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Benefits and Risks of Caffeine-Containing Beverages and Food Products: A Scientific Review

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ABSTRACT

The aim of study is to evaluate the comprehensive effects of coffee and caffeine consumption on human health, by reviewing recent scientific studies, and to highlight both the benefits and potential health risks associated with excessive intake. **Methodology**: the paper presents a narrative review of recent peer-reviewed studies evaluating the physiological and health effects of coffee and caffeine consumption and explores the comprehensive effects of coffee consumption on human health, with a focus on caffeine's physiological impact. A review of recent scientific studies was conducted to evaluate both the beneficial and adverse health outcomes associated with coffee intake. The analysis highlights coffee's antioxidant properties and its positive effects on metabolism. However, the **findings** also emphasize that excessive caffeine consumption may lead to negative cardiovascular effects, sleep disturbances, and increased risk of gastroesophageal reflux, especially in individuals with pre-existing gastrointestinal conditions. Furthermore, habitual intake of caffeine-rich products including coffee, tea, chocolate, and energy drinks has been associated with a heightened risk of hypertension, arrhythmias, type 2 diabetes, liver disease, obesity, and symptoms of caffeine dependence. Emerging evidence also points to potential psychological consequences, such as reduced cognitive performance, reduced resilience to stress, and impaired tolerance to sleep deprivation. Based on these findings, healthcare providers are encouraged to evaluate patients' caffeine consumption and counsel those with high intake on the possible risks. **Conclusion:** These insights underscore the importance of moderation in caffeine use and highlight the need for individualized guidance to minimize health complications.

1. INTRODUCTION

The therapeutic effects of caffeine-containing beverages are dose-dependent, with moderate consumption conferring various health benefits, while excessive intake poses significant physiological risks. The interplay between caffeine and other bioactive compounds in coffee influences its overall impact on human health, warranting a balanced approach to its consumption. Further research is necessary to elucidate the long-term consequences of chronic caffeine intake and to establish refined guidelines for safe and beneficial use.

2. DOSE-DEPENDENT THERAPEUTIC EFFECTS OF CAFFEINATED BEVERAGES

Given that coffee and other caffeine-containing beverages are among the most widely consumed drinks globally, their physiological effects both beneficial and adverse are observed across large populations. Consequently, their widespread consumption has a significant impact on public health. Recent scientific studies describe purified caffeine as an alkaloid with analeptic, cardiotonic, and psychostimulant pharmacological properties, primarily exerting its effects through excitatory modulation of the central nervous system. Like many bioactive compounds, caffeine exhibits a dual effect on human physiological systems, particularly when consumed regularly or in excessive quantities. In this context, this review aims to provide a concise synthesis of existing research on the impact of caffeine and its associated compounds on human biological systems.

Caffeine, the principal active constituent of these beverages, exerts dose-dependent effects on the human body. While moderate intake is associated with stimulant and tonic effects, excessive consumption may have inhibitory and deleterious consequences. Notably, caffeine

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accumulation in the bloodstream exceeding a concentration of 80 mg/L poses severe health risks and, in extreme cases, can be fatal. The majority of caffeine-related fatalities are linked to the concurrent consumption of caffeine-containing "energy drinks" with other stimulants [1]. Consequently, the U.S. Food and Drug Administration (FDA) has issued guidelines advising against exceeding a daily caffeine intake of 400 mg, cautioning against excessive consumption of caffeinated products such as coffee, tea, energy drinks, chocolate, and carbonated soft drinks [2].

2.1. Pharmacokinetics and Metabolic Pathways of Caffeine

Recent data indicate that a single cup of freshly brewed coffee contains approximately 60–80 mg of caffeine, with variations depending on brewing methods, where caffeine concentrations may range between 60–140 mg per serving [3]. Upon ingestion, caffeine reaches peak plasma concentration within 15–120 minutes and undergoes hepatic enzymatic metabolism, with its systemic effects persisting for 3–6 hours prior to hepatic elimination [4]. The primary metabolic pathway for caffeine clearance is mediated through the cytochrome P450 enzyme system, particularly CYP1A2, which catalyzes caffeine conversion into three principal metabolites: paraxanthine, theobromine, and theophylline. These metabolites contribute to caffeine's prolonged physiological activity. Additionally, caffeine metabolism results in the accumulation of uric acid derivatives, which may exacerbate conditions such as gout and contribute to inflammatory joint pain [5].

2.2. Mechanism of Action: Caffeine as an Adenosine Receptor Antagonist

The primary mode of action of caffeine on human organ systems stems from its structural similarity to adenosine, enabling it to competitively inhibit adenosine receptor binding. By occupying these receptors, caffeine disrupts adenosine-mediated signaling pathways, which play a crucial role in modulating states of wakefulness and fatigue. Under normal physiological conditions, prolonged wakefulness leads to an increase in endogenous adenosine levels, promoting drowsiness and facilitating neuroprotective mechanisms that support cognitive recovery and cellular repair. By antagonizing adenosine receptors, caffeine overrides these regulatory pathways, inducing artificial wakefulness and sustained alertness [6]. However, this disruption of homeostatic sleep regulation can lead to compensatory mechanisms that increase dependence on caffeine for sustained cognitive function.

2.3. Coffee Components Biochemical and Physiological Effects

The main component of coffee, caffeine, exerts a stimulatory influence on multiple physiological systems, including the nervous, cardiovascular, respiratory, and excretory systems. The pharmacological effects of caffeine are modulated by various bioactive compounds present in coffee, which can enhance or mitigate its physiological impact. The roasting process influences the chemical composition of coffee, altering the bioavailability of beneficial compounds. For instance, the thermal degradation of trigonelline results in the liberation of niacin (vitamin B3), enhancing its intestinal absorption, whereas polyphenolic compounds undergo partial degradation, reducing their antioxidant potency [7].

Coffee is rich in polyphenols, including chlorogenic acids, which exhibit potent antioxidant and anti-inflammatory properties. These compounds contribute to the mitigation of oxidative stress and may lower the risk of chronic diseases. The presence of theobromine, a structurally related xanthine derivative, tempers the overstimulating effects of caffeine, resulting in a more balanced and sustained energy response [8]. Additionally, research suggests that coffee consumption may confer neuroprotective benefits, potentially reducing the risk of neurodegenerative disorders such as Alzheimer's and Parkinson's disease due to the synergistic effects of caffeine, trigonelline, and chlorogenic acids [9].

Caffeine has also been implicated in mood regulation, as it modulates neurotransmitter levels, particularly dopamine and serotonin. This mechanism underlies its mild antidepressant effects and potential role as a mood-enhancing agent [10]. Furthermore, coffee is a source of essential micronutrients such as potassium and magnesium, which contribute to cardiovascular health when consumed in moderation [11].

2.4. Potential Health Benefits and Risks of Caffeine Consumption

The anti-inflammatory and insulin-sensitizing properties of chlorogenic acids suggest a protective role in metabolic disorders, with evidence indicating a reduced risk of type 2 diabetes and cardiovascular diseases in moderate coffee consumers [12]. Additionally, dose-dependent effects of coffee-derived fiber compounds may enhance gastrointestinal motility and support beneficial gut microbiota composition, potentially offering protective effects against colorectal cancer [13].

Hepatic health may also be influenced by coffee consumption, with studies suggesting a reduced risk of fatty liver disease, cirrhosis, and hepatocellular carcinoma due to the antioxidant and anti-inflammatory actions of coffee bioactives [14]. Moreover, diterpenes such as cafestol and kahweol, predominantly present in unfiltered coffee, have been identified as bioactive compounds that modulate liver enzyme activity, potentially exerting chemopreventive effects [15].
Here's an enriched and more scientifically advanced version of your conclusion

3. NEGATIVE EFFECTS OF CAFFEINE-CONTAINING FOODS AND BEVERAGES

While moderate consumption has been associated with potential health benefits, epy excessive caffeine intake poses significant health risks including neurological, cognitive disorders, endocrine disruptions with metabolic dysregulation, hemodynamic and cardiovascular implications, gastrointestinal and hepatic impact, skeletal and mineral metabolism disruptions, neuropsychiatric and addiction concerns, reproductive, developmental risks and so on. The following is a comprehensive review of the negative effects associated with caffeine-containing foods (e.g., chocolate) and beverages (e.g., coffee, tea, cola-based soft drinks, and energy drinks), supported by recent scientific literature.

3.1. Disruption of Sleep-Wake Homeostasis and Cognitive Impairment

Caffeine's primary mechanism of action involves disrupting normal sleep-wake cycles antagonism of adenosine receptors. Studies published in the *Journal of Clinical Sleep Medicine* have demonstrated that caffeine consumption, particularly within six hours of bedtime, significantly reduces total sleep duration and impairs sleep architecture [16]. Chronic caffeine intake can lead to sleep fragmentation, increased sleep latency, and reduced slow-wave sleep, which are critical for cognitive function and memory consolidation. Moreover, prolonged caffeine use may induce tolerance and withdrawal syndromes, leading to a paradoxical decline in wakefulness and cognitive efficiency.

3.2. Cardiovascular System Dysregulation

Caffeine acts as a potent stimulator of the sympathetic nervous system, triggering the release of catecholamines such as epinephrine and norepinephrine. This results in acute elevations in blood pressure, increased cardiac output, and tachycardia, which may contribute to hypertension and arrhythmias in susceptible individuals. A 2021, 2023 meta-analysis linked excessive caffeine consumption to an elevated risk of myocardial infarction and atrial fibrillation, particularly in genetically slow caffeine metabolizers [17,18]. Unfiltered coffee, rich in diterpenes such as cafestol and kahweol, has also been associated with increased low-density lipoprotein cholesterol levels, further exacerbating cardiovascular risk [19].

3.3. Metabolic and Endocrine Disruptions

Caffeine influences glucose homeostasis through its effects on cortisol and insulin secretion. Acute caffeine intake can lead to transient hyperglycemia, followed by a compensatory hyperinsulinemic response. Long-term exposure has been implicated in reduced insulin sensitivity and increased risk of type 2 diabetes mellitus. Additionally, caffeine-induced fluctuations in cortisol levels contribute to adrenal dysregulation, which may predispose individuals to metabolic syndrome and weight gain. Interestingly, caffeine's effects on appetite regulation are bidirectional, with some individuals experiencing appetite suppression, while others exhibit increased caloric intake due to reactive hypoglycemia.

2.4. Gastrointestinal and Hepatic Complications

Caffeine stimulates gastric acid secretion, which can exacerbate conditions such as gastroesophageal reflux disease, gastritis, and peptic ulcers. Studies published in the *Tzu Chi Medical Journal* indicate that caffeine accelerates gastric emptying, which may contribute to gastrointestinal discomfort, nausea, and bloating [20]. Additionally, while moderate coffee intake has been associated with hepatoprotective effects, excessive consumption may impair liver function by altering cytochrome P450 enzyme activity, affecting drug metabolism and increasing susceptibility to hepatotoxicity leading to cirrhosis.

2.5. Skeletal and Mineral Homeostasis Disruptions

Chronic caffeine intake has been linked to calcium depletion and impaired bone mineralization, particularly in postmenopausal women and elderly populations. A 2021 study published in "Food Chemistry and Toxicology" demonstrated a significant correlation between high caffeine consumption and increased urinary calcium excretion, contributing to bone demineralization, osteoporosis, and elevated fracture risk [21]. This effect is further exacerbated in individuals with inadequate dietary calcium

intake, emphasizing the need for nutritional considerations in caffeine consumers.

3.6. Neuropsychiatric Effects and Dependency Potential

Caffeine stimulatory effects on the central nervous system can lead to increased anxiety, agitation, and mood disturbances, particularly in individuals with preexisting psychiatric conditions. A 2024 study in *Frontiers in Psychology* highlighted caffeine role in stimulating cortisol and epinephrine secretion, which may exacerbate symptoms of generalized anxiety disorder, panic attacks, and emotional dysregulation [22,23]. Additionally, caffeine dependence is a clinically recognized phenomenon, with withdrawal symptoms including headaches, irritability, fatigue, and cognitive impairment. The development of caffeine tolerance necessitates increasing doses to achieve the same stimulant effects, further reinforcing dependence [24,25].

3.7. Adverse Pregnancy and Reproductive Outcomes

Caffeine readily crosses the placenta, and due to the fetus limited metabolic capacity, it remains in fetal circulation for an extended duration. A 2022 study published in *JAMA Network Open* identified a dose-dependent relationship between maternal caffeine intake and adverse pregnancy outcomes, including miscarriage, preterm birth, intrauterine growth restriction, and low birth weight [26]. Given these findings, health authorities recommend strict limitations on caffeine intake during pregnancy to avoid potential teratogenic effects.

3.8. Impairment of Psychomotor Performance and Alertness

Contrary to popular belief, excessive caffeine consumption does not necessarily enhance cognitive performance. Recent studies using electroencephalogram recordings have shown that while caffeine initially enhances alertness, chronic overconsumption may lead to delayed reaction times and psychomotor retardation. This paradoxical effect results from downregulation of adenosine receptors and neuroadaptive changes in excitatory neurotransmission, ultimately reducing sustained attention and cognitive flexibility.

3.9. Optimizing Caffeine Consumption for Health Benefits

To optimize health benefits while mitigating risks, individualized caffeine consumption strategies should consider genetic predispositions (e.g., CYP1A2 polymorphisms affecting caffeine metabolism), existing medical conditions, and lifestyle factors. The good news is that the adverse physiological effects of caffeine are largely reversible in most, if not all, individuals. For instance, upon discontinuing caffeine intake, adenosine receptor levels can gradually revert to their baseline over days to weeks, allowing the body to restore its normal sensitivity to external stimuli [27].

Further research should explore precision nutrition approaches to tailor caffeine intake recommendations, ensuring a balance between its neurostimulatory properties and potential adverse effects. Future research should focus on personalized caffeine consumption guidelines, integrating genetic polymorphisms in ADORA2A (adenosine receptor sensitivity) as well to optimize health outcomes while minimizing risks.

4. Conclusion

While caffeine-containing foods and beverages remain a staple in global diets, their overconsumption poses significant health risks. The adverse effects span multiple physiological systems, including neurological, cardiovascular, metabolic, gastrointestinal, skeletal, and reproductive domains. However, these negative outcomes are largely dose-dependent and reversible upon cessation or moderation.

Conflict of Interest

No conflict of interest is declared by tehe authors. In addition, no financial support was received.

Ethics Committee

This study did not require approval from an Ethics Committee.

Author Contributions

Conception and design of the study: AMFK; Data collection: AMFK; Data analysis: AMFK; Data Interpretation: AMFK; Drafting the article and/or its critical revision: AMFK; All authors have read and agreed to the published version of the manuscript.

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