Health Benefits of Coffee: A Review of Existing and Emerging Science

Introduction

Given that coffee is so widely consumed in different cultures around the world, there has been considerable interest in recent years as to the impact of coffee consumption on human health. The discovery that coffee may be a significant source of dietary antioxidants has led to the notion that coffee is not merely a dietary source of caffeine, but rather a source of nutritionally beneficial dietary components. Furthermore, several recent epidemiological investigations have suggested a relationship between consumption of coffee and a reduced risk for certain diseases, such as type 2 diabetes, colon cancer and liver cancer. Thus, a greater understanding of the potentially significant health benefits associated with coffee consumption is now being realized (Nehlig, 2004; Higdon and Frei, 2006). This review will briefly outline some of the known advantages relating to coffee consumption in regard to physical and cognitive performance and several other emerging health benefits.

Health Benefits of Coffee Antioxidants

In order to understand the health benefits of antioxidants, it is important to first review the concept of free radicals. Free radicals are formed when oxygen interacts with certain molecules in the body. Once formed, these highly reactive oxygen species react with cellular components such as proteins, lipids and DNA and, in some cases, cause damage to these cellular components (often referred to as oxidative damage). The human body has a natural defense system consisting of enzymes that act as endogenous antioxidants that quench these reactive oxygen species. These antioxidant enzymes are superoxide dismutase, glutathione peroxidase and catalase (Fang et al, 2002). However, an imbalance in the production of free radicals and the endogenous antioxidant systems leads to oxidative damage and, ultimately, to a general condition known as oxidative stress. Long-term exposure to oxidative stress and a chronic imbalance in the body's antioxidant systems has been implicated in the etiology of several disease states, including cardiovascular and metabolic diseases, some cancers and many of the deleterious effects associated with aging (Barbaste et al, 2002; Fang et al, 2002).

Fortunately, antioxidants are produced naturally by the body and are also available in certain foods and beverages. Dietary antioxidants are predominantly derived from plant sources that, once consumed, can interact with the unstable free radicals in the body to reduce cellular damage and, ultimately, reduce oxidative stress. In fact, the endogenous antioxidant enzymes may work together with antioxidants from dietary sources to reduce oxidative stress caused by free radicals (Barbaste et al, 2002; Fang et al, 2002). Examples of these dietary antioxidant compounds include vitamin C, vitamin E and carotenoids, as well as members of a family of compounds known as polyphenols. Polyphenols constitute an important source of dietary antioxidants and are found in plant-derived foods and beverages such as fruits and vegetables, teas, cocoa, wine and coffee. Polyphenols exhibit considerable antioxidant activity in vitro (Fang et al, 2002). Consumption of polyphenols from fruit and vegetables is thought to be at least partially responsible for the relationship between fruit and vegetable intake and decreased risk for certain diseases (Barbaste et al, 2002; Manach et al, 2005; Fresco et al, 2006).

Coffee is surprisingly rich in antioxidants that have the potential for a number of health benefits. Chlorogenic acid, a phenolic acid similar to the polyphenols discussed above, is the principal antioxidant in coffee. Antioxidant activity of coffee polyphenols has been demonstrated in both in vitro and in vivo studies (Richelle et al, 2001; Natella, 2002; Somoza et al, 2003; Bichler et al, 2007) and has also been demonstrated in a recent human intervention trial (Steinkellner et al, 2005). Furthermore, additional compounds (known as melanoidins) are formed by the Maillard reaction that occurs during roasting of coffee beans. It is thought that these compounds, in addition to polyphenols, may contribute significantly to coffee's antioxidant activity (Dupas et al, 2006). Thus, coffee serves as a considerable source of antioxidants that may contribute to the protection of healthy cells and tissues from exposure to oxidative stress.

Coffee and Caffeine

Effects on Hydration

Traditionally, it has been thought that, since caffeine can exert a mild diuretic effect, consumption of caffeinated beverages should be limited due to the potential dehydration effects that may be associated with caffeine consumption. Recent research, however, has put this recommendation into question. For example, it now appears that caffeine-containing beverages do not significantly increase 24-hour urine volume, thus supporting the notion that caffeine-containing beverages actually contribute to overall hydration, as opposed to being a deterrent to hydration status (Armstrong et al, 2005). It is now thought that the hydration provided by the water component of the beverage outweighs the influence of any caffeine-induced diuresis, and that caffeinated fluids contribute to the daily human water requirement in a manner that is similar to pure water. Scientific evidence does not support the claim that caffeine-containing beverages promote dehydration (Armstrong et al, 2007). In addition, tolerance to caffeine, as seen in habitual users, may reduce the likelihood that a detrimental fluid-electrolyte imbalance will occur. A recent review of the scientific literature found that individuals who exercise will not incur detrimental fluid-electrolyte imbalances if they consume caffeinated beverages in moderation (Armstrong, 2002). In fact, there is no evidence to support caffeine restriction on the basis of impaired thermoregulation or changes of hydration status at levels less than 300-400 milligrams per day (Ganio et al, 2007). It is also important to note that the scientific evidence that caffeine does not significantly contribute to dehydration is strong enough that The Institute of Medicine's Food and Nutrition Board 2004 report on Dietary Reference Intakes states that caffeinated beverages contribute to adequate hydration status in a similar manner to non-caffeinated beverages.

Effects on Cognition

The benefit for which coffee is most widely consumed is its ability to act as a stimulant and enhance mental acuity and alertness, a benefit clearly resulting from its caffeine content. Research findings regarding the effects of caffeine and overall cognitive performance have been somewhat mixed, depending on the types of tests employed, owing to the specificity of the central nervous system effects of caffeine, as well as to the conditions and time of day during which the tests are performed. Despite this, there are a large number of studies showing that caffeine increases alertness. In general, acute caffeine ingestion improves performance of simple tasks that benefit from a high level of alertness and vigilance (Smith, 2002; Lieberman, 2003). The effects of acute caffeine ingestion on more complex cognitive tasks and memory are less clear due to variation in experimental designs, but some research indicates a positive effect of caffeine. In fact, a large cross-sectional study found a significant positive relationship between coffee intake and cognitive performance (Jarvis, 1993). In terms of practical applications, the research points toward the significant safety benefit that can arise from caffeine ingestion in tasks ranging from nighttime driving and shift work, when arousal can be particularly low (Boivin et al, 2007). In fact, the effects of coffee and napping in relation to driver alertness were examined on nighttime driver performance (Phillip et al, 2006). Study participants consumed 125 milliliters of coffee containing 200 milligrams of caffeine before a driving task between 6:00 and 7:20 pm, or 2:00 and 3:30 am. It was found that coffee or napping at night statistically significantly reduces driving impairment without altering subsequent sleep.

Although scientific and anecdotal evidence points toward the acute benefits of caffeinated coffee consumption on cognitive performance, only recently has there been an appreciation for the potential long-term benefits associated with coffee consumption on cognition as specifically related to age-related cognitive decline. There is recent data to suggest that chronic coffee consumption may provide long-term benefits in terms of cognitive function and may even slow or prevent age-related cognitive decline. In a study of more than 1500 men and women with average ages of 73 and 72 years, respectively, cognitive function was assessed along with lifetime and current coffee consumption (Johnson-Kozlow et al, 2002). It was found that higher lifetime coffee consumption in women was associated with significantly better performance on six of twelve cognitive tests. Furthermore, current coffee consumption was associated with improved performance on two of the cognitive tests (Johnson-Kozlow et al, 2002). In a more recent investigation, coffee consumption and 10-year cognitive decline was assessed in 676 healthy men born between 1900 and 1920 (van Gelder et al, 2007). Results indicated that the men who consumed coffee had significantly less 10-year cognitive decline than men who did not drink coffee. In fact, there seemed to be an optimal amount of coffee consumption, with the least cognitive decline occurring when 3 cups of coffee were consumed per day. The cognitive decline that was experienced by those drinking 3 cups per day was over 4 times smaller than that of non-coffee drinkers. Further, yet another study published recently examined overall caffeine

consumption in a community-based sample of subjects 65 years of age and older. It was found that the stimulant properties of caffeine appeared to reduce cognitive decline in women without dementia, especially at higher ages (Ritchie, 2007). In summary, although it is not yet clear what components of coffee appear to influence these findings (i.e., coffee antioxidants, caffeine or combinations), the collective results of these studies suggest there may be some important cognitive health implications resulting from coffee consumption. Future research should continue to examine this relationship between acute and chronic coffee consumption and age-related cognitive decline in order to more accurately define the relationship, determine potential mechanisms and determine if there are any potential relationships with the development of Alzheimer's disease (Johnson-Kozlow et al, 2002).

Effects on Physical Performance

While the mechanism of the ergogenic effect of caffeine for physical performance is still a matter of debate, three primary theories have been proposed: 1) caffeine stimulates catecholamine (or adrenaline) release which, in turn, stimulates adipose tissue lipolysis; 2) the beneficial effects of caffeine on concentration, fatigue and alertness might also play a role in reducing perceived exertion; and 3) caffeine can stimulate the mobilization of calcium in muscle cells for enhanced muscle contraction (Graham, 2001). There are several studies that have examined the ergogenic effects of caffeine in the context of exercise and, in general, have demonstrated that caffeine can enhance endurance performance lasting between 30-120 minutes and, at the very least, may decrease perception of effort in the absence of any measured performance enhancements (Graham, 2001). It is important to note, however, that almost all of the studies that examine exercise performance and caffeine have utilized pure caffeine and have not examined the effects of caffeine when ingested as part of a food or beverage source, such as coffee. The results of one study on the effects of caffeinated coffee on exercise performance is particularly worth noting since it examined caffeinated coffee versus caffeine independent of coffee. Graham et al. (1998) studied the effects of the same dose of caffeine ingested as either caffeinated coffee or as pure caffeine with water and the subsequent metabolic and endurance exercise responses. It was found that although the bioavailability of caffeine was not different between the caffeinated coffee and the pure caffeine conditions, the metabolic effects of pure caffeine ingestion and caffeinated coffee ingestion are, in fact, quite different. Although more research is necessary to understand the effect of caffeinated coffee on exercise performance, these findings suggest that there may be some other compounds in coffee besides caffeine that have profound effects on energy metabolism. Further support for the potential metabolic alterations induced by intrinsic coffee compounds will be even more apparent in later sections (see Type 2 Diabetes).

Emerging Health Benefits of Coffee

Type 2 Diabetes

As the understanding of the intrinsic health benefits of coffee consumption grows, several studies have been published in recent years that point toward some remarkable potential benefits of coffee consumption in terms of disease risk. One of the most exciting findings that has come to light within the past five years is that of a strong relationship that has been demonstrated in epidemiological studies between coffee consumption and a decreased risk for development of type 2 diabetes. In a landmark cohort study published in *The Lancet* in 2002, in which more than 17,000 Dutch men and women between the ages of 30 and 60 years were studied, coffee consumption was associated with a significantly lower risk of developing type 2 diabetes. In fact, it was demonstrated that those individuals who drank seven or more cups of coffee per day were significantly less likely to develop type 2 diabetes (van Dam and Feskens, 2002). Since the publication of this research in 2002, 16 out of 18 cohort studies have associated increased coffee consumption with decreased diabetes incidence. In addition, 11 out of 12 cross-sectional studies have associated increased coffee consumption with decreased diabetes risk factors (van Dam, 2006). Indeed, it is important to note that the size of a typical cup of coffee can vary not only across individuals but also across cultures. Although a typical cup is eight fluid ounces, surely for some individuals a typical "cup" of coffee may greatly exceed eight fluid ounces.

The apparently strong relationship between coffee consumption and type 2 diabetes risk is even more striking given the research that points toward transient negative effects of acute caffeine ingestion on glucose tolerance in lean, obese and type 2 diabetic individuals (Graham et al, 2001; Petrie et al, 2004; Robinson et al, 2004). More specifically, these studies have shown that acute caffeine ingestion can induce a transient decrease in glucose uptake and an increase in plasma free fatty acids. In contrast, there is recent evidence to suggest that when caffeine is consumed as a part of coffee, these potentially deleterious effects

of caffeine are blunted by what may be positive effects of coffee on glucose tolerance (Battram et al, 2006; Johnston et al, 2003). Thus, although a mechanism has not yet been established, it appears biologically plausible that coffee may be exerting some direct anti-diabetic effects that may lead to the preventive effects observed in the population-based studies. Additional research is certainly warranted to further characterize the interaction between coffee and glucose tolerance and to further define the mechanism(s) of action involved.

Liver Health

There is a growing body of evidence that coffee consumption may have significant protective effects on liver health (Higdon and Frei, 2006). For example, a large scale cohort study in Japan found a significant inverse relationship between coffee consumption and risk for hepatocellular carcinoma (Inoue et al, 2005). In fact, it was found that consuming at least 5 cups per day resulted in a 76% lower risk of hepatocellular carcinoma compared to non-coffee drinkers. In addition, a recent meta-analysis has confirmed these findings from Japan and several studies in European populations (Montella, et al, 2007). There is also research to suggest that coffee consumption may have a protective effect against liver damage and, ultimately, in the development of cirrhosis (Higdon and Frei, 2006). These population-based studies will need to be followed up with additional work to determine potential mechanisms for a protective effect of coffee on diseases of the liver.

Digestive Health

There is evidence to suggest that coffee consumption could have some preventive effects on the development of colon cancer; however, it should be noted that the results of this research are mixed, depending on the experimental design employed. In general, case control studies have demonstrated that coffee consumption is inversely associated with the risk for colon cancer, while prospective cohort studies have not demonstrated such an effect (Higdon and Frei, 2006). There have been several proposed physiological mechanisms to explain a potential preventive effect of coffee consumption on the risk for colon cancer, including increase in colonic motility, elimination of carcinogens, improved antioxidant status of the colon due to the intrinsic antioxidants contained in coffee and decreased synthesis and secretion of bile acids (Higdon and Frei, 2006). Nevertheless, these are all proposed mechanisms that do not yet have strong scientific support. Thus, more research is necessary to determine if there are any definitive relationships between coffee and colon cancer and better understand the potential mechanisms involved.

Summary

Coffee is indeed a complex beverage that contains a mixture of known and unknown chemicals, all of which may be highly dependent upon the method of preparation (i.e., light versus dark roast; filtered versus unfiltered) and variation in cup size. Our understanding of the health benefits provided by coffee is growing, but there is still much research to be done to accurately characterize the many components involved and the effect that these many components and combinations have on human health. Further, possible detrimental effects that accompany high-caloric additions to coffee should also be taken into account when interpreting findings (van Dam, 2006). Although some groups, such as individuals with hypertension, should continue to limit caffeinated beverages, it seems that overall there is little evidence of health risk and some research suggests that there are some significant health benefits for adults consuming moderate amounts of coffee (3-4 cups per day) (Nehlig, 2004; Higdon and Frei, 2006). While more research is needed to define the potential mechanisms involved with these health benefits, existing research continues to be promising. Hence, there appears to be no need to restrict coffee consumption among healthy individuals, and there may be potentially beneficial health reasons to encourage those individuals who enjoy coffee to continue.

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