ABSTRACT

Caffeine's Origin, Chemistry, and Systemic Effects

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This thesis examines the structure of caffeine: its chemistry, its mechanisms of action in the body, and ultimately, how that plays into its impact on the oral cavity. The opening chapter serves as an introduction, providing a historical account of coffee and a discussion of its chemical components, creating a foundation for the paper to highlight its well-known component: caffeine. In the second chapter, caffeine's impact on glucose metabolism and Type 2 Diabetes is addressed. The third chapter investigates caffeine's effects on cognitive performance, alertness, and its mode of action in the brain, and the fourth chapter analyzes the association of caffeine intake and the development of periodontal disease. Finally, the fifth chapter will discuss caffeine's role in dental staining. This research serves to educate readers on caffeine's impacts on metabolism, psyche, and dentition.

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CAFFEINE'S ORIGIN, CHEMISTRY, AND SYSTEMIC EFFECTS

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By

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CHAPTER 1

Introduction

Coffee holds an essential place in everyday diets across the globe. In fact, it is the second most consumed beverage in the world, behind water.[1] Whether it is enjoyed over ice or mixed with cream, this caffeine-containing drink provides a buzz that keeps consumers coming back for more. Although coffee is enjoyed for its smooth texture and alluring aroma, its caffeine content plays a vital role in its popularity. Caffeine, or 1,3,7-trimethylxanthine, is naturally present in coffee beans and primarily exerts its biological effects as an antagonist on the body's adenosine receptors.[2] When adenosine receptors are blocked, the brain remains awake and bypasses the drowsiness that is normally felt as the day progresses. Coffee beans hold widespread popularity and are accessible worldwide, but coffee beans find their origins in the country of Ethiopia.

The coffee bean is found on trees that belong to the genus *Coffea*. Worldwide, the two main species consumed are *C. arabica* and *C. canephora*, also known as Arabica and Robusta coffee respectively.[1] Coffee trees bear fruits, called ripe-cherries, which are picked by hand. Historically, there are legends that Abyssinian shepherds would eat the ripe-cherries of *Coffea* trees raw or roasted. These shepherds found that the stimulation from the fruits was beneficial to completing their daily activities, and thus, served as pioneers of caffeine consumption for centuries to come.[1] To further explain, the book *Napoleon's Buttons* describes the spread of coffee throughout the world.[3] By the end of the fifteenth century, *Coffea* trees had expanded from the Ethiopian highlands into the Islamic world via Muslim pilgrims. In the seventeenth century, coffee was introduced to

Europe. Its popularity grew amongst physicians and Church and government officials, and soon, there were over two thousand coffee houses in London. In addition to the biological effects it provided, the cultivation of coffee also served an important role in the economy of the New World. Specifically, coffee began to dominate the agriculture sector in Brazil. Coffee trees took over huge land masses that were previously used for sugar plantations, radically changing the country's environment. As the coffee cultivation began to fuel great economic growth, Brazil built a railway system to transport their coffee to major ports. This fiscal boom also had socioeconomic effects on the country. In order to keep up with agricultural demands, Brazil relied on poor immigrants from Italy to work on their plantations after slavery was abolished in 1888. The new influx of immigrants completely changed the cultural dynamic of the country, and workers were heavily exploited. Additionally, using available land for monoculture meant that Brazilians were unable to plant a variety of necessities. As a result, the agriculture sector in Brazil became vulnerable; a pest infection of coffee trees could completely wipe out their economy. A similar pattern of exploitation and overreliance also took place in other coffee-growing Central American countries.

As mentioned earlier, Arabica and Robusta are the two major species of coffee beans consumed worldwide. Arabica is considered the most popular species, comprising 70% of worldwide production compared to Robusta's 30%.[3] The discrepancy in consumption may come down to the palatability of the two species. While Robusta is considered very strong and bitter in flavor, Arabica is known for its smooth and sweet notes. Additionally, Arabica coffee beans contain half the caffeine content of Robusta beans.[4] As a result, Robusta is consumed in smaller amounts and is typically part of coffee blends. In addition to caffeine content, the two species differ notably in their lipid, polysaccharide, oligosaccharide, and chlorogenic acid content as well (Figure 1).

Components	*C. arabica* (Arabica) (%)	*C. canephora* (Robusta) (%)
Caffeine	0.9–1.2	1.6–2.4
Minerals	3.0–4.2	4.0–4.5
Lipids	12.0–18.0	9.0–13.0
Trigonelline	1.0–1.2	0.6–0.75
Proteins	11.0–13.0	11.0–13.0
Aliphatic Acids	1.5–2.0	1.5–2.0
Chlorogenic Acids	5.5–8.0	7.0–10.0
Oligosaccharides	6.8–8.0	5.0–7.0
Polysaccharides	50.0–55.0	37.0–47.0

Figure 1: Composition of raw coffee for the two main species of coffee (percentages are expressed in terms of dry matter)[1]

As a whole, coffee is a complex chemical mixture that contains much more than just caffeine. In fact, coffee contains over a thousand chemicals. In addition to carbohydrates, lipids, and nitrogenous compounds, coffee is also rich in vitamins, minerals, alkaloids and phenolic compounds.[1] The main phenolic compounds in coffee are called chlorogenic acids, or CGA. The main CGA species found in coffee beans are caffeoylquinic acids (CQA), dicaffeoylquinic acids (diCQA), feruloylquinic acids (FQA), *p*-coumaroylquinic acids, and mixed diesters of caffeoylferuloyl-quinic acids (CFAQ).[5] Coffee beans can also contain other minor CGA groups, with contents varying during different stages of the fruit maturation cycle. CGA provide physiological benefits, such as defense against UV radiation and resistance to pathogens. In addition, CGA take part in the flavor, aroma, and color of coffee during the roasting process. While roasting coffee beans, parts of the CGA in coffee become isomerized, dehydrated, and hydrolyzed. In fact, up to 95% of CGA content can be lost during intense roasting conditions.[5] Figure 2 depicts the chemical transformation of CGA during roasting. Although roasted coffee beans only contain from 0.5-7.0% CGA content, coffee is still considered one of the most abundant sources of CGA.

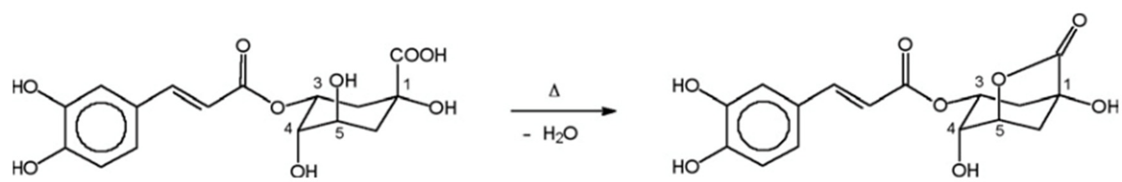


Figure 2: Formation of 1,5-γ-quinolactone (one of the major chlorogenic acid lactones in coffee) from CGA during roasting. [5]

Along with CGA, nitrogen-containing compounds called melanoidins also contribute to the color and flavor of roasted coffee. Melanoidins are brown polymers formed when sugars and amino acids combine in a Maillard reaction during roasting.[5] In addition to their color and flavor properties, melanoidins also possess biological and health benefits. Although research is still ongoing to fully understand the biological activities of melanoidins, several studies have indicated their antioxidant activity. In humans, the antioxidant activity of coffee melanoidins corresponds with protection against oxidative damage. One study describes that melanoidins' protective effects were observed on human hepatoma HepG2 cells under oxidative stress.[7] With their antioxidant properties, melanoidins can aid in preventing the development of liver cancer. Similarly, it was observed that coffee melanoidins play a role as inhibitors of lipoxidation. Lipoxidation is associated with the development of atherosclerosis; thus, melanoidins provide major health benefits for several systemic diseases. In addition to antioxidant benefits, melanoidins also possess antimicrobial properties. Their antimicrobial activities were tested against the bacterial status of both Gram-positive and Gram-negative strains. In the study, it was found that melanoidins did provide antimicrobial action against both strains, with greater effects against the Gram-positive bacterial strains. Additionally, it was found that melanoidins in coffees with higher degrees of roast provided greater antimicrobial benefits than in instant coffees with less roasting.

Although there are many chemicals playing into coffee's systemic effects, the following chapters will focus specifically on the role of caffeine. Chapter 2 will examine multiple studies that have investigated caffeine's effects on glucose metabolism as it relates to Type 2 Diabetes. Additionally, caffeine is widely popular for its psychological effects. Chapter 3 will discuss studies that have assessed caffeine's effects on cognitive performance and alertness. Chapter 4 will be examining caffeine's effects on periodontal disease, and Chapter 5 will investigate its role in dental staining. Caffeine is an integral component in the daily lives of many; the aim is to understand and educate on its health impacts.

CHAPTER 2

Caffeine's Effect on Glucose Metabolism

Caffeine affects the body in many ways: physically, psychologically, and physiologically. One of the debated physiological effects of caffeine is its impact on the development of Type 2 Diabetes. Type 2 Diabetes is a medical condition resulting from insulin-resistance, and consequently, an increase of glucose in the bloodstream.[8] When insulin is unable to effectively store glucose into cells, the glucose remains in the blood and can cause damage to nerves and blood vessels. Although some studies have discovered that caffeine consumption decreases the risk of diabetes, others have found no correlation between caffeine intake and diabetes.

Some studies suggest that caffeine may have positive health effects, including a decrease in the risk of Type 2 Diabetes. Harvard School of public health led a four-year study to determine the correlation between caffeine consumption and Type 2 Diabetes.[9] Subjects agreed to either increase their daily coffee consumption by more than one cup a day, or lower their daily coffee consumption by more than one cup a day. The study also analyzed the effects of increasing and decreasing decaffeinated coffee drinkers' consumptions by more than one cup a day. In the study, it was found that participants with increased caffeinated coffee consumption had a 11% lower risk of Type 2 Diabetes than those that did not change their coffee consumption. Participants with decreased caffeinated coffee consumption had a 17% higher risk for diabetes. Additionally, changing participants' daily decaffeinated coffee consumption did not reveal any change in diabetes risk. The results of this study indicate that coffee, and specifically the caffeine it contains, may have positive health benefits for most people.

A Finnish study also found that caffeine intake may decrease the risk of Type 2 Diabetes. This study measured the incidence of Type 2 Diabetes in Finnish men and women with varying levels of daily coffee consumption, up to seven cups a day.[10] The study collected surveys from 6,974 Finnish men and 7,655 Finnish women without history of coronary heart disease or stroke. Data was collected in 1982, 1987 and 1992 through self-administered questionnaires for coffee consumption and physical activity. Participants' blood pressure and body mass index (BMI) were measured at a study site and diagnoses of Diabetes Mellitus were reported by the National Discharge Register and the Drug Register of the National Social Insurance Institution. It was found that individuals with lower coffee consumption (0-2 cups daily) tended to have a higher risk for Type 2 Diabetes, compared to those with higher coffee consumption (Figure 3).

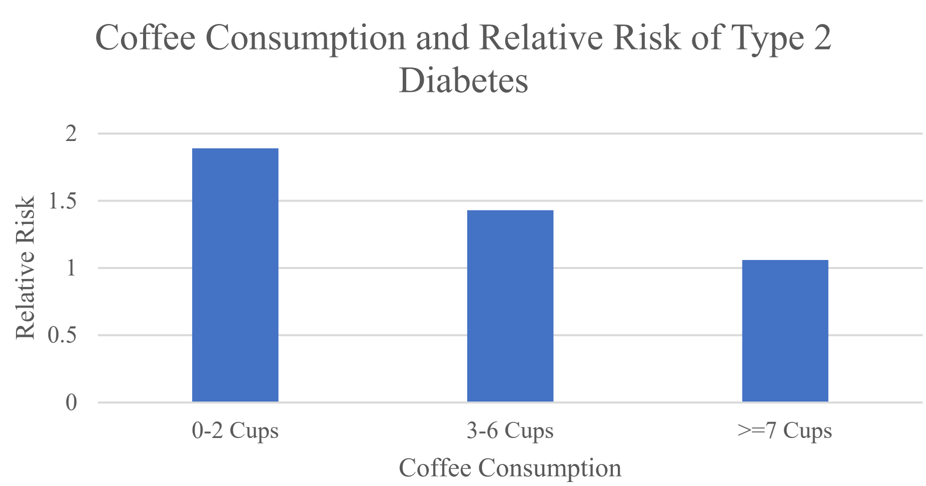


Figure 3: Correlation between coffee consumption and relative risk of Type 2 Diabetes in Finnish population[11]

In contrast, some studies have found that there is no decrease in Type 2 Diabetes risk with an increase in coffee consumption. One study was performed by the National Institute of Diabetes and Digestive and Kidney Diseases on a population of Pima Indians in the United States.[12] Questionnaire forms were filled out by 2,680 individuals from 1978 to 1992, indicating their daily coffee consumption. Additionally, the oral glucose tolerance test (OGTT) and the 1985 World Health Organization criteria were used to diagnose diabetes. After their follow-up, it was found that 824 individuals were diagnosed with diabetes. Overall, it was found that there was not a statistically significant correlation between coffee consumption and the development of diabetes (Figure 4).

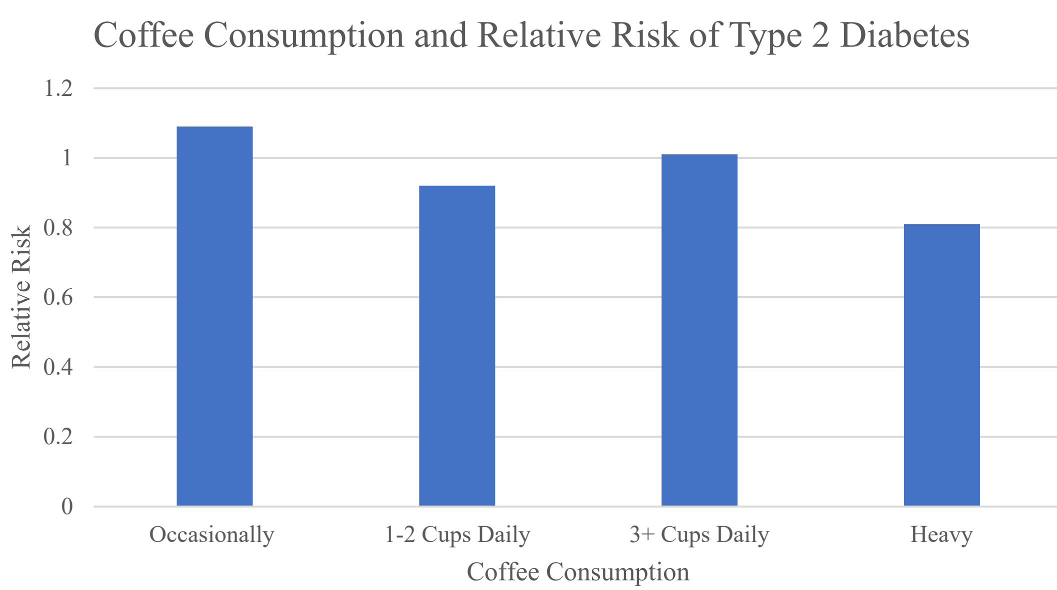
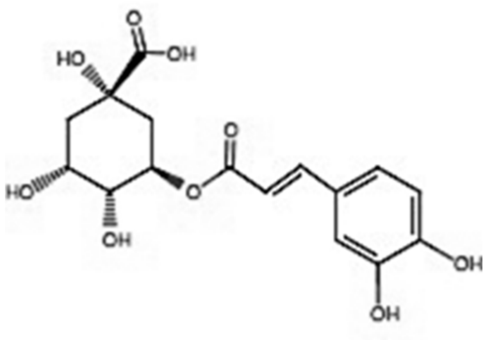
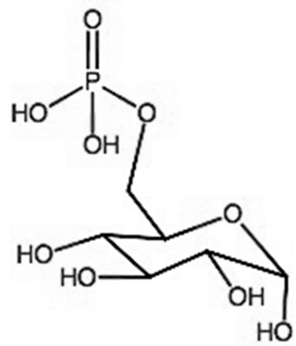


Figure 4: Correlation between daily coffee consumption and relative risk of Type 2 Diabetes in Pima Indian population[12]

There are several mechanisms that could potentially explain the inverse relationship between coffee consumption and Type 2 Diabetes. First, the chlorogenic acid present in coffee could act as a competitive inhibitor to glucose-6-phosphate translocase, which is involved in the terminal step of gluconeogenesis.[2]



Chlorogenic Acid



Glucose-6-Phosphate

Figure 5: Chemical structures of chlorogenic acid and glucose-6-phosphate

Due to this inhibition, glucose cannot be formed. Reduction of glucose will help in preventing Type 2 Diabetes, as it is caused by the build-up of glucose in the blood.

Additionally, the caffeine contained in coffee is said to increase metabolism, which may help manage weight gain in individuals. Many over-the-counter weight loss products contain caffeine, as it increases metabolic rates. A study in the American Journal of Clinical Nutrition explored caffeine's slimming effects.[13] The study was a blind test of caffeine and a placebo, including 12 individuals that regularly drank moderate amounts of coffee. The test subjects were given oral gelatin capsules, 6 containing placebos and 6 containing caffeine in varying amounts (100, 200, or 400 mg). All participants abstained from food, coffee, tea, and chocolate at least 12 hours before each test for unhindered results. The subjects were also instructed to abstain from physical activity the morning of their tests; data was collected in two consecutive trials, at least three days between each. During each test, energy expenditure, plasma concentrations of hormones, blood pressure, and heart rate were measured. It was found that caffeine intake did increase energy expenditure in the participants (Figure 6).

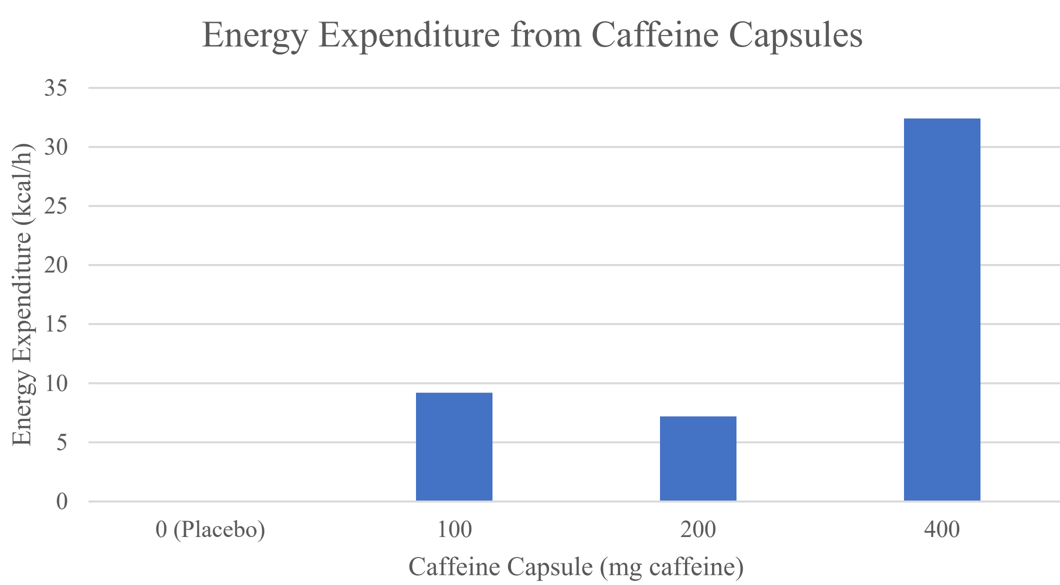


Figure 6: Energy expenditure as a consequence of caffeine intake[13]

Excess body weight can cause negative health effects, including Type 2 Diabetes. The cells in the body can become less sensitive to insulin when an individual is carrying excess weight.[8] When the body becomes insulin-resistant, glucose is unable to enter the body's cells and will remain in the bloodstream at a high concentration. Increasing energy expenditure can increase weight loss, thus promoting health and serve as an aid in preventing diabetes. So, it makes sense that increasing caffeine intake can decrease the risk of developing Type 2 Diabetes.

CHAPTER 3

Caffeine's Neurological and Psychological Effects

Caffeine affects the body in many ways: physically, psychologically, and physiologically. This chapter will focus on several psychological impacts of caffeine. Caffeine acts as an antagonist to adenosine receptors in the brain, causing a variety of psychological consequences. A popular benefit to a morning cup of coffee is wakefulness. However, a caffeine boost can become detrimental when restlessness extends into nighttime hours, causing insomnia. Additionally, one of the debated psychological effects of caffeine is anxiety. Although some studies have discovered that caffeine alleviates anxious symptoms, others have found opposing results.

One of the most sought-after effects of caffeine is wakefulness. Worldwide, students and adults rely on coffee to remain alert and energized during their busy work days. The perception of alertness is caused by caffeine's antagonism of adenosine receptors.[14] Acetylcholine is a neurotransmitter that promotes wakefulness, and is present in high amounts when the brain is active during the day. Adenosine is associated with the slowing of brain activity, as it regulates the activity of acetylcholine neurons. When adenosine inhibits acetylcholine neurons at the end of the day, brain activity gradually slows to prepare for sleep. However, caffeine acts as a potent inhibitor of adenosine (Figure 7), allowing acetylcholine to remain active longer. As a result, caffeine combats adenosine-driven drowsiness throughout the day.

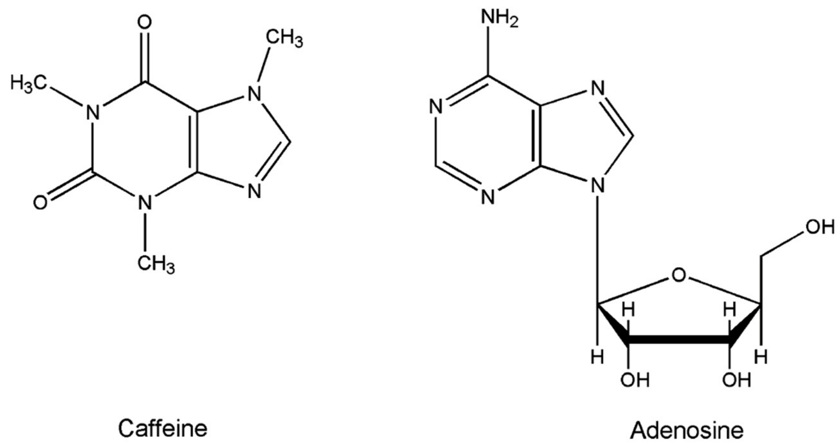


Figure 7: Chemical structures of caffeine and adenosine[2]

However, high doses of caffeine can take wakefulness to the next level, inducing conditions such as insomnia. Once caffeine enters the body, its stimulating effects will persist for hours; it takes about six hours for one half of ingested caffeine to be eliminated.[15] Because of this, caffeinated beverages consumed mid-day or later can cause insomnia when falling asleep at night. One study researched the association between caffeine-induced insomnia and age and gender.[16] About 75,500 Brazilians between the ages of 18-75 participated in a large web-based survey. Participants answered questions about their caffeine intake and insomnia, and the survey results were analyzed. It was found that as age increased, caffeine-induced insomnia also increased. Additionally, in this study, women suffered from a higher degree of insomnia than men. It was suggested that this discrepancy could be due to the hormonal differences in men and women. Estrogen, a female sex hormone, can interact with adenosine receptors and affect sleep patterns in women.

Additionally, studies have considered the correlation between caffeine consumption and anxiety. One survey assessed the psychological effects of caffeine on the incidence of anxiety.[17] College students completed Spielberger State-Trait Anxiety Questionnaires to determine the relationship between coffee consumption and their levels of state and trait anxiety. The State-Trait Anxiety Questionnaire consists of twenty questions testing for state anxiety, and twenty questions testing for trait anxiety.[18] All questions are graded on a 4-point scale, with a higher score indicating greater anxiety. State anxiety refers to someone's anxious response to a sudden, stressful stimulus.[19] On the other hand, trait anxiety is a characteristic, or someone's tendency to feel anxious in response to stressful stimuli. It was found that moderate and high levels of coffee consumption correlated with significantly higher state anxiety scores on the Spielberger State-Trait Anxiety Questionnaire (Figure 8).

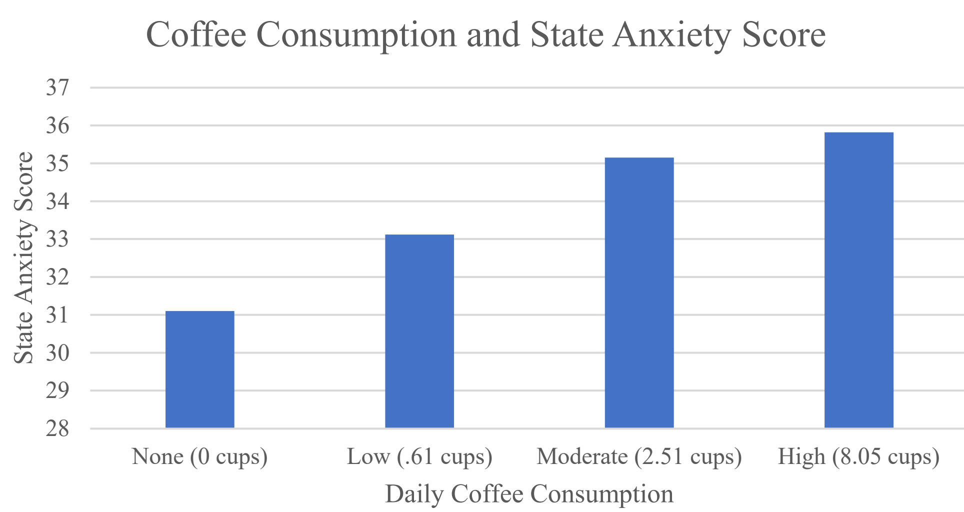


Figure 8: Correlation between coffee consumption and state anxiety in college student population[17]

Trait anxiety scores also increased with coffee intake. However, once daily coffee consumption reached a high level, trait anxiety scores were less than those with a moderate level of intake. Still, when compared to no coffee consumption, there was an increase in trait anxiety with all levels of coffee consumption (Figure 9).

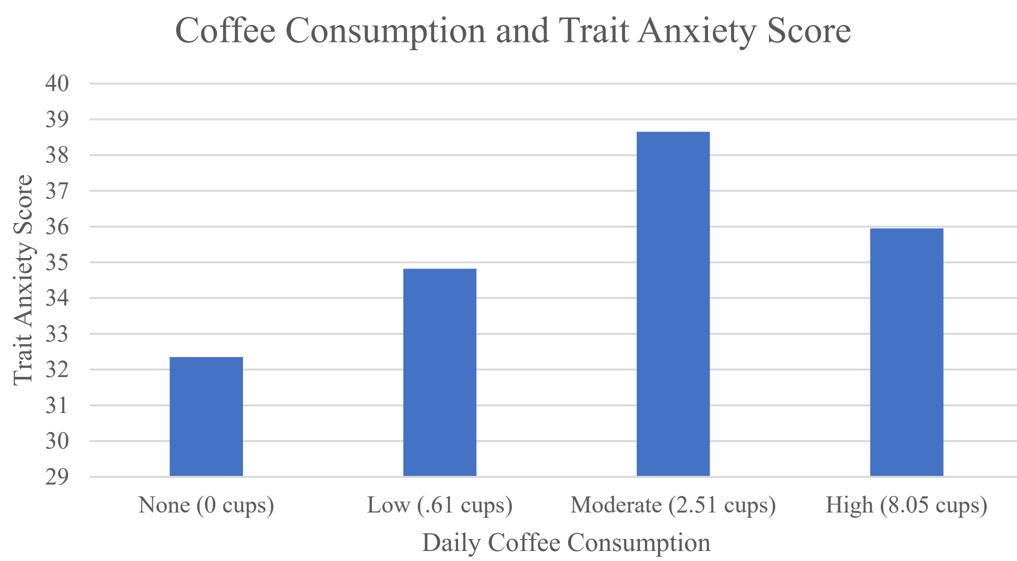


Figure 9: Correlation between coffee consumption and trait anxiety in college student population[17]

Although there is evidence that caffeine may cause anxiety, there are also studies that have found caffeine to eliminate worry. One experiment used mice to observe the relationship between acute caffeine intake and anxiety.[20] Mice were injected at the same time each day (9:00 AM) for eight days in a row before data was collected. The first three days, the mice were injected with saline to get a baseline reading of their anxiety levels. Then, caffeine was injected into the mice on days 4-8 to see if there was a noticeable behavior change. The anxiety levels were measured using an open field exploration test.

In this test, the mice were placed into a bright open field. It was predicted that anxious mice would remain near the sides and not enter the center area, as it is classically considered a higher-stress environment. In contrast, the less-anxious mice would move around and enter the center more frequently. Mice were placed into the bright field for 30 minutes and their distances traveled and average speeds were measured. Because the mice traveled farther distances at higher speeds with caffeine injections, it can be concluded that they felt less anxious when stimulated by caffeine (Figure 10 and Figure 11).

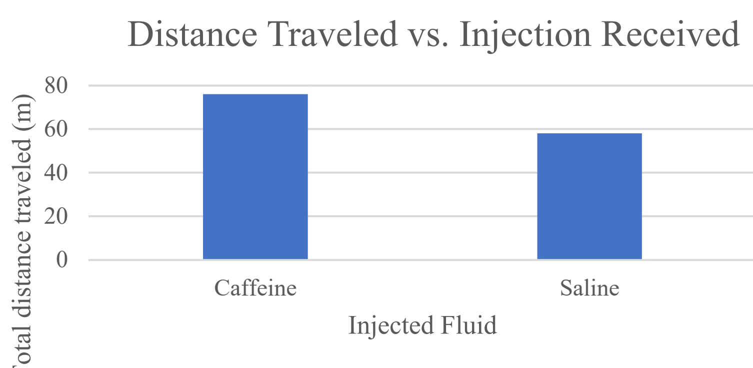


Figure 10: Relationship between caffeine injections and distance traveled by mice[20]

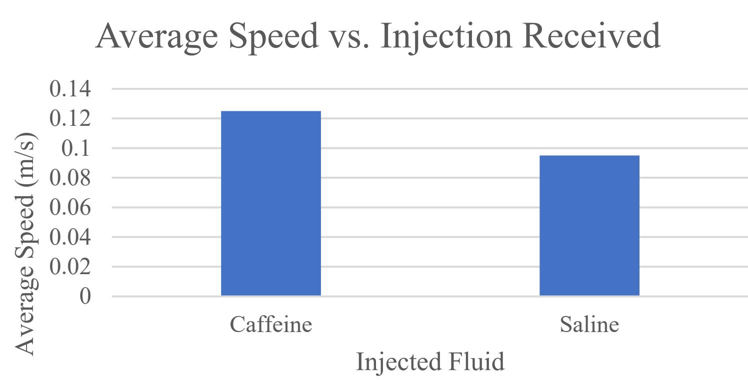


Figure 11: Relationship between caffeine injections and average speed of mice[20]

They were more comfortable moving around the bright, open field and into the center with caffeine in their systems. Another study performed on college-aged boys found no increase in anxiety with the intake of caffeine.[21] In this study, 3,778 respondents filled out food frequency questionnaires (reporting daily caffeine intake), and the General Well-Being Questionnaire to measure their levels of anxiety. After data analysis, it was found that there was no significant correlation between caffeine intake and anxiety in the test subjects. Because there are conflicting results from studies on caffeine and anxiety, it has been speculated that caffeine may affect anxiety only when it is consumed above a threshold level.[21] Additionally, other factors like the time period after consumption, caffeine source, and frequency of consumption may affect the results of experiments testing for anxiety.

CHAPTER 4

Caffeine's Effect on Periodontal Disease

Another controversial effect of caffeine is its impact on the development of periodontal disease. The Mayo Clinic describes periodontitis (periodontal disease) as an infectious inflammatory disease of gum tissue, resulting in alveolar bone loss and ultimately tooth loss.[22] When plaque builds up between teeth, gum tissue becomes inflamed, allowing pockets to form. These pockets can become deeper over time and fill with increasing amounts of plaque, tartar, and bacteria. Ultimately, these deep infections can cause loss of gum tissue, alveolar bone, and teeth if left untreated. This chapter will focus on how caffeine relates to the development of periodontitis. Some studies suggest that caffeine consumption may decrease alveolar bone loss associated with periodontitis, while others suggest that the effects of periodontitis are elevated with caffeine intake.

One study found that periodontal disease was reduced with higher caffeine intake in a population of adult males.[23] Data was collected from a cohort of 1,231 male veterans in good health. The men regularly received dental and medical care in private practice offices. Experimental subjects reported their average daily caffeine intake, and followed-up with a calibrated periodontist examination every 3 years, for up to 30 years in total. At each check-up, data was collected for each subject based on radiographs and clinical findings. Each tooth was analyzed for bone loss scores, periodontal probing depth, bleeding on probing, number of teeth, and the extent of supragingival plaque. Once the data was analyzed, it found there was no significant impact of caffeine consumption in categories other than alveolar bone loss. The data revealed that alveolar bone loss scores were significantly lower over time in men with higher caffeine consumption (Figure 12).

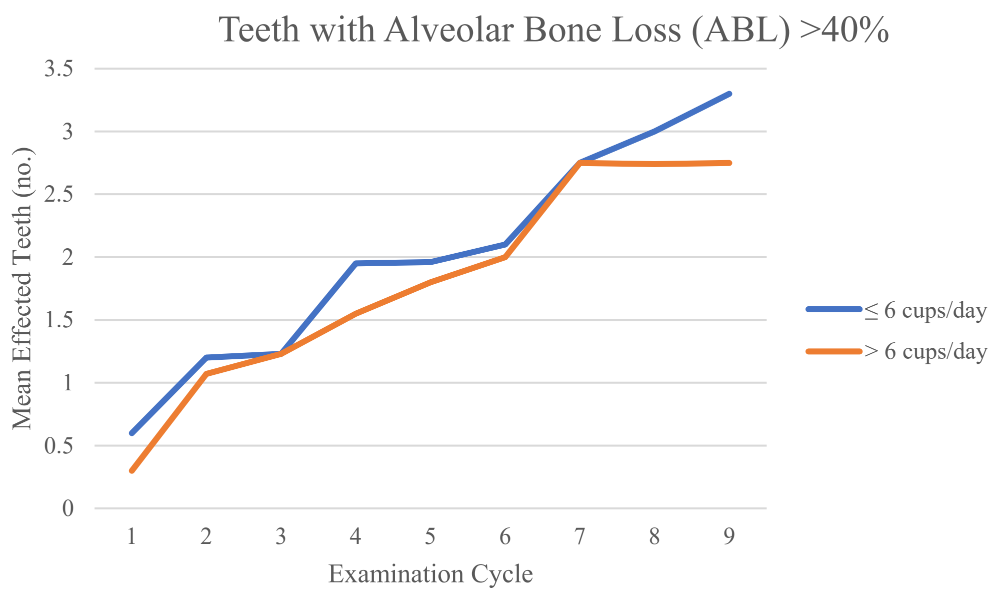


Figure 12: Correlation between caffeine consumption (reported through cups of coffee) and number of teeth with >40% alveolar bone loss in male cohort[23]

Alveolar bone loss is one of the hallmark effects of periodontitis. When pockets between teeth form from gum inflammation and excess plaque, they fill with bacteria, and can cause the loss of tissue, bone, and teeth.[22] This study suggests that increased caffeine consumption may decrease the alveolar bone loss associated with periodontitis.

In an orthodontic study on rats, researchers analyzed the effect of caffeine consumption on tooth movement. Although the study focused on tooth movement, the results also support the hypothesis that caffeine may decrease the development of periodontal disease.[24] To begin, forty male rats participated and were divided into four groups; groups of ten rats each received varying amounts of caffeine for 3 days: 0 g/day, 1 g/day, 2 g/day, or 3 g/day. After the three day period, orthodontic appliances were inserted onto the rats' teeth, consisting of braces linking the maxillary incisors and first molars. Caffeine consumption remained constant within the groups for two more weeks. At the end of this period, the distance between the 1st and 2nd molars were measured to analyze tooth movement. Additionally, osteoclast count was recorded for each subject.

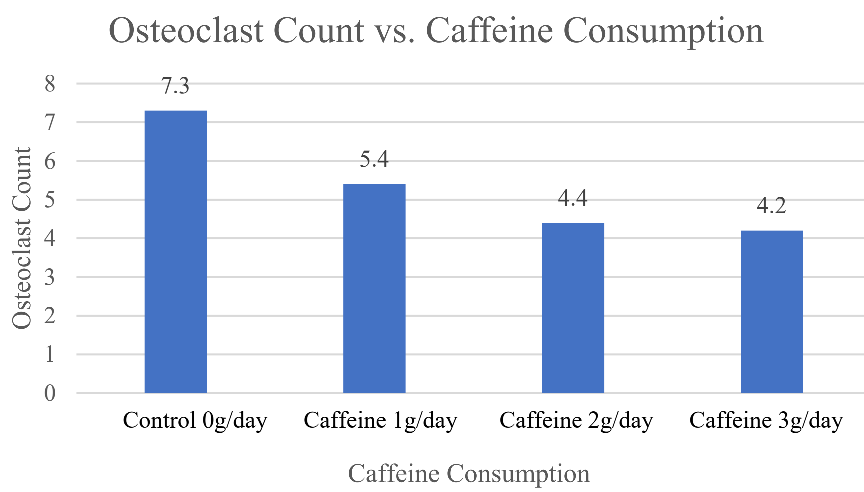


Figure 13: Correlation between caffeine consumption and orthodontic tooth movement in rats. Tooth movement was measured using a millimeter inter-proximal gauge.[24]

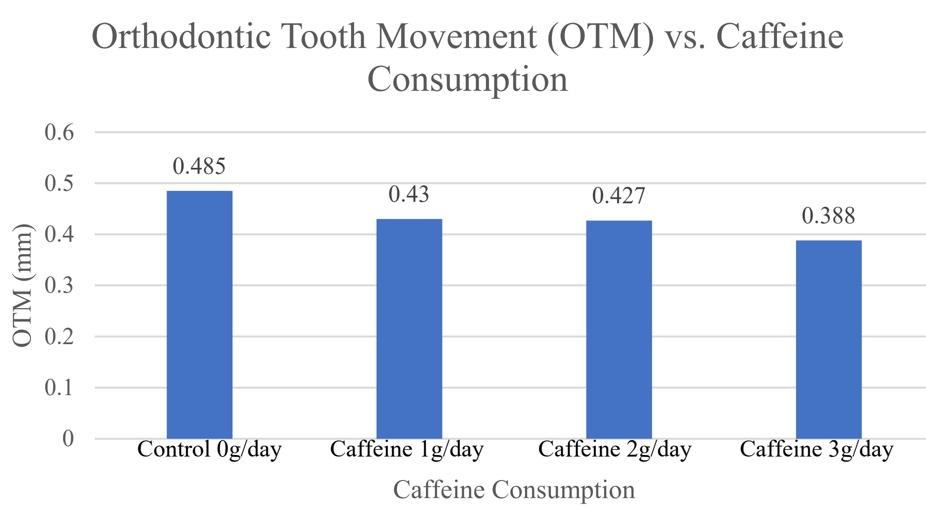


Figure 14: Correlation between caffeine consumption and osteoclast count in rats. Osteoclast counts were determined using histological analysis of molar roots under a light microscope.[24]

The results show that increased caffeine consumption reduced tooth movement and osteoclast counts (Figure 13 and Figure 14). This finding is significant when discussing periodontal disease. Periodontitis involves the activation of osteoclasts and subsequent resorption of alveolar bone.[25] Higher levels of osteoclasts indicate a higher severity of periodontal disease. As a result, the lower counts of osteoclasts in caffeine-consuming rats indicate a lower level of periodontitis. Additionally, periodontitis can be a result of intense orthodontic tooth movement. When teeth are moved quickly, bone loss can increase from the application of orthodontic force.[26] Thus, the lower tooth movement observed in caffeine-consuming rats may also indicate a reduction in periodontal disease linked to the consumption of caffeine.

However, there have also been opposing results. In a study of a Korean male population, it was found that increased caffeine consumption correlated with higher incidence of periodontitis.[27] In the study, 16,730 participants were surveyed in various health categories, including caffeine intake and periodontal status. Trained and calibrated dentists evaluated each participant's teeth based on the World Health Organization's community periodontal index (CPI). The CPI scores represent periodontal status: 0: normal, 1: gingival bleeding, 2: calculus, 3: a shallow pocket or moderate periodontitis, 4: a deep pocket or severe periodontitis. The data was collected and the relationship between caffeine intake and periodontitis was evaluated.

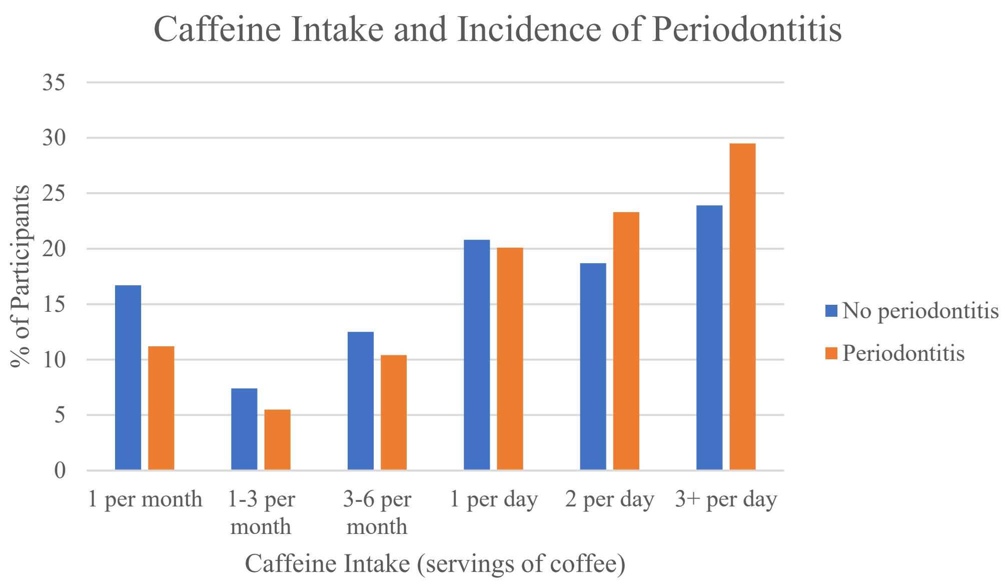


Figure 15: Correlation between caffeine consumption and incidence of periodontitis in a population of Korean males. Periodontitis is defined in the study by having a CPI score of 3 or higher.[27]

Based on the results of the study, men with higher caffeine intakes did have a higher incidence of periodontitis compared to those with lower caffeine intakes (Figure 15). However, this study was done as a one-time survey; not a cohort with follow-up measurements. If the men with higher caffeine intakes reduced their consumption and were analyzed over time, it would be interesting to see whether the periodontal effects would change.

Ultimately, the results of these studies provide differing conclusions of caffeine's effect on osteoclastogenesis. Whether caffeine consumption enhances or decreases the activity of osteoclasts and the subsequent alveolar bone loss connected with periodontitis is not definite. More studies would be necessary to further evaluate caffeine's impacts. Because two of the referenced studies used coffee as their caffeine source, it would be valuable to examine whether other components in coffee (rather than caffeine) are involved in periodontitis.

CHAPTER 5

Caffeine's Effect on Tooth Staining

Caffeine's impact on tooth staining is a highly-debated topic. It has been proposed that switching a daily cup of coffee to decaffeinated coffee can lower the amount dental discoloration. It is also postulated that tea will have a lower effect on tooth staining than coffee, due to its lower caffeine content. While there is varying evidence on caffeine's staining effects, this chapter will explore the mechanism of tooth staining and the role (if any) that caffeine plays in discoloration.

To begin, tooth staining from coffee is caused by a group of compounds called tannins. Tannins are water soluble compounds that are naturally found in plant-based beverages. The extrinsic discoloration of teeth is commonly associated with consumption of tannin-containing beverages like coffee and tea (Figure 16 and Figure 17).[28]

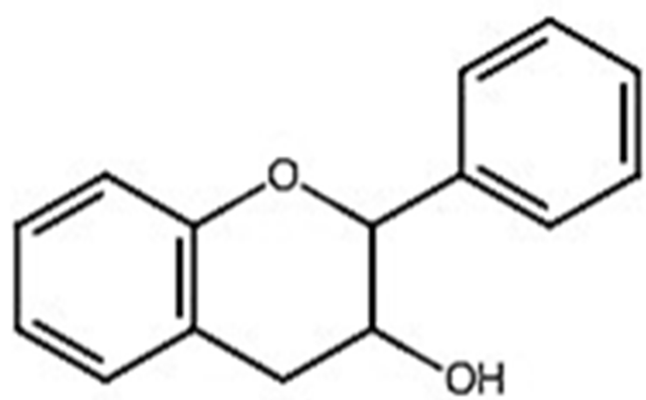


Figure 16: Flavan-3-ol, one of the "tannins" found in tea

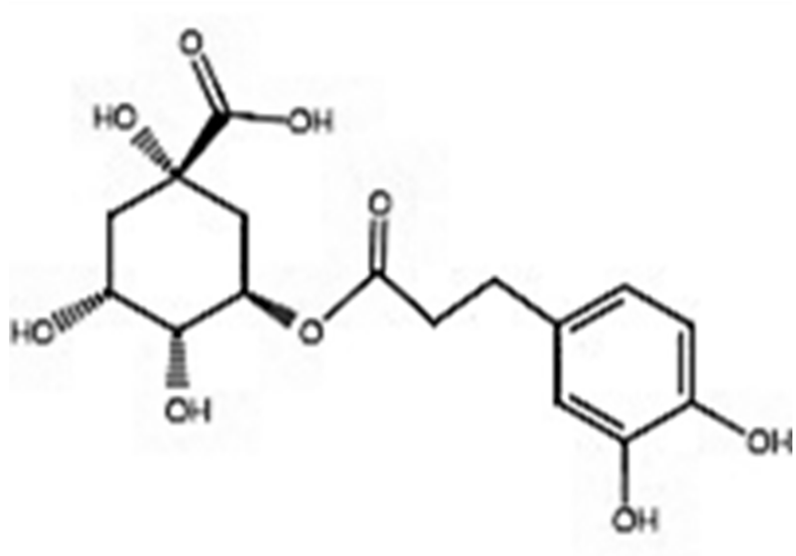


Figure 17: Chlorogenic acid, one of the “tannins” found in coffee

The term “tannin” refers to a category of chromogenic substances, which includes phenolic compounds.[29] As discussed in chapter one, phenolic compounds, namely chlorogenic acids (CGA), are prevalent in coffee. Tannins in tea and coffee interact with the protein-rich surface of the tooth enamel, creating an insoluble tannin-protein complex. Subsequently, when dark beverages are consumed (coffee, cola, red wine), their pigments attach to the insoluble tannin complexes and are difficult to remove. As a result, teeth appear discolored, and the staining can be long-lasting.

In addition to tannins, research has been conducted to determine if additional components of tea and coffee, such as caffeine, contribute to staining. One study looked at the effect of different beverages on tooth staining. In the experiment, 45 sample incisors were exposed to one of five staining solutions: artificial saliva (control), coffee, tea, cola, or red wine.[30] Initially, the teeth were uniformly home-bleached six hours daily for a total of two weeks. After the bleaching period, initial color measurements were taken and the teeth split into five groups and assigned to their solutions. The teeth were immersed in their sample solutions for multiple time periods: 15 minutes, 6 hours, 1 week, and 1 month. The resulting color values were measured and recorded for each time period. Then, mean ΔE values were calculated for each sample solution, representing the color change after each trial (Figure 18).

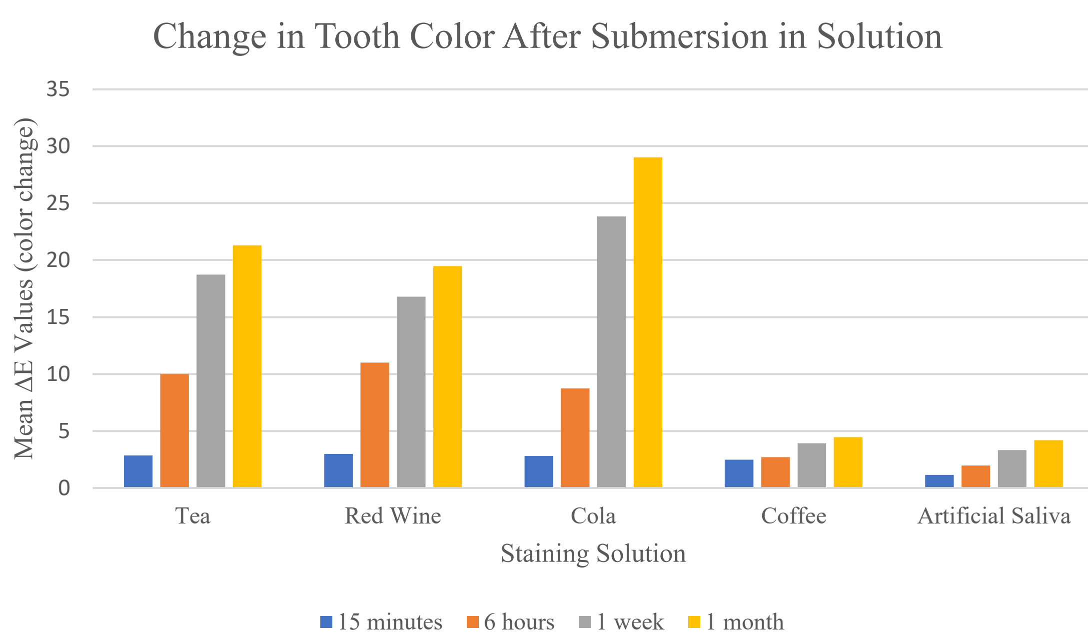


Figure 18: Change in tooth color values after submersion in various staining solutions[30]

After the results were analyzed, it was found that coffee had the smallest difference in tooth staining when compared to the control group, artificial saliva. Of the staining solutions tested, coffee contains the highest caffeine content, with 96 mg per cup. Tea has an average of 28 mg per cup, cola has 22 mg per cup, and red wine has 0 mg per cup.[31] The authors of this study concluded that caffeine does not have a significant impact on tooth discoloration. However, this could serve as evidence for other interactions, such as a protective effect against staining.

However, it is difficult to draw this conclusion about caffeine when there are studies with differing results. Another study conducted a similar experiment, but evaluated tooth discoloration using tea, coffee, red wine, cola and water.[32] For this evaluation, 25 cylindrical brass specimens were uniformly made into "teeth" using resin composite. This ensured homogenous test subjects, instead of using real teeth with varying compositions. The specimens were divided into five groups and stored in their staining solution (tea, coffee, red wine, cola, or water) for 24 hours. Before and after the staining procedure, a colorimeter was used to measure the color factor of each test specimen. After the exposure to staining solutions, the color difference was calculated to observe each solution's staining effects. The following was the observed ranking of staining differences, in increasing order: water < cola < tea < coffee < red wine. These results contradict the earlier study discussed, as coffee was found to stain more than tea, cola, and water, which have comparatively lower amounts of caffeine. However, it is interesting that red wine caused the highest level of discoloration, as red wine contains no caffeine, just like water.

Overall, tooth staining is a complex process that may not have one definitive source. It is possible that a combination of factors can influence dental discoloration, and as such, it is difficult to rule out caffeine's role in staining.

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