Nutrition Bulletin

REVIEW

DOI: 10.1111/nbu.12150

Is tea a healthy source of hydration?

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Abstract

After water, tea is the most commonly consumed beverage worldwide, with over 80% of adults drinking tea in the UK. Lay concerns about caffeine have led to questions about the suitability of tea as a source of hydration. Several controlled trials have examined the effect of moderate caffeine consumption on fluid balance, from tea or other sources, concluding that intakes of up to 400 mg of caffeine, or six to eight servings of tea daily, are consistent with normal hydration. Unlike water, or other caffeinated beverages, tea is rich in flavonoids: plant compounds associated with health. There is now a growing body of evidence linking regular tea consumption with heart health, cognitive health, dental benefits and bodyweight management suggesting that tea may offer a healthy source of hydration. These studies are discussed in the context of typical tea intakes in the UK.

Keywords: caffeine, cardiovascular health, dental health, flavonoids, hydration, tea

Introduction

Globally, tea is a beverage which has been consumed for centuries, with earliest mentions of it being drunk in China, over 5000 years ago (Blumberg 2013). Tea came to Europe in the 18th century, with tea houses becoming commonplace in and around London by the 1750s (Cobbett 1985). Nowadays, tea is the most widely-consumed beverage in the world after water (Hodgson & Croft 2010). Black tea is the most popular type, representing 78% of the tea produced worldwide, 20% is green and 2% oolong (Siddiqui *et al*. 2004). Tea infusions are produced by adding hot water to the leaves from the tea plant, *Camellia sinensis*. Herbal or fruit teas are not strictly teas as they come from plant species other than *Camellia sinensis*.

Different processing methods are used to make the hundreds of varieties of tea available. Black teas (*e.g.* Assam, Darjeeling), consumed mainly in Western countries (International Tea Committee 2010), are produced from young leaves of the tea plant, which are dried (withered) and crushed before undergoing extensive oxidation (also known as fermentation) and firing. This process generates theaflavins and thearubingins that create the distinctive colour and flavour of black tea (BNF 2003). Green (unoxidised) tea, which is consumed mainly in East Asia, North Africa and the Middle East, is made by steaming or 'pan-firing' the tea leaves to suspend enzyme action and minimise oxidation followed by cutting and/or rolling the leaves and drying. Oolong tea (*e.g.* Formosa oolong and Tie Guan Yin) requires a shorter oxidation period than black tea, giving it a taste and colour somewhere between green and black teas. In addition, there are hundreds of scented and flavoured speciality teas, such as Lapsang Souchong (black tea, scented with smoke), Earl Grey (black tea, with bergamot) and Jasmine (green tea, scented with jasmine flowers).

How much tea is consumed in the UK?

The amount of tea consumed in the UK has decreased in the past 30 years from around seven servings per day to an average of three servings per day (BNF 2003) with current intakes even lower at just over two servings

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Table 1 Tea infusion consumption (g/day) from NDNS rolling programme (2008/2009–2010/2011) (consumers only)

	Age of consumer (years)				
	1.5–3	4–10	11–18	19–64	≥65
Total NDNS sample	303	613	666	1186	305
% tea consumers	17.5	21.9	41.0	72.8	82.6
Mean daily consumption (g/day) (SD)	88 (100)	112 (91)	201 (193)	542 (390)	648 (406)
Minimum (g/day)	3	6	7	2	4
Maximum (g/day)	567	503	1583	3060	2040
95th percentile of intakes (g/day)	293	300	605	1230	1444

Reference: Ruxton and Bond (in press) (based on secondary analysis of NDNS rolling programme, Years 1–3).

daily (Ruxton & Bond, in press). Latest market data (International Tea Committee 2014) show that 115 272 metric tons were imported for UK consumption in 2013, of which 97.5% was black tea. The *National Diet and Nutrition Survey* (*NDNS*) rolling programme (Years 1–3: 2008–2011) collected dietary data from 6828 individuals aged 1.5 years and older, and includes data on tea, coffee and water intakes combined (Bates *et al*. 2012). A secondary analysis extracted mean daily tea consumption (in grams which is equivalent to millilitres) as well as 'high' consumption, *i.e*. intakes at or above the 95th percentile (Ruxton & Bond, in press). As presented in Table 1, the analysis found that up to 83% of UK adults drink tea, with adults aged ≥65 years drinking more than those aged 19–64 years (648 g vs. 542 g per day). A typical serving of tea in the UK contains 240 g of water added to 3.1 g of tea (Ruxton & Hart 2011).

Components of tea

Tea leaves contain an array of compounds, including amino acids, cellulose, lignans, organic acids, mono- and polysaccharides, methylxanthines, flavonoids and related polyphenols (Blumberg 2013). Whilst tea has negligible macronutrient content, it is of great nutritional significance owing to the presence of flavonoid polyphenols, which are plant-derived antioxidant compounds, as well as small quantities of micronutrients, caffeine and L-theanine (the dominant amino acid in tea).

Polyphenols

Approximately 35% of the weight of fresh tea leaves comprises flavonoids and related polyphenols, making tea an important dietary source of these compounds (Blumberg 2013). The types and proportion of polyphenols varies according to the season, age of the tea leaf and the climate, as well as the tea processing method. The majority of polyphenols in tea are of the flavonoid group, including catechin, epicatechin, epigallocatechin, quercetin, and the dimeric theaflavins and oligomeric thearubigins resulting from further processing. Black and green teas have different types and proportions of flavonoids present, but the total polyphenol content is considered to be similar (Stangl *et al*. 2006). An average cup of tea is estimated to have 200 mg of total flavonoids (Wiseman *et al*. 1997). Black tea is usually higher in theaflavins and thearubigins and, although it contains significant amounts of catechins, green tea is higher in the catechin polyphenols, notably epicatechin and epigallocatechin. The content of flavonol glycosides is similar in both green and black teas (BNF 2003).

Polyphenols in tea are of great interest as *in vitro* and *in vivo* studies suggest that they have antioxidant, anti-inflammatory and antiproliferative properties (Ruxton 2009; Mulvihill & Huff 2010; Dwyer & Peterson 2013). Studies of the bioavailability of polyphenols in tea have demonstrated significant increases in plasma levels of flavonoids after acute and chronic tea intakes (Warden *et al*. 2001; Widlansky *et al*. 2005). However, comparisons between black and green teas suggest that the flavanols in black tea are less well absorbed than those in green tea (Rietveld & Wiseman 2003). Part of this issue could be the difficulties in tracking metabolites from the more complex black tea flavonoids through biological organisms.

Despite the generally poor bioavailability of black tea flavanols, they appear to be bioactive in the body and are consumed in large amounts in the UK diet, estimated at around 83 mg per day, providing 82% of total dietary flavonoids (Ruxton 2008a). It has been reported more recently that most of the flavonoids (48%) in the UK diet are thearubigins (Zamora-Ros *et al*. 2013).

A review of 93 human intervention studies reported that consumption of flavanols from tea was associated with increased plasma antioxidant activity, decreased lipid peroxide and improved resistance to oxidation of low-density lipoprotein (LDL)-cholesterol (Williamson & Manach 2005). Green tea consumption has been shown to have a greater effect on raising plasma antioxidant levels than black tea (Henning *et al*. 2004), but given the low habitual consumption of green tea in the UK diet, it is not a significant contributor to flavonoids intake.

In the UK, data from the 1980s indicate that 98% of black tea is consumed with milk added (Hertog *et al*. 1997). Some questions have been raised about whether adding milk to tea affects flavonoid bioavailability. In a review of the evidence, Stanner (2007) reported that there was a split in the reported findings, with similar numbers reporting a significant reduction in bioavailability or bioactivity as those finding no effect. More recently, Dwyer and Peterson (2013) recognised that addition of lemon, milk or honey may affect bioavailability, but the mechanisms need further study.

Micronutrients

Tea naturally contains a range of micronutrients. These include the B group vitamins riboflavin, niacin and folate, as well as potassium, manganese, zinc and fluoride. The amount of these micronutrients in tea is influenced by infusion time (BNF 2003). In general, the contribution of tea to overall micronutrient intake is relatively small, although a recent review suggested that tea provides around 70% of dietary fluoride in the UK (Ruxton 2014).

Caffeine

Tea contains naturally-occurring methylxanthines, including caffeine, theobromine, theophylline, as well as xanthine, hypoxanthine and guanine. All except caffeine are found in minute quantities in brewed tea (Maughan & Griffin 2003).The amount of caffeine in tea is largely dependent on the brewing time, but caffeine content can vary between 1–90 mg per 100 ml, although the average is taken to be 17 mg per 100 ml of brewed tea (FSA 2004). Given that the mean daily intake of tea among adult consumers (19–64 years) in the UK is 542 g (Ruxton & Bond, in press), the mean daily caffeine intake from tea is approximately 92 mg.

Studies have shown that moderate intake of caffeine (up to 400 mg per day) leads to benefits in terms of cognitive performance, physical endurance and alertness (Ruxton 2008b); conversely, concerns have been raised that excessive intakes of caffeine increase the risks of low birthweight, dehydration, anxiety, headaches and sleep disturbance (Care Study Group 2008; Einöther & Martens 2013; Killer *et al*. 2014).

The European Food Safety Authority (EFSA) recently published draft guidelines on safe levels of caffeine, recommending that, for adults aged 18–65 years, 400 mg of caffeine per day including single doses of up to 200 mg are safe (EFSA 2015). For pregnant women, up to 200 mg per day is considered safe, while 3 mg per kg bodyweight per day is appropriate for children and adolescents. These figures are well within current mean intakes of tea in the UK. Indeed, in a review of the benefits and risks of caffeinated drinks and hydration, Ruxton (2008b) reported that the majority of benefits associated with caffeine are found within low to moderate caffeine intakes of 37.5 to 400 mg per day, which equates to 1 to 8 cups of tea per day.

Recommended fluid intakes

The amount of fluid that an individual should consume to maintain adequate hydration is extremely variable and there are several guidelines that offer advice, the most important of these in Europe being the Dietary Reference Values from EFSA (2010) (Table 2). These do not make specific recommendations regarding which drinks should be included, but recognise that water is consumed from different sources including foods and beverages, and state that regular and moderate consumption of caffeinated drinks does not result in the impairment of hydration status.

Table 2 Dietary references values for water

Age	Adequate fluid intakes (foods and beverages)
Infants ≤6 months	100–190 ml per kg/day
Infants 6–12 months	800–1000 ml/day
Children 1–2 years	1100–1200 ml/day
Children 2–3 years	1.3 litres/day
Children 4–8 years	1.6 litres/day
Boys 9–13 years	2.1 litres/day
Girls 9–13 years	1.9 litres/day
Adults (age 14+) (Male)	2.5 litres/day
Adults (age 14+) (Female)	2.0 litres/day
Adults (age 14+) (Female) pregnant	2.3 litres/day
Adults (age 14+) (Female) lactating	2.7 litres/day

Source: European Food Safety Agency (2010).

To complicate this further, there is evidence to suggest that physiological adaptations occur to preserve plasma osmolality, even with very low fluid intake (Perrier *et al*. 2013). There is also lack of consensus on what constitutes optimal hydration and how to measure it, which makes it rather difficult to research the topic and make comparisons between studies.

In the literature, the amount of fluid needed daily by healthy adults of all ages varies remarkably. One study (Bellisle *et al*. 2010) found that requirements ranged from 0.416 litres up to 4.316 litres per day and studies of fluid intake have shown variations from 0.6 litres to 3.5 litres per day (Ozen *et al*. 2014). A recent review of 24-hour beverage consumption in British adults aged up to 64 years (Gibson & Shirreffs 2013) reported that mean total water intakes were 2.53 litres and 2.03 litres per day for men and women, respectively, with hot beverages being consumed most in the morning and tea and coffee accounting for over 40% of the total.

Hydration and health

The human body is 45–75% water by weight (Benelam & Wyness 2010). Water has a number of roles in the body and is a major component of body fluids, including blood, synovial fluid (in joints), saliva and urine. The amount of body water is very tightly controlled and even small increases in serum osmolality will stimulate thirst and secretion of antidiuretic hormone (ADH) to increase renal concentrating capacity, whereas decreased osmoconcentration will result in increased, more dilute urine production. Severe dehydration is fatal but even mild dehydration equating to a 1–2% loss of bodyweight leads to headaches, fatigue and reduced physical and mental performance (Shirreffs *et al*. 2004; Ritz & Berrut 2005; Shirreffs 2005). Chronic mild dehydration is associated with constipation, urinary tract infections, coronary heart disease and stroke (Manz & Wentz 2005). Conversely, an excess of water consumed very rapidly can result in low blood sodium (hyponatraemia) which can cause lung congestion, brain swelling, headache, confusion, seizures and eventually coma (Benelam & Wyness 2010).

Water can provide 100% of a person's fluid requirement, but other beverages are typically consumed. Furthermore, some beverages provide nutrients and other substances which may have an influence on health. For example, milk provides energy, protein, riboflavin, calcium and iodine, juices provide free sugars and may contain vitamin C and other bioactive substances, while tea and coffee contain flavonoid polyphenols but also caffeine in differing amounts. Sugars-sweetened beverages provide large amounts of free sugars, while energy drinks may contain free sugars and high doses of caffeine.

Caffeine and hydration

Media reports that caffeinated drinks can adversely affect hydration, as well as ill-advised public health messages to drink a glass of water alongside caffeinated beverages (RCN/NPSA 2007), may have fuelled concerns about the value of caffeinated beverages in maintaining healthy hydration.

Theoretically, caffeine may adversely affect hydration because it increases blood flow to the kidneys and inhibits reabsorption of sodium, calcium and magnesium, stimulating urine output and thus causing water loss (Birkner *et al*. 2006). Much of the evidence underpinning the proposed diuretic action of caffeine has been limited to acute human randomised controlled trials (RCT) using caffeine pills at moderate to high doses; *i.e*. amounts well above those found in food/beverage sources, rather than caffeinated drinks. Two studies (Wemple *et al*. 1997; Bird *et al*. 2005) reported modest diuretic effects of caffeine pills at a dose of 370–612 mg per day in healthy adults. Conversely, Armstrong *et al*. (2005) found no significant effect of caffeine pills providing 3–6 mg/kg bodyweight over 5 days on electrolyte and renal markers of hydration in cyclists. A review of the evidence from 41 studies on caffeine (Ruxton 2008b), which also examined the effects on hydration of caffeinated drinks, concluded that there was no significant impact on hydration of caffeine intake of 1.4–6 mg per kg bodyweight but reported benefits associated with low to moderate caffeine intake (37.5–400 mg/day), equating to 1 to 8 cups of tea. It has been estimated that, in the UK, most of the 4 mg per kg bodyweight average caffeine intake originates from tea (Thomas 2003).

A recent, small ($n = 50$) crossover study of male moderate coffee drinkers (Killer *et al*. 2014) found that, compared with 3 days of drinking four 200 ml cups of water, the same amount of coffee produced no significant differences in a wide range of haematological and urinary markers of hydration status. Hydration markers included the gold standard method of estimating total body water – the doubly-labelled water dilution technique (deuterium oxide). Another study (Silva *et al*. 2013) used the same markers to investigate the effects of consuming caffeine tablets (5 mg/kg/day) versus a placebo for four days in 30 low caffeine users. Again, no changes were observed in total body water when measured on days 1 and 4 of the study.

Building tolerance to the renal effects of caffeine may be one factor which influences any impact of caffeinated drinks on hydration. From the studies on caffeine and hydration there is a suggestion that higher levels of caffeine can cause dehydration after a period of abstinence of as little as 4 days, but adaptation occurs rapidly (Killer *et al*. 2014). Taken as a whole, the evidence from studies which have investigated the effects of caffeine ingested in beverages and in tablets, in various doses, using a range of markers of hydration status, in either caffeine consumers or caffeine abstainers (caffeine naïve) have produced varied data. However, the general trend is that high doses of caffeine in caffeine naïve subjects may increase urine volume in the short-term, but this is not seen at low to moderate acute caffeine doses, nor does it occur after chronic caffeine consumption (Killer *et al*. 2014).

Tea and hydration

To date, only two studies have specifically examined the influence of tea on hydration. Scott *et al*. (2004) reported a study of 13 members of an expedition at high altitude finding no significant differences in urine specific gravity, urine electrolytes (Na+ or K+) or urine colour after *ad libitum* tea versus water consumption. While this study was non-randomised and was conducted in a small group of climbers, it did test the impact of tea consumption in an environment where the risk of dehydration is high.

More recently, Ruxton and Hart (2011) carried out a randomised crossover trial comparing black tea and water in 21 healthy males who had abstained from caffeine, alcohol and vigorous exercise for 24 hours. Those in the test groups consumed 4 or 6 cups (240 ml) of black tea, providing 168 and 252 mg of caffeine, respectively. All tea was provided at regular intervals and included 20 ml of semi-skimmed milk. Compared with the control group (who consumed only boiled water), no differences were observed in any of the hydration markers in blood or urine, nor were there any significant differences in mean 24-hour urine output. The authors concluded that consuming up to six servings of tea in a day (<1440 ml) had no adverse effects on hydration. These amounts are considerably higher than mean tea intakes in adults 19–64 years (542 ml) and adults ≥65 years (648 ml) but are similar to intakes at the 95th centile for adults ≥65 years (see Table 1). This suggests that current average tea intakes, *i.e*. two to three servings of tea daily, are highly unlikely to cause excessive diuresis. As this study was carried out in healthy males, it is yet to be established whether females, older adults or children demonstrate a similar response.

Tea has been highly ranked as a beverage of choice for hydration as well as for its phytochemical properties (Popkin *et al*. 2010). Dietary guidelines in some countries, such as Germany and Japan, explicitly recommend tea for hydration (Blumberg 2013). Nevertheless, there are safe limits for caffeine intake and high consumers of caffeinated beverages should consider whether their habitual caffeine intakes fall within generally healthy limits.

Suitability of tea for children

Until recently, specific guidelines were lacking on how much caffeine children could safely consume. The FSA (2013) recommends that children should consume caffeine only in moderation while the Children's Food Trust (2012) recommends avoiding tea and other caffeinated drinks or foods. EFSA's (2015) draft guidance suggests that 3 mg caffeine per kg bodyweight per day is a safe level for children and adolescents aged 3–18 years. This latest advice, which is based on the available evidence, also suggests that tea can be safely consumed by children within these limits. This is in accordance with a review of caffeinated drinks in children (Ruxton 2013) which suggested, based on Canadian guidelines, that children and adolescents should limit daily caffeine intake to 2.5 mg per kg bodyweight per day (equivalent to 1–2 cups of tea per day). As Table 1 shows, children aged 10 years and younger at the 95th centile of tea intake are within this guideline but older children at the 95th centile are not.

BNF (2013) recently published a healthy hydration model for children aged 4–13 years which advises that up to 2 cups per day of unsweetened weak tea with milk is appropriate for younger children, increasing to 2–3 cups per day for older children. Concerns have been raised about the impact of drinking tea on iron status as the polyphenols in tea could potentially inhibit bioavailability of non-haem iron. However, SACN (2010) concluded that consumption of tea has little effect on iron status in practice and does not need to be restricted.

Tea and health

There is now good evidence from observational studies, backed up by *in vitro*, *in vivo* and human trials, that regular consumption of tea is associated with a range of health benefits. Most of the proposed benefits are attributed to flavonoids, although caffeine and L-theanine may also be of significance.

Tea consumption may also influence mortality. The multi-ethnic prospective *North Manhattan Study* of 2461 healthy adult participants (Gardener *et al*. 2013) observed that, after 11 years' follow up, there was a small but significant inverse association between tea consumption and all-cause mortality. Each additional cup of tea consumed per day resulted in 9% lower overall mortality. In particular, tea consumption of over 2 cups daily was protective against non-vascular death during the 11-year follow-up period, with a 37% lower risk when the highest versus lowest tea drinking populations were compared. A similar finding was seen for cancer where a 67% lower risk of cancer mortality during the 11-year follow-up period was reported for high vs. low tea consumers.

There can be conflicting results in RCTs of tea as strength of infusion and type of tea consumed can influence the available bioactive compounds and, thus, related health outcomes. Nevertheless, even if the overall impact of tea on health is small, considering that tea is the second most consumed beverage globally, there could be important benefits for public health (Peters *et al*. 2001).

Cardiovascular health

The most compelling health evidence arises from reported links between tea and cardiovascular disease (CVD) risk, including coronary heart disease and stroke. CVD remains the number one cause of death worldwide and represents a huge global health burden. Epidemiological studies have provided convincing evidence for an association between tea consumption and reduced cardiovascular risk (van Duynhoven *et al*. 2013) and a number of cross-sectional and prospective studies as well as detailed meta-analyses, have examined the links between tea consumption and CVD risk.

Hartley *et al*. (2013) reviewed the evidence from 11 RCTs of over 3 months' duration and found that black tea consumption significantly reduced LDL-cholesterol and systolic and diastolic blood pressure (BP). Specifically, in pooled analyses, black tea significantly reduced LDL-cholesterol by 0.43 mmol/l (95% CI: –0.56, –0.31). The meta-analysis also showed a statistically significant reduction of 1.85 mmHg (95% CI: –3.21, –0.48) in systolic BP, but no significant change in diastolic BP. Regarding green tea, significant reductions were reported in total and LDL-cholesterol [mean difference –0.62 mmol/l (95% CI: –0.77, –0.46) and –0.64 mmol/l (95% CI: –0.77, –0.52)], respectively, and for systolic and diastolic BP [mean difference –3.18 mmHg (95% CI: –5.25, –1.11) and –3.42 mmHg (95% CI: –4.54, –2.30)], respectively. However, the review was unable to draw conclusions about the number of cups of tea per day required as the included studies used varying doses of tea or tea extracts.

Zhang *et al*. (2014) conducted a similar systematic review and meta-analysis and found that an increase of 3 cups of tea per day had a significant impact on CVD risk factors. Data from 22 prospective studies suggested reduced relative risk (RR) for coronary heart disease [RR = 0.73 (95% CI: 0.53, 0.99)]. However, an earlier review (Arab *et al*. 2013) based on 5 meta-analyses of green and black tea consumption or flavonoid consumption and CVD incidence and mortality, found a heterogeneous effect when all CVD was included. However, where stroke risk was the outcome measure, the data summarised from 14 studies were highly consistent. The relative risk of stroke incidence and mortality was 0.80 (95% CI: 0.65, 0.98) for flavonoids and 0.79 (95% CI: 0.73, 0.85) for tea when the highest versus the lowest intakes were considered.

A recent meta-analysis of RCTs (Liu *et al*. 2014) found that green tea significantly reduced systolic BP by 2.1 mmHg (95% CI: –2.9, –1.2) and diastolic BP by 1.7 mmHg (95% CI: –2.9, –0.5). Black tea significantly reduced systolic and diastolic BP by 1.4 mmHg (95% CI: –2.4, –0.4) and 1.1 mmHg (95% CI: –1.9, –0.2), respectively. Similar results were demonstrated in a recent small RCT (Grassi *et al*. 2015).

Several feasible mechanisms for these effects have been postulated. Liu *et al*. (2014) suggested that tea catechins may lower the risk of CVD by enhancing antioxidant activity, improving endothelial dysfunction, attenuating metabolic syndrome, inhibiting angiotensin converting enzyme (ACE), preventing cardiac hypertrophy and protecting mitochondria from damage. Tea consumption may also have an influence on markers of inflammation via tea flavonoids suppressing the signalling pathways (Suzuki *et al*. 2009) and reducing both platelet activation and plasma C-reactive protein (Steptoe *et al*. 2007). More recently, tea has been found to stimulate the gut microbiota to produce microbial bioconversion products which may have a beneficial role in cardiovascular health (van Duynhoven *et al*. 2013). The potential antioxidant actions of tea flavonoids have also been explored, suggesting that they may prevent oxidation of LDL-cholesterol, although findings have been mixed and antioxidant potential depends on the bioavailability (Hollman *et al*. 2011; Ruxton & Mason 2011). The most likely mechanism, however, is that tea flavonoids have a beneficial effect on endothelial function and flow-mediated dilatation of the brachial artery. Intervention studies have demonstrated

that tea flavonoids appear to improve the bioactivity of nitric oxide (Grassi *et al.* 2013). Since reduced bioactivity of nitric oxide in endothelial dysfunction is likely to be one of the earliest stages of atherogenesis, such a link with tea flavonoids could provide some explanation of the favourable impact of tea on heart health.

Taken as a whole, evidence indicates a potential role for tea in lowering the risk of CVD which, given the high intakes of tea in some countries, could represent beneficial population changes in blood lipids and BP, and potentially CVD incidence (Emberson *et al.* 2004). However, the lack of consensus on mechanisms and optimal intakes suggests that further research is needed.

Weight management

According to traditional Chinese belief, tea helps to control bodyweight (Hursel *et al.* 2011). Certainly, tea is calorie free unless milk, sugar or other caloric substances are added, and so represents a suitable beverage choice for weight management. Furthermore, tea constituents may also modestly increase energy expenditure. Meta-analyses and reviews speculate that caffeine and catechins may stimulate fat oxidation via the sympathetic nervous system, promoting energy expenditure and potentially supporting weight loss by counteracting the decrease in metabolic rate that occurs during weight loss (Hursel *et al.* 2011; Hursel & Westerterp-Plantenga 2013). This needs to be confirmed in appropriate human studies.

A review of 18 studies (Jurgens *et al.* 2012) reported that green tea preparations induced no meaningful weight loss in overweight or obese adults. In contrast, a recent RCT (Bohn *et al.* 2014) found that, compared with a placebo drink, consuming 3 cups of black tea daily (made from tea extract) for 3 months resulted in a statistically significant reduction in bodyweight (–0.64 kg) and waist circumference (–1.88 cm). Another RCT (Li *et al.* 2015) of patients with type 2 diabetes found that tea consumption significantly reduced waist circumference [–2.70 cm (95% CI: –4.72, –0.69)]. While these effects are clearly modest compared with the results of drug trials or calorie-reduced diets, unsweetened tea could be suggested as a useful alternative to other beverages that may be consumed within weight management diets. More RCTs are needed as the evidence base is very small.

Type 2 diabetes

In a review of the evidence on tea and type 2 diabetes, Ruxton and Mason (2011) reported a potentially protective effect of drinking 1–4 cups of black tea daily, while a major meta-analysis of 9 cohort studies covering over 300 000 people for up to 18 years (Jing *et al.* 2009) reported that 4 or more cups of green tea daily was associated with a significant reduction of type 2 diabetes. More recently, a meta-analysis of 10 RCTs found that green tea, or its extract, significantly decreased fasting glucose and haemoglobin A1c concentrations in patients with diabetes (Li *et al.* 2015). These early positive results for tea drinking now need to be confirmed with other clinical studies, while mechanistic evidence is urgently needed.

Cognitive function

Tea has been associated anecdotally with mental health benefits, such as relaxation, improved concentration and mood. These effects may result from interactions between bioactive tea constituents, or may simply be due to feelings associated with the sensory properties of tea, including smell, colour, temperature and mouth feel (Einöther & Martens 2013), or cultural and social associations between tea and relaxation.

There has been abundant research on the impact of caffeine on cognitive performance, but this evidence now includes several studies on tea consumption. In a review of the effects of tea consumption on attention and mood, Einöther and Martens (2013) reported a consistent finding that acute tea consumption improves attention, self-reported alertness and mental arousal. A recent systematic review and meta-analysis (Carnfield *et al.* 2014) reported small to moderate effects on cognitive function and mood, which were attributable to L-theanine and caffeine. Although caffeine is known to increase acetylcholine and dopamine transmission in the brain, implicated in attention and higher cognitive functions, less is known about L-theanine, which is a highly bioavailable amino acid that is virtually unique to tea. Whereas caffeine is absorbed rapidly (peak plasma levels from 30 minutes after consumption; Einöther & Martens 2013), L-theanine is absorbed more slowly, with reported peak plasma from 50 minutes (Van der Pijl *et al.* 2010), and so the acute effects may lag behind caffeine (Carnfield *et al.* 2014). Bryan (2008) suggested that L-theanine may interact with caffeine to enhance attention switching and the ability to ignore distraction, both of which reflect cognitive function, while Vuong *et al.* (2011) reported that L-theanine appeared to improve concentration and learning. The cognitive effects of caffeine are seen in both naïve consumers as well as habitual consumers of caffeinated beverages (Ruxton 2008b).

As well as having acute effects, there is limited evidence, mainly from observational studies in Asian populations, that regular tea consumption is associated with slower cognitive decline (Kuriyama *et al*. 2006; Noguchi-Shinohara *et al*. 2014). Here, it is postulated that the chronic effects are due more to tea flavonoids than caffeine or L-theanine (Ng *et al*. 2008).

The potential role of tea in maintaining cognitive function clearly needs further study, particularly in relation to mechanisms which may be due to tea constituents, hydration or expectations.

Cancer

Epidemiological studies on tea and cancer have found conflicting results, with some reporting that drinking tea significantly reduces cancer mortality (Gardener *et al*. 2013) while other studies report no associations (Yuan 2013; Yu *et al*. 2014). Much of this research has been carried out in Asian countries where tea, particularly green tea, is consumed in higher volumes that in the UK, making the findings less relevant to Western populations. A review of 51 studies of cancer and green tea (Boehm *et al*. 2009) found that, although the evidence was conflicting for liver, prostate, ovarian and oral cancer, there was limited evidence of an overall protective effect.

Proposed mechanisms for a protective effect of tea have been explored, including modulation of cellular redox environment, enhanced expression of phase II metabolic pathways and inhibition of growth factor signalling, and there is some evidence from human intervention studies that tea can slow cancer progression (Lambert 2013). The discrepancy between the theoretical protective effect and results from observational data may be in part due to differences in tea doses, but could include other confounding factors such as type of tea, use of valid biomarkers and other dietary and non-dietary confounding variables (Yuan 2013).

Dental health

Studies have reported a potential beneficial role of drinking tea on dental health and there is emerging evidence that tea flavonoids help to protect against caries and periodontitis with fewer reported decayed, missing or filled teeth in tea drinkers (Abd Allah *et al*. 2011; Varoni *et al*. 2012). Suggested mechanisms include antiviral and antimicrobial effects, inhibition of plaque bacteria and changes in the salivary milieu (Abd Allah *et al*. 2011). Additionally, green tea polyphenols have been reported to reduce halitosis through modification of odorant sulphur components (Narotzki *et al*. 2012).

Tea is estimated to provide the majority of fluoride in the diet and, as black tea infusions have a mean fluoride content of 4.9 mg/l, many types qualify for a dental health claim under EU regulations (Ruxton 2014). Fluoride is recognised for its role in promoting dental health as incorporation of fluoride into the enamel matrix of teeth improves resistance to decay (EFSA 2013). However, tea should be consumed without added sugar to maximise any dental health benefits (Benelam & Wyness 2010).

Bone health

Evidence from cross-sectional and retrospective studies suggests that tea consumption could have a positive impact on bone health, reducing bone mineral losses and lowering the risk of osteoporotic fractures in adults (Shen *et al*. 2013). These findings are supported by *in vitro* and animal studies, suggesting that tea polyphenols enhance osteoblastogenesis whilst suppressing osteoclastogenesis (Shen *et al*. 2013). The presence of fluoride in tea may also have a beneficial effect on bone density and hardness by embedding fluoride within the hydroxyapatite (Ruxton 2014), although there is no evidence for this improving mechanical strength (EFSA 2013). Adding milk to tea may also support normal bone health due to the calcium content, although this is likely to represent only a small contribution to daily calcium requirements. Concerns about the fluoride content of tea and its impact on dental and skeletal fluorosis are not borne out by recent evidence suggesting that estimated fluoride intakes from tea are well within tolerable upper intake levels for fluoride (Ruxton & Bond 2015).

Conclusion

Tea is consumed by the majority of adults in the UK, especially older adults, with black tea the most popular choice. Studies using amounts of caffeine that are consistent with daily tea drinking as well as studies directly on tea indicate that tea contributes to normal hydration when up to six servings are consumed daily. This is in contrast to beliefs that tea is a dehydrating beverage. As well as providing fluid, tea contains active components, such as flavonoids, L-theanine, caffeine and fluoride, which may provide health benefits in relation to cardiovascular and dental health. Emerging evidence links regular tea consumption with reduced risk of type 2

diabetes and some cancers, as well as normal cognitive health. Thus, unsweetened tea may be considered a healthy means to achieve normal hydration.

Acknowledgements

This work was funded by the Tea Advisory Panel, which is supported by an unrestricted educational grant from the UK Tea and Infusions Association, the trade association for the UK tea industry. For further information, see www.teaadvisorypanel.com. The content of this paper reflects the opinion of the authors.

Conflict of interest

Dr C. Ruxton is a consultant to the Tea Advisory Panel, which is supported by the UK Tea and Infusions Association, and received an honorarium for writing this paper, as did Dr F. Phillips. Dr T. Bond serves on the Tea Advisory Panel and is an employee of AVT Tea Services Ltd.

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