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Abstract

Energy drink usage as a stimulant is on the rise among adolescents and young adults. While these drinks have positive energizing effects, they pose significant health concerns. This paper examines the adverse cardiovascular effects of energy drinks and the components that could possibly be responsible. Analysis was conducted by reviewing and comparing many studies available in this area of research. Studies of energy drinks in general and energy drinks versus drinks containing caffeine alone were analyzed. Additionally, this review investigated studies of the specific ingredients in energy drinks such as caffeine, taurine, guarana, and sugar. This review found that energy drinks cause varying degrees of adverse cardiovascular effects when consumed in specific dosages. While the highest levels of consumption led to arrythmias, syncope and death, lower levels led to increased QTc interval and increased blood pressure. Longer lasting effects of energy drinks, such as possible energy-drink induced hypertension, were also uncovered. The effects of energy drinks were deemed greater than those caused by caffeine alone. When analyzing energy drinks' ingredients, caffeine, sugar, and guarana were found likely responsible for the adverse effects of energy drinks, while the effect taurine was less convincing. Overall, while energy drinks were found to be safe in small and infrequent amounts, significant public health concerns were related to increased and habitual use.

Introduction

Energy drinks are widely used stimulants that are said to enhance performance, alertness, and concentration. Marketing of these beverages specifically targets adolescents and young adults, many of whom are said to take advantage of these drinks and their stimulant effect. Despite the perceived 'invincibility' connoted by names such as 'Monster' and 'Red Bull,' these pick-me-ups may pose significant health concerns. Substances present in energy drinks such as caffeine, sugar, and taurine have numerous hemodynamic effects. As such, these drinks are suspected of leading to various health threats including adverse cardiovascular events. These range from high blood pressure to cardiac arrythmias, which, in more extreme cases, can lead to sudden cardiac death. The goal of this review is to evaluate the following question: What are the energy drink-related cardiovascular health concerns, are they valid, whom do they concern, and how do energy drinks lead to these events?

Methods

This review was conducted by typing keywords and phrases such as "energy-drinks," "energy drinks and cardiovascular effects," "the effects of energy drinks," "energy drinks and mechanisms," and the like into database search engines such as EBSCO and ProQuest. The databases were accessed through Touro College, Einstein Medical College, and Johns Hopkins University. Many articles were also retrieved through Google Scholar.

Results and Discussion

How widespread is the usage of these drinks, and who is using them?

Energy drink sales have been steadily increasing since the turn of the century and are not expected to decrease in the near future. In 2006, the industry's retail market value was already $5.4 billion (Packaged Facts, 2007), a value dwarfed by 2016's $25 billion market (Packaged Facts, 2017).

Young adults are the heaviest consumers. Whether one gender drinks more heavily than the other is arguable. According to the NIH, the most common drinkers are men of ages 18-34 (NIH, 2018). Furthermore, in a study of 496 college students, 51% reported using energy drinks more than once a month on average. Of these users, most said they used one energy drink at a time. More concerning though, is that a considerable subgroup admitted to using three or more drinks at a time when mixing energy drinks with alcohol. In contrast to the NIH data, this study found 53% of the users to be female, trumping the 42% who were male by a significant percentage. It should be noted that while the results of this study are comparable to those of similar studies, they should serve solely to paint a general picture, as the 496 participants were all from one college (Malinauskas et al., 2007).

Studies of the rampancy of energy drink usage in adolescents also show worrisome results. The CDC reports that 30-50% of adolescents consume energy drinks (CDC, 2016). Even higher rates were found in two studies done in Canada and the US, in 2012 and 2014, respectively, which found that two thirds of participants used energy drinks occasionally, with others consuming them monthly, or even weekly (Azagba, et Al., 2014; Miller, et al., 2018). Therefore, when weighing the damage of energy drink usage, we must bear in mind that the affected population not only includes many adults under 30, but also a great number of adolescents, on whom the damage may have longer-lasting consequences.

The Substances in Energy Drinks

While energy drinks contain various ingredients, their main active ingredient is caffeine. It is well known that the amount of caffeine in energy drinks varies greatly, with most drinks containing between 50 and 360 milligrams. More importantly, many of these drinks fall into the 100 mg – 200 mg range. A formal study that measured caffeine content of 14 energy drinks found values ranging from 67 mg – 240 mg, and an even wider range of 34 mg-330 mg in energy shots (smaller, more concentrated drinks) (Attipoe, et al, 2016). These doses are not higher than the amounts of caffeine in many coffees such as those sold by Starbucks and Dunkin Donuts. This, and the fact that there is a decaffeinated '5-hour Energy' drink, suggests that caffeine may not be the only factor causing the effects attributed to energy drinks.

Consequently, this review should also consider the other ingredients and their functions. These substances include glucose, ginseng, high amounts of taurine, B vitamins, green tea extract, guarana (a seed that contains caffeine), green coffee extract, carnitine (an amino acid), glucuronolactone, and inositol. When analyzing the effects of these ingredients, though, caffeine should not be disregarded. The fact that much is known about caffeine's effect on the body and that energy drink manufacturers employ high amounts of caffeine in the making of their drinks implies that caffeine may still be the most important ingredient to study.

Cardiovascular/Hemodynamic Effects of Energy Drinks/Caffeine

Many studies have analyzed the hemodynamic influence of energy drinks. Some studies' results are consistent, while others are contradictory. These differences are often due to differences in dosages of energy drinks. Since caffeine is considered their most active ingredient, this review will group studies by caffeine dosage in the tested drinks when trying to compare studies and their results.

Whereas caffeine is known to have numerous energetic and hemodynamic effects on the body, the FDA advises that doses of less than 400 mg of caffeine a day are generally safe. Still, the administration says that safe dosages can only truly be set on an individual basis, as levels of sensitivity vary throughout the population (FDA, 2018). This is one of the many factors that can account for variation between results of studies, even when similar dosages of caffeine were used.

Energy Drink Dosage as a Factor: Extreme Caffeine as a Danger

A retrospective analysis of 101 patients who arrived at the emergency room having consumed extreme amounts of caffeine showed that many displayed conditions such as tachypnea, tachycardia, and arrhythmia. Seven patients experienced cardiac arrest. Of the 101 patients, most survived after treatment, but three of the seven who developed cardiac arrest died. The patients' estimated caffeine dosages were between 1.2 g to 82.6 g of caffeine with a median ingestion of 7.2 g. Although hard to believe, some of these patients consumed these dosages using energy drinks. Consequently, while this study illustrates the dangers of extreme caffeine usage, the results hardly concern the general public, as a person would have to drink 37 cans of a highly caffeinated energy drink within a few hours to reach the minimum lethal dosage of caffeine in this study, 6 mg. (Kamijo, et al, 2018) More important though, is that this study shows that caffeine and energy drinks certainly affect blood flow, heart rate, and other vital variables. Whether or not smaller amounts of caffeine can induce the same conditions remains to be determined.

More Moderate Dosages: Case reports

Even in smaller amounts, caffeine, and energy drinks specifically, can have serious pathogenic effects. There have been many case reports describing episodes of energy-drink related cardiovascular incidents, including cardiac arrest, which developed after the patients had consumed much lower dosages than those mentioned in the above study.

In one such case, a 28-year-old, otherwise-healthy motocross racer experienced cardiac arrest after just seven or eight cans (640 mg) of a caffeinated energy drink (Berger, Alford, 2009). In another, a 16-year-old volleyball player experienced repeated episodes of orthostatic tachycardia and rapid changes in blood pressure, diagnosed as reversible postural tachycardia syndrome. This was ultimately attributed to her usage of Red Bull, of which she had started to drink 4-5 cans daily (400 mg at most) (Terlizzi, et al., 2008). Moreover, doctors report cardiovascular events linked to dosages not only less than the previous study, but to doses that are less than FDA-recommended safe consumption. A 23-year-old woman presented with supraventricular tachycardia at 219 bpm after just one GNC speed shot (250 mg of caffeine) and a Mountain Dew (55 mg/12oz) (Nagajothi, et al., 2008). Lastly, and most intriguing, is the case of a 28-year-old basketball player who fell unconscious while playing and later died after drinking only three 250 ml energy drinks, amounting to only 180 mg of caffeine (Avci, et al., 2013). Although case reports cannot stand alone as evidence, that the patients in these cases were otherwise healthy and that doctors ruled out other probable causes, as well as the myriad of similar case reports, give reason to believe that the energy drinks could have caused these negative outcomes. It is important to note that high physical activity after consumption is a characteristic of many of these cases (Avci et al., 2013; Berger, Alford, 2009; Terlizzi, et al., 2008), suggesting that exercise plays a role precipitating these side effects.

More Moderate Dosages: Formal Studies

In order to scientifically test if energy drinks have these cardiovascular and hemodynamic effects on the general public, many researchers have conducted studies which gave specific amounts of energy drink to young, healthy participants, measured vital signs before and after ingestion, and determined the drink's hemodynamic effects either using participants as their own controls or splitting the participants into case and control groups.

Energy drinks containing 320 mg of caffeine seemed to consistently raise QTc intervals as well as systolic blood pressure. Two studies that had healthy adult cohorts consume such energy drinks found similar results regarding these two parameters (Fletcher, et al., 2017; Kozik, et al., 2018). These results are concerning because prolonged QTc intervals are known to lead to dangerous cardiac arrhythmias, or changes in heart rhythm (Priori, et al., 2003). Furthermore, the second study found QTc to rise to extremely high levels of above 500ms in eight participants (Kozik, et al., 2018). As with the above case studies, these extreme findings developed after physical activity, and QTc normalized once participants rested. This points to the positive relationship between the degree of physical activity and the severity of the effects of energy drink consumption.

While more moderate dosages do not cause electrocardiographic effects in most people, they still have consistent hemodynamic effects. Researchers in at least seven different studies found that energy drinks with caffeine dosages ranging from 77 mg to 215 mg did not increase QTc (Brothers, et al., 2016; Elitok, et al., 2015; Garcia, et al., 2016; Hajsadeghi, et al., 2015; Ragsdale, et al., 2009; Shah, et al., 2016; Steinke, et al., 2009). On the other hand, in at least nine studies where blood pressure changes were measured, results showed that energy drinks containing anywhere between 114-215 mg of caffeine consistently raised systolic blood pressure (Brothers, et al., 2016; Elitok, et al., 2015; Garcia, et al., 2016; Grasser, et al., 2014a; Hajsadeghi, et al., 2015; Marczinski, et al., 2014; Ragsdale, et al., 2009; Shah, et al., 2016; Steinke, et al., 2009). Many of these studies found an increase in diastolic blood pressure and/or heart rate as well (Elitok, et al., 2015; Grasser, et al., 2014a; Hajsadeghi, et al., 2015; Marczinski, et al., 2014; Shah, et al., 2016; Steinke, et al., 2009). Although many of these studies used seemingly small participant groups, the number of necessary participants was statistically calculated beforehand. Moreover, since multiple studies have shown similar results, the size of the studies is less of a concern. In total, the studies show that even moderate amounts of caffeine tend to raise blood pressure. A rise in blood pressure can be induced by many factors, including exercise alone, and this may not be a public health concern if the effect is transient.

Small Dosages: Formal Studies

In terms of the potential detrimental effects mentioned above, energy drinks with a small amount of caffeine do not seem dangerous for healthy people. Studies in which participants were given dosages of up to 80 mg found hemodynamic and electrophysiologic parameters to be for the most part unchanged, with the exception of an increase in heart rate found in one study (Hajsadeghi, et al., 2015; Ragsdale, et al., 2009).

Effects on Patients with Cardiovascular Disease

While it seems that caffeinated energy drinks used in moderation are safe for most healthy people, for the large population of those with cardiovascular abnormalities and diseases, they may not be as safe. Studies of the cardiovascular effects of energy drinks show that while these drinks may not directly cause more serious hemodynamic or electrophysiologic effects in this group than in healthy subjects (Gray, et al., 2017), these same effects may be safe for healthy people, but may indirectly cause more serious consequences in people with underlying cardiovascular compromise. People with cardiovascular diseases are often predisposed to dangerous arrythmias, which can lead to syncope and sudden cardiac death (Priori, et al., 2003). Ingesting energy drinks, which affect the sympathetic nervous system, cardiac function, and blood pressure, increases the chances for arrythmia development. For example, one serious type of arrhythmia-caused myocardial event is known to occur when a ventricular premature beat sparks during the T-wave and leads to circus action in the heart. Therefore, substances like energy drinks, which lengthen the QT interval, increase the possibility of this extra beat landing on the T-wave. Although it would be hard to test these concepts in a formal study, many case studies have reported patients with previous cardiovascular diseases whose arrythmias developed after energy drink consumption (Dufendach, et al., 2012; Rottlaender, et al., 2012; Rutledge, et al., 2012).

Furthermore, since many cardiovascular diseases go undiagnosed, the dangers of caffeine consumption affect a larger population than just those with diagnosed cardiac diseases. Many case studies describe people whose cardiac syndromes came to light only after an adverse effect, caused by energy drinks, lead to a cardiovascular evaluation (Dufendach, et al., 2012; Rutledge, et al., 2012).

Longer-Lasting Effects

A further concern is that studies indicate that moderate doses in repeated amounts may have a long-term effect. In two studies, participants were instructed to drink the energy drink for seven consecutive days. Hemodynamic measurements were taken on the first and seventh days at baseline and after consumption. In one study, on the first and seventh days, heart rate increased by 7.8% and 11%, systolic blood pressure by 7.9% and 9.6%, and diastolic blood pressure by 7.0% and 7.8%, respectively. While the increases in heart rate and systolic blood pressure were not statistically significant, the increase in diastolic blood pressure was (Steinke, et al., 2009). The second study did not find any statistically significant changes between the days but did notice a trend of increased blood pressure after chronic consumption of the energy drink (Shah, et al., 2016). These data point to the possibility that the effects of the drinks on blood pressure can, in fact, last more than a few hours.

These results are strengthened by those of a differently designed study of 333 adolescents, in which hemodynamic measurements were taken at baseline, during emotional stress, and during recovery without the ingestion of caffeine. Serum caffeine at the time of the study was determined to be nonexistent or trivial. At the start of the lab sessions, the teenagers were asked about their habitual caffeine consumption. The study found that total peripheral resistance was significantly higher in those who reported high habitual caffeine consumption (about 258 mg per day) during exercise and at rest. The researchers also noticed a slight trend of increasing systolic and diastolic blood pressure correlated with high, medium, and low habitual consumption groups. This suggests that daily caffeine ingestion and blood pressure are directly proportional (James, et al., 2018). As increased blood pressure is a precursor to many serious cardiovascular complications, the implication that energy drinks cause not only transient, but lasting increases in blood pressure is of concern. It is possible that these long-lasting effects more strongly influence young chronic drinkers than adults, but more extensive studies would have to be conducted to confirm this hypothesis.

Caffeine Consumption Patterns Considered

When analyzing safe amounts of energy drinks, caffeine consumption patterns should not be overlooked. Since caffeine offers consumers a positive feeling, they tend to want to increase consumption. The efficacy of caffeine is in keeping drinkers awake, many habitual users gradually sleeping less and drinking more. Lastly, with habitual consumption, some drinkers develop tolerance to caffeine (Shah, et al., 2016). One the one hand, this may render habitual consumers less susceptible to the sudden negative developments associated with caffeine. One the other hand, this tolerance may lead them to slowly increase their caffeine intake to a level that will affect them negatively. Therefore, it is likely that many energy drink consumers may start drinking at a safe level and later reach dangerous levels of consumption (Malinauskas, et al., 2007). To reinforce this point, most of the energy drink-related case reports were not of suicide attempts, but rather of consumers who had mistakenly increased their dosage to a dangerous level.

What in Energy Drinks is Causing these Effects? Energy Drinks versus Caffeine

While it is clear that energy drinks can have serious cardiovascular effects, the question of which ingredients are causing those effects is still a disputed topic. There have been many studies in which researchers tried to isolate the effects of one ingredient as it relates to the general effects of the drinks.

Even so, it is understood that while energy drinks' other ingredients can have some effects, their caffeine content plays a big role in the health effects mentioned. Proving this, researchers tested the hemodynamic effects of caffeinated energy drinks versus those of decaffeinated or non-caffeinated energy drinks. In both studies reviewed, studiers found changes in various blood pressure parameters to be greater after the caffeinated version of the same drink (Kurtz, et al., 2013; Phan, Shah, 2014).

Knowing caffeine to be the most apparent active ingredient, researchers attempted to clarify whether the other substances in energy drinks could possibly strengthen the drinks' effects.

As a first step towards analyzing the other ingredients, many studies attempted to test the consumption of energy drinks versus the consumption of caffeine. In four such studies, energy drinks were found to have a greater effect on the parameters that researchers watched. While not all the studies observed changes in identical parameters, variables such as QTc interval, systolic and diastolic blood pressure, cardiac contractility and stroke volume were found to be more affected by energy drinks than by the caffeinated control drink (Baum, et al., 2001; Doerner, et al., 2014; Fletcher, et al., 2017; Franks, et al., 2012). Three studies similar to the previous ones reported that they did not see any difference between energy drinks and caffeine in these parameters. This could give reason to doubt the previous studies but does not for the following reasons: Two of the studies not only did not see a difference, but also did not observe any cardiovascular effects after either drink, so their results may not be a good means for comparison of the two. (Brothers, et al., 2016; Laizure, et al., 2017) Also, one of the studies used a Guru energy drink that lacked taurine and sugar, two ingredients that are often focused on in evaluation of the drink's effect. (Laizure, et al., 2017) Lastly, the third study only measured parameters for twenty-five minutes following energy drink consumption (Pettit, et al., 2013). This is not a valid analysis as many studies have shown that the effects of energy drinks are apparent one, two, or three hours after drinking and many times cannot be seen during the first hours (Fletcher, et al., 2017; Grasser, et al., 2014a; Elitok, et al., 2015). Moreover, in a graph of this study's data, heart rate elevation after energy drink consumption starts to slightly surpass the caffeine-induced elevation just at the end of the twenty-five-minute interval (Pettit, et al., 2013). Based on the time taken to see results in other studies, it is highly probable that the researchers would have seen a more prominent difference had they measured parameters for longer. Therefore, although the above studies report varying results, it is likely that energy drinks have a greater effect on the cardiovascular system than caffeine itself. This begs the question of which ingredients in energy drinks could be causing these effects.

Energy Drink Ingredients and Their Effects

Energy drinks contain many ingredients that may be active, including taurine, guarana, sugar, and caffeine, among others, as mentioned earlier. Some of these substances have not yet been widely researched, others have been researched but remain highly questionable, and a few seem to have a significant role in the results seen. This review will explore some of the oft-studied ingredients.

Taurine

Taurine is a naturally occurring nonessential amino acid. It has been studied numerous times, but with results that create a very wide spectrum of possible effects. Some studies do show amplified cardiovascular effects when caffeinated drinks containing taurine were compared with non-taurine-containing caffeinated drinks (Baum, et al., 2001; Doerner, et al., 2014). The validity of their conclusions is doubtful, though. One study showed a subtle, yet significant increase in left ventricle contractility, but did not report the ingredients of the energy drink in question other than its taurine and caffeine content. Since it is possible that there were many other role-playing ingredients, this cannot serve as a controlled study of taurine's effects (Doerner, et al., 2014). Another study with a similar deficiency attributed an increase in stroke volume and contractility to taurine but did not account for the glucuronolactone present in the study drink that was not present in the control (Baum, et al., 2001). Glucuronolactone is an organic metabolite often used in energy drinks. Whether or not it has cardiovascular effects is unknown, but the fact that this study disregarded its presence in the drink in question weakens the conclusion that the augmented effects were due to the taurine. Moreover, aside from the ambiguity of these results, many studies of taurine have shown that it does not have detrimental cardiovascular effects, but rather, it has cardioprotective effects. One such study showed that taurine had systolic and diastolic blood pressure-lowering effects and also led to a decrease in plasma catecholamine levels (Fujita, et al., 1987). These results suggest that not only does taurine not intensify caffeine's negative hemodynamic effects, it attenuates them. It should be noted though, that this study tested taurine alone versus a placebo, as opposed to the above studies which investigated taurine in combination with caffeine. Thus, the prospect that the body reacts differently to taurine in these two circumstances cannot be discounted. As such, the discrepancies throughout the research on taurine and the limitations of the studies make it hard to determine whether the compound contributes to energy drinks' negative cardiovascular effects. Studies that are better controlled would have to be done in order to solidify any claims in this area.

Guarana

Guarana, also called zoom or Brazilian cocoa, is a seed originating from the Amazon basin and is present in many energy drinks. Guarana is known to be between 2-7.5% caffeine in composition (Beck, 2005), a concentration higher than any other known plant in the world, which contributes to its cardiovascular effects. It also contains compounds such as theobromine, theophylline, tannins, and saponins. Aside from these compounds, it is important to note that guarana is a fatty seed. Therefore, guarana is not as readily soluble as caffeine, a polar substance, and its components take longer to dissolve into the blood stream. Although the seed's longer absorption period and strong effects have not been confirmed with certainty, a study that tested the effects of guarana versus a caffeine pill containing the same amounts of caffeine observed an increase in systolic blood pressure after ingestion of guarana that was not seen after the caffeine ingestion. This result was observed at the two-and-a-half-hour mark, pointing to guarana's slow dissolution span (Meyer, Ball, 2004). Thus, although the amount used in the study was greater in concentration than the guarana in energy drinks, it is possible that when guarana is combined with caffeine in energy drinks, its composition and solubility produce greater cardiovascular effects than caffeine alone.

Sugar

The sugar content in one serving of most energy drinks ranges from about 27 g - 37 g in smaller cans to about 57 g in larger drinks. In comparison to the American Heart Association's recommendation for maximum added sugar intake per day, most of these measurements match or exceed the suggested maximum doses of 25 g and 37.5 g, for men and women respectively (AHA, 2018). It stands to reason that if energy drinks contain so much of this risky substance, sugar can play a role in the cardiovascular effects seen.

A small, yet well-designed study tested the participants' reactions to four drinks on four separate days in order to test the effects of sugar, caffeine, and taurine. Subjects consumed Red Bull (containing sugar, caffeine, taurine, and other ingredients), sugar-free Red Bull (identical to the first drink except for the sugar content), water with 120 mg of caffeine, or water itself, after which cardiovascular parameters were measured. Researchers found that all of the caffeinated drinks caused similar increases in systolic and diastolic blood pressure. They noted, however, that although the blood-pressure raising effect of all three beverages seemed to be the same, the mechanisms raising the BP varied between the different drinks. While the two caffeinated, yet sugar-free drinks raised total peripheral resistance, the sugar drink raised many myocardial parameters such as stroke volume, cardiac output, and contractility. These increases were not seen after any other drink. Moreover, the sugar-containing drinks lowered total peripheral resistance. These results suggest that while caffeine alone might have a similar effect on blood pressure when compared to caffeine and sugar combined, the former seems to act through a vascular route, and the latter by a cardiac route (Miles-Chan, et al., 2015).

The above effects seen after the sugar-sweetened, caffeinated Red Bull appear to be caused by an additive effect of the two active substances, as the sugar does not have these effects on its own. In a study of sugared drinks' effects on the cardiovascular system, researchers showed that while fructose raised blood pressure, sucrose and glucose – the two sugars used in energy drinks – did not. These sugars did raise cardiac output and heart rate, though (Grasser, et al., 2014b). Therefore, the effects of the Red Bull energy drink – to increase cardiac output, heart rate, and blood pressure – could not have been caused by sugar alone but must have been an additive result achieved by combining the two substances.

This study further suggests that taurine's affects are negligible, as the caffeinated drinks with and without taurine seemed to have the same cardiovascular effects.

Caffeine - Mechanisms

Aside from merely understanding that caffeine is the most active cardiovascular agent in energy drinks, we can also attempt to clarify the possible mechanisms by which it acts. Caffeine, a methylxanthine, is a stimulant known to work by the following three mechanisms: Firstly, caffeine competitively inhibits adenosine receptors. Adenosine is a fundamental component in sleep regulation and plays a role in making a person tired. Secondly, caffeine stimulates catecholamine release¬, causing raised levels of epinephrine (adrenaline) and norepinephrine (noradrenaline), which stimulate the sympathetic nervous system and increase blood pressure. Lastly, caffeine increases the release of calcium from the sarcoplasmic reticulum, thereby stimulating muscle contractility (Rana, et al., 2010). All of these mechanisms can explain effects attributed to caffeine in energy drinks.

Other Possible Mechanism by which Energy Drinks Adversely Affect the Cardiovascular System

Endothelial Dysfunction

Another explanation for energy drinks' adverse effects on the cardiovascular system is that they have been shown to lead to endothelial dysfunction by increasing platelet aggregation and decreasing the reactive hyperemia index (Worthley, et al., 2010). Increased dysfunctional platelet aggregation can lead to thrombosis and cardiac arrest. Also, a reduced reactive hyperemia index indicates vessels that are not able to adapt to normal increases in blood pressure as well as they should be. This wearing-down of the blood vessels makes the system more susceptible to adverse effects because it cannot adapt as well to changes in pressure and flow.

Biochemical Changes in Heart Muscle

Long term energy drink consumption by male Wistar rats followed by heavy exercise has been shown to increase glucose and glycogen concentration in their heart muscle. After feeding these rats energy drinks versus water for thirty days and then having them swim to exhaustion, researchers found increased levels of glucose and glycogen in the heart muscle of the rats exposed to energy drinks. Although the buildup of glycogen seems contradictory to caffeine's usual effect of increasing glucose concentration by activating AMPK (Amp activated protein kinase), it is possible that the when the compound is chronically activated, glycogen synthase is activated allosterically and overcomes AMPK's usual inhibition of glycogen formation. This is of concern due to glycogen's association with incidents caused by the pre-excitation syndrome arrythmia. Glycogen has been found in increased concentrations in the heart after adverse events caused by pre-excitation syndrome (Munteanu, et al., 2018). This suggest another possible mechanism by which energy drinks precipitate arrythmias.

Conclusions

There are two public health concerns. The first, is that while arrythmia-related deaths are rare and most patients with an increased risk of abnormal heart rhythms do not actually have fatal arrhythmias, the introduction of energy drinks will increase the frequency of fatal arrythmias in this population. The second and more troubling concern is the possibility that energy drinks are causing slight increases in blood pressure in habitual consumers, who are generally young. Increased blood pressure by even small amounts has been convincingly shown to increase the risk for stroke and death due to cardiovascular events. On a public health level, if more and more adolescents and young adults use energy drinks and have increased blood pressure, the rate of hypertension-related deaths will rise in the foreseeable future. The benefits of these drinks must therefore be weighed against the adverse possibilities.

Since many of the currently available studies used small subject groups, the need for larger studies to further clarify results cannot be overlooked. With time, the long-term effects of these relatively new substances can be studied. Population studies comparing those who consumed higher levels of energy drinks versus those who consumed caffeine through coffee and versus those who abstained from both should be conducted.

As with most foods – especially those that contain active substances – energy drinks consumed occasionally and in moderation seem to be reasonably safe for healthy people. Consumers should be careful not to increase consumption to the point that it becomes habitual or reaches the unsafe levels discussed in this study.

Consumers should be warned not to overuse these substances and to avoid using them before strenuous activity, as many of the more serious adverse events mentioned above occurred after increased activity. Government authorities should consider requiring manufacturers to warn buyers about the potential side effects mentioned in this review to prevent the occurrence of serious energy-drink related adverse events.

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