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EFFECTS OF CAFFEINE CONSUMPTION ON SLEEP QUALITY AMONG MEDICAL STUDENTS: A REVIEW

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Abstract

Background: A common stimulant is caffeine, especially among medical students who must balance rigorous coursework and erratic sleep patterns. With an emphasis on sleep length, onset delay,disruptions, and general restfulness, this review investigates how coffee use affects the quality of sleep in this population.

Results: The main way that caffeine works is as an adenosine receptor antagonist, which increases alertness but may also interfere with regular sleep cycles by lowering melatonin levels and altering circadian rhythms. Caffeine dependence, the effects of various caffeine sources, when to take it, and other risk factors for restless nights are also covered in the review. Research indicates that while moderate caffeine consumption may improve alertness and cognitive function, excessive or poorly timed consumption, particularly later in the day, can seriously reduce the quality of sleep.

Conclusion: These results highlight the necessity of raising awareness and implementing focused interventions to encourage medical students to consume coffee responsibly and practise improved sleep hygiene.

Introduction:-

Caffeine is a plant alkaloid with the chemical structure of $C_8H_{10}N_4O_2$, which also resembles purines, and a molecular weight of 194.19 g/mol. The IUPAC name for caffeine is widely known as 1,3,7-trimethylxanthine ("Caffeine for the Sustainment of Mental Task Performance", 2001). People worldwide widely consume caffeine for its stimulating effects on the central nervous system. Caffeine primarily acts as an adenosine receptors antagonist. Adenosine is a neurotransmitter responsible for promoting relaxation and sleep by binding to its receptors in the brain. By blocking adenosine receptors, it can increase alertness and reduce drowsiness. Besides, caffeine can also increase release of neurotransmitters, enhance cognitive function, increase urine production and potentially lead to an increase in heart rate and blood pressure, depending on individual sensitivity.

Caffeine can be found in coffee, tea and various beverages. As for coffee, there are several factors that can influence caffeine levels such as type of coffee bean, brewing method and serving sizes. There are many types of coffee beans

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like Arabica, Robusta, Excelsa, Liberica and many more. For example, Arabica beans have less caffeine level than Robusta beans. Brewing methods like espresso yields higher caffeine concentration compared to drip brewing. Larger servings contain significantly more caffeine compared to small servings. As example, there is approximately 96mg of caffeine for 8-ounce cup of brewed coffee. On the other hand, tea contains L-theanine as additional compound to differentiate it from coffee. Tea also has various types and different concentrations of caffeine. As example, in 8-ounce cup, black tea and green tea contain approximately 48mg and 29mg of caffeine, respectively.

Sleep is a naturally occurring physiological state characterized by reduced physical activity, altered consciousness, and diminished responsiveness to external stimuli. It plays a critical role in biological processes such as cognitive restoration, metabolic regulation and immune function. Sleep quality refers to an individual's subjective assessment of their sleep experience, encompassing factors such as sleep onset latency, continuity, duration, and the sense of refreshment upon awakening. High-quality sleep typically characterized by falling asleep quickly (within 30 minutes), minimal awakenings during the night, and feeling rested and restored upon waking (Kline, 2013).

Good quality sleep is crucial for both physical and mental health. The benefits of getting enough sleep include strengthening the immune system, enhancing memory, lowering stress level, improving productivity and boosting mood and mental wellbeing. In contrast, inadequate sleep can lead to several negative consequences such as loss of focus on work, poor decision making, feeling anxious and prone to illness (Fehling, 2004).

Caffeine is often consumed by students in Malaysia to stay awake and improve focus, especially during late-night study sessions. Besides, this habit has drawn a bigger concern towards medical students, as they want to improve alertness and cognitive performance due to demanding workload, lengthy study sessions, and clinical rotations. However, consuming too much caffeine can interfere with sleep cycles, resulting in exhaustion, poor sleep, and long- term health issues. Promoting better study habits and overall well-being among aspiring medical professionals requires an understanding of the connection between coffee intake and sleep quality. This issue is important because medical students are relying more on caffeine to handle their academic workload, sometimes sacrificing their sleep in the process. This review aims to discuss the level of caffeine consumption among medical students and its impact on various aspects of sleep, including duration, sleep onset latency, disturbances, and overall sleep quality. It also seeks to assess patterns of caffeine intake and their correlation with sleep quality. The findings may help inform targeted interventions to improve sleep habits and promote more mindful caffeine consumption among medical students.

Mechanism of Action of Caffeine:-

Caffeine has been widely used among people worldwide, especially students and workers for their function as a stimulant. It is understood that consuming caffeine would help someone to maintain their alertness and reduce the onset of fatigue. This happens when caffeine works on the A1 and A2A receptor, by increasing the cortisol level, simultaneously acting on the hypothalamo-pituitary-adrenal axis (Ng et al., 2022). The caffeine will block the adenosine receptor, which is A1 and A2A receptor, and this process is said to be one of the most important mechanisms of action of caffeine (Reddy et al., 2024).

Caffeine is an antagonist of adenosine. As their chemical structure is almost the same, the nerve cells are not able to differentiate between caffeine and adenosine (Reddy et al., 2024). Physiologically, adenosine will bind to its receptor and induce drowsiness, but when caffeine binds instead, it will inhibit this function (Reddy et al., 2024). A1 and A2A receptor is mostly associated with cognitive skills, arousal, and sleep cycle (Ng et al., 2022). Caffeine also promotes relaxation and a feeling of well-being in stressful situations by sensitizing a particular group of cannabinoid receptors in the brain, which is triggered by the stimulation of cortisol (Ng et al., 2022). This is also one of the other reasons why students opt for caffeine, aside for its effect on reducing the onset of fatigue. As it is widely known, being a student may be extremely stressful, especially for medical students, due to the massive syllabus that they must cover, therefore it is not surprising if they consume more caffeine than other degree students.

Other than that, melatonin secretion is also disrupted due to the non-specific inhibition of caffeine towards the adenosine receptor (Ng et al., 2022). When this happens, the melatonin level will decrease, hence disrupting the sleep wake cycle, because melatonin is a neurohormone that regulates sleep cycle (Ng et al., 2022). Therefore, there may be some people who may experience difficulty in sleeping or increased sleep latency when they consume too much caffeine, as shown by the people in Massachusetts (Ng et al., 2022). Another mechanism of action of caffeine aside from the brain is towards the peripheral organs such as the heart (Reddy et al., 2024). In the heart, there is also adenosine receptor, which will be inhibited by the caffeine. When the adenosine receptor on the heart, specifically at

the pacemaker cell is inhibited, the braking effect of adenosine is lost, thus causing irregular heartbeat, or also known as palpitations (Reddy et al., 2024).

Caffeine Dependence:-

Caffeine dependence is a growing concern, particularly among individuals with high stress and irregular sleep patterns such as medical students. While moderate caffeine consumption can help improve focus and alertness, over time, frequent use may lead to both psychological and physiological dependence (Amer et al., 2023). Caffeine works by blocking adenosine receptors in the brain, which normally promote sleep and relaxation. This action temporarily increases dopamine activity and alertness, giving users a sense of improved mood, concentration, and energy (Divya Rajaseharan et al., 2021).

However, repeated use of caffeine even within commonly consumed amounts of 85– 250 mg can lead to the body adapting to its effects. This means that over time, users may need higher doses to feel the same level of alertness, which is a hallmark sign of tolerance (Weibel et al., 2020). When caffeine consumption is suddenly stopped, users often experience withdrawal symptoms like headaches, fatigue, irritability, and poor concentration. These symptoms typically begin 12–24 hours after the last intake and can last for several days (Weibel et al., 2020). Such withdrawal effects are a strong indicator that physical dependence has developed (Amer et al., 2023).

Caffeine dependence is characterized by a pattern of use where individuals continue consumption despite negative consequences, struggle to reduce intake, and may prioritize caffeine use over important daily activities (Divya Rajaseharan et al., 2021). The DSM-5 currently does not classify caffeine addiction as a formal substance use disorder, but it does recognize caffeine withdrawal as a clinical condition and encourages further research on caffeine-related dependence (Amer et al., 2023). The ICD-10, however, acknowledges caffeine dependence syndrome as a medical condition, which includes behavioral and physical symptoms such as craving, loss of control, and continued use despite harm.

Medical students are especially vulnerable to caffeine dependence due to long hours of study, night shifts, and sleep deprivation. These factors often lead them to rely heavily on caffeine to stay awake and mentally alert. Unfortunately, this often forms a cycle where poor sleep leads to more caffeine use, and more caffeine use worsens sleep quality (Weibel et al., 2020). Though most healthy adults can safely consume up to 180 mg daily, excessive intake especially above 400 mg can result in caffeine intoxication, with symptoms such as anxiety, tremors, and rapid heartbeat (Amer et al., 2023). Overall, while caffeine can provide short-term benefits, its overuse may result in dependency that negatively affects both mental and physical health. Awareness, education, and moderation are key in preventing caffeine dependence, especially in vulnerable groups like medical students.

Effect of Different Sources of Caffeine Toward Sleep Quality:-

People may initially think of coffee when discussing caffeine, but there are a variety of caffeine sources that are ingrained in civilizations all around the world. Despite coffee being the most popular caffeine-containing beverage, we all meet caffeine in our daily lives, whether intentionally or unintentionally (Irem et al.,2023). Caffeine can be found in a variety of plant parts, including leaves, beans, and fruit. Roasted coffee beans, such as robusta and arabica, as well as tea leaves, are the most common sources of dietary caffeine worldwide (Reddy et al., 2024). Caffeine, in addition to being naturally present, can be artificially manufactured in laboratories, such as it was widely found in most of the soda and energy beverages (Reddy et al., 2024). Among foods, coffee, tea, chocolate, and soft drinks are the most common types of caffeine (Reddy et al., 2024). While tea and soft drinks are the most common sources of caffeine for teenagers, adults typically consume coffee. Additionally, caffeine can also be found in over the counter and prescription drugs used to treat allergies, colds, and headaches (Reddy et al., 2024).

In the study conducted among medical students in Turkey in 2023, it shown that more than 80% of medical students consumed caffeine such as tea, solid foods having caffeine, and coffee on their daily life. Empirical data reveals that caffeine use, which is found in tea, drinks, and coffee, is regarded safe if taken in moderation (Nasir et al., 2023). A small dose of caffeine (200 to 400 mg) increases alertness while consuming significant doses of caffeine (more than 400 mg) generates unpleasant physiological effects, such as changing the sleep cycle (Nasir et al., 2023). As university students often experience sleep deprivation, it influences their caffeine intake in their daily life. In fact, 71% of college students reported having inadequate sleep and feeling unrested for at least five of the previous seven days (Irem et al.,2023). Therefore, the current study discovered that as students' sleep quality declined, their caffeine uses increased (Irem et al.,2023).

Furthermore, a study of medical school students found that most students consume coffee in moderation and only slightly raised in high-stress situations such as exams (Irem et al.,2023). Other studies have also shown that when students are stressed, they consume more caffeine-containing beverages, such as energy drinks (Irem et al.,2023). Similarly, a study conducted among second-year medical students in Pakistan in 2010 found that intake of caffeinated beverages rose during stressful times such as exam periods (Irem et al.,2023).

The benefits of it may include increased alertness, productivity, focus, and concentration by acting as an antagonist effect on adenosine receptor, which is a neurotransmitter that makes you feel tired, leading to increased wakefulness and concentration. (Pacheco. D, 2024). According to occupational health, alertness which is crucial for job productivity is the ability to sustain concentration on a work over an extended length of time. (Herqutanto et al., 2024). Therefore, people tend to take at least one cup of caffeine especially in the morning to keep productive in their works.

However, as said before, increase caffeine intake can also potentially affect the regulation of sleep in an individual. Personally, sleep requirements might differ from person to person. In individuals who have poor health outcomes, low sleep quality has been strongly linked to insomnia by reducing the total sleep time and excessive daytime sleepiness, both of which have a negative impact on behaviour, social competence, and academic achievement. (Ayub Ali, 2021). Then, to support optimum health, adults should consistently get seven or more hours of sleep each night. (Jones. T, 2024). Therefore, the advised cut-off period for caffeine usage is at least eight hours before bedtime to prevent this adverse effect. If you usually go to bed at 10 p.m., for instance, limiting caffeine after 2 p.m. to help in reducing the sleep issues. (Pacheco. D, 2024).

Effect of Different Timing Intake of Caffeine on Sleep Quality:-

Caffeine's effects on sleep quality are closely tied not just to how much is consumed, but also to when it is consumed. Caffeine acts primarily by blocking adenosine receptors in the brain, reducing the natural buildup of sleep pressure and promoting wakefulness (Gardiner et al., 2024). While this mechanism is useful for improving alertness, especially in cases of sleep deprivation, its timing plays a major role in determining whether caffeine consumption disrupts subsequent sleep.

Studies consistently show that evening caffeine consumption has a significant negative effect on sleep. Taking caffeine within three hours of bedtime is associated with delayed sleep onset, more frequent nighttime awakenings, reduced total sleep time, and lower sleep efficiency (Gardiner et al., 2024). Doses between 100–600 mg can worsen these effects, and larger doses are linked to greater disturbances. Additionally, caffeine has been shown to reduce deep (NREM stage 3) sleep while increasing lighter sleep stages, particularly at doses over 300 mg (Gardiner et al., 2024).

Research among adolescents also supports these findings. Lunsford-Avery et al. (2021) observed that afternoon and evening caffeine use led to poor sleep health indicators such as delayed bedtimes and reduced sleep duration, although poor sleep did not strongly predict increased caffeine use the next day. Similarly, Hu et al. (2020) found that while habitual daytime caffeine use in middle-aged adults did not directly shorten nightly sleep duration, shorter sleep one night predicted greater caffeine consumption the following day, suggesting a cycle of dependency where poor sleep leads to more caffeine use and vice versa.

Beyond immediate sleep disruption, caffeine may also influence the body's circadian rhythms. Zhang et al. (2024) highlighted that caffeine could modulate circadian patterns by enhancing responsiveness to light cues and helping to offset the natural morning decline in performance. While their findings were focused on improving physical performance, they emphasize that caffeine timing significantly affects the body's biological rhythms, and misuse could potentially disturb the natural sleep-wake cycle.

Taken together, these studies emphasize that late-day caffeine intake is particularly harmful for sleep, while morning intake is less disruptive. However, individual differences such as caffeine metabolism rate, habitual use, and sensitivity must also be considered (Gardiner et al., 2024). For the general population, and especially for vulnerable groups such as students and shift workers, it is strongly recommended to avoid caffeine consumption in the late afternoon and evening to support healthy sleep patterns.

Risk Factors That Contribute ToA Poor Sleep Quality In Relation With Caffeine Consumption:-

Sleep is an obligatory biological process in life, as it involves brain function and body physiology such as metabolism, regulation of appetite, immune system, cardiovascular system, and hormonal activity (Teker &Yakşi, 2021). A decent quality sleep is necessary for physical and mental health. Sleep quality includes aspects like regular routine of sleep, sleep latency, and total duration of sleep (Hussein & Abu Negm, 2019). Poor sleep quality leads to mental, emotional, and motivational disorders. There are several factors that contribute to poor sleep quality. These include psychological, physiological, and environmental factors.

In the aspect of psychological factors, stress, tension, and worry are the highest reasons for reduced sleep quality (Eduviere et al., 2021). Academic stress and anxiety consequently affect the transition to sleep among students. Physiological factors such as age, chronic illnesses, dietary habits and genetics including genders and ethnicities may have an impact on poor sleep quality (Wang et al., 2023). Physical activity and lifestyle also affect a poor sleep quality. Food that is sugary and highly processed is related to poor sleep quality (Claydon et al., 2023). An increase in caffeine consumption is associated with the interruption of sleep.

Deficiency in vitamin D intake may also impair sleep (Sejbuk et al., 2022). In the environmental aspect, conditions like overexposure to light, noise and sound have a negative effect on sleep quality (Haylı& Avcı, 2023). As an example, the emission of blue light from smartphones reduces sleep quality (Chang et al., 2021). Financial problems also contribute to inadequate quality of sleep (Maciel et al., 2023).

In relation to caffeine consumption, recent studies have shown its impact on sleep quality. Caffeine leads to increase alertness and delaying sleep onset. The consumption of caffeine has effect on sleep by lowering total sleep time by 45 minutes in average and sleep efficiency by 7%, while increasing sleep onset latency by 9 minutes and wake after sleep onset by 12 minutes (Gardiner et al., 2023). Caffeine intake also prolonged the duration and proportion of light sleep while shortening deep sleep stages. Thus, avoiding caffeine consumption before bedtime is suggested. Other than that, frequent caffeine intake causes delay in REM sleep promotion and weakening sleep quality. This may lead to difficulties in awakening and feeling tiredness upon waking (Weibel et al., 2021). This also shows how uncontrolled caffeine intake can interfere circadian rhythm. Overall, poor sleep quality leads to impaired memory and attention, and negatively affects psychological, physical, and social life (Alnawwar et al., 2023).

Conclusion:-

Medical students frequently use caffeine as a coping mechanism to deal with their academic stress and lack of sleep. Although it has short-term positive effects on mood and cognition, excessive use, particularly in the evening, is strongly linked to poorer sleep, prolonged sleep latency, and disturbed sleep architecture. These results are greatly influenced by variables including caffeine supply, timing of ingestion, and individual sensitivity. Furthermore, the vicious cycle of insufficient sleep leading to increased caffeine consumption—and vice versa—can exacerbate dependence and worsen general health. To reduce these hazards, it is crucial to support educational programs about stress reduction, the value of getting enough sleep, and appropriate coffee habits. Future research should examine long-term trends in caffeine consumption and create organised interventions that are suited to the particular needs of medical students.

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