**Shiga toxin-producing *Escherichia coli* (STEC)**

Adèle Yates

*Escherichia coli* are bacteria that form part of the normal gut flora of humans and other warm-bodied animals. Although most *E. coli* are considered harmless, certain strains can cause severe illness, particularly Shiga toxin-producing *E. coli* (STEC). Infection with STEC is the main cause of haemolytic uraemic syndrome (HUS), a condition which can be fatal.

**Description of the organism**

*E. coli* are Gram-negative, rod-shaped bacteria and are members of the family Enterobacteriaceae. Other species of the genus *Escherichia* include *E. adecarboxylata, E. blattae, E. fergusonii, E. hermanii* and *E. vulneris*.

Pathogenic *E. coli* are classified into specific groups based on the mechanisms by which they cause disease and clinical symptoms. These categories include enterohaemorrhagic *E. coli* (EHEC), enteroaggregative *E. coli* (EAEC), enteroinvasive *E. coli* (EIEC), enteropathogenic *E. coli* (EPEC), enterotoxigenic *E. coli* (ETEC) and diffusely adhering *E. coli* (DAEC) (Montville and Matthews 2005). STEC are Shiga toxin producing *E. coli*, they are also known as verocytoxin-producing *E. coli* (VTEC). The STEC strains that cause haemorrhagic colitis (bloody diarrhoea) belong to the EHEC group (Yoon and Hovde 2008). EHEC is the most serious of the pathogenic *E. coli* in developed countries, however, in developing countries EPEC is a major issue in children (Meng and Schroeder 2007; Ochoa et al. 2008).

Strains of *E. coli* can be characterised serologically based on the detection of specific O (somatic), H (flagella) and K (capsule) antigens. For most *E. coli* strains the O and H antigens are sufficient to identify the strain. For example, *E. coli* O157:H7 is the leading cause of STEC infections internationally (Meng and Schroeder, 2007; Gyles 2007).

**Growth and survival characteristics**

The growth and survival of *E. coli* depends on a number of environmental factors such as temperature, pH, water activity and the composition of the food (refer to Table 1).

The temperature range for growth of *E. coli* is 7–8 to 46 °C, with an optimum temperature of 35–40 °C (ICMSF 1996). Heat resistance of *E. coli* in food is dependent on the composition, pH and water activity of the food. The heat resistance of *E. coli* increases as the water activity of the food decreases. Also, *E. coli* is more resistant to heat when it is in stationary phase compared to log phase growth (Desmarchelier and Fegan 2003). Low temperature has little effect on *E. coli* survival. Strawn and Danyluk (2010) showed that *E. coli* O157:H7 was able to survive on mangoes and papayas stored at -20 °C for at least 180 days.

*E. coli* grow in a broad pH range of 4.4–10.0, with an optimum pH of 6–7 (Desmarchelier and Fegan 2003). A study by Molina (2003) demonstrated STEC are tolerant to acidic conditions with many STEC strains able to survive at pH 2.5–3.0 for over 4 hours. *E. coli* O91:H21 was able to survive at pH 3.0 for more than 24 hours. Arnold and Kaspar (1995) found that *E. coli* O157:H7 is more tolerant to acid when it is in stationary phase or starved during log-phase growth. Therefore STEC may be able to survive and grow in food products previously considered too acidic to support the survival of foodborne pathogens. The effect of pH on *E. coli* survival, however, is dependent on the type of acid present. For example, *E. coli* O157:H7 can survive in a growth medium adjusted to pH 4.5 with hydrochloric acid but not when adjusted to the same pH with lactic acid (ICMSF 1996).
The minimum water activity (aw) required for growth of *E. coli* is 0.95, or approximately 8% sodium chloride. In sub-optimal temperature or pH conditions, a higher aw value is required for growth of *E. coli* (Desmarchelier and Fegan 2003).

*E. coli* are facultative anaerobic organisms so do not require oxygen for growth, however, they grow better in aerobic conditions (Meng and Schroeder 2007).

**Table 1: Limits for growth when other conditions are near optimum (ICMSF 1996; Desmarchelier and Fegan 2003)**

<table>
<thead>
<tr>
<th></th>
<th>Minimum</th>
<th>Optimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°C)</td>
<td>7–8</td>
<td>35–40</td>
<td>46</td>
</tr>
<tr>
<td>pH</td>
<td>4.4</td>
<td>6–7</td>
<td>10.0</td>
</tr>
<tr>
<td>Water activity</td>
<td>0.95</td>
<td>0.995</td>
<td>–</td>
</tr>
</tbody>
</table>

**Symptoms of disease**

Infection with STEC can lead to no clinical symptoms (asymptomatic infection) or can cause abdominal cramps, diarrhoea (may progress to bloody diarrhoea), vomiting and fever. The onset of illness is 3–8 days (median of 3–4 days), with most patients recovering in 10 days (WHO 2005; Meng and Schroeder 2007). In some cases, patients develop haemolytic uremic syndrome (HUS). HUS is characterised by haemolytic anaemia, thrombocytopenia (decrease in blood platelets) and kidney failure. HUS can also have neurological effects and cause seizures, stroke and coma (WHO 2005; Meng and Schroeder 2007). Approximately 6.3% of patients develop HUS with a fatality rate of 4.6%. Children are more susceptible, with 15.3% of children under five years of age developing HUS (Gould et al. 2009).

STEC are shed in the faeces of infected individuals for several weeks. In children the median shedding time is 13 days (range of 2–62 days) for individuals with diarrhoea. In people who develop HUS, bacterial shedding occurs for 21 days (range 5–124 days) (Meng and Schroeder 2007; Pennington 2010).

**Virulence and infectivity**

STEC strains produce two types of Shiga toxins (Stx1 and Stx 2). Stx1 is virtually identical to the toxin produced by *Shigella dysenteriae* 1. Stx2 is significantly associated with human disease (Spears et al. 2006). Stx are toxic to Vero cells (African green monkey kidney cells) and so are also known as verotoxins (VT). The term STEC is used interchangeably with VTEC. In the laboratory, Vero cells can be used to detect Stx activity, as Stx causes Vero cell death (Desmarchelier and Fegan 2003; Meng and Schroeder 2007).

Due to the acid resistance of STEC, when ingested it is able to survive the stomach environment and attach to the cells of the intestine. Some STEC strains form a characteristic attaching and effacing lesion on the intestinal cells. The presence of these lesions is a risk factor for the development of HUS (Gyles 2007). Once STEC has colonized the intestinal track, if sufficient Stx is produced it will bind to the vascular endothelial cells in the colon, resulting in the death of these cells. This damage to the blood vessels of the colon causes bloody diarrhoea. If sufficient Stx is taken up by the blood and circulated through the body, this can lead to impaired kidney and neurological function and the development of HUS (Desmarchelier and Fegan 2003; Gyles 2007).
Mode of transmission

STEC are transmitted by the faecal-oral route by either consumption of contaminated food or water, from direct contact with infected animals or via person-to-person contact (Gyles 2007).

Incidence of illness and outbreak data

Infection with STEC is a notifiable disease in all Australian states and territories. The incidence of STEC infections notified in Australia in 2008 was 0.5 cases per 100,000 population (106 cases), which includes both foodborne and non-foodborne cases. This is a slight increase from the 2003–2007 mean of 0.4 cases per 100,000 population per year (ranging from 0.2–0.5 cases per 100,000 population per year). *E. coli* O157 was the most common STEC identified in Australia in 2008 (26% of cases), the next most common were *E. coli* O111 and O26. There were 16 cases of STEC-associated HUS reported in Australia in 2008 (OzFoodNet 2009; NNDSS 2010).

The notification rate for STEC in New Zealand in 2008 was 3.0 cases per 100,000 population (128 cases). This was higher than the 2007 rate of 2.4 cases per 100,000 population. There were 3 cases of HUS associated with STEC reported in New Zealand in 2008 (ESR 2009).

In the US the notification rate for STEC in 2008 was 1.76 cases per 100,000 population. This was a slight increase from the 2007 rate of 1.62 cases per 100,000 population (CDC 2010). In the EU there were 0.7 cases of STEC infection per 100,000 population in 2008 (ranging from 0–4.8 cases per 100,000 between countries). This was a 8.7% increase in the number of cases from 2007 (EFSA 2010).

The incidence of STEC infections has a seasonal association, with the number of cases increasing during the warmer months. In Australia STEC is most prevalent from November to April (OzFoodNet 2009).

Outbreaks of STEC have been associated with undercooked hamburger meat, fresh produce, unpasteurised juices, salami, game meat, cheese and raw (unpasteurised) milk (Yoon and Hovde 2008; FDA 2009) (refer to Table 2).
Table 2: Selected major foodborne outbreaks associated with STEC (>50 cases and/or ≥1 fatality)

<table>
<thead>
<tr>
<th>Year</th>
<th>Strain</th>
<th>Total no. cases (fatalities)</th>
<th>Food</th>
<th>Country</th>
<th>Comments</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>O157:H7</td>
<td>80</td>
<td>Raw pre-packaged cookie dough</td>
<td>USA</td>
<td>STEC isolated from sample of cookie dough at the factory, however, it was different to the outbreak strain</td>
<td>(CDC 2009)</td>
</tr>
<tr>
<td>2006</td>
<td>O157:H7</td>
<td>205(3)</td>
<td>Pre-packaged spinach</td>
<td>USA</td>
<td>STEC isolated from river, cattle and wild pig faeces near spinach field</td>
<td>(California Food Emergency Response Team 2007)</td>
</tr>
<tr>
<td>1996-1997</td>
<td>O157:H7</td>
<td>490(20)</td>
<td>Cooked meat products</td>
<td>Scotland</td>
<td>Either inadequate cooking or cross-contamination from raw meat to cooked products</td>
<td>(Bell and Kyriakides 1998)</td>
</tr>
<tr>
<td>1995</td>
<td>O111:H-</td>
<td>161(1)</td>
<td>Uncooked fermented mettwurst</td>
<td>Australia</td>
<td>No starter culture used, pH drop during fermentation and water activity during drying not monitored. Product released before maturation was completed.</td>
<td>(South Australia Coroner 1995)</td>
</tr>
</tbody>
</table>

Occurrence in food

The major animal reservoir of STEC is ruminants, in particular cattle and sheep (Gyles, 2007). Individual animals can carry more than one serotype of STEC (Barlow and Mellor 2010). Meat derived from these animals may become contaminated with STEC organisms if the meat is exposed to faecal material during processing. A study of Australian beef cattle faecal samples showed 10% of samples (n=300) were STEC positive, E. coli O157 was isolated in 1.7% of all samples (Barlow and Mellor 2010). Barlow et al. (2006) isolated STEC from 16% of ground beef (n=285) and 40% of lamb cuts (n=275) sampled in Australia, although of serotypes not associated with reported human cases in Australia. The detection of STEC at a substantially higher rate in lamb is consistent with the higher concentration and prevalence of E. coli on sheep carcasses compared to beef carcasses (Phillips et al. 2001a; Phillips et al. 2001b). The reported prevalence of STEC in bulk tank milk internationally is 0–33.5% (FSANZ 2009).

STEC outbreaks have occurred due to the consumption of fruits and vegetables. Fresh produce may be contaminated due to irrigation with contaminated water or the use of soil treated with farm effluent (Fremaux et al. 2008). The presence of STEC on seafood and poultry at retail may be due to cross-contamination or harvesting seafood from contaminated waters (Desmarchelier and Fegan 2003). STEC has been found to survive for months in soil, manure, water trough sediments. It can survive for long periods of time in water and has been isolated from ponds, streams, wells and water troughs. Waterborne transmission of STEC has been reported, both from contaminated drinking water and from recreational water (e.g. swimming) (WHO 2005; Yoon and Hovde 2008; Fremaux et al. 2008).
Host factors and immunity

People of all ages are susceptible to infection with STEC. However, the young and the elderly are more likely to develop the more serious symptoms (FDA 2009).

Dose response

The dose response relationship for STEC is complicated by the number of serotypes and the association of STEC with a variety of foods.

Dose response models have been developed for *E. coli* O157:H7. Teunis et al. (2004) used data from an *E. coli* O157:H7 outbreak at a school in Japan to estimate the dose required to cause disease. In children the estimated ingested dose was 31 organisms, with 25% of exposed children becoming ill. In adults the estimated ingested dose was 35 organisms, with 16% of exposed adults becoming ill. Haas et al. (2000) used data from a prior animal study undertaken by Pai et al. (1986) and validated their model by comparison with two human outbreaks, one foodborne and the other waterborne, that occurred in the US. This model estimated that the dose required for 50% of the exposed population to become ill was 5.9 × 10^5 organisms. The corresponding probability of illness for the ingestion of 100 organisms was 2.6 × 10^-4. The US Food and Drug Administration (FDA) has suggested that from the compilation of outbreak data and taking into consideration the ability of *E. coli* O157:H7 to be passed from person-to-person, the infective dose may be similar to that of *Shigella* spp. (as few as 10 organisms (FDA 2009).

Human feeding trial data has been used to generate a dose response model for non-O157:H7 *E. coli* (E. coli O111 and O55) (Haas et al. 2000). The model estimated the dose required for 50% of the exposed population to become ill was 2.55 × 10^6 and the probability of illness for ingestion of 100 organisms was 3.5 × 10^-4.

Recommended reading and useful links


http://www.fda.gov/Food/FoodSafety/FoodborneIllness/FoodborneIllnessFoodbornePathogensNaturalToxins/BadBugBook/ucm071284.htm

http://www.who.int/topics/escherichia coli_infections/en/
References


Parts of this document have been published in previous FSANZ microbiological risk assessments for poultry meat and dairy (including raw milk products) – these are available on the FSANZ website [www.foodstandards.gov.au](http://www.foodstandards.gov.au)

Last updated February 2011