relatively significant consumer group of energy drinks [39]. Between 1999–2010, nearly 3/4 of individuals aged 2–22 in the USA consumed caffeine. During this period, a decline in the consumption of cola-type carbonated beverages was observed, while there was an increase in the consumption of coffee and energy drinks [40]. There is a lack of available epidemiological data for subsequent years, but based on market analysis, it can be speculated that the peak popularity of energy drinks among the paediatric population may have occurred after 2010. Currently, there is no scientifically proven safe dosage for children, but many non-scientific sources suggest a limit of 100mg/day. The Canadian government recommends a caffeine intake not exceeding 45mg/day for ages 4–6 years, 62.5mg/day for ages 7–9, 85mg/day for ages 10–12, and 2.5mg/kg of body weight for individuals above 13 years of age [41]. For this reason, it is important to analyze the impact on children, whose developing bodies are more vulnerable to various exogenous factors.

The implications mentioned in previous paragraphs were mainly related to adults. Due to the limited number of publications regarding the paediatric population, assessing the impact of energy drinks on children is challenging. A study conducted on individuals aged 12–18 indicates that energy drinks are responsible for an increase in blood pressure and heart rate [42,43]. Additionally, the impact on the cardiovascular system has been demonstrated in a publication where an increase in arterial stiffness associated with the consumption of these products was described in a research group with an average age of 14.5 [44]. From a study conducted between 2009–2014, it was found that there is a correlation between children's exposure to caffeine and an increase in body mass index (BMI) and waist circumference (WC) [45]. Energy drinks, as a source of simple sugars, also contribute to the development of metabolic disorders [46]. Wee JH et al. demonstrated an association between the consumption of these products and the occurrence of allergic diseases, such as asthma, rhinitis, and atopic dermatitis [47]. Among adolescents aged 12–18, it has been observed that the most common adverse effect after consuming energy drinks is headache (76%) and every second user of these products perceived their impact on their behaviour [48]. In the group of users with a mean age of 13, ranging from 11–16 years old, problems with falling asleep, waking up, and self-reported behaviour regulation and metacognition were noted [49].

Interactions. Excessive consumption of energy drinks and caffeinated shots in society increases the need to understand the risks associated with simultaneous consumption of these products with alcohol or medications. Combining alcohol with energy drinks is a highly popular practice among young adults and adolescents. Although it is not fully understood why these age groups are so inclined towards this combination, some literature suggests that it may be related to improving the taste of alcohol and seeking an additional source of energy [50]. It has been demonstrated that consuming energy drinks with alcohol enhances the euphoric effects of the alcohol, acts as a stimulant, prolongs the drinking session, and also increases the likelihood of developing the alcohol use disorder (AUD) [51]. Alcohol mixed with energy drinks leads to a greater tendency for activities, such as driving under the influence of alcohol [52], exceeding permissible speed limits, driving without seat belts fastened, engaging in risky sexual behaviours, and an increased inclination to reach for psychoactive substances [53,54]. Individuals consuming energy drinks with alcohol, compared to those consuming alcohol alone, are more susceptible to accidents and physical injuries [55]. The combination of alcohol with energy drinks has a very adverse effect on the cardiovascular system. From available studies, it is evident that alcohol alone increases the risk of atrial fibrillation[56], but when combined with an energy drink, the effect is compounded, significantly increasing not only the risk of atrial fibrillation [57], but also the risk of other cardiac rhythm disorders and myocardial damage [58–62].

Another crucial aspect involves the interactions between the components of energy drinks or caffeinated shots with medications, and their serious health consequences. It has been demonstrated that the main component of energy drinks – caffeine, can cause disruptions in the absorption, metabolism, and elimination of drugs. Caffeine induces an increase in gastric acid secretion, leading to a decrease in gastric juice pH. Depending on the medication, this can result in increased or decreased absorption in the gastrointestinal tract. Studies have proven that caffeine consumption can reduce the absorption of substances such as midazolam, thyroxine, or iron preparations. Conversely, consuming the same amount of caffeine can enhance the absorption of acetylsalicylic acid, paracetamol or ketoprofen, intensifying their analgesic effects [53,63]. There are also medications

whose distribution can be disturbed by the inhibition and saturation of enzymes by caffeine. Simultaneous intake of caffeine with these substances results in their prolonged activity in the body. Some of these medications include lidocaine, propafenone, propranolol, verapamil, warfarin, ropivacaine, methotrexate, clozapine, haloperidol, olanzapine, and amitriptyline. Caffeine also increases glomerular filtration, leading to an increased volume of excreted urine and faster elimination of drugs such as oxandrolone and epioxandrolon [64].

It has been proven that caffeine reduces blood clotting, therefore consuming it concurrently with anticoagulant medications, such as warfarin or heparin, can result in bleeding complications and a tendency to bruise easily [53]. Excessive caffeine consumption also contributes to decreased tissue sensitivity to insulin and disrupts the action of hypoglycaemic medications, which can result in the persistence of abnormal glycaemia in diabetic patients [32]. Additionally, caffeine is an antagonist of Z-drugs (zaleplon, zolpidem, zopiclone) and benzodiazepines, significantly affecting the efficacy of therapy with these medications [53]. In combination with duloxetine, an improvement in cognitive function has been observed, and the combined use of duloxetine and caffeine yielded better results than duloxetine monotherapy. However, the combination of caffeine with duloxetine is associated with an increased risk of serotonin syndrome [65].

Guarana is another ingredient found in energy drinks and caffeinated shots. There is limited information available regarding the interactions of guarana with specific medications. It is assumed that the effects of consuming guarana may be similar to those described earlier for caffeine [53]. In a study conducted on rats, it was shown that guarana extract interacts with amiodarone. This combination significantly reduces the concentration of the drug, which may contribute to the loss of the antiarrhythmic effect of the medication and ineffective treatment of patients [66].

It has been shown that ginseng interacts with medications, primarily by inhibiting the activity of cytochrome P450, responsible for metabolizing many drugs [53]. Ginseng interacts with anticoagulant drugs such as warfarin, acenocoumarol, and antiplatelet medications [67]. In both drug groups, the consumption of ginseng intensifies their effects, leading to an increase in bleeding complications in patients [68]. Additionally, combining ginseng with oral hypoglycaemic drugs and insulin, increases the risk of hypoglycaemia and its dangerous complications in diabetic patients [53]. A serious complication may arise from combining ginseng with monoamine oxidase inhibitors. Patients have reported symptoms such as severe headaches, tremors, insomnia, elevated blood pressure, manic episodes, and increased depressive symptoms [69–71].

Studies show that taurine supplementation leads to a reduction in blood pressure [72]; however, combining taurine with a high dose of caffeine in energy drinks may have the opposite effect and result in an increase in blood pressure [73]. In hypertensive patient groups, excessive consumption of energy drinks may render drug therapy less effective, and fail to produce the desired outcomes.

Overdose, abuse and forensic aspects. Energy boosters are considered relatively safe stimulants used by people to prevent drowsiness. However, there are cases of symptoms of overdose, especially after consuming a large quantity of drinks in a short period. These symptoms are primarily associated with the excessive intake of caffeine, the main stimulating substance used in the production of energy drinks. They include seizures, vomiting, increased sweating, accelerated heart rate, palpitations, elevated blood pressure, headache, sleep disturbances, and anxiety [74–77]. The majority of them are mild and resolve spontaneously or with symptomatic therapy, without leaving a lasting impact on health [78]. In cases of severe overdoses, cardiac symptoms, such as chest pain or ST segment elevation and prolonged QT interval in electrocardiographic examination, are also described, together with elevated troponin and NT-proBNP values indicating a significant life-threatening condition [79–82]. Additionally, hypokaalemia and increased blood glucose levels may occur [83,84]. Rare cases of deaths related to the overdose of energy drinks, including in the paediatric population, have been reported [84,85]. These cases usually resulted from accidentally exceeding the dose considered lethal due to consuming too many energy drinks or mixing them with other products containing caffeine [86]. These may include over-the-counter medications containing caffeine to enhance their effect [87]. Other instances involve herbal remedies containing unreported caffeine, such as infusions [74]. However, based on media notes, case reports regarding this issue are underrepresented in scientific literature. Death usually occurs due to cardiac rhythm disturbances and coronary vasospasm, making post-mortem examination unable to conclusively determine the cause of death [84,85,88]. In such cases, differentiation from other potential causes of sudden cardiac death is usually required [84]. Cases of perforation in the gastrointestinal tract due to the high concentration of caffeine after ingesting energy-boosting products have also been reported [83]. Pre-disposing factors to death from a high dose of caffeine in energy drinks may include silent heart defects, conduction disorders, and cardiomyopathies [84,89–91]. Complications within the liver and stomach associated with prolonged intake of high doses of energy drinks, resulting from addiction, may also occur. These complications may arise from the action of other flavour additives enriching the drinks [37].

Toxicological studies play a crucial role in diagnosis [92], and the caffeine concentration in blood can be determined [74] with the typical method used being gas chromatography. Although the lethal concentration of caffeine in the blood is still a subject of scientific debate, the levels of caffeine considered life-threatening range from 80–180 mg/L, with toxic symptoms potentially occurring at 15–20 mg/L [93]. However, cases of survival after poisoning with much higher caffeine concentrations have been reported [94]. This is believed to be due to individual characteristics and genetic polymorphisms related to the activity of the CYP1A2 isoform of the P-450 cytochrome, involved in substance metabolism [74,84]. Caffeine presence can also be assessed by analyzing urine, cerebrospinal fluid, saliva, bile, dental calculus, and tissue fragments, such as kidney or spleen [74,81,95–98]. Additionally, when analyzing cases of deaths due to energy drink overdose, it is crucial to collect witness reports regarding the victim's symptoms and analyze the scene of the incident to search for elements indicating intensive consumption, such as empty cans of drinks. Furthermore, interactions and overlapping effects with other substances used for stimulatory or narcotic purposes should be taken into consideration

[99]. Powders and tablets containing caffeine used for self-preparation of energy drinks or as weight loss products are also significant [81,100]. In such cases, a small amount of the product contains a high concentration of caffeine which, in the event of a mistake in preparing the dose for dissolution, can pose a significant threat [86]. Furthermore, numerous cases of intentional caffeine overdose in the form of suicide attempts have been reported [81,101,102]. Typically, they concern young individuals and are characterized by the consumption of a large quantity of the product, often reaching a dose of the active substance ingested in several grams. [74,81,85,88,101].

CONCLUSIONS

The popularity of energy drinks and caffeinated shots poses a significant challenge for medicine. Their complex composition makes it difficult to assess their impact on users. An analysis of available literature indicates that the use of these products may have a negative effect on various systems in the human body, particularly the cardiovascular system. It is also important to consider the potential interactions of individual ingredients such as caffeine, guarana, and taurine with medications and other substances. Consuming excessive amounts of these products can lead to various symptoms of overdose, including seizures, vomiting, increased heart rate, and even severe cardiac complications.

Cases of deaths associated with the overdose of these beverages, especially among younger individuals, highlight the need for awareness of the risks associated with their excessive consumption. Many countries have taken legislative actions to restrict access to energy drinks for minors, and introduced advertising limitations. Further analyses are needed to comprehensively understand the impact of energy boosters on the human body, with particular attention to consumption by children.

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