

REVIEW ARTICLE

Anti-cariogenic properties of tea (*Camellia sinensis*)

J. M. T. HAMILTON-MILLER

Department of Medical Microbiology, Royal Free and University College Medical School, Rowland Hill Street, London NW3 2PF

Various components in green and black tea, the beverages made by infusing appropriately processed dried leaves of *Camellia sinensis*, notably simple catechins, have properties *in vitro* that suggest an anti-cariogenic activity. These include: a direct bactericidal effect against *Streptococcus mutans* and *S. sobrinus*; prevention of bacterial adherence to teeth; inhibition of glucosyl transferase, thus limiting the biosynthesis of sticky glucan; inhibition of human and bacterial amylases. Studies in animal models show that these *in-vitro* effects can translate into caries prevention. A limited number of clinical trials in man suggest that regular tea drinking may reduce the incidence and severity of caries. If substantiated, this could offer a very economical public health intervention.

Introduction

Japanese folklore has it that drinking green tea ‘makes the mouth clean’ [1] and more specifically that ‘there is an old tradition that those who drink a large amount of green tea have less tooth decay’ [2]. It is rewarding to investigate this belief more closely in the light of the increasing scientific knowledge acquired over the last decade about the biological properties of components of tea (*Camellia sinensis*).

Pathogenesis of dental caries

Dental caries is a very common chronic disease, arising from interplay between oral flora, the teeth and dietary factors. The major aetiological players are thought to be the two α -haemolytic ‘mutans group’ streptococci, *Streptococcus mutans* and *S. sobrinus*, although several other types of bacteria (notably lactobacilli and actinomyces) may also be involved [3, 4]. The nature of the condition does not readily lend itself to conventional antibacterial therapy (i.e., the use of an antibiotic active against the causal agent), and prevention is largely directed towards the individual host –

e.g., diet, mechanical factors – and the public health measure of fluoridation of drinking water.

The pathogenesis of dental caries may involve three distinct processes: (1) adherence of the bacteria to the tooth; (2) formation of glycocalyx due to synthesis of a sticky glucan by the action of the bacterial enzyme glucosyl transferase on sucrose; and (3) accumulation of biofilm (plaque), within which there is continuing acid production by constituent bacteria (including streptococci and lactobacilli) able to metabolise carbohydrates at low pH values. This acid demineralises the enamel.

The second and third of these steps depend on a supply in the mouth of appropriate carbohydrate substrates, most favourably sucrose. The latter can become available either directly (sugar ingested in food or drink) or be derived from dietary starch by the action of bacterial or salivary amylases, or both. Of particular relevance in this context is the trapping of carbohydrates as or on food particles remaining in the mouth for considerable periods.

Potential anti-cariogenic actions of tea

Tea or some of its various components have been shown to interfere specifically with each of the processes described above. In addition to these potentially anti-cariogenic effects, there is also a direct bactericidal effect on *S. mutans*.

Received 18 July 2000; revised version accepted 8 Oct. 2000.

Corresponding author: Prof J. M. T. Hamilton-Miller (e-mail: j.hamilton-miller@rfc.ucl.ac.uk).

Chemical composition of tea

Much of the work described below was done with green tea, but many of the results are also applicable to black tea. The main chemical difference between green and black tea is that the former contains simple catechins (polyphenols with mol. wt < 450 Da) whereas in the latter many of these have been oxidised and condensed, during a manufacturing process known as 'fermentation', to larger, dark-coloured molecules including theaflavins (500–1000 Da) and thearubigins (> 1 kDa). However, black tea still contains simple catechins, examples of which are epicatechin (EC), epicatechin gallate (ECG) and epigallocatechin gallate (EGCG). A cup of green tea prepared in the normal way contains 0.5–1 g of catechins/L [1], and black tea contains about one-third of this figure. The catechins and (in black tea) theaflavins are the microbiologically active molecules [5].

A third type of tea, oolong, is described as 'semi-fermented'. It contains a mixture of monomeric and oligomeric catechins.

It is widely believed that tea contains 'tannins'; however, this is a misconception [6]. Tannins are toxic, bitter-tasting high mol. wt compounds (> 1.5 kDa), typically found in tree bark, and are present as a defence mechanism against plant predators; they are not found in the beverage made from tea.

Anti-streptococcal activity

Several papers describe inhibitory and bactericidal activity against *S. mutans* or *S. sobrinus* in extracts of green or black tea or catechins derived from such preparations [1, 7–9]. Figures for the activities of the individual catechins vary somewhat: Muroi and Kubo [10] found no activity at 500 mg/L but others [1, 7] reported minimum inhibitory concentrations of individual catechins as between 50 and 500 mg/L. However, the consensus is that a 'cup of tea' concentration is inhibitory and often bactericidal.

Kubo and colleagues [10, 11] studied the 10 most abundant 'flavour compounds' in green tea; these are volatile, terpene or terpene-like compounds. They found inhibitory activity for some, and synergy between certain pairs. However, MICs were in excess (often by a considerable amount) of concentrations found in tea beverage, in which total flavour compounds amount to only about 7 mg/L.

Inhibition of adherence

Otake *et al.* [12] showed that a mixture of simple catechins extracted from green tea (consisting mainly of EGCG, EGC and its epimer gallic acid, EC and ECG), at 100 mg/L (i.e., less than 'cup of tea' concentration), caused very substantial inhibition of

adherence of *S. mutans* to saliva-coated hydroxyapatite. Pretreatment of the substrate had little effect, showing that the phenomenon was a consequence of a specific interaction with the bacteria.

Matsumoto *et al.* [13] reported that both high and low mol. wt fractions from oolong tea bound to bacterial surface proteins, decreasing their hydrophobicity and thus inducing cellular aggregation.

Inhibition of glucosyl transferase

Several workers have demonstrated that the enzymic activity of glucosyl transferase from *S. mutans* and *S. sobrinus* is inhibited by tea catechins. Otake *et al.* [12] and Hattori *et al.* [14] both found that EGCG and ECG were more active than other catechins, but the former group reported greater potency (EGCG at 167 mg/L caused 91% inhibition) than that found by the latter (EGCG at 450 mg/L caused 50% inhibition). Other plant compounds with a higher mol. wt than these simple tea catechins have also been reported to inhibit glucosyl transferase, e.g., oligomeric catechins from oolong tea [2, 15], hop bract polyphenols of 36–40 kDa [16], gallotannins [17] and procyanidins from betel nuts [18].

Inhibition of salivary and bacterial amylases

Kashket and Paolino [19] found that tea beverage inhibited salivary amylase, under conditions existing in the mouth during and shortly after ingestion of a tea drink. More recently, Zhang and Kashket [20] have shown that brews of several black and green teas also suppressed amylase activity from *S. mutans*. Black teas were more active against both types of enzyme, a finding that was interpreted as suggesting that higher mol. wt polyphenols (more abundant in black tea) were responsible. Such a conclusion can be explained at least in part by the results of Hara and Honda [21], who found that not only simple catechins but also theaflavins (present only in black tea) inhibited salivary amylase. Zhang and Kashket [20] also demonstrated that the fluoride content of the tea brews tested did not correlate with amylase inhibition, and further that the enzyme's activity was unaffected by NaF, added in concentrations up to 10 mg/L.

Mode of action

Virtually nothing is known about the mechanism by which tea extracts exert the antibacterial and other biological effects described above. EGCG and EC have been reported to disrupt reconstituted bacterial membranes in a model system [22]; however, although tea and its components show broad-spectrum antibacterial activity [5], unlike an antiseptic, this activity is selective.

Catechins are known to have an affinity for proteins; this is clearly shown by a decrease in antibacterial

activity of tea in the presence of serum (protein binding was 82%) [5]. This property (known as 'astringency') contributes to the sensation known as 'mouthfeel' experienced when drinking tea. It can be speculated that inhibition of enzymes such as amylases and glucosyl transferase, and of the adherence of *S. mutans* mediated by fimbriae, fibrils or other protein surface components (alone or in combination) [23], might be accounted for by interactions between EGCG and related compounds with these proteins, causing distortion of tertiary structure and loss of function. This theory requires experimental verification.

Anti-cariogenic activity of tea *in vivo*

The findings described above suggest that tea drinking or the use of specific extracts of tea may prevent or slow down the progression of caries. However, without clinical evidence, the information remains of academic interest only.

Pharmacokinetic studies have shown that following rinsing of the mouth with tea, catechins can be found in the saliva for up to 60 min [24], and that the enzymic breakdown of starch on food particles trapped in the mouth was markedly reduced [20]. Kaneko *et al.* [25] found that the anti-plaque effect of rinsing the mouth with 20 ml of a tea catechin 0.25% solution persisted for up to 90 mins.

Animal models have been used successfully to show that various tea extracts can prevent or reduce caries formation. Definitive experiments have been done in

rats and hamsters (Table 1) [26–29]. Ooshima *et al.* [30] found that the oligomeric catechin fraction from oolong tea was superior to green tea in caries prevention.

Unsurprisingly, there have been few trials in man and none has produced an entirely satisfactory outcome. With so many potentially confounding factors it is difficult to design a study likely to produce a definitive result. Five studies are summarised in Table 2 [31–35]. Elvin-Lewis and Steelman [31] found significantly lower DMFT and plaque scores in children who habitually drank one-to-three cups of tea per day than in those whose intake was only one-to-two cups per week (this report is in Abstract form only). The prospective trials by Onisi *et al.* [32, 33] showed that Japanese schoolchildren given one cup of green tea ('bancha') daily for 250 days had a 50% reduction in the most common types of carious lesions compared with a control group not given tea, and a reduction in incidence of caries during the first year was maintained thereafter. A recent study in the UK found that 14-year-old children who drank tea (whether with added sugar or not) had a significantly lower DMFT score than coffee drinkers [34]. Two further studies should be mentioned: Ramsey *et al.* [36] reported 25 years ago that there was a significant inverse correlation in children between amounts of tea drunk daily and DMFT score; they attributed this at the time to an increased fluoride intake. Pashaev and Akhmedbeili [37] treated 800 children with black tea tincture and other measures, and found this to be highly caries-preventative; however, it is difficult in this case to discern the relative contributions of the various interventions.

Table 1. Caries inhibition by tea: animal experiments

Reference no.	Animal and caries induction	Intervention	Outcome
12	SPF rat, <i>S. mutans</i>	Sunphenon* 0.05%	40% decrease in caries on sulcal, buccal, approximal surfaces
26	SPF rat, diet, <i>S. mutans</i> , <i>S. sobrinus</i>	Oolong tea fractions 0.5–5 mg/g	Plaque index reduced 32–50%; caries score reduced 22–54%; p < 0.05
27	Rat, diet	Tea 3% infusion	Control: 71 lesions in 17 animals Test: 22 lesions in 9 animals p < 0.03
28	Rat, diet, <i>S. mutans</i>	Green or black tea infusion	Sulcal caries score reduced 25%; p < 0.05
29	Hamster, diet	Acid tea (pH 3.6) 120 ml/day	Caries score reduced 33–47%; p < 0.05

SPF, specific pathogen-free.

*Mixture of monomeric catechins from green tea.

Table 2. Caries inhibition by tea: results in man

Reference no.	Subjects	Control and test group	Outcome
31	106 children	Tea drinkers <i>versus</i> non-tea drinkers	Test group had lower DMFT and plaque scores; p < 0.05
32	298 children	Cup of 'bancha' tea daily for 250 days; cross-over	Pits and fissures reduced 53%; proximal sites reduced 57%; no change at free gingival sites
33	450–500 children	Cup of 'bancha' tea daily for 250 days; historical controls	Pits and fissures reduced 13–32%
34	3875 children	2552 tea drinkers <i>versus</i> 1323 coffee drinkers	DMFT reduced 13.5%; p < 0.001
35	35 volunteers	Rinsing with oolong fractions <i>versus</i> water	Mean plaque index reduced 21%; p < 0.001

Prospects

As the above shows, there is now a solid body of scientific evidence that strongly suggests that tea and certain of its components may exert a significant anti-cariogenic effect, by virtue of various activities against α -haemolytic streptococci. However, there seems to have been no investigation of activity against lactobacilli, actinomyces or other bacteria considered [3, 4] to play a role in the initiation and progression of caries. Such studies would be of interest.

Formal proof of a useful anti-cariogenic effect of tea by means of clinical trial is still elusive, although the results summarised in the preceding paragraphs are suggestive and engender hope. Chemically defined extracts of tea are available in certain countries (e.g., Japan) where they are used for a surprisingly wide range of applications (e.g., in face masks and filters for vacuum cleaners). Incorporation of such products into chewing gums, toothpastes, mouthwashes and dental floss is a real possibility, and such avenues are worth exploring.

I am most grateful to Professor Michael Wilson for his helpful comments on the manuscript.

References

- Sakanaka S, Kim M, Taniguchi M, Yamamoto T. Antibacterial substance in Japanese green tea extract against *Streptococcus mutans*, a cariogenic bacterium. *Agr Biol Chem* 1989; **53**: 2307–2311.
- Nakahara K, Kawabata S, Ono H *et al.* Inhibitory effect of oolong tea polyphenols on glucosyltransferases of mutans streptococci. *Appl Environ Microbiol* 1993; **59**: 968–973.
- Hardie JM, Whaley RA. Plaque microbiology of crown caries. In: Newman HN, Wilson M (eds) *Dental plaque revisited* Cardiff, Bioline. 1999: 283–294.
- Beighton D, Brailsford SR. Plaque microbiology of root caries. In: Newman HN, Wilson M (eds) *Dental plaque revisited* Cardiff, Bioline. 1999: 295–312.
- Yam TS, Shah S, Hamilton-Miller JMT. Microbiological activity of whole and fractionated crude extracts of tea (*Camellia sinensis*), and of tea components. *FEMS Microbiol Lett* 1997; **152**: 169–174.
- Wheeler SR. Tea and tannins. *Science* 1979; **204**: 6.
- Kawamura J, Takeo T. Antibacterial activity of tea catechin to *Streptococcus mutans*. *J Jap Soc Food Sci Technol* 1989; **36**: 463–467.
- Rasheed A, Haider M. Antibacterial activity of *Camellia sinensis* extracts against dental caries. *Arch Pharm Res* 1998; **21**: 348–352.
- You SQ. [Study of feasibility of Chinese green tea polyphenols (CTP) for preventing dental caries.] *Chung Hua Kou Chiang Hsueh Tsu Chih* 1993; **28**: 197–199, 254 [in Chinese; English abstract from Medline].
- Muroi H, Kubo I. Combination effects of antibacterial compounds in green tea flavor against *Streptococcus mutans*. *J Agr Food Chem* 1993; **41**: 1102–1105.
- Kubo I, Muroi H, Himejima M. Antimicrobial activity of green tea flavor components and their combination effects. *J Agr Food Chem* 1992; **40**: 245–248.
- Otake S, Makimura M, Kuroki T, Nishihara Y, Hirasawa M. Anticaries effects of polyphenolic compounds from Japanese green tea. *Caries Res* 1991; **25**: 438–443.
- Matsumoto M, Minami T, Sasaki H, Sobue S, Hamada S, Ooshima T. Inhibitory effects of oolong tea extract on caries-inducing properties of mutans streptococci. *Caries Res* 1999; **33**: 441–445.
- Hattori M, Kusumoto IT, Namba T, Ishigami T, Hara Y. Effect of tea polyphenols on glucan synthesis by glucosyltransferase from *Streptococcus mutans*. *Chem Pharm Bull* 1990; **38**: 717–720.
- Hamada S, Kontani M, Hosono H *et al.* Peroxidase-catalysed generation of catechin oligomers that inhibit glucosyltransferase from *Streptococcus sobrinus*. *FEMS Microbiol Lett* 1996; **143**: 35–40.
- Tagashira M, Uchiyama K, Yoshimura T, Shirota M, Uemitsu N. Inhibition by hop bract polyphenols of cellular adherence and water-insoluble glucan synthesis of mutans streptococci. *Biosci Biotechnol Biochem* 1997; **61**: 332–335.
- Kakiuchi N, Hattori M, Nishizawa M, Yamagishi T, Okuda T, Namba T. Studies on dental caries prevention by traditional medicines. VIII. Inhibitory effect of various tannins on glucan synthesis by glucosyltransferase from *Streptococcus mutans*. *Chem Pharm Bull* 1986; **34**: 720–725.
- Hada S, Kakiuchi N, Hattori M, Namba T. Identification of antibacterial principles against *Streptococcus mutans* and inhibitory principles against glucosyltransferase from the seed of *Areca catechu* L. *Phytother Res* 1989; **3**: 140–144.
- Kashket S, Paolini VJ. Inhibition of salivary amylase by water-soluble extracts of tea. *Arch Oral Biol* 1988; **33**: 845–846.
- Zhang J, Kashket S. Inhibition of salivary amylase by black and green teas and their effects on the intraoral hydrolysis of starch. *Caries Res* 1998; **32**: 233–238.
- Hara Y, Honda M. The inhibition of alpha-amylase by tea phenols. *Agr Biol Chem* 1990; **54**: 1939–1945.
- Ikigai H, Nakae T, Hara Y, Shimamura T. Bactericidal catechins damage the lipid bilayer. *Biochim Biophys Acta* 1993; **1147**: 132–136.
- Handley PS, McNab R, Jenkinson HF. Adhesive surface structures on oral bacteria In: Newman HN, Wilson M (eds) *Dental plaque revisited* Cardiff, Bioline. 1999: 145–170.
- Tsuchiya H, Sato M, Kato H, Okubo T, Juneja LR, Kim M. Simultaneous determination of catechins in human saliva by high-performance liquid chromatography. *J Chromatog B Biomed Sci Appl* 1997; **703**: 253–258.
- Kaneko K, Shimano N, Suzuki Y *et al.* Effects of tea catechins on oral odor and dental plaque. *Oral Ther Pharmacol* 1993; **12**: 189–197.
- Ooshima T, Minami T, Aono W *et al.* Oolong tea polyphenols inhibit experimental dental caries in SPF rats infected with mutans streptococci. *Caries Res* 1993; **27**: 124–129.
- Onisi M, Ozaki F, Yoshino F, Murakami Y. An experimental evidence of caries preventive activity of non-fluoride component in tea. *J Dent Hlth* 1981; **31**: 86–90.
- Rosen S, Elvin-Lewis M, Beck FM, Beck EX. Anticariogenic effects of tea in rats. *J Dent Res* 1984; **63**: 658–660.
- Kempler D, Anasie J, Westreich V, Gedalia I. Caries rate in hamsters given non-acidulated and acidulated tea. *J Dent Res* 1997; **56**: 89.
- Ooshima T, Minami T, Matsumoto M, Fujiwara T, Sobue S, Hamada S. Comparison of cariostatic effects between regimens to administer oolong tea polyphenols in SPF rats. *Caries Res* 1998; **32**: 75–80.
- Elvin-Lewis M, Steelman R. The anticariogenic effects of tea drinking among Dallas school children. *J Dent Res* 1986; **65**: 198.
- Onisi M, Shimura N, Nakamura C, Sato M. A field test on the caries preventive effect of tea drinking. *J Dent Hlth* 1981; **31**: 13–19.
- Onisi M. The feasibility of a tea drinking program for dental public health in primary schools. *J Dent Hlth* 1985; **35**: 134–144.
- Jones C, Woods K, Whittle G, Worthington H, Taylor G. Sugar, drinks, deprivation and dental caries in 14-year-old children in the north west of England in 1995. *Community Dent Health* 1999; **16**: 68–71.
- Ooshima T, Minami T, Aono W, Tamura Y, Hamada S. Reduction of dental plaque deposition in humans by oolong tea extract. *Caries Res* 1994; **28**: 146–149.
- Ramsay AC, Hardwick JL, Tamacas JC. Fluoride intakes and caries increments in relation to tea consumption by British children. *Caries Res* 1975; **9**: 312.
- Pashaev CA, Akhmedbeili RM. [The results of comprehensive caries prophylaxis in children under endemic goiter conditions.] *Stomatologiia* 1993; **72**: 61–64 [in Russian; abstract from Medline].