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REVIEW

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Emerging evidence for tea benefits

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Summary

Tea is the most commonly consumed beverage in the world, after water. Associations between regular tea drinking and a reduced risk of coronary heart disease are well established. The mechanism may relate to bioactive compounds found in tea, which exert anti-arteriosclerotic, anti-oxidative and anti-inflammatory effects. However, evidence for other diverse health benefits is emerging. The aim of this review was to evaluate research on three new areas of interest in relation to tea drinking: (1) weight management (and glycaemic control); (2) oral health; and (3) gut health. Databases were searched for meta-analytical, human intervention and epidemiological studies published between 1990 and 2013. For weight management, modest, positive effects were found for green tea when ingested by overweight/obese adults, possibly related to thermogenic effects. Epidemiological studies indicate that tea drinking in general may protect against tooth loss, certain oral/digestive cancers and *Helicobacter pylori* infection, although the studies were few in number with differing methodologies. A growing body of mechanistic studies suggests that tea has anti-cariogenic, anti-adhesive, anti-bacterial and possible pre-biotic effects – all with the potential to impact positively on the pathogenesis of chronic diseases. Clearly, larger trials are needed to confirm these effects in humans and establish optimal intakes. In the meantime, tea drinking appears to be a simple and beneficial way to support health.

Keywords: glycaemic control, gut health, oral health, tea, weight management

Introduction

After water, tea (*Camellia sinesis*) is the second most widely consumed beverage in the world (Hodgson & Croft 2010). Tea is also one of the most cost-effective beverages available (Khan & Mukhtar 2013). Black, green and oolong teas represent 78%, 20% and 2% of world tea consumption, respectively. While all of these teas originate from the same plant, their chemical composition varies depending on geographical location, agricultural practices, processing methods and degree of maturation (Oliveira *et al.* 2013).

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As shown in Figure 1, green and white teas are not oxidised, thus contain large amounts of polyphenols, also known as catechins, which include (–)–epicatechin (E), (–)–epigallocatechin (EGC), (–)–epicatechin-3-gallate (ECG) and (–)–epigallocatechin-3-gallate (EGCG). A typical cup of green tea (2 g leaves and 200 ml water) contains 240–320 mg catechins, with EGCG providing 30–50% of that amount (Grove & Lambert 2009; Oliveira *et al.* 2013). Oolong tea, although partially oxidised, contains six different bioactive catechins (Wang *et al.* 2012). In contrast, black tea leaves are fully oxidised, which leads to the conversion of catechins to theaflavins and thearubigins (Grove & Lambert 2009). Black tea also contains phenolic acids (caffeic, quinic and gallic acid) and theanine (Dufresne & Farnworth 2001), while most teas are a source of caffeine (Zhang *et al.* 2012).

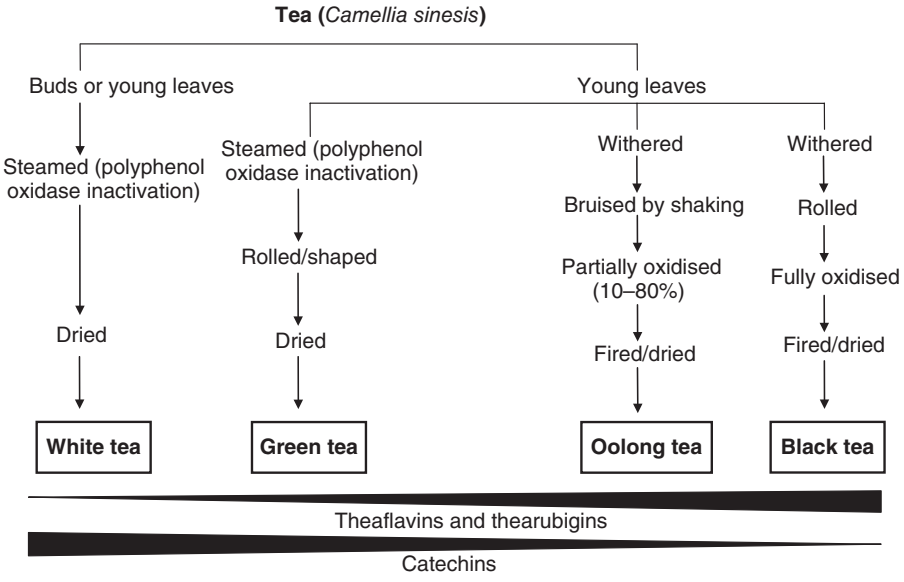

Figure 1 Bioactive compounds and processing of different tea forms.
Source: Adapted from Oliveira *et al.* (2013).
Note: The black bar at the bottom of the figure indicates the levels/bioavailability of the various tea components, that is black tea is higher in theaflavins while white tea is higher in catechins.

There is growing evidence that drinking tea on a regular basis may help support health (Venkateswara *et al.* 2011). Previous reviews have reported that black tea, in excess of three cups per day, is associated with a lower risk of myocardial infarction (Ruxton 2008) and a reduced risk of stroke (Ruxton & Mason 2012). A recent review of epidemiology studies also concluded that green tea, at intakes of >5 cups per day, reduced vascular disease risk, possibly by lowering low-density lipoprotein cholesterol levels (Maeda-Yamamoto 2013). An increased intake of three cups of tea daily (black, green and oolong) has been associated with reductions in total and ischemic stroke of 13% and 24%, respectively (Shen *et al.* 2012). In terms of mechanisms of action, animal studies indicate that green tea extract (at doses of 50 mg/kg) may reverse endothelial dysfunction (Minatti *et al.* 2012) with the catechin EGCG being associated with reduced hyperplasia in the intima region of the carotid artery (Orozco-Sevilla *et al.* 2013).

Other authors have identified both catechins and theaflavins as likely compounds to explain the physiological effects of tea consumption (Khan & Mukhtar 2013). As past tea research has often focused on cardiovascular benefits, this paper aimed to critically review three emerging areas of interest. Areas for future work and likely mechanisms will also be considered.

Methods

MEDLINE and The Cochrane Library were searched for meta-analytical, human intervention trials and epidemiological studies relating to three key areas of tea and health. These were weight management (and glycaemic control), oral health and gut health, which included balance of microflora (see Table 1 for search terms). The search was limited to black, green, oolong and herbal teas, as these are the most frequently consumed varieties in Western countries (Siddiqui *et al.* 2004). While Tables 2–4 only contain evidence from human studies, underpinning evidence from animal and *in vitro* studies are included in the review and summarised in Table 5.

The Scottish Intercollegiate Guidelines Network (2011) were applied and used as a guide to the weight placed on studies with meta-analyses and randomised controlled trials (RCT) ranking higher than epidemiological studies (Table 1). Dates of publication were restricted from January 1990 to April 2013. Inclusion criteria were: (1) studies on tea; (2) adults as subjects; and (3) tea ingested as a beverage/drink. An attempt was made to establish how much tea (cups or ml) was ingested, although many authors did not report this. The reference lists of scientific papers and reports were also searched and relevant papers identified.

Studies looking at catechin-enriched beverages, such as those by Wang *et al.* (2010) and Maki *et al.* (2009) were included, as were mixtures of catechins added to foods/drinks, such as those used in the work of Hursel & Westerterp-Plantenga (2009), Bryans *et al.* (2007) and Westerterp-Plantenga *et al.* (2005). Papers focusing on powders, supplements or mouthwashes, that is tea not ingested in beverage form were excluded from the main review and study tables, so that findings could be directly translated to tea drinkers. However, findings

Table 1 Search terms and SIGN criteria used for grading evidence

Health outcome	Search terms
Weight management	'tea and weight management', 'tea and weight loss', 'tea and body composition', 'tea and satiety'
Glycaemic control	'tea and glycaemic control', 'tea and blood glucose levels', 'tea and blood sugar levels'
Oral health	'tea and oral health', 'tea and dental health', 'tea and tooth loss', 'green tea and halitosis'
Gut health	'tea and gut health', 'tea and digestive health', 'tea and gastrointestinal health', 'tea and bowel disease', 'tea and bowel cancer', 'tea and gut flora', 'tea and colonic bacteria', 'tea and microflora'.
SIGN criteria for grading evidence:	
RCT, meta-analysis, systematic reviews of RCT.	
Systematic reviews of case–control or cohort studies, and case–control or cohort studies with a moderate to high probability that the relationship is causal.	
Non-RCT, interventions or case reports.	
Expert opinion.	

Source: SIGN; Scottish Intercollegiate Guidelines Network (2011).
The search term 'tea' included, green, oolong and herbal varieties.
Key: RCT, randomised controlled trial.

from these studies have been described in a broader context.

Weight management

The International Obesity Task Force (2010) claims that around 1 billion adults worldwide are overweight with a further 475 million classified as obese, although when Asia-specific cut-offs are applied this increases obesity rates to 600 million globally. Increasingly, bioactive foods are being considered for the treatment and prophylaxis of certain diseases, which include obesity management (Astrup *et al*. 2010).

Regular ingestion of green, white and oolong teas have been found to increase energy expenditure by around 4–5% and fat oxidation by 10–16%, theoretically supporting weight loss, as well as counteracting the decreases in metabolic rate that can be a side effect of energy restriction (Hursel & Westerterp-Plantenga 2010). In terms of specific mechanisms, tea catechins (and caffeine) may act by inhibiting enzymes thought to induce thermogenesis, fat oxidation and preserve fat-free mass (namely catechol O-methyl-transferase and phosphodiesterase) (Diepvens *et al*. 2007; Hodgson *et al*. 2013), while other suggestions include modifications in appetite, up-regulation of hepatic fat oxidation enzymes and reduced nutrient (fat) absorption (Rains *et al*. 2011). Overall, green tea is thought to have multiple actions on body fat, possibly by inhibiting these enzymes and by impeding gut fat absorption (Thavanesan 2011).

A Cochrane review analysing data from 12 RCTs found that green tea consumption induced a small, but statistically non-significant, weight loss in overweight or obese adults, although intakes in some studies may have not been high enough to produce clinical benefits (Jurgens *et al*. 2012). However, a meta-analysis of 11 studies on green tea catechins concluded that consumption produced statistically significant reductions in bodyweight and significantly maintained bodyweight after a period of weight loss (Hursel *et al*. 2009). The impact of catechin intake in Asian populations appeared greater than in Caucasian populations, although this difference was not statistically significant.

Turning to evidence from separate intervention trials, as shown in Table 2, seven studies conducted on overweight subjects found weight-loss benefits for green tea when consumed for more than 6 weeks. For example, Basu *et al*. (2010) concluded that drinking four cups of green tea daily over 8 weeks led to significant reduction in bodyweight (-2.5 ± 0.7 kg $P < 0.05$) among obese adults with metabolic syndrome, while Westerterp-Plantenga *et al*. (2005) found similar weight loss effects when a daily green tea mixture (270 mg ECG, 150 mg caffeine/day) was drunk by obese adults with low habitual caffeine intakes.

Some studies used green tea with enhanced catechin levels. One 90-day RCT found that daily consumption of two servings of an extra-high catechin-rich tea (886 mg catechins, 198 mg caffeine/day) significantly reduced bodyweight by 1.2 kg, waist circumference by 1.9 cm and levels of abdominal body fat by 0.7 kg ($P < 0.05$) (Wang *et al*. 2010). Similarly, a 12-week RCT by Maki *et al*. (2009) found that ingestion of a green tea catechin beverage (625 mg catechins, 39 mg caffeine/day) also led to reductions in total abdominal fat when

Table 2 Tea, weight management and glycaemic control

Study	Participants	Type/amount of tea	Methods	Outcomes
Weight management:				
Pan *et al.* (2013) Singapore	Data pooled from cohort studies.	All beverage intakes reported	Weight changes recorded at 4-year intervals, beverage intakes and lifestyle behaviours also recorded.	Substitution of SSBs or fruit juices with other beverages (*e.g.* coffee, tea, diet beverages, low-fat and whole milk) were significantly and inversely associated with weight gain at the end of the 4 years.
Yang *et al.* (2012) Taiwan	30 adults	650 ml catechin-rich green tea beverage plus inulin (534 mg catechins, 11.7 g inulin)	6-week intervention study. Participants divided to ingest tea (control), or green tea + inulin (experiment)	The experimental group lost 1.29 and 0.82 kg fat mass indicating that green tea + inulin may support weight loss.
Carter and Drewnowski (2012) USA	NR	Different beverage mixtures	The effects of three beverage conditions studied in relation to their effects on satiety.	Ingestion of the beverage containing fibre, green tea catechins and caffeine led to the lowest hunger and highest fullness ratings.
Basu *et al.* (2010) USA	35 adults with obesity and MetS	Four cups green tea/day	8-week RCT. Participants randomised to three groups: (1) four cups water/day (control); (2) four cups of green tea/day; or (3) green tea extract (two capsules and four cups water daily). Markers of glycaemia measured at weeks 4 and 8.	Green tea beverage (and extract) significantly reduced bodyweight and BMI at 8 weeks ($P < 0.01$ and $P < 0.05$, respectively) when compared with controls.
Bouchard *et al.* (2010) Canada	3823 (part of 2003–2004 NHANES)	Tea and coffee intakes (cups) reported (65% women only drank tea). Mean tea intake was one cup per day.	Observational cohort. Intakes assessed using frequency intake questionnaires. BMI and abdominal obesity measured using waist circumference measurements.	Men drinking ≥2 cups tea daily had a lower BMI and WC than those who never drank tea ($P \leq 0.05$). However, associations were no longer significant after adjustment for additive use, indicating their use in tea may be associated with obesity.
Josic *et al.* (2010) Sweden	14 healthy adults	300 ml green tea or water (providing 26.5 mg caffeine, 8.5 mgEC, 29.9 mg ECG, <1 mg EGC and 10.8 mg EGCG per 100 ml)	1-day RCS. Subjects ate a meal and drank wither green tea or water with this. Blood samples and satiety scores measured at 0,15,30,45,60,90 and 120 minutes.	Ingestion of the green tea drink with a meal resulted in a significantly higher post-prandial satiety at 15 minutes ($P = 0.005$), 45 minutes ($P = 0.045$), 60 minutes ($P = 0.025$), and 90 minutes ($P = 0.030$), than the reference meal.
Stendell-Hollis *et al.* (2010) USA	54 overweight breast cancer survivors	Decaffeinated green tea, 960 ml daily (4 cups; 240 ml per cup). Green tea bags contained 550–700 mg tea solids providing 58.9 mg catechin/bag, 32.2 mg and 6.7 mg caffeine/bag.	6-month pilot RCT. Participants randomized to drink decaffeinated green tea or a herbal placebo.	Mean tea intake was 5952 ml per week (24 cups) and associated with a significant reduction in energy intake ($P = 0.02$) and slight reduction (−1.2 kg) in bodyweight.
Wang *et al.* (2010) China	182 moderately overweight adults	Catechin-enriched green tea	90-day RCT. Subjects consumed either: (1) two servings of a control drink; (2) one serving of control drink and one serving of extra high catechins; (3) two servings of high catechins; or (4) two servings of extra high catechins	Consumption of two servings of extra high catechins led to significant reductions in waist circumference, bodyweight and body fat ($P < 0.05$)
He *et al.* (2009) China	102 diet-induced overweight and obese adults.	Oolong tea (8 g per day)	6-week intervention. Oolong tea drank daily, body fat levels measured using ultrasonic echo methods.	Oolong tea led to reductions in bodyweight and fat, thought to be caused by improvements in lipid metabolism.
Hursel *et al.* (2009) Netherlands	Meta-analysis	Green tea	11 studies looking at green tea and weight loss	Catechins significantly decreased bodyweight and significantly maintained bodyweight after a period of weight loss ($P < 0.001$).
Hursel and Westerterp-Plantenga (2009) Netherlands	80 overweight and moderately obese adults.	Green tea (270 mg EGCG) caffeine mixture	16-week RCT. A very low-energy diet for 4 weeks followed by 3 months of ingesting a green tea-caffeine mixture or placebo and either an adequate or high-protein diet.	The green tea–caffeine mixture improved weight maintenance through thermogenesis, fat oxidation, sparing of fat free mass after bodyweight loss in moderately obese subjects.

Table 2 *Continued*

Study	Participants	Type/amount of tea	Methods	Outcomes
Maki *et al*. (2009) USA	107 overweight and obese adults	Green tea (625 mg catechins)	12-week RCT. Randomly assigned to receive a beverage containing a high or lower dose of catechins. They were asked to maintain their energy intake and engage in ≥180 minutes/week moderate intensity exercise.	There was a trend towards greater weight loss in the higher intake catechin group ($P = 0.079$), but changes in fat mass did not differ.
Nagao *et al*. (2009) Japan	43 patients with T2DM not receiving insulin therapy	Green tea containing 582.8 mg or 96.3 mg (control) catechins.	12-week RCT. Patients ingested tea containing the lower or higher dose of catechins daily for 12 weeks.	Waist circumference was significantly reduced at week 12 in the high catechin versus the control group.
Reinbach *et al*. (2009) Denmark	27 adults	Green tea (599 mg catechins, 77 mg caffeine)	6-week RCT. Subjects randomized to 3 weeks of negative and positive energy balance during which capsaicin, green tea, sweet pepper, capsaicin + green tea or placebo were ingested for 10 days.	Together capsaicin and green tea suppressed hunger and increased hunger more during a state of negative energy balance.
Auvichayapat *et al*. (2008) Thailand	60 obese Thais	Green tea	12-week RCT. Subjects ate three energy-controlled meals a day prepared by the Nutritional Unit and were allocated to a green tea or placebo group.	At weeks 8 and 12 weight loss was significantly higher ($P < 0.05$) in the green tea group and at week 8 energy expenditure was significantly (183.38 kJ/day) higher ($P < 0.001$)
Westerterp-Plantenga *et al*. (2005)	76 overweight and moderately obese adults	Green tea (270 mg ECG, 150 mg caffeine/day).	16-week RCT. A very-low energy diet for 4 weeks followed by 3 months of ingesting a green tea-caffeine mixture or placebo.	In habitual low-caffeine consumers, the green tea–caffeine mixture improved weight maintenance.
Kovacs *et al*. (2004) Netherlands	104 overweight and moderately obese adults	Green tea (104 mg/day caffeine, 573 mg/day catechins or which was 323 mg EGCG)	17-week intervention. 4 weeks weight maintenance followed by 13 weeks of receiving green tea or a placebo.	Weight maintenance after 7.5% body-weight loss was not affected by the green tea treatment.
Glycaemic control:				
Stote *et al*. (2012) USA	20 adults	Cocoa and green tea beverages	5-day RCS. Ate a controlled diet along with four cocoa beverages, or tea with a matched flavanol content (30–900 mg per day).	Green tea was found to lower fibrinogen concentrations ($P = 0.0003$), but markers of glycaemia, inflammation and oxidation stress were not found to be affected in the short term.
Baer *et al*. (2011) USA	19 healthy men	Oolong tea or a control beverage (1.4 l/day)	5-day DB RCS. Participants drank three oolong tea or a control beverage daily followed by the assessment of fasting markers of glycaemia.	Oolong tea, or oolong tea with catechins did not have any significant effects on glucose metabolism.
Bryans *et al*. (2007)	16 healthy adults	1 or 3 g instant black tea (350 mg/g polyphenolic compounds)	RCS. Fasted subjects consumed four interventions which included 250 ml water plus 1 or 3 g black tea and glucose/caffeine in water. Blood samples taken at fasting and every 30–150 minutes.	The 3 g instant tea caused GI complaints, so data were withdrawn. Plasma glucose levels were significantly ($P < 0.01$) lower at 120 minutes after ingestion of the 1 g tea compared with the control and caffeine drinks. Insulin levels were also elevated in the tea group ($P < 0.01$) compared with the caffeine drink at 150 minutes.
Hosoda *et al*. (2003) Japan	20 free-living subjects with T2DM	Oolong tea or water (1500 ml/day)	30-day RCS. Subjects with T2DM were randomized to drink oolong tea or water. Plasma glucose levels were measured at the start and end of the study.	Oolong tea significantly lowered plasma glucose levels ($P < 0.001$) by the end of the study.

Abbreviations: BMI, body mass index; DB, double-blind; E, epicatechin; ECG, epicatechin-3-gallate; EGC, epigallocatechin; EGCG, epigallocatechin-3-gallate; MetS, metabolic syndrome; NHANES, National Health and Nutrition Examination Survey; NR, not reported; RCS, randomised crossover study; SSB, sugar-sweetened beverages; T2DM, type 2 diabetes mellitus.

Table 3 Tea and oral health

Study	Participants	Type/amount of tea	Methods	Outcomes
Hildebrand *et al.* (2013) USA	968 432 adults at baseline	Tea and coffee intakes (cups) reported	Prospective cohort and nested case–control. Beverage intakes were self-reported.	No associations were found for tea drinking although coffee intake was inversely associated with oral/pharyngeal cancer mortality.
Radoi *et al.* (2013) France	689 cases with oral squamous cell carcinoma and $n = 3481$ controls	Tea and coffee intakes (cups) reported	Case–control study. Intakes determined using interviews and questionnaires.	There was a reduced risk of oral cavity cancer among individuals with the highest quartile intakes (OR 0.39 95% CI 0.21–0.70). The joint effect was also multiplicative.
Allah *et al.* (2011) Egypt	87 adult citizens (32 female and 55 male aged 13–71 years)	Black tea	1-day intervention. Subjects drank tea and saliva bacterial counts measured before and 1 hour after.	Black tea had a strong anti-microbial effect, significantly reducing cariogenic bacterial counts of *Streptococcus mutans* and *Lactobacillus* after 1 hour, with 3–4 cups daily being most effective.
Matheson *et al.* (2011) USA	2.5 million adults	All beverage intakes reported.	Secondary analysis of NHANES cohort study data collected through questionnaires.	Individuals who drank hot tea were half as likely to have MRSA nasal carriage compared with non-hot tea drinkers (OR 0.47, 95%CI 0.24–0.93)
Koyama *et al.* (2010) Japan	25 078 adults at baseline	Green tea intakes.	Prospective cohort study (cross-section of data used). Questionnaires about green tea intake and tooth loss completed.	Drinking ≥1 cup green tea/day was significantly associated with a reduced risk of tooth loss. In men, ORs for tooth loss were 1.00 (reference) for <1 cup/day, 0.82 (95% CI, 0.74–0.91) for 1–2 cups/day, 0.82 (95% CI, 0.73–0.92) for 3–4 cups/day, and 0.77 (95% CI, 0.66–0.89) for ≥5 cups/day. Data for women and cut-off points were essentially the same.
Ren *et al.* (2010) USA	481 563 adults at baseline	All beverage intakes reported.	Prospective cohort and nested case–control study. Beverage intakes were self-reported.	Compared to adults not drinking tea, drinking ≥ 1 cup/day was inversely associated with pharyngeal cancer risk (OR 0.37 95% CI 0.20–0.70).
Tanaka *et al.* (2008) Japan	1002 pregnant women	All beverage intakes reported.	Prospective cohort study (cross-section of data used). Dietary habits and dental health evaluated using questionnaires.	Compared with the lowest intakes of green tea intermediate but not highest intakes of green tea were associated with increased tooth loss. There were no associations for black tea.

Abbreviations: CI, confidence interval; OR, odds ratio; MRSA, methicillin-resistant *Staphylococcus aureus*; NHANES, National Health and Nutrition Examination Survey.

compared with the control group (–7.7% vs. –0.3% $P = 0.013$), when drunk as part of a calorie-controlled diet and exercise programme. This suggests that green tea may help to enhance exercise-induced changes in abdominal fat (Maki *et al.* 2009). Equally, the combined effects of green tea and satiating/thermogenic agents may have multimodal effects on weight loss and appetite. One intervention study found that daily consumption of a 650-ml catechin-rich green tea beverage combined with inulin (534 mg catechins and 11.7 g inulin) led to significant reductions in bodyweight, body mass index and fat mass (Yang *et al.* 2012).

In terms of satiety, a 6-week crossover study showed that the combined effects of capsaicin capsules and a green tea beverage (599 mg catechins, 77 mg caffeine) reduced energy intake by sustaining satiety and suppressing hunger (Reinbach *et al.* 2009). Shorter *in vivo* studies indicate that mixtures of caffeine, green tea catechins and soluble fibre decrease appetite and energy intake when compared with other energy-matched beverages (Carter & Drewnowski 2012). In one crossover trial, the ingestion of 300 ml of green tea was found to enhance reported satiety levels compared with a water control (Josic *et al.* 2010).

Table 4 Tea and gut health

Study	Participants	Type/amount of tea	Methods	Outcomes
Nechuta *et al.* (2012) USA	69 310 non-smoking, non-drinking Chinese women	Habitual tea intakes measured.	Prospective cohort. Tea intakes (self-reported) investigative in relation to digestive cancer risk.	Compared with women who never drank tea, regular tea (mostly green) consumption was associated with a ↓ risk of all digestive cancers combined (HR 0.86, 95% CI 0.74–0.98); a trend that strengthened with the amount and number of teas drank.
Sinha *et al.* (2012) USA	489 706 adults	Caffeinated and decaffeinated tea intakes reported.	Prospective cohort and nested case–control study. Diet and lifestyle questionnaire completed.	Tea consumption was not associated with colorectal cancer risk.
Cerhan *et al.* (2001) USA	$n = 685$ and $n = 655$ colon and rectal cancer cases and $n = 242$ controls.	All types. Low tea consumption defined as <3.1 cups per day; medium 3.1–5.0 cups per day; and high >5 cups daily.	Case–control study. Tea consumption assessed using questionnaire	After data adjustments for age, sex, education, physical activity, smoking, coffee intake, fibre and fruit/vegetable intake no associations between tea consumption and colon and/or rectal cancer were found.
Jin *et al.* (2012) Japan	10 adults	Green tea	10-day intervention. Subjects drank green tea for 10 days and then stopped drinking it for 7 days. Faecal samples were analysed for microbiota content.	Inter-individual differences were noted. Green tea consumption was associated with ↑numbers of *Bifidobacteria*.
Shibata *et al.* (2000) Japan	636 adults living in a farming village	Habitual beverage intakes measured.	Cross-sectional. Lifestyle habits self-reported and screening of *Helicobacter pylori* IgG antibodies undertaken.	More than 10 cups of green tea daily was associated with a reduced risk of CAG (OR 0.63, 95%CI 0.43–0.93).
Toyonaga *et al.* (2000) Japan	365 adults	Habitual intakes measured.	Nested case–control. Lifestyle habits self-reported and screening of *H. pylori* IgG antibodies undertaken.	Tea intakes were a little higher in *H. pylori* negative compared with positive subjects.
Shinchi *et al.* (1997) Japan	566 males	Dietary and lifestyle habits assessed	Cross-sectional. Self-reported beverage and lifestyle habits.	No protective associations were found linking green tea intakes to reduced risk of *H. pylori* infection.

Abbreviations: CAG, chronic atrophic gastritis; CI, confidence interval; HR, hazard ratio; IgG, immunoglobulin G.

Table 5 Summary of systematic review results

Health outcome	Strength and amount of evidence from human studies	References
Weight management	Moderate evidence for a slightly positive effect of green tea on weight loss among overweight or obese adults from meta-analysis, cohort and randomized trials.	Jurgens *et al.* (2012); Basu *et al.* (2010); Stendell-Hollis *et al.* (2010); Wang *et al.* (2010)
	Evidence supporting that other thermogenic enhancing *e.g.* capsaicin or satiating dietary constituents *e.g.* inulin may support green tea in contributing to weight loss.	Yang *et al.* (2012); Reinbach *et al.* (2009)
	A weak positive association found for oolong tea and reductions in bodyweight and fat in one study.	He *et al.* (2009)
Glycaemic control	Strong evidence from meta-analysis that green tea catechins (from tea, extract and supplement trials) lower fasting blood glucose levels when studies are 12 weeks or longer duration.	Zheng *et al.* (2013)
	Good evidence from a meta-analysis that intakes of tea are associated with reduced risk of diabetes.	Huxley *et al.* (2009)
	Evidence from two RCS that black and oolong tea lower plasma glucose levels.	Bryans *et al.* (2007); Hosoda *et al.* (2003).
Oral health	Evidence from two large epidemiological studies that tea drinking reduced oral/pharyngeal cancer risk.	Radoi *et al.* (2013); Ren *et al.* (2010)
	Evidence from one study indicating green tea ingestion may reduce risk of tooth loss. Findings from second study were less conclusive.	Koyama *et al.* (2010); Tanaka *et al.* (2008)
	Emerging evidence that hot tea may reduce MRSA nasal carriage.	Matheson *et al.* (2011)
	Evidence from one intervention study that black tea reduces cariogenic bacterial levels.	Allah *et al.* (2011)
	Evidence from animal studies and *in vitro* work indicating that green tea/extract extract has anti-bacterial activity, or helps to reduce bacterial adhesion.	Araghizadeh *et al.* (2013); Naderi *et al.* (2011); Hirasawa *et al.* (2006); JH Lee *et al.* (2006).
	Evidence from animal studies and *in vitro* work indicating that black tea/extract has anti-bacterial activity.	Linke and LeGeros (2003)
Gut health	Tea ingestion (mostly green) associated with a reduced risk of combined digestive cancers in one study. No associations found in other epidemiological studies.	Nechuta *et al.* (2012)
	Emerging epidemiological evidence that green tea may reduce chronic atrophic gastric risk and protect against *Helicobacter pylori* infections.	Shibata *et al.* (2000); Toyonaga *et al.* (2000)
	Evidence from animal studies and *in vitro* work indicating that tea inhibits *H. pylori* growth, or helps to protect against its harmful effects.	Ankolekar *et al.* (2011); Stoicov *et al.* (2009); Lee *et al.* (2009); Akai *et al.* (2007); Takabayashi *et al.* (2004); Matsubara *et al.* (2003); Yanagawa *et al.* (2003); Mabe *et al.* (1999)
	Emerging evidence that green tea may have pre-biotic effects as demonstrated in one intervention study.	Jin *et al.* (2012)
	Evidence from animal studies and *in vitro* work indicating that tea has pre-biotic effects.	Molan *et al.* (2010); Axling *et al.* (2012); Vodnar and Socaciu (2012); HC Lee *et al.* (2006)

Key: MRSA, methicillin-resistant *Staphylococcus aureus*; RCS, randomised crossover studies.

Only one study has reported links between oolong tea consumption and reductions in bodyweight/fat (He *et al*. 2009). Most evidence points towards ingestion of green tea catechins having a statistically significant impact on weight management in overweight/obese adults. From a clinical perspective, levels of weight loss are likely to be modest suggesting that the most practical role for tea is as part of a wider weight loss programme that includes energy restriction, exercise and ingestion of other satiety/thermogenic agents. Both green and black teas are suitable beverages to include in weight-management programmes as they are naturally calorie free. Further, well-designed RCTs, especially using different doses of green and black tea catechins, should be conducted, given the non-significant findings of the Cochrane review and the lack of studies on black tea in the literature.

Glycaemic control

Studies examining the impact of tea consumption on glycaemic control were included in this review because impaired glycaemia is an underpinning risk factor for overweight and obesity (Thorens 2008). A meta-analysis of 22 RCTs, involving 1584 subjects, found that green tea catechins significantly lowered fasting

blood glucose levels [–1.48 mg/dl; 95% confidence interval (CI): –2.57, –0.40 mg/dl] when ingested with or without caffeine, in particular in studies with a duration of 12 weeks or longer (Zheng *et al*. 2013).

As shown in Table 2, four randomised trials have studied the effects of tea ingestion on markers of glycaemia. Two focused on oolong tea (Hosoda *et al*. 2003; Baer *et al*. 2011), one on green tea (Stote *et al*. 2012) and one on instant black tea (Bryans *et al*. 2007). Work by Baer *et al*. (2011) did not find any association between oolong tea and glucose levels, possibly because the trial was conducted on healthy adults over 5 days. However, a longer crossover trial on patients with type 2 diabetes mellitus found that drinking 1.5 litres of oolong tea daily significantly reduced plasma glucose levels after 30 days (Hosoda *et al*. 2003). Stote *et al*. (2012) did not find any improvements in glucose levels or markers of inflammation when cocoa and green tea beverages were consumed in a 5-day crossover trial. However, in a four-way crossover trial Bryans *et al*. (2007) discovered that the ingestion of 1 g of instant black tea in 250 ml of water significantly lowered plasma glucose levels at 120 minutes ($P < 0.01$) when compared with caffeinated and control beverages. It was concluded that phenolic compounds in tea may help to attenuate post-prandial glycaemia by elevating the insulin response (Bryans *et al*. 2007).

On the whole, there appears to be good evidence suggesting that green tea catechins help to regulate blood glucose levels. Evidence from animal and human studies have shown that green tea extract appears to increase insulin sensitivity, after oral glucose tolerance tests have been undertaken (Wu *et al*. 2004; Venables *et al*. 2008). Other *in vitro* animal studies have also shown that EGCG appears to have insulin-enhancing activity (Anderson & Polansky 2002). More studies are now needed to confirm whether these effects persist when catechins are consumed in the long-term as part of normal tea consumption.

Oral health

Japanese folklore considers that 'green tea makes the mouth clean' (Sakanaka *et al*. 1989). Traditional practices in India also involve placing tea dust on leaves and brushing these against the teeth to prevent dental disease (Patel & Venkatakrishna-Bhatt 1988). In recent years, such beliefs have been explored in scientific studies.

The pathogenesis of dental disease involves acid production by oral bacteria, in response to carbohydrate exposure, which dissolves tooth enamel (caries) and initiates an inflammatory response in dentin and activating matrix metalloproteinases (enzymes involved with wound healing) (Southward 2011). Black and green teas are thought to have anti-cariogenic effects through reducing inflammation and preventing the adhesion and growth of bacteria linked with periodontal disease (Hamilton-Miller 2001; Chatterjee *et al*. 2010). Evidence from mechanistic studies on green tea indicates that the high EGCG content has anti-oxidant, anti-microbial and anti-collagenase effects, all of which could help to prevent periodontal diseases (Venkateswara *et al*. 2011) and smoking-related gum disease (Desjardins & Grenier 2012).

Five large epidemiological studies have investigated beverage intakes in relation to oral health (Table 3). One American cohort study found that drinking ≥1 cup tea daily was inversely associated with pharyngeal cancer risk [odds ratio (OR) 0.37, 95% CI 0.20–0.70] compared with those not drinking tea (Ren *et al*. 2010). Such associations, however, were not found in another cohort using a similar study population (Hildebrand *et al*. 2013) possibly because the questionnaire focussed on coffee consumption. However, tea drinking was associated with a reduced risk of oral cavity cancers (OR for the highest quartile of tea was 0.39, 95% CI 0.21–0.70) even after controlling for confounders using data from the French ICARE Study (Radoi *et al*. 2013).

Two studies reported links between tea drinking and reduced risk of tooth loss. In the Japanese Osaka Cohort Study, drinking ≥1 cup green tea daily significantly reduced tooth loss risk (Koyama *et al*. 2010). A cohort study on pregnant women found an association between reduced tooth loss and green tea (but not black tea; Tanaka *et al*. 2008). However, it should be considered that the methods were not well described and may be confounded by the fact that sugar is not usually added to green tea. Another large cohort study found that regular consumers of hot tea were significantly less likely to have methicillin-resistant *Staphylococcus aureus* nasal carriage than non-consumers (OR 0.47, 95% CI 0.24–0.93) (Matheson *et al*. 2011).

Animal studies reported that black tea extract significantly reduced caries formation, even in the presence of sugars (Linke & LeGeros 2003). This has been supported by an *in vivo* study showing that levels of the cariogenic bacteria, *Streptococcus mutans* and *Lactobacillus*, significantly reduced (by 60–99.9% and 91–98%, respectively) after 1 hour of drinking black tea (Allah *et al*. 2011). Moderate intakes (3–4 cups per day) appeared to be the most effective. Animal and *in vitro* work also suggests that green tea has anti-bacterial activity (Naderi *et al*. 2011; Araghizadeh *et al*. 2013). Green tea EGCs have been found to reduce acid production in dental

plaque (Hirasawa *et al*. 2006) while green tea polysaccharides prevent adhesion of pathogenic bacteria (JH Lee *et al*. 2006). Controlled trials looking at the impact of tea on dental caries in humans are lacking.

Green tea extract may modify odorant sulphur components, helping to reduce halitosis (Narotzki *et al*. 2012). A small experimental study on 15 men found that pouring green tea powder onto the back of the tongue reduced oral malodour and levels of volatile sulphur compounds, which are known to contribute to halitosis (Lodhia *et al*. 2008). This is supported by an *in vitro* study, which found that green tea extract helped to neutralise volatile sulphur compounds (Zeng *et al*. 2010). Now, further clinical trials are needed, using green tea beverages as an intervention, rather than as powders or extracts.

Gut health

There is growing evidence that gut health and associated microbiota balance may play a role in the pathogenesis of disease (Wu *et al*. 2013). As polyphenols have a low bioavailability, a proportion is metabolised by colonic bacteria, which break down the phenolic skeleton producing smaller metabolites, which may then go on to have further physiological effects (van Duynhoven *et al*. 2011; Calani *et al*. 2012). Six epidemiological studies and one intervention trial were identified, which looked at tea and gut/digestive health or microflora, details of which are in Table 4.

There was conflicting evidence linking tea consumption with a reduced risk of digestive cancers. The Shanghai Women's Health Study, an 11-year prospective cohort, found that women who drank ≥150 g green tea per month (2–3 cups daily) had a 21% reduced risk of digestive cancers, but especially colorectal and stomach/esophageal cancers (Nechuta *et al*. 2012). However, data from other studies are less conclusive. After extensive adjustment of confounders, no links between tea (hot or iced) and colorectal cancer risk were reported by a US cohort study (Sinha *et al*. 2012) or the Iowa case–control study (Cerhan *et al*. 2001).

Helicobacter pylori infection is one of the most common bacterial infections in man, a type 1 carcinogen and a risk factor for gastric cancer (Stoicov *et al*. 2009). Epidemiological and intervention studies were few in number, but one study of 636 adults found that high intakes of green tea (more than 10 cups daily) reduced chronic atrophic gastritis risk; a precancerous lesion of the stomach linked with *H. pylori* infection (OR 0.63 95% CI 0.43–0.93; Shibata *et al*. 2000). In one case–control study, patients who were *H. pylori* negative had marginally higher tea intakes when compared with adults who tested positive for the bacteria (tea intakes were 737 g/day versus 601 g/day) (Toyonaga *et al*. 2000).

Eight animal and *in vitro* studies suggested that tea can inhibit *H. pylori* growth, or protect against its harmful effects. Ankolekar *et al*. (2011) found that all tea types (white, green, oolong and black) inhibited *H. pylori* and could be used as a low-cost dietary support to combat this infection. Other *in vitro* studies indicate that green tea catechins, namely EGCG play a role in reducing *H. pylori* growth (Mabe *et al*. 1999; Yanagawa *et al*. 2003; Takabayashi *et al*. 2004; Stoicov *et al*. 2009), and also appears to play a role in reducing gastric inflammation (Matsubara *et al*. 2003; Stoicov *et al*. 2009), bacterial ahesion (Lee *et al*. 2009), with green tea polyphenols appearing to reduce cell apoptosis caused by *H. pylori* (Akai *et al*. 2007).

Pre-biotics stimulate the growth of so-called 'beneficial' strains of bacteria, such as *Bifidobacteria* and *Lactobacilli*, while increasing resistance to pathogens (Panesar *et al*. 2012). There is emerging evidence that tea consumption may modify the gut microbiome with the potential to improve the colonic environment. A recent human intervention study found that after 10 days of drinking green tea, faecal *Bifidobacteria* counts increased, suggesting a pre-biotic effect (Jin *et al*. 2012). Animal studies have shown that supplementation with green tea powder improves *Lactobacillus* levels, when measured in small intestine tissue and faecal contents (Axling *et al*. 2012). Vodnar and Socaciu (2012) reported that green tea improves the survival of *Bifidobacteria* in a simulated gastrointestinal environment, while HC Lee *et al*. (2006) in an *in vitro* study found that tea phenolics reduced the growth of pathogenic bacteria, with commensal bacteria being less affected. There is also evidence that selenium-rich green tea may be superior in terms of its bifidogenic and lactogenic effects, when compared with other types (Molan *et al*. 2010).

Overall, from the available evidence, tea phenolics appear to contribute to the modulation of human gut microbiota and inhibition of *H. pylori*, which may have broader, long-term effects on health. Further epidemiological studies where tea consumption is investigated as a primary, rather than as a secondary health outcome, are now needed, as well as good quality case–control studies and RCTs.

Discussion

A summary of results from this review is given in Table 5. It is already well established and reported

elsewhere that tea consumption (an excess of three cups daily) may reduce the risk of myocardial infarction, although more human RCTs are needed to establish other cardiac effects (Ruxton & Mason 2012). Data from epidemiological studies indicate that black and green tea consumption may reduce heart disease and stroke risk by between 10% and 20% at intakes of 3–4 cups daily (Ruxton 2008; Bohn *et al*. 2012). The most likely mechanisms to explain these effects relate to the high-flavonoid content of teas (van Dam *et al*. 2013; Khan & Mukhtar 2013). Green tea catechins in particular have been associated in meta-analyses with disease prevention and lower plasma glucose levels (Zheng *et al*. 2013).

Black and green teas appear to have similar heart health effects and a similar overall flavonoid content (Deka & Vita 2011), although the specific catechins vary. For the emerging benefits of weight management, gut health and oral health, there are more studies on green tea than black tea. Many of the positive findings in relation to green tea may be caused by the higher EGCG content of green tea, or simply because the thearubigins and theaflavins in black tea are not as well studied. The potential roles of oolong and herbals tea are largely neglected in comparison.

This review identified that drinking green tea may have weight loss benefits among overweight and obese adults, and could be integrated within weight management programmes. Green tea catechins in doses of 270–1200 mg/day seem to have the most benefit in terms of influencing bodyweight and composition (Rains *et al*. 2011). In terms of possible mechanisms, it is thought that green tea catechins may exert their actions by acting on the sympathetic nervous system, increasing energy expenditure and leading to additional fat oxidation. Caffeine, also present in tea, may also contribute to some of these effects (Rains *et al*. 2011). Increasingly, there appears to be a trend towards using bioactive ingredients as a natural tool to manage obesity (Astrup *et al*. 2010). With the current rise in geriatric obesity, it is thought that catechins could be used to help regulate bodyweight where other treatment options are limited (Hurt & Wilson 2011). However, as the amount of weight loss is likely to be small from a clinical perspective, a more effective approach may be to combine intakes of thermogenic or satiety agents, such as green tea, as part of a wider weight loss strategy involving energy restriction and exercise.

As green tea polyphenols and caffeine may act synergistically on body composition, further studies using decaffeinated tea are needed to 'separate out' the weight loss effects and fully understand the likely mechanisms (Westerterp-Plantenga 2010). Previously, it was thought that caffeine may adversely affect hydration. However, recent experimental work suggests that tea is only a moderate source of caffeine and four to six (240 ml) servings of tea, providing 168 or 252 mg caffeine, respectively, have no deleterious effects on normal hydration when compared with water (Ruxton & Hart 2011). In another study, where healthy men consumed varying levels of caffeine, up to 6 mg/kg bodyweight daily, markers of hydration status were mostly unaffected by caffeine intake (Armstrong *et al*. 2005).

In terms of the limited evidence on oral health, attention has focused on oral cancer risk. Two large epidemiological studies (Ren *et al*. 2010; Radoi *et al*. 2013) found that tea drinking reduced oral/pharyngeal cancer risk, but such associations were not found in other cohorts. This highlights how the diversity of beverages consumed and variations in reported intakes makes it difficult to isolate the effects of tea *per se*. As tea drinking is thought to play a role in the repair of cellular damage (Radoi *et al*. 2013), this could be of particular benefit to smokers. There is a growing body of evidence that green tea polyphenols may reduce inflammation and oxidative stress in the oral cavity linked to smoking, as well as defending healthy cells from malignant transformation, by inducing apoptosis in oral cancer cells (Narotzki *et al*. 2012).

While two epidemiological studies indicate that green tea may prevent tooth loss (Koyama *et al*. 2010) well-designed studies controlling adequately for confounders, such as sugar intake, are needed. Although there is a clear need for more clinical studies, *in vitro* work suggests that tea exposure may reduce cariogenic bacteria levels, helping to improve dental health and prevent halitosis. Interestingly, a recent *in vitro* study found that adding green tea extract to soft drink mixtures reduced tooth surface loss by 15–40%, suggesting that the addition of green tea extract to soft drinks could help to lower their erosive potential (Barbosa *et al*. 2011). There is also some evidence that black tea has anti-fungal activity against oral *Candida* and could be used for therapeutic applications in the future (Sitheeque *et al*. 2009).

Turning to gut health, tea consumption could be used as a low-cost dietary support to combat *H. pylori* (Ankolekar *et al*. 2011). As *H. pylori* resistance to antibiotics has become a serious problem, tea and tea catechins could be a safe and alternative way to help control *H. pylori*-related infection (Matsubara *et al*. 2003). There is also growing evidence that tea polyphenols can kill and inhibit the growth of

microorganisms and modulate colonic flora, although the effects depend on the amount consumed and the bioavailability (Landete 2012). Increasingly, there is interest in how the gut could influence energy homeostasis, with modifications of gut microbiota being seen as one way to treat people with obesity (DiBaise *et al*. 2008). Given the emerging effects of tea on both weight management and human bacteria, further research may identify additional mechanisms involving modulation of the gut microbiota.

Finally, when disentangling evidence linking tea and health it is important to take other elements into consideration. Firstly, some trials use multi-interventions, which make it difficult to separate out the effects of tea. Secondly, as highlighted in a previous review (Gardner *et al*. 2007), modes of tea preparation (*e.g.* brew strength and consumption patterns) also need to be considered, as these could impact on the efficacy of tea compounds, for example additional sugar in relation to oral health. Thirdly, clinical outcomes depend on the full compliance of subjects, which is not always clearly outlined in intervention studies and could impact on study findings. Finally, it is also important to consider that the degree of fermentation may affect the bioactive properties of tea, with green, unfermented tea tending to have a stronger anti-microbial activity than black tea, which is completely fermented (Chou *et al*. 1999). More research on non-Asian populations is also needed. Given the emergence of *in vitro* studies looking at potential pre-biotic effects of tea, this field of work would particularly benefit from further larger clinical trials.

Conclusion

There has been an emergence of studies investigating the broader health benefits of tea, but especially green tea. Taken together, there appears to be moderate evidence that drinking green tea may have a role to play in weight management programmes, particularly when doses of catechins are up to 1200 mg/day (Rains *et al*. 2011). In relation to oral health, there is evidence that drinking 3–4 cups black tea daily could help to reduce levels of cariogenic bacteria (Allah *et al*. 2011), but the findings from this trial need to be replicated. In terms of gut health, the effects of tea drinking on the microbiome certainly seem to offer promise, but there is presently insufficient evidence to make any recommendations about intakes. Better quality trials and epidemiological studies investigating tea and health as primary rather than as secondary outcomes are now needed to build on these findings.

Conflict of interest

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