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Review Article

Does Green Tea Help to Fight against Obesity? An Overview of the Epidemiological Reports

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Abstract

Obesity is an increasing public health concern due to increased risk of related disorders. However, appropriate prevention and early management of obesity are changes in lifestyle patterns including physical activity and diet. Additional use of dietary agents for the prevention of obesity would be of tremendous benefits. It has been shown that green tea helps to reduce obesity when consumed on daily basis. Anti-obesity effect of green tea has been associated with its content of caffeine and catechins particularly (-)-epigallocatechin-3-gallate (EGCG). A number of studies have explored the effects of green tea on the overweight and obesity conditions. Many human epidemiological studies, demonstrated beneficial effects of green tea or green tea catechins rich in EGCG in overweight management. The consumption of green tea or its catechins helps in significant reduction of body mass index (BMI), body weight and body fat by increasing postprandial thermo genesis and fat oxidation. In addition, it was also found to reduce blood cholesterol, triglyceride, glucose and insulin levels. Several studies have hypothesized biological mechanisms whereby green tea may reduce adipocyte lipogenesis, decrease fat absorption, as well as suppressed appetite and nutrient absorption. In spite of all these benefits, the optimal dose of green tea is still not clear. This article provides a comprehensive overview of the human studies addressing the potential anti-obesity and its related benefits of green tea and its contents, particularly catechins.

Keywords: Green tea; Catechins; Anti-obesity; Fat oxidation; Thermo genesis

Introduction

Obesity is rapidly reaching epidemic proportion worldwide and has become a public health burden. It is strongly associated with the risk of various diseases including diabetes mellitus, , hypertension, neurological disorders, cardiovascular diseases and even some types of cancer [1,2], and promotes premature death. Obesity is associated with the expansion of adipose tissue, deposition of fat, elevation of plasma free fatty acids, blood cholesterol and blood glucose levels [3,4]. These disorders arise due to imbalance of metabolic, endocrine, neurological and nutritional factors [5,6]. Most of the studies have reported that the lack in physical activities, overeating, binge eating, junk food, fast food, highly processed foods and drinking sugar-sweetened beverages are the risk factors of obesity [6]. However, in some cases, genetic predisposition, family history, and ethnicity have been associated with obesity [7].

WHO estimated that more than 1.4 billion adults were overweight, of these over 200 million men and nearly 300 million women were obese and more than 40 million children under the age of five were overweight [8]. In Saudi Arabia, prevalence of obesity ranged from ~14% in children to ~83% in adults [9]. The observed prevalence and pattern of overweight/obesity in Saudi Arabia is due to urbanization, which has a significant impact on different aspects of lifestyle factors specially sedimentation and eating habit [10,11].

The preventive intervention of overweight and/or obese individuals is a key issue globally. World Health Assembly in 2004 reviewed the increasing incidence of obesity and its related diseases. Finally they found that improvement of diets and physical activity patterns at global, regional and local population levels will be helpful in preventing obesity [8]. However, researchers are also investigating the functional foods that could be probably helpful in prevention of obesity and related diseases. There are many controversies about the role of green tea and its effects on health and diseases. In view of these, we explored the beneficial effects of green tea and green tea catechins in healthy obese human subjects. This review has also focused on the patho-physiological model of obesity onset and the probable mechanism through which the green tea may prevent obesity and its related problems. It would be of great interest to the general population and especially those who are undergoing initiation and progression of obesity.

The epidemiological research data of green tea were in this paper collected up to December 2013, through cross-referencing, using various resources like Pubmed, Medline, Embase, Science direct, Biological abstracts, and Thomson Reuters, Web of Science.

Green Tea Composition

Green tea is a popular beverage made from the leaves of *Camellia sinensis* var. sinensis and *Camellia sinensis* var. assamica plant (family-Theacease). Thousands of years ago, it was believed that drinking of green tea has medicinal efficacies in the prevention and treatment of many diseases, and so longevity is often associated with the green tea drinking habit [12]. In the recent past years, numerous studies

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have revealed several physiological responses of green tea, which may promote health and may also be useful for prevention and treatment of some chronic diseases. Green tea catechin epigallocatechin gallate (EGCG) has been reported for anticancer, antiobesity, antidiabetes effectiveness and prevention of cardiovascular diseases [13,14]. However, caffeine and EGCG catechins are also considered as active substances of green tea, which associated with energy expenditure, fat oxidation and weight loss in obese subjects [15]. Other catechins and polyphenolic compounds of green tea have been reported for various pharmacological activities [16-18], which reflect the increasing interest in the possible health benefits of green tea.

Green tea is produced from freshly harvested young leaves by immediate steaming to prevent enzymatic fermentation. Steaming processes inactivate the polyphenolic oxidase enzyme, which is capable for oxidation of tea catechins to oligomeric and polymeric derivatives. Though, young leaves processed for fully enzymatic oxidation (fully-fermentation), in which catechins is converted into the aflavins and the arubigins, is known to be a feature of the black tea, while limited enzymatic oxidation (semi-fermentation) is known to produce Oolong tea [17].

Catechins content in green tea infusion depends on species, harvesting variables, and brewing methods. Wu and Wei, estimated ~90 mg of EGCG in a cup of green tea (2.5 g of green tea leaves in 200 ml of water) [19], whereas, Higdon and Frei, estimated EGCG content about 30-130 mg/237 mL green tea infusion [20]. Cabrera et al. estimated ~32.5 mg of caffeine content in 1g of green tea infusion [21].

Mechanism of antiobesity action of the green tea

To date, metabolomics have established enormous possibilities for the onset of obesity [4]. The changes in metabolic network are uniquely poised to increase obesity and obesity-related diseases, and finally disordered whole body systems [22]. The metabolomics concept of obesity is almost similar with the old concept of energy balance model. In other obese individuals the level of total caloric expenditure is lower than caloric intake, resulting in fat accumulation in adipose tissue [5]. It has been reported that overeating not only accumulates high caloric energy, it also enhances stomach capacity which activates gastric stretch receptors and mechanoreceptors that regulate signals for again and again eating [23]. Adversely, slow rate of gastric emptying, delayed duodenal release of cholecystokinin and therefore also delayed satiety signals [24], enhances over eating. Hence, overeating results in weight gain [25], and onset of obesity [26]. Green tea polyphenols elevate cholecystokin in hormone that decreases food intake and suppresses appetite [27]. Green tea beverage has also been alter energy balance through their interference with the metabolism of lipid and carbohydrate by virtue of their antioxidant and physicochemical effect as well as their ability to activate metabolic enzymes [20,28].

High concentration of lactate in the plasma may be an indicator of hepatic glucose production and hepatic lipid synthesis [29], which may also results in the onset of obesity [4]. Complex molecules, like starch and glycogen are hydrolytically broken down by α-glycosidase enzyme into glucose molecules. Glucose molecules either used as metabolic energy or in excess, are converted into lactate [30]. Some studies have reported that, theaflavins and catechins retard starch digestion through inhibition of α-glucosidase [31], salivary amylase and pancreatic amylase activities [32]. However, caffeine stimulates the cori-cycle where lactate move from muscles to the liver and converted into pyruvate [33]. Finally pyruvate is converted into glucose by lactate dehydrogenase and circulates back to the muscles [33]. Hence, green tea's role as a starch blocker minimizes lactate concentration and reduces carbohydrate utilization [34].

Free fatty acids compositions, especially saturated fatty acids have been positively associated with the development of obesity and cardiovascular related diseases including diabetes and hypertension [35,36]. Metabolically, free fatty acids either are catabolized in mitochondria to produced energy and excess lipids stored in adipose tissue or elsewhere as triglycerides [37]. Studies have shown that green tea extracts inhibit fatty acid synthase [38], increase lipid metabolism through the intervention in the process of adipogenesis and lipolysis [39]. Green tea catechins inhibit gastric lipase and pancreatic lipase [40], which is involved in lipid digestion. This inhibition is apparently due to catechins reduced lipolysis of long-chain triglycerides [41] and interference with the emulsification, digestion and micellar-solubilization of lipids that support intestinal absorption of dietary lipids [42,43]. This notion suggests that the reduced lipid emulsification and digestibility may be responsible for lowering intestinal absorption of dietary lipids, including triglyceride, cholesterol, and other lipophilic compounds [44]. Green tea also lowers plasma cholesterol by increasing fecal bile acids and cholesterol excretion [45].

Neurological factors, particularly sympathetic nervous system (SNS) regulates energy balance in both basal and stimulated (exercise, food intake and stress) conditions via interference with the metabolic rate and facultative thermogenesis [46]. This low activity of SNS is associated with weight gain and onset of obesity [47]. A study has shown that an obese population with low SNS activity gained more and more weight [48]. The actual role of SNS is to stimulate adrenal medulla that secretes catecholamines, epinephrine and norepinephrine, which is circulated in the body through blood [47]. The active norepinephrine (NE) binds to fat cells surface receptor and stimulates the activity of hormone sensitive lipase (HSL) so that fat could be used as fuel. Adversity, catechol O-methyl-transferase (COMT) is an enzyme encoded by the COMT gene, that degrades NE and prevents the breakdown of fat [48]. Some studies have revealed that green tea catechins, especially EGCG inhibits COMT and caffeine inhibits trancellular phosphodiesterases that break down NE-induced cAMP [49,50]. This notion indicated that the thermogenic properties of green tea could reside primarily in an interaction between its high content of catechins and the presence of caffeine that sympathetically released noradrenaline and inhibits tran-cellular phosphodiesterases [51]. Hence, such synergistic interaction between catechins and caffeine may result in increased CNS activity that prolongs sympathetic stimulation of thermogenesis, energy expenditure, and fat oxidation [52,53], which could be helpful in obesity management intervention.

Various pilot studies have been designed to evaluate the beneficial effects of green tea extracts and green tea catechins specially (-)-epigallocatechin gallate (EGCG) in healthy obese overweight volunteers (Table 1). The concentration of EGCG in green tea beverage or capsules used in the various studies ranged from 100 to

Table 1: Summary of the important studies related to the effect of the Green tea consumption on the overweight and obese subjects.

Study design	Dose (per day), duration, tea brand*	Authors' conclusion	Reference/country
Multi-center, uncontrolled. Participants: 70 BMI: 25-32	GT AR_{25} 4 cap [375 mg catechins, of which 270 mg EGCG] 3 months	GT capsule consumer significantly decreases body weight and waist circumference.	[40] France
Double-blind, placebo controlled BMI: 25.1 ± 1.2 Participants: 10	Placebo [cellulose] Caffeine [150 mg] GTE [270 mg EGCG and 150 mg caffeine] 24 hours AR25, Arkopharma Laboratories, Nice, France	GTE consumer significant increases EE and fat oxidation.	[51] France
Randomized, cross-over, controlled Participants:12 BMI: 18-30	Control [water] Caffeine [270 mg] Half-strength tea 1500 ml [331 mg catechins (122 mg EGCG)] Full-strength tea 1500 ml [662 mg catechins (244 mg EGCG)] 3 days, self-prepared	EE and fat oxidation were high in full strength tea consumers followed by caffeine consumers and half strength tea consumers.	[54] Japan
Randomized, case-controlled Participants: 12 BMI: 24.8±0.8	GT1 350 ml [77.7 mg catechins +80.15 mg caffeine] GT2 350 ml [592.9 mg catechins +81.9 mg caffeine] 12 weeks, self-prepared	EE and fat oxidation were higher in high catechins group followed by lower catechins group.	[55] Japan
Double blind, cross-over, placebo controlled Participants: 31 BMI: 20.25	Placebo [3g fibersol-2] GT 2100 mg [540 mg catechins (282 mg EGCG) + 300 mg caffeine] 3 days Choladi TCTG; Nestle Co., Choladi, India	GT consumers significantly increase EE and fat oxidation.	[56] Switzerland
Cross-over, double blind, placebo controlled Participants: 15 BMI: 22·4 ±1·6	Placebo [caffeine 150 mg] GT1[catechins 493.8 mg (242.4 mg EGCG) + caffeine 150 mg] GT2 [catechins 645 mg (607.2 mg EGCG) + caffeine 150 mg] GT3 [catechins 684 mg (1.8 mg EGCG) + caffeine 150 mg] 1day Unilever Research & Development, Colworth, UK	GT consumers non-significantly increase of EE, fat oxidation and decrease respiratory quotient.	[57] Denmark
Randomized double-blind, placebo controlled Participants: 6 BMI: 29.1	Placebo [300 mg lactose] GT [300 mg EGCG] 2 days, Teavigo™ by DSM Nutritional products (Basel, Switzerland)	Postprandial respiratory quotient significantly decreases whereas EE did not significantly change.	[58] Germany
Randomized, double-blind placebo controlled Participants: 12 BMI: 31.3±0.8	Placebo [lactose] Dose 1[300 mg EGCG] Dose 2[600 mg EGCG] Dose 3[200 mg caffeine] Dose 4[300 mg EGCG/200 mg caffeine] 3days Teavigo™ by DSM Nutritional products (Basel, Switzerland)	Low dose of EGCG increases fat oxidation, which was equal to the 200 mg caffeine consumers, whereas high EGCG did not show this effect.	[59] Germany
Randomized, double-blind placebo controlled Participants: 16 BMI 24.6 ± 1.2	Placebo [gelatin capsule] GT [405 mg EGCG] 2 days Teavigo capsule	Short-term consumption of Teavigo capsule did not increase resting metabolic rate and the thermic effect of feeding.	[60] USA
Randomized, double-blind, placebo controlled. Participants: 14 BMI: 20-27	Placebo [cellulose] [600 mg caffeine + 270 mg EGCG] [600 mg caffeine + 600 mg EGCG] [600 mg caffeine + 900 mg EGCG] [600 mg caffeine + 1200 mg EGCG] 1 day	Caffeine along with EGCG significantly increases EE and fat oxidation.	[61] Canada
Randomized, cross-over, controlled Participants: 11 BMI: 21.2±2.5	Control (water) Oolong tea 300 ml [206 mg catechins, of which 81 mg was EGCG and 77 mg caffeine] GT 300 ml [293 mg catechins, of which 156 mg was EGCG and 161 mg caffeine] Single administration Suntory Ltd (Osaka, Japan	Oolong tea consumer increases EE more than GT.	[62] Japan

Case-control Participants: 23 BMI: 24-25	Low dose GTE [118.5 mg catechins, of which 32 mg EGCG and 75 mg caffeine] High dose GTE [483.0 mg catechins, of which 300 mg EGCG and 75.5 mg caffeine] 12 weeks	Low dose of GT reduces body weight, BMI and insulin. High dose of GT reduces body weight, BMI, body fat, visceral fat, cholesterol, glucose and insulin.	[63] Japan
Randomized, parallel, double-blind, placebo controlled Participants: 100 BMI: > 27	Placebo [1200 mg cellulose] GT 1200 mg [491 mg catechins (302 mg EGCG)] 12 weeks	GT consumer slightly reduces body weight and body fat, whereas significant reduces LDH-cholesterol and triglyceride levels.	[64] Taiwan
Randomized, placebo-controlled Participants: 60 BMI > 25kg	Placebo [cellulose] GT 750 mg [catechins 140.8 mg (100 mg EGCG) + 86.5 mg caffeine] 12 Weeks Herbal One Co., Ltd., Nakornprathom, Thailand	GT capsule consumer significantly decreases body weight, respiratory quotient and increased EE.	[65] Thailand
Double blind, controlled Participants: 195 BMI: 22.5-30	Control GT 750 ml [catechins 41.1 mg (9.3 mg EGCG)] GT1, 750 ml [catechins 444.3 mg (152.3 mg EGCG)] GT2, 750 ml [catechins 665.9 mg (229.8 mg EGCG)] 12 weeks THEA-FLAN 90S produced by ITO EN, Ltd, Shizuoka, Japan	GT1 and GT2 consumers' decreases body weight, BMI and abdominal fat area, total fat area and visceral fat area.	[66] Japan
Randomized double-blind, controlled Participants: 240 BMI: 26.8±2	Control 340 ml [96.3 mg catechins (4.9 mg EGCG) and 75 mg caffeine] GT 340 ml [582.8 mg catechins (29.5 mg EGCG) and 72.3 mg caffeine] 12 weeks	GT consumers decrease body weight, BMI, body fat, waist circumference, hip circumference, visceral fat area, subcutaneous fat area, low-density lipoprotein (LDL) and cholesterol.	[67] Japan
Randomized, placebo controlled Participants: 192 BMI: 24-35	Placebo 250 ml [30 mg catechins +10 mg caffeine] GT1 250 ml [458 mg catechins +104 mg caffeine] GT2 250 ml [468 mg catechins +126 mg caffeine] GT3 250 ml [886 mg catechins +198 mg caffeine] 90 days	GT consumer reduces body fat. While, GT3 consumer decreases intra-abdominal fat, waist circumference and body weight.	[68] China
Randomized, double-blind controlled Participants: 118 BMI: 24-40	Control 350 ml [catechins 86.2 mg (14.8 mg EGCG) + caffeine 40.4 mg] GT 350 ml [catechins 609.3 mg (125.5 mg EGCG) + caffeine 68.6 mg] 12 weeks Kao Corporation, Tokyo, Japan	GT beverage consumer reduces body weight, BMI, visceral fat area and total body fat.	[69] China
Randomized single blind controlled Participants: 30 BMI: 29.90 ± 4.93	Control [water] GT [1 sachet in 1.5 liter water] 25 days Green tea (BOH®)	GT consumer significantly decreases body weight, BMI and waist circumference.	[71] Malaysia
Randomized, single-blind, controlled Participants: 35 BMI: 36.1	Control [Water] GT 4 cups[catechins 928 mg (440 mg ECGC) + 8.96 mg caffeine] GT 2 caps[catechins 870 mg (460 mg ECGC) + 3.6 mg caffeine] 8 weeks	Both GT beverage and capsule consumers significantly decreases body weight and BMI. Also, GT beverage decreases lipid peroxidation and LDL-cholesterol.	[72] USA
Randomized, double-blind, placebo-controlled Participants: 226 BMI: 25-35	Placebo control drink GT beverage [540 mg catechins] 12 weeks	GT beverage consumer decreases body weight and body fat, abdominal total fat, visceral fat, and subcutaneous fat area.	[73] Japan
Randomized, double-blind placebo-controlled Participants: 41 BMI: 23-30	Placebo control drink GT beverage 680 mL [339.8 mg catechins with a galloyl moiety] 12 weeks	GT beverage consumer decreases abdominal fat and visceral fat area.	[74] Japan
Randomized, double-blind, placebo-controlled Participants:81 BMI≥25	Placebo control drink De-caffeinated GTE drink [548 mg catechins] 12 weeks	De-caffeinated GTE reduces body weight, waist circumference, abdominal body fat and blood lipids.	[76] Japan
Case-control Participants:100 BMI≥25	Oolong tea 8 g [EGCG 153.3 mg and caffeine 141 mg] 6 weeks Fujian Tea Import and Export Co., Ltd. (China)	Oolong tea decrease body weight, body fat, subcutaneous fat and waist size.	[78] China
Randomized, double-blind, controlled Subjects with normal exercise BMI: 24-30 Participants: 80	Control [126.5 mg catechins, of which 25.2 mg was EGCG and 81 mg caffeine] GT 340 ml [588 mg catechins, of which 115 mg was EGCG and 83 mg caffeine] 12 weeks	GT consumer significantly reduces body weight, BMI, body fat mass, visceral fat area, subcutaneous fat area and hip circumference.	[80] Japan

Controlled, parallel Subjects with treadmill exercise Participants: 14 BMI: 24.5±2.6	Control 500 ml [non-catechins beverage] GT 500 ml [570.4 mg catechins (218.4 mg EGCG) + ~40 mg caffeine] 2 months	GT consumer non-significantly increases EE and sedentary fat oxidation at rest and during exercise.	[81] Japan
Randomized, placebo controlled Subjects with moderate exercise BMI: 25-39.9 Participants: 38	Placebo [lactose 2 caps]. Teavigo® 2 caps [EGCG 300 mg] 12 weeks	Teavigo® consumer non-significantly reduces total body fat, abdominal fat, waist circumferences and intra-abdominal adipose tissue.	[82] Australia
Cross-over, placebo controlled Subjects with exercise Participants:12 BMI: 23.9	Placebo [1517 mg gluten-free corn flower]. GT (3caps) [polyphenols 890 mg (366 mg EGCG), caffeine-free] 24 hour Healthspan, St Peter Port, UK	GT consumer increases fat oxidation rates during moderate-intensity exercise.	[83] UK
Randomized, double-blind, controlled Participants:132 BMI:25-40 Subjects with moderate exercise	Control [39 mg caffeine] GT 500 ml [625 mg catechins (EGCG 214.4 mg) + 39 mg caffeine] 12 weeks	GT beverage consumer significantly reduces body weight, subcutaneous, abdominal fat areas, triglyceride and free fatty acid.	[84] USA
Randomized, double- blind, controlled Participants: 12 BMI: 22.9 Subjects with moderate exercise	Control [77.6 mg caffeine] GT 340 ml [catechins 572.8 mg (EGCG 100.5 mg) + caffeine 76.7 mg] 10 weeks	GT consumer with moderate exercise increases whole body fat utilization and non-significant decreased in body weight and BMI.	[85] Japan
Clinical trial, controlled Participants: 19 BMI: 24±0.5 Subjects with moderate exercise	Control drink [No catechins] GT drink [570 mg catechins] 12 weeks	GT consumer increases fat oxidation rate during exercise and contributes to body fat reduction.	[86] Japan
Clinical trial, controlled Participants: 192 BMI: 24.9±0.2 Subjects with moderate exercise	Control drink [No catechins] GT beverage [278 mg catechins] GT beverage [570 mg catechins] GT beverage [845 mg catechins] 12 weeks	Body fat was effectively reduces by the long term intake of catechins in combination with physical activity	[87] Japan
Double blind, controlled Participants: 38 BMI: 24.5-25 Subjects with LED	Control 340 ml [catechins 21.76 mg]. GT 340 ml [catechins 686.8 mg]. 12 weeks Self-prepared	GT consumer significantly decreases body weight, BMI, body fat and subcutaneous fat, waist circumference.	[89] Japan
Double-blind, placebo controlled Participants: 46 BMI:27.6±1.8 Subjects with LED	Placebo [2790 mg maltodextrin] GTE [1206.9 mg catechins (595.8 mg EGCG) and 236.7 mg caffeine] 87 days	GT with LED had no additional benefit.	[90,91] Netherland
Randomized parallel, placebo-controlled Participants: 104 BMI:25-35	Control [placebo] GT 6 cap [573 mg catechins (323 mg EGCG), and 104 mg caffeine] 4 weeks weight loss + 13 weeks weight maintenance	Up to 4th week, a subject reduces body weight, fat mass and free fat mass. During the weight-maintenance period, GT consumer regains body-weight, mainly due to increase of free fat mass.	[92] Netherlands
Randomized, double blind, placebo controlled , Participants: 76 BMI: 27.5 ± 2.7 Subjects with LED and habitual caffeine consumers for 4 weeks.	Low habitual caffeine [<300 mg caffeine]. High habitual caffeine [>300 mg caffeine]. Low habitual caffeine + GT cap [375 mg catechins (270 mg EGCG) and 150 mg caffeine] High habitual caffeine + GT cap [375 mg catechins (270 mg EGCG) and 150 mg caffeine] GT intervention for 3 months with normal diet. Novartis CH, Nyon,Basel, Switzerland	High caffeine consumer reduces body weight, fat mass, and waist circumference more as compare to the low caffeine consumers. While, during weight maintenance period, GT with low caffeine further reduces body weight, waist and body fat.	[93] Netherlands
Randomized, placebo-controlled, double-blind Sedentary subjects Participants:135 BMI: 28-38	Placebo [946 mg lactose] GT 1060 mg [catechins 800 mg], decaffeinated 6 weeks Sunphenon 90LB; Taiyo Kagaku Ltd, Japan	GT consumer significantly decreases body weight. Also suggested that the GT-catechins protecting weight gain.	[94] UK

BMI=Kg/m^2, GT=green tea; GTE= green tea extract, EGCG= epigallocatechin gallate; LED=Low energy diet
*Tea brand name is not reported by all authors.

600 mg/day, while the duration of the studies varied from one day to one year. The test items was administered either in the form of capsules containing green tea extract, at up to six capsules/day or beverages at up to 1500 ml/day. However, no adverse effect has been reported in these studies.

Effects of green tea on energy expenditure and fat oxidation

Dulloo et al. [51], first approach for obesity management was to reduce energy intake or increase energy expenditure (EE). They found that daily consumption of green tea extract, containing catechins-375 of which 270 mg EGCG and 150 mg caffeine, significantly increased 24-h EE, which contributed to the fat oxidation by 41.5% in healthy men. This landmark finding resulted in the design of various models or hypothesis to test the effect of green tea (beverage, extracts, and capsules) in overweight or obese subjects. Some of the studies conducted for very short duration have insignificant result on 24-h EE and fat oxidation, whereas long duration studies constantly infer beneficial effects of green tea not only on 24-h EE and fat oxidation but also for the maintenance of body composition. Rumpler et al. [54], measured EE and fat oxidation in healthy men, who were either taking 270 mg caffeine or low strength tea (containing catechins-331 mg of which EGCG 122 mg), or full strength tea (containing catechins-662 mg) for 3 days. They found EE increase in caffeine consumer by 3.4%, half strength tea consumer by 0.5%, and full strength tea consumer by 2.9%, while fat oxidation in caffeine, half strength tea and full strength tea consumers were 8%, 2%, 12% respectively. Similarly, EE and fat oxidation was higher in high catechins consumer (containing catechins-592.9 mg and caffeine 81.9 mg) as compared to the lower catechins consumer (containing catechins-77.7 mg and caffeine 80.15 mg) after 12 weeks in overweight subjects [55]. The trend of fat oxidation (3.3%) and thermo genesis (4.6%) in healthy male and female subjects in response to drinking of green tea extracts (containing catechins-450 mg of which 282 mg EGCG and 300 mg caffeine) has been supported by another study in recent past in which tea extract was supplemented for 3 days [56]. A recent study, investigated the effect of green tea on normal weight healthy males who have received either caffeine capsule (150 mg), or green tea catechins, GT1 containing catechins-493 mg of which 150 mg caffeine, GT2 containing catechins-645 mg of which 150 mg caffeine, GT3 containing catechins-886 mg of which 150 mg caffeine for a day only [57]. The result found insignificant tendencies towards increase of EE, fat oxidation and decrease of respiratory quotient (RQ) especially in high catechins groups vs caffeine-only. Although, it was suggested that 300 mg of EGCG Teavigo™ capsule supplemented for 2 days increased fat oxidation through reducing the postprandial RQ in overweight men [58]. Thielecke and his colleagues again reported that 300 mg of EGCG Teavigo™ capsule supplemented for 3 days in obese men have increased postprandial fat oxidation, whereas high content of EGCG (600 mg) did not exert this effect [59]. They also reported that there were no synergism effects of EGCG and caffeine in fat oxidation. This study provided the first evidence that the low concentration of EGCG has a potential to moderate effect on the fat oxidation rather than the high concentration of EGCG. Another study also supported this notion, in which green tea Teavigo capsule containing high content of EGCG (405 mg) did not increase the resting metabolic rate (RMR) and thermic effect of feeding (TEF) in healthy males and females subjects supplemented for 2 days [60].

Most of the studies reported that the magnitude of fat oxidation was noticeable in a group who had consumed green tea catechins containing both EGCG and caffeine [55,56]. Exceptionally, few studies have highlighted the role of caffeine on EE and fat oxidation rather than catechins. Single administration of caffeine (600 mg) along with EGCG (270 mg) increased the EE by 8%, fat oxidation by 20g/day and decrease of RQ by 0.02 in healthy men [61]. However, further increase of EGCG concentration (up to 1200 mg) along with caffeine (600 mg) did not increase the EE and fat oxidation. However, in this case, most probably, high content of caffeine may mask the role of green tea EGCG and vice versa. One study compared the effect of green tea (containing catechins-293 mg of which 156 mg EGCG + 161 mg caffeine) with the Oolong tea (containing catechins-206 mg of which 81 mg EGCG + 77 mg caffeine). The authors found that a single administration of both teas cumulative by increased EE without affecting fat oxidation and RQ in overweight females [62]. Overall, it was concluded that moderate concentration of green tea consumption for a long duration of time might be beneficial on EE and fat oxidation in obese subjects.

Effects of green tea on the body composition

Most of the researchers reported a significant beneficial effect of green tea on body composition. However, each finding does not have similar extent of beneficial effect may be due to difference in the green tea dose, forms and so forth. A comparative study revealed that the low dose of green tea extracts (containing catechins-118.5 mg of which 32 mg EGCG + 75 mg caffeine) slightly reduced body composition, while an increase of green tea dose (containing 483.0 mg catechins, of which 300 mg EGCG + 75.5 mg caffeine) significantly reduced weight by 1.1Kg, BMI by 1.48%, waist circumference by 1.68%, body fat ratio by 6.53% and decreased blood cholesterol level by 13 mg/ mL, glucose level by 3.5 mg/mL and insulin level by 1.3 µg/mL in healthy men after 12 weeks consumption [63]. Moderately overweight male and female subjects, who ingested green tea capsule (AR_{25}) containing catechins-375 mg of which 270 mg EGCG for 3 months reported decrease of body weight by 4.6% and waist circumference by 4.48% [40]. However, 12 weeks ingestion of green tea capsules, containing catechins-491 mg of which 302 mg EGCG and 27 mg caffeine, resulted in slightly reduced body weight (0.12 Kg) and body fat (0.05 Kg) in the obese females [64]. Another study reported a significant reduction of body weight (2.7 Kg), BMI (2.97 Kg/m^2), body fat (3.82%) and waist circumference (3.86 cm) in obese male and female subjects who ingested green tea capsule containing small amounts of catechins (containing catechins-140.8 mg, of which 100 mg EGCG + 27 mg caffeine) over 12 weeks [65].

Obese men and women subjects, who ingested green tea beverage (containing catechins-444 mg or 665 mg) daily had significantly reduced body weight by 1.4 Kg, BMI by 0.4 Kg/m^2, waist circumference by 0.7 cm, total fat area by 15 cm^2 and decreased total blood cholesterol level by 0.11-0.23 mmol/L over 12 weeks [66]. In a similar study, a group of healthy men decreased body weight by 1.7 Kg, BMI by 0.6 Kg/m^2, body fat mass by 2.3 Kg, waist circumference by 2.5 cm, hip circumference by 2.3 cm, visceral fat area by 10.3 cm^2 and total fat area by 16.0 cm^2, who were drinking 340 mL/day green tea beverage (containing catechins-582.8 mg of which 29.5 mg EGCG and 72.3

mg caffeine) as compared to a group of control drink (containing catechins -96.3 mg of which 4.9 mg EGCG and 75 mg caffeine) over 12 weeks [67]. In addition, high catechins group also decreased LDL-cholesterol level to a greater extent as compared to the control drink group. These two studies were almost similar to a study in the recent past study [68]. The authors of this study applied the same approach in moderately overweight subjects, who were offered to consume 250 mL self-prepared green tea drink. Control group ingested drink containing 30 mg catechins and 10 mg caffeine; GT1 group's drink containing 458 mg catechins and 104 mg caffeine; GT2 group's drink containing 468 mg catechins and 126 mg caffeine; GT3 group's drink containing 886 mg catechins and 198 mg caffeine daily for 90 days. They found that all groups decreased body composition except the control group. GT1 and GT2 groups decreased body weight by 1.1%, waist circumference by 1.1-1.3%, intra-abdominal fat area by 5-4.2%, and body fat by 2.7-3.1%. However, GT3 group reduce body weight by 1.7%, waist circumference by 2%, intra-abdominal fat area by 7.1%, and body fat by 2.4% [68]. A recent study has also shown significant decrease of body weight by 1Kg, BMI by 0.4 Kg/m^2, visceral fat area by 9.4 cm^2 and body fat by 0.5% in healthy overweight and obese subjects, who consumed catechins-enriched green tea beverage (containing 609.3 mg catechins and 68.7 mg caffeine) for 12 weeks [69]. Similarly, continuous consumption of catechins beverage (catechins -588 mg) for one year had significantly reduce body weight, BMI and visceral fat areas as compared to the control group who consumed catechins -126 mg [70]. A study has also reported that, the consumption of 1.5 L self-prepared green tea beverage/day for 25 days significantly reduced body weight by 1.45 Kg, BMI by 0.63 Kg/m^2 and waist circumference by 0.66 cm in obese females [71]. Basu et al. [72], separately assigned moderately overweight subjects to consume either green tea beverage (4 cups/day) or extract supplementation (2 capsules/ day) for 8 weeks. Both green tea beverage (containing catechins-928 mg of which 440 mg EGCG + 8.96 mg caffeine) and green tea extract capsule (containing catechins-870 mg of which 460 mg EGCG + 3.6 mg caffeine) significantly reduced body weight by 2.5 and 1.9 Kg, BMI by 0.9 and 0.7 Kg/m^2, triglyceride by 14.8 and 23.0 mg/dL respectively, suggesting the role of green tea flavonoids along with catechins in improving the features of metabolic syndrome in obese subjects [72].

Daily ingestion of green tea beverage (containing 540 mg catechins), significantly reduces body weight, body fat mass, waist, hip, abdominal total fat area, abdominal visceral fat area and abdominal subcutaneous fat area in obese women and men subjects over 12 weeks [73]. In another study the beverage containing tea catechins-169.9 mg with a galloyl moiety was supplemented (2 bottles/ day) to the healthy women for 12 weeks significantly reduced visceral fat area [74]. Similarly, high dose (500 mL) of green tea beverage containing catechins 540 mg, ingested for 12 weeks significantly decreased visceral fat area, body weight, and waist circumference [75]. In a study on healthy men assigned to consume decaffeinated GTE beverage (containing catechins-548 mg) over 12 weeks it was found that they reduced body weight, waist circumference, and body fat including visceral fat area and blood cholesterol level [76]. In another study, green tea supplemented to the obese individuals for 12 weeks reduced body weight by 6.8Kg, total body fat by 7.6% and decreased low-density lipoprotein cholesterol [77].

An Oolong tea which also containing EGCG 153.3 mg and caffeine 141 mg was supplemented to the diet-induced overweight and obese subjects for 6 weeks. It showed significant reduction of the body weight by 2.9 Kg, waist size by 2.58 cm, and decrease of cholesterol and triglyceride level by 20% in the dyslipidemia subjects [78]. In addition, a survey reported that the 13,916 Japanese workers who consumed green tea daily had significantly lower levels of total serum cholesterol [79]. Overall, it was concluded that the consumption of green tea catechins leads to improvements in body composition, reduced abdominal fat and improved metabolic disorders.

Green tea with moderate exercise

Some researchers have observed the beneficial effect of green tea catechins on body composition with the addition of exercise interventions. Ingestion of green tea beverage (340 mL) containing catechins-588 mg of which 83 mg caffeine, for 12 weeks had significantly reduce body weight by 1.69 Kg, BMI by 0.66 Kg/m^2, body fat mass by 1.54 Kg, total fat area by 26.37 cm^2, visceral fat area by 8.71 cm^2, subcutaneous fat area by 17.66 cm^2 and waist circumference by 1.87 cm in overweight and obese subjects, who did greater duration of exercise during the study periods [80]. This study provided the first evidence that the catechins have the potential effect on fat oxidation in moderately practicing exercise subjects. In addition to the most remarkable findings observed in healthy subjects who consumed a green tea beverage, containing 570.4 mg catechins of which 218 mg EGCG, for 8 weeks increased fat oxidation at rest and during exercise by 37% and 32% respectively [81]. It was concluded that the green tea beverage non-significantly increased sedentary fat oxidation at rest while during exercise significantly increased fat oxidation [81]. In another set of study, highly purified green tea capsule Teavigo® (300 mg EGCG) was supplemented to healthy obese subjects for 12 weeks, who was performing exercise routinely by 135 min/week of walking or running. They insignificantly reduced body fat by 0.04%, abdominal fat mass by 0.07 Kg, visceral fat area by 6.5 cm and waist circumference by 1.02 cm, and significant decreased plasma glucose level by 0.09 mmol/L [82]. Similarly, active normal-weight men, who ingested caffeine free green tea capsule containing 890 mg polyphenols of which 366 mg was EGCG, significantly increased fat oxidation during 30 min of cycling exercise compared with placebo during a 24 hours study [83]. Maki et al. [84], randomly assigned overweight and obese subjects to consume either green tea containing 625 mg catechins of which 39 mg was caffeine or caffeine 39 mg with the moderate exercise (≥180 min/week). The green tea catechins group significantly reduced body weight by 2.2%, total fat mass by 5.2%, total abdominal body fat area by 7.7%, intra-abdominal fat area by 8.7%, and also decreased triglyceride by 11.2%, total cholesterol by 5.3%, and free fatty acid by 0.05% as compared to the control group that reduced body weight by1%, total fat mass by 3.5%, total abdominal body fat area by 0.3%, intra-abdominal fat area by 1.4%, and decreased total cholesterol by 2.4%. In a recent study, normal subjects performed a cycle ergometer exercise at 60% of VO_2 peak (60 min/day, 3 days/week) and daily consumed either 340 ml of beverage containing 572.8 mg EGCG and caffeine 76.7 mg or only caffeine (77.6 mg) for 10 weeks [85]. The green tea beverage group reduced body weight by 0.6 Kg, and BMI by 0.2 Kg/m^2 and fat oxidation during 90-min exercise was 6.0 ± 0.2 kcal/min. Similarly, healthy male subjects ingested a green tea beverage (containing catechins 570 mg) for 12 weeks. The rate of fat oxidation during exercise was increased in association with an increase in the

intensity of exercise in the catechins group [86]. In addition, the findings in healthy male subjects, who ingested green tea beverage (containing catechins-845 mg) for week 12, confirmed that the body fat is reduced by the long term intake of catechins in combination with physical activity or regular exercise [87]. The effects of low dose of green tea catechins (containing catechins ~160mg of which ~70 mg EGCG) on energy metabolism during sub maximal cycling exercise for 2 hours was evaluated over 3 weeks [88]. In this study green tea consumption did not influence indices of fat and energy metabolism and suggested only slight effects on the whole-body metabolism. Over all, it was suggested that habitual green tea ingestion in combination with moderate-intense exercise was beneficial to increase the proportion of whole body fat utilization.

Green tea with control energy diet

The most common view is that obesity is a result of excess energy intake over energy expenditure, therefore, it was believed that diet and exercise intervention are effective in the loss of body weight and improving body composition. Nagao et al. [89], supplemented green tea (containing catechin-700 mg) for 12 weeks in healthy subjects along with low energy diet, which showed significant reduction of body weight by 2.4 Kg, BMI by 0.8 Kg/m^2, body fat mass by 1.4Kg, and waist circumference by 3.4 cm, total fat area by 26.7 cm^2 and visceral fat area by 10.1cm^2 among the study subjects. This approach provided direct evidence that green tea catechins can contribute to lifestyle changes related to weight management. However, in a similar set of study the authors did not find differences of body weight and body fat in the obese subjects who ingested green tea extracts (containing catechins-1206.9 mg of which 236.7 mg caffeine) along with control diet over 12 weeks [90-91]. The authors noted that, the study subjects were habitual caffeine consumers (200-400 mg caffeine/d). Hence, from the above finding two possibilities may be concluded, firstly, the effects of catechins are not additional to the weight reducing effect of the low calorie diet, secondly high catechins content especially high EGCG mask the effect on body fat oxidation.

Green tea during weight maintenance

Intervention of low energy diet was studied in weight loss programs in which participant were habitual caffeine consumers. Low energy diet (2·1 MJ/d) intervention for first 4 weeks reduced body weight (7·5 %) and BMI (2.2 Kg/m^2) due to loss of fat mass by 4 Kg and free fatty acid by 2.4 Kg in healthy obese subjects [92]. However, during weight maintenance period of 13 weeks, participants consumed habitual diet and green tea capsule (containing catechins-573 mg of which 323 mg EGCG and 104 mg caffeine). In this study, habitual high caffeine consumption was associated with a higher weight regain as compared to the habitual low caffeine consumption. They conclude that weight maintenance after 7.5% body-weight loss was not affected by green tea treatment and that habitual caffeine consumption affected weight maintenance in the green tea treatment [92]. In another similar study, overweight and obese participants were divided into low habitual caffeine (<300 mg caffeine) or high habitual caffeine (>300 mg caffeine) consumer and supplemented with low energy diet (2.1MJ/d) for first four weeks [93]. High caffeine consumers reduced weight, fat mass and waist circumference more than low caffeine consumers during the weight loss period. During the weight maintenance period of 3 month, participants received green tea-caffeine mixture capsules containing 270 mg EGCG and 150 mg caffeine and normal food diet. They found that green tea still reduced body weight, waist circumference, and respiratory quotient in low caffeine consumers, whereas in high level caffeine consumers this effect of green tea catechins was not observed [93]. The authors speculated that the magnitude of habitual high caffeine intake might have masked the green tea catechins effects [92,93].

Green tea in the subjects with sedentary life style

Recently, Brown et al. [94], studied the decaffeinated green tea extract capsule effect on sedentary obese males subjects. They assigned the intervention group to consume 530 mg decaffeinated green tea extract capsule containing ~ 400mg total catechins/capsule, twice daily for 6 weeks. They found that the green tea consuming group decreased body weight by 0.64 Kg whereas control group increased the body weight by 0.53 Kg. The result suggested that there is a protective role of green tea catechins against weight gain in sedentary life subjects.

Green tea in obese children

Effects of green tea in obese or near-obese Japanese children were also studied. Green tea supplemented either in high dose of catechins (catechin-576 mg) or low dose (catechins-75 mg) once a day for 24 weeks. There were no significant differences in body fat mass, between the low and high dose groups whereas waist circumference, systolic blood pressure and low-density lipoprotein cholesterol were greater in the high dose catechins group [95].

Conclusion

Several epidemiological studies in this review have revealed the relationship of green tea and tea catechins consumption to energy metabolism and body weight control during exercise, sedentary life style, low energy diet and as usual life pattern of healthy obese subjects. Most of the epidemiological reports have documented the potential benefit of green tea for the prevention of obesity and its related disorders due to the synergistic effects of its constituents. Most of the investigators found that green tea catechins plus caffeine significantly reduced obesity as compared with either caffeine or caffeine-free catechins. Green tea catechins ingestion not only stimulates thermo genesis and fat oxidation, it also reduces body mass, visceral fat and total body fat. However, green tea intervention has more putative benefits when ingested on daily basis along with the physical activities. We hope that this review will be beneficial to the people who are undergoing initiation and progression of obesity and its related problems. There is also a need for further quality studies over longer periods with larger samples on this important subject, as majority of the published studies are conducted with a small sample size and for a short period.

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