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The antimicrobial possibilities of green tea

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Green tea is a popular drink, especially in Asian countries, although its popularity continues to spread across the globe. The health benefits of green tea, derived from the leaves of the *Camellia sinensis* plant, have been studied for many years. Fairly recently, researchers have begun to look at the possibility of using green tea in antimicrobial therapy, and the potential prevention of infections. The particular properties of catechins found in the tea have shown promise for having antimicrobial effects. There are four main catechins (polyphenols) found in green tea: (-)-epicatechin (EC), (-)-epicatechin-3-gallate (ECG), (-)-epigallocatechin (EGC), and (-)-epigallocatechin-3-gallate (EGCG). Three of these, ECG, EGC, and EGCG have been shown to have antimicrobial effects against a variety of organisms. These catechins have exhibited a variety of antimicrobial mechanisms. The results of studies on the antimicrobial effects of green tea have shown that the potential for preventive and therapeutic purposes is present. Further data collection on studies performed with human consumption during the course of infections, and studies on the occurrence of infections in populations that consume regular amounts of green tea will be necessary to complete the picture of its antimicrobial possibilities.

Keywords: antimicrobial, green tea, synergism, catechins, EGCG

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INTRODUCTION

Tea is a very popular drink world-wide. It is produced from the plant *Camellia sinensis*, which is grown in at least 30 countries, and grows best in certain tropical and subtropical regions (Gupta et al., 2014). Tea is mainly produced as four varieties; white, green, Oolong, and black. White tea is made from very young tea leaves or buds; green tea is made from mature unfermented leaves; Oolong tea from partially fermented leaves; and black tea from fully fermented leaves (Jigisha et al., 2012; Gupta et al., 2014). Most of the black tea produced is consumed in the United States, Oolong tea is most popular in China and Taiwan, and green tea is most popular in China, Japan, and Korea (Cabrera et al., 2006). Among the health benefits that have been studied using green tea are: as an antioxidant, anti-inflammatory, anticarcinogenic, in cardiovascular health, oral health, and as an antimicrobial. Antioxidant effects come from the ability of green tea to limit the amount of free radicals by binding to reactive oxygen species (ROS) (Serafini et al., 2011; Jigisha et al., 2012; Gupta et al., 2014). Anti-inflammatory effects may be a result of increased production of IL-10, an anti-inflammatory cytokine. Inflammation is involved in, among other conditions, arthritis, cardiovascular disease, aging, and cancer (Serafini et al., 2011; Jigisha et al., 2012). The anticarcinogenic effects of green tea have been seen in many types of cancer, and the mechanisms may include inhibiting angiogenesis and cell growth, and inducing apoptosis in cancer cells (Serafini et al., 2011; Jigisha et al., 2012; Subramani and Natesh, 2013). Cardiovascular effects include the antioxidant and anti-inflammatory effects, and consumption of green tea has been shown to inhibit

atherosclerosis, reduce lipid levels overall, and improve the ratio of LDL to HDL (Serafini et al., 2011; Jigisha et al., 2012). The effects for oral health are related to both teeth and gums. The main cause of dental caries is the bacteria *Streptococcus mutans*. Green tea has a direct **antimicrobial** effect on this bacteria, plus it seems to inhibit the attachment of the bacteria to oral surfaces. In addition, green tea is a natural source of fluoride (Jigisha et al., 2012; Gupta et al., 2014). Green tea has been shown to have antimicrobial effects against a variety of gram positive and gram negative bacteria (e.g., *Escherichia coli*, *Salmonella* spp., *Staphylococcus aureus*, *Enterococcus* spp.), some fungi (e.g., *Candida albicans*), and a variety of viruses (e.g., HIV, herpes simplex, influenza) (Jigisha et al., 2012; Steinmann et al., 2013). These antimicrobial effects will be discussed in more detail later in this paper.

KEY CONCEPT 1 | Antimicrobial
Antibacterial agents attack microorganisms through four main mechanisms: inhibiting cell wall synthesis (β-lactams drugs, such as the penicillins and cephalosporins), inhibiting protein synthesis (aminoglycosides, tetracyclines, etc.), inhibiting nucleic acid synthesis (fluoroquinolones), or inhibiting metabolic pathways (trimethoprim, sulfonamides). Antiviral agents may target host cell entry, interfere with various stages of viral replication or assembly, or interfere with virus release from the host cell. Since fungi are eukaryotes, antifungal agents have to key in on differences between human and fungal cell processes. Because the parasites are a widely diverse group of organisms, antiparasitic agents are quite often specific for a certain parasite or related parasite group (e.g., nematodes).

GREEN TEA COMPOSITION

The medically important components of green tea are the polyphenols, most importantly the flavonoids. The main flavonoids in tea are the catechins, making up 30–40% of the water-soluble solids in green tea (Wang and Ho, 2009; Roowi et al., 2010). The different types of tea vary in the amount of catechins that they contain, with green tea containing the most, then Oolong tea, then black tea. The initial steaming process in the production of green tea destroys the enzyme polyphenol oxidase, thus protecting the polyphenol content. There are four main catechins in tea. (-)-epicatechin (EC), (-)-epicatechin-3-gallate (ECG), (-)-epigallocatechin (EGC), and (-)-epigallocatechin-3-gallate (EGCG). In green tea, EGCG is the most abundant, representing approximately 59% of the total catechins. EGC is next, making up approximately 19%. Then ECG, at 13.6%; and EC, at 6.4% (Cabrera et al., 2006; Jigisha et al., 2012). In addition to the type of tea, the amount of catechins can be affected by: where on the plant the leaves are harvested, leaf processing, geographical location, growing conditions, and tea preparation (Fernandez et al., 2002; Lin et al., 2003; Cabrera et al., 2006).

In order for any of the components of green tea to be a health benefit they have to have **bioavailability** This is most commonly assessed by measuring plasma, urine, and perhaps (in directed studies) tissue levels of the components after ingestion; usually by taking samples at regularly timed intervals. Various studies conducted using consumption of green tea beverage (Henning et al., 2004; Stalmach et al., 2009; Clifford et al., 2013), green tea extract (Lee et al., 1995; Yang et al., 1998; Henning et al., 2004), or specific catechins (Chow et al., 2001; Van Amelsvoort et al., 2001), have shown that ECG, EGCG, and metabolites of EC and EGC can be detected in blood plasma; and metabolites of EC and EGC only can be detected in urine. The peak concentration in blood plasma occurs at approximately 2 h after ingestion; and the peak concentration in urine occurs approximately 4–6 h after consumption. Some studies were performed using various dosages of the catechins, and show that the bioavailability of the catechins is directly proportional to the amount consumed (Nakagawa et al., 1997; Yang et al., 1998; Chow et al., 2001, 2003; Ullmann et al., 2003). **Table 1** shows a summary of the results of these various bioavailability studies, giving data specifically for EGCG and EGC. The most abundant catechins in green tea, EGCG and EGC, also occur in the greatest concentration in the body after consumption (EGCG in plasma, and EGC in both plasma and urine).

KEY CONCEPT 2 | Bioavailability
Bioavailability is a measure of how much of a substance can be found in blood, tissues, urine, etc., after being introduced into the body. Enough of the substance must be present at the site of an infection in order to be useful in fighting the microorganism(s) involved.

In a previous study (Reygaert and Jusufi, 2013), it was projected that using a brewed preparation of Japanese green tea (containing approximately 20 mg of EGC per gram of tea) would result in approximately 150 mg of ECG per cup of tea. The amount of EGC excreted in the urine would be approximately 3.5 mg per cup of tea.

ANTIMICROBIAL PROPERTIES OF GREEN TEA

In addition to the direct antimicrobial effects of catechins discussed below (damage to the bacterial cell membrane, inhibition of fatty acid synthesis, inhibition of enzyme activity, etc.), there are also some effects that may contribute to the total antimicrobial effect in infected individuals. These effects include inhibition of inflammation (particularly inflammation caused by oxidative stress, such as vascular), more specifically, by increasing the synthesis of nitric oxide (Yamakuchi et al., 2008), inhibiting angiotensin II and IL-6-induced C-reactive protein expression (Li et al., 2012), suppression of IL-6 and RANKL production in infected osteoblast-like cells (Ishida et al., 2007), inhibiting IL-8 production (Hirao et al., 2010), and inhibiting hyaluronidase activity (activated by chronic inflammation) by inhibition of IL-12 (Adcocks et al., 2002).

DAMAGE TO THE BACTERIAL CELL MEMBRANE

Many of the direct effects of tea catechins are a result of the catechins binding to the bacterial lipid bilayer cell membrane which then causes damage to the membrane (Sirk et al., 2008, 2009). This damage can then lead to a variety of related antimicrobial effects. Researchers studying *Escherichia coli* found that when exposed to green tea polyphenols, the bacterial response was changed regulation of 17 individual genes. Nine genes were upregulated and eight were downregulated. One of the major outcomes of this change in regulation was damage to the bacterial cell membrane (Cho et al., 2007). Tea catechins have less effect on gram negative bacterial cell membranes due to the fact that the LPS outer membrane of gram negative bacteria is negatively

Table 1 | Bioavailability of green tea catechins.

Catechin source	Initial dose	Plasma concentration (peak time) EGCG, EGC	EGC in urine/24 h (peak time)	References
Green tea (bottled)	EGCG 230 μmol EGC 257 μmol	EGCG ∼55 *n*mol/L (∼1.9 h) EGC ∼205 *n*mol/L (∼2.2 h)	∼33 μmol	Clifford et al., 2013
Green tea (brewed)	EGCG 214 mg EGC 270 mg	EGCG ∼80 *n*mol/L (∼1.3 h) EGC ∼740 *n*mol/L (∼1.3 h)	ND	Henning et al., 2004
Green tea extracts	EGCG 193 mg EGC 25 mg	EGCG ∼150 *n*mol/L (∼2.7 h) EGC 110 *n*mol/L (∼2.6 h)	ND	Henning et al., 2004
Green tea extracts	EGCG 88 mg EGC 82 mg	EGCG ∼135 ng/ml at 4 h EGC ∼ 140 ng/ml at 1 h	∼3.0 mg (3–6 h)	Lee et al., 1995
Green tea (bottled)	EGCG 235 μmol EGC 260 μmol	EGCG ∼55 nM (∼1.9 h) EGC ∼126 nM (∼2.2 h)	∼33 μmol	Stalmach et al., 2009
EGCG EGC	EGCG 688 mg EGC 459 mg	EGCG ∼1.3 μmol (∼3.9 h) EGC ∼5.0 μmol (∼1.7 h)	ND	Van Amelsvoort et al., 2001
Green tea extracts	EGCG 110 mg EGC 102 mg	EGCG ∼119 ng/ml (∼1.6 h) EGC ∼148 ng/ml (∼1.4 h)	∼3000 μg (4–6 h)	Yang et al., 1998

charged (Ikigai et al., 1993). Bacterial cell membrane damage inhibits the ability of the bacteria to bind to host cells (Sharma et al., 2012), and inhibits the ability of the bacteria to bind to each other to form biofilms, which are significant in pathogenesis (Blanco et al., 2005). Bacterial membrane damage also results in an inability of the bacteria to be able to secrete toxins (Sugita-Konishi et al., 1999; Shah et al., 2008). Directly related to the homeostasis of the bacterial cell membrane is fatty acid synthesis.

INHIBITION OF FATTY ACID SYNTHESIS

Fatty acids in bacteria have important functions; as a component of phospholipid cell membranes (and mycolic acid in cell walls of mycobacteria), and as an excellent energy source. Researchers have recently begun to look at the potential of targeting fatty acid biosynthesis for antimicrobial drug development (Wang and Ma, 2013). Researchers have found that green tea components (especially EGCG) inhibit specific reductases (FabG, FabI) in bacterial type II fatty acid synthesis (Zhang and Rock, 2004; Li et al., 2006). Inhibition of fatty acid synthesis by green tea has also been found to inhibit bacterial production of toxic metabolites (Sakanaka and Okada, 2004).

INHIBITION OF OTHER ENZYME ACTIVITY

In addition to the enzymes involved in fatty acid synthesis, research with green tea has been shown to have effects on other essential bacterial enzymes. Researchers found that green tea catechins have an inhibitory effect on protein tyrosine phosphatase and cysteine proteinases in certain anaerobic oral bacteria (Okamoto et al., 2003, 2004). Researchers have also found that green tea catechins have the ability to interfere with DNA replication by interacting with, and thereby inhibiting the function of DNA gyrase (Grandišar et al., 2007). Studies on antifolate activity in microorganisms have shown that green tea polyphenols can inhibit the enzyme dihydrofolate reductase in bacteria and yeast, effectively blocking the ability of the microorganisms to synthesize folate (Navarro-Martinez et al., 2005, 2006). More recently is has been discovered that bioflavonoids (including those from green tea) could inhibit the activity of bacterial ATP synthase, reducing the ability of the microorganisms to produce enough energy (Chinnam et al., 2010).

OTHER INHIBITORY EFFECTS

Researchers have found that green tea catechins have inhibitory effects on many other bacterial functions. One such effect is inhibiting synthesis of PBP2′ in methicillin-**resistant** *Staphylococcus aureus* **(MRSA)** This inhibition leads to reversal of resistance to β-lactam drugs (Yam et al., 1998). Another effect on bacteria is the inhibition by green tea catechins on the conjugative transfer of the R plasmid in *Escherichia coli* (Zhao et al., 2001a). This could lead to decreased sharing of antimicrobial genes between bacteria. Research on staphylococci has shown the ability of green tea catechins to inhibit the activity of efflux pumps. In this particular study the efflux pump was Tet(K) which is involved in resistance to tetracycline (Sudano Roccaro et al., 2004). This same type of activity could very well-occur with other efflux pumps, which could enhance the ability of certain drugs to have an antimicrobial effect. A study performed with

KEY CONCEPT 3 | Resistant

Microorganisms have a variety of methods that they use to overcome antimicrobial agents (antimicrobial-resistance). There are four main mechanisms that are used: inhibiting uptake of a drug, increased excretion of a drug (e.g., efflux pumps), structural or functional modification of the microorganism drug target, or inactivating the drug directly. This antimicrobial-resistance may be acquired from another similar organism, or a result of a mutation in one or more of the microorganism's own genes.

KEY CONCEPT 4 | MRSA

Methicillin-resistant *Staphylococcus aureus* (MRSA) have acquired a gene that allows production of an altered penicillin-binding protein (PBP), PBP2′. PBPs are transpeptidases that are used in the synthesis of the peptidoglycan layer of the bacterial cell wall. PBP2′ has a greatly reduced affinity for most of the β-lactam drugs, making these drugs ineffective against MRSA. This makes the treatment of infections with MRSA much more difficult and costly.

Helicobacter pylori found that green tea catechins blocked the ability of the bacteria to bind to the toll-like receptor-4 (TLR-4) on gastric epithelial cells (Lee et al., 2004). This would lead to a drastic reduction in that organism's ability to cause gastric disease. There are also inhibitory effects found with viruses. Research with HIV-1 has shown that green tea EGCG binds to the CD4 T-cell receptor, blocking the binding of the virus. This ability to block viral cell binding has been proposed for use in therapy for HIV-1 infection (Williamson et al., 2006).

SYNERGY OF GREEN TEA WITH ANTIMICROBIALS

Researchers have taken the concept of green tea catechins as having antimicrobial effects and expanded on this by performing studies that would determine if the green tea catechins might work synergistically with known antimicrobial agents. Many of these studies have focused on *Staphylococcus aureus* (particularly MRSA), *Staphylococcus epidermidis*, and *Escherichia coli*, among others. Examples of those studies have found that green tea catechins work synergistically with tetracycline against *S. aureus* and *S. epidermidis* (Sudano Roccaro et al., 2004; Fanaki et al., 2008); with penicillin against *S. epidermidis* (Haghjoo et al., 2013); with penicillin, oxacillin, ampicillin/sulbactam, and imipenem against MRSA (Hu et al., 2001, 2002; Zhao et al., 2001b; Stapleton et al., 2006; Aboulmagd et al., 2011); and with chloramphenicol, ciprofloxacin, and cefotaxime against isolates of *E. coli* having various levels of resistance, including extended-spectrum beta-lactamase **(ESBL)** producers (Fanaki et al., 2008; Cui et al., 2012a; Passat, 2012).

KEY CONCEPT 5 | ESBL

Extended-spectrum β-lactamase (ESBL) producing organisms are most often members of the gram negative *Enterobacteriaceae* family. Beta-lactamases are enzymes produced by the organism that are able to hydrolyze β-lactam drugs, rendering these drugs inactive. Like MRSA, the ESBLs have an increased resistance to penicillins and cephalosporins, but are sensitive to carbapenems and β-lactamase inhibitors (drugs that inhibit the activity of β-lactamases and are used together with a β-lactam drug, such as ampicillin/sulbactam). Many ESBL producers are also multidrug-resistant organisms (MRSOs), making treatment of these infections very difficult.

GREEN TEA CATECHINS ANTIMICROBIAL SCOPE

A large variety of research has been performed assessing whether or not green tea has antimicrobial activities. A summary of examples of this research is included in **Table 2**. The research results shown do suggest that green tea may be effective against many organisms. The research is pretty well-balanced between gram positive and gram negative organisms, with a few viruses, fungi and a parasite also represented. The main gram positive organism represented is *S. aureus*. That is not surprising considering the ongoing menace of MRSA. The most commonly studied gram negative organism is *E. coli*. These results represent potentially useful information for battling the emerging threat of ESBL and Carbapenem-resistant *Enterobacteriaceae* **(CRE)** organisms. In a previous study, green tea extract was shown to be effective against *E. coli* strains isolated from UTIs. Many of these isolates (59/80) were multi-drug resistant (MDROs), and six of the strains were ESBLs (Reygaert and Jusufi, 2013). The results shown in **Table 2**, along with the possible synergistic activities mentioned earlier, suggest that green tea could be extremely useful as an antimicrobial agent. There are certain things to keep in mind when viewing the results in **Table 2**. First, is the type of green tea and the preparation used. The research may have used green tea from various locations around the globe. For the experiments, the preparation may have included freshly brewed green tea, green tea extracts (water, alcohol), or purified extracts of certain of the green tea catechins. There are also various other factors that may affect the composition of the tea (refer to the section on green tea composition). The second thing to pay attention to is the type of result reported. There are four basic types of results shown: growth in colony-forming units (CFUs), or plaque-forming units (PFUs) for viruses; minimal inhibitory concentration (MIC); the size of zones of inhibition; and the optical density (O.D.) of growth in liquid cultures. The percentage of increase or decrease of any of these parameters may also be shown. In addition, for viruses, other growth or detection measures made be shown. Overall, the results indicate that green tea has great potential as an antimicrobial agent.

KEY CONCEPT 6 | CRE

Carbapenem-resistant *Enterobacteriaceae* (CREs) are similar to ESBLs. These organisms are resistant to all β-lactam drugs, and are not inactivated by β-lactamase inhibitors. The most common ESBL-producing organisms are *Escherichia coli* and *Klebsiella pneumoniae*. Treatment options are extremely limited for infections involving these organisms.

DISCUSSION

The data discussed shows that green tea catechins EGCG and EGC are bioavailable in plasma (both) and urine (EGC only) at potentially therapeutic levels and in a timely manner (see **Table 1**). Antimicrobial studies using various green tea extracts have shown that there is a huge potential for the use of green tea in antimicrobial therapy (see **Table 2**). In a previous study, the amount of EGC from brewed Japanese green tea excreted in the urine was calculated to be approximately 3.5 mg per cup of tea. Since the results of the study showed that most of the bacterial strains tested were susceptible to EGC levels of $\leq$0.72 mg, one cup of tea should be able to control growth of the bacteria for up to 6 h or even longer (Reygaert and Jusufi, 2013).

While the research results that have been discussed suggest that green tea may be effective against many organisms, there are certain issues that need to be addressed concerning these results. The first issue is how the results are displayed. The difficulty of assessing these types of results, and how these results relate to each other among the different research groups, can be confusing. This brings us to the second major issue. Various agencies, such as the Clinical and Laboratories Standards Institute (CLSI) in the United States, have strict protocols for the determination of antimicrobial susceptibility. Most of the research results that have been performed using green tea have not necessarily followed any of these types of guidelines. Therefore, the results of these experiments may differ from what the results would have been if strict protocols had been used. In the future, it will be most helpful if researchers would take the time to use these protocols. That will make comparing the results, and assessing if the results

Table 2 | Antimicrobial activity of green tea.

Source	Organisms studied	Antimicrobial activity	References
Water extraction	MRSA	MIC as low as 0.78 mg/ml	Aboulmagd et al., 2011
Methanol extraction	*Enterococcus faecalis*	MIC 15.63 μg/ml	Aman et al., 2013
Water/ethyl acetate extraction	*Actinomyces actinomycetemcomitans*	MIC 6.25 mg/ml	Araghizadeh et al., 2013
	Porphyromonas gingivalis	MIC 12.5 mg/ml	
	Prevotella intermedia	MIC 12.5 mg/ml	
	Streptococcus mutans	MIC 2.58-3.98 mg/ml	
Methanol extraction	*Escherichia coli*	MIC 0.8 mg/ml	Archana and Abraham, 2011
	E. faecalis	MIC 1.6 mg/ml	
	Salmonella typhi	MIC 1.2 mg/ml	
	Staphylococcus aureus	MIC 0.8 mg/ml	
Alcohol extraction	*E. coli*	MIC most $\leq$20 μg/ml	Bandyopadhyay et al., 2005
	S. aureus	MIC most $\leq$20 μg/ml	
	Vibrio cholerae	MIC most $\leq$30 μg/ml	
Standardized water extract	MRSA	MICs of 30 strains 50–180 μg/ml	Cho et al., 2008
Pure EGCG	*E. coli*	MIC 500 mg/ml	Cui et al., 2012b
	Pseudomonas aeruginosa	MIC 500 mg/ml	
	S. aureus	MIC 100 mg/ml	
	S. mutans	MIC 100 mg/ml	
Pure EGCG (Vero cells)	HSV-1	12× ↓ PFUs 50 μM	de Oliveira et al., 2013
Water extraction	*E. coli*	3× ↓ CFUs 10 mg/ml	Fanaki et al., 2008
Pure EGCG 50 μM	HIV-1 (infected lymphocytes)	No p24 core antigen detected	Fassina et al., 2002
Pure EGCG 10 μM	Hepatitis C virus (Huh 7.5.1 cells)	CPE reduced by 90%	Fukazawa et al., 2012
Pure EGCG	*Stenotrophomonas maltophilia* (40 isolates)	MIC $\leq$256 mg/ml	Gordon and Wareham, 2010
Pure EGCG	*Candida albicans*	MIC of 90% $\leq$250 mg/L	Hirasawa and Takada, 2004
Catechin mixture	*P. gingivalis*	MIC 1.0 mg/ml	Hirasawa et al., 2002
Water extraction 50 mg/ml	*Proteus mirabilis*	Zone 21.8 mm	Kim et al., 2008
	Streptococcus pyogenes	Zone 17.3 mm	
Pure EGCG 50 mg/ml	*Proteus mirabilis*	Zone 24.2 mm	Kim et al., 2008
	Streptococcus pyogenes	Zone 19.0 mm	
Pure EGCG 200 μM	*Listeria monocytogenes*	Decreased intracellular growth $10^6 \rightarrow 10^2$ CFUs	Kohda et al., 2008
Water extraction (in watermelon juice) to 0 CFUs	*E. coli*	250 mg/ml at 6 days	Kristanti and Punbusayakul, 2009
	L. monocytogenes	100 mg/ml at 4 days	
	S. aureus	75 mg/ml at 3 days	
	Salmonella typhimurium	175 mg/ml at 5 days	
Ethanol extract 4.5 mg	*E. coli*	Zone 13 mm	Kumar et al., 2012
	P. aeruginosa	Zone 10 mm	
	S. aureus	Zone 12 mm	
Ground tea leaves 1% wt/vol	*Bacillus cereus*	24% ↓ CFUs at 24 h	Lee et al., 2009
Water extraction	*L. monocytogenes*	MIC 0.68 mg/ml	Mbata et al., 2008
Methanol extraction		MIC 0.26 mg/ml	
Methanol extraction	*S. mutans*	MIC 100 mg/ml	Naderi et al., 2011
Pure EGCG	*Acinetobacter baumannii*	50% MIC 0.312 mg/ml 90% MIC 0.625 mg/ml	Osterburg et al., 2009
Water extraction 2 mg/ml	*Trypanosoma cruzi* (in mouse blood)	905 of organisms lysed	Paveto et al., 2004
Water extraction	MRSA	MIC 400 μg/ml	Radji et al., 2013
	MDR *P. aeruginosa*	MIC 800 μg/ml	
Water extraction	*Aspergillus niger*	MIC 50 mg/ml	Rao et al., 2014
	P. aeruginosa	MIC 50 mg/ml	
	S. aureus	MIC 50 mg/ml	
Standardized water extract	*E. coli* (79 UPEC strains)	MICs $\leq$2.5–4.0 mg/ml	Reygaert and Jusufi, 2013

(Continued)

Table 2 | Continued

Source	Organisms studied	Antimicrobial activity	References
Water extraction	Influenza viruses H1N1	0 PFUs at 500 μg/ml	Shin et al., 2012
Ethanol extraction	H3N2 (all in MDCK cells)	0 PFUs at 500 μg/ml	
Pure EGCG	H5N2	0 PFUs at 500 μg/ml	
Pure EGCG 12.5 μg/ml	MRSA	Oxacillin MIC reduced to 1 μg/ml	Stapleton et al., 2006
Water extraction 50 μg/ml	Influenza viruses H1N1	PFUs ↓ 100%	Song et al., 2005
	H3N2 (all in MDCK cells)	PFUs ↓ 90%	
	Influenza B	PFUs ↓ 95%	
Ethanol extract 9.375 mg	*Helicobacter pylori*	Zone 7.5 mm	Stoicov et al., 2009
Standardized green tea extract 40 μg/ml	Hepatitis B virus (in HepG2-N10 cells)	99% ↓ HBsAg 93% ↓ HBeAg	Xu et al., 2008
Water extraction	*S. aureus*	MIC 0.28 mg/ml	Yam et al., 1997
	S. epidermidis	MIC 0.41 mg/ml	
	Yersinia enterocolitica	MIC 0.41 mg/ml	
Pure EGCG 100 μg/ml	MRSA	O.D. ↓ 0	Zhao et al., 2001b
	MSSA	O.D. ↓ 0	
	S. epidermidis	O.D. ↓ 0	

are meaningful so much easier. In addition (and most importantly), in order for the results to be able to be translated into clinical use, the protocols will need to be followed. That having been addressed, it is still very encouraging to look at the research performed and see that green tea could very possibly be an effective antimicrobial agent, especially against multidrug-resistant strains, and in particular, MRSA and ESBL producing organisms. Hopefully, in the future, researchers will be able to study the effects of green tea on infections in humans. This type of research is a critical part of determining the antimicrobial capabilities of green tea. It might possibly be incorporated into research with other antimicrobial compounds. Perhaps naturopathic practitioners could begin to collect data on patients using green tea. With emerging multidrug-resistant organisms and the lack of effective new antimicrobial drugs being produced, we cannot afford to ignore the potential of green tea.

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