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EspJ Is a Prophage-Carried Type III Effector Protein of Attaching and Effacing Pathogens That Modulates Infection Dynamics

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Enterohemorrhagic Escherichia coli, enteropathogenic E. coli, and Citrobacter rodentium are highly adapted enteropathogens that successfully colonize their host’s gastrointestinal tract via the formation of attaching and effacing (A/E) lesions. These pathogens utilize a type III secretion system (TTSS) apparatus, encoded by the locus of enterocyte effacement, to translocate bacterial effector proteins into epithelial cells. Here, we report the identification of EspJ (E. coli-secreted protein J), a translocated TTSS effector that is carried on the 5′ end of the cryptic prophage CP-933U. Infection of epithelial cells in culture revealed that EspJ is not required for A/E lesion activity in vivo and ex vivo. However, in vivo studies performed with mice demonstrated that EspJ possesses properties that influence the dynamics of clearance of the pathogen from the host’s intestinal tract, suggesting a role in host survival and pathogen transmission.

Enterohemorrhagic Escherichia coli (EHEC), enteropathogenic E. coli (EPEC) (35), and Citrobacter rodentium (29) are highly adapted enteropathogens that successfully colonize their host’s gastrointestinal tract via the formation of attaching and effacing (A/E) lesions (reviewed in references 13 and 28). These lesions are characterized by the localized destruction (effacement) of intestinal epithelial microvilli, an intimate attachment between the bacterium and the host cell apical membrane, and the formation of pedestal-like structures containing high concentrations of actin (26) and intermediate filaments (2) directly beneath sites of bacterial attachment. Formation of A/E lesions is mediated by a filamentous type III secretion system (FTTSS) apparatus (20, 42) responsible for the translocation of bacterial effectors into eukaryotic cells, where they subvert host cell signaling (13). The TTSS apparatus is encoded on a pathogenicity island called the locus of enterocyte effacement (LEE). The LEE was first described in EPEC coded on a pathogenicity island called the locus of enterocyte effacement (LEE) (13). The TTSS apparatus is encoded by the locus of enterocyte effacement, to translocate bacterial effector proteins into epithelial cells. Here, we report the identification of EspJ (E. coli-secreted protein J), a translocated TTSS effector that is carried on the 5′ end of the cryptic prophage CP-933U. Infection of epithelial cells in culture revealed that EspJ is not required for A/E lesion activity in vivo and ex vivo. However, in vivo studies performed with mice demonstrated that EspJ possesses properties that influence the dynamics of clearance of the pathogen from the host’s intestinal tract, suggesting a role in host survival and pathogen transmission.

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Table 1. Strains and plasmids used in this study

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<td>pCX340</td>
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Strains: The EPEC E2348/69 and EHEC O157:H7 were used in this study. The EPEC strain E2348/69 and EHEC O157:H7 were used in this study. The bacterial strains and plasmids used in this study are shown in Table 1. Bacteria were grown in Luria-Bertani (LB) medium or in Dulbecco's modified Eagle's medium. When appropriate, additional antibiotics were added at the following concentrations: ampicillin, 100 µg/ml; kanamycin, 50 µg/ml; nalidixic acid, 50 µg/ml; and tetracycline, 12.5 µg/ml. Minimal medium consisted of M9 salts supplemented with 1% glucose.

MATERIALS AND METHODS

Bacterial strains, plasmids, and growth conditions. The bacterial strains and plasmids used in this study are shown in Table 1. Bacteria were grown in Luria-Bertani (LB) medium or in Dulbecco's modified Eagle's medium. When appropriate, additional antibiotics were added at the following concentrations: ampicillin, 100 µg/ml; kanamycin, 50 µg/ml; nalidixic acid, 50 µg/ml; and tetracycline, 12.5 µg/ml. Minimal medium consisted of M9 salts supplemented with 1% glucose.

Translocation assay. Translocation assays were performed as described by Charpentier and Oswald (6). Wild-type and ΔF59 EPEC E2348/69 strains carrying derivatives of the pCX340 plasmid, a cloning vector encoding the mature form of TEM-1 β-lactamase, were subcultured in LB medium supplemented with tetracycline and incubated for 16 h at 37°C. The cultures were diluted 1/100 in Dulbecco's modified Eagle's medium supplemented with 10% fetal calf serum and 2 mM glutamine at 37°C for 3.5 h (preactivation). HeLa cells grown on glass coverslips were infected with 1 ml of preactivated bacterial culture and incubated at 37°C in 5% CO2. After 30 min of infection, IPTG (isopropyl-β-D-thiogalactopyranoside) was added at a final concentration of 1 mM, and the coverslips were incubated for an additional hour. The cell monolayers were washed three times with phosphate-buffered saline (PBS) and covered with 100 µl of PBS plus 25 µl of 6× CCF2/AM solution freshly prepared from the CCF2/AM Loading kit (Invitrogen) (final concentration of CCF2/AM, 1 µM). The cells were incubated in darkness at room temperature for 2 h and then washed three times with PBS and observed under a Nikon Eclipse E600 fluorescence microscope using a UV-2A filter set (330- to 380-nm excitation). Pictures were taken using a Nikon DXM1200 digital camera.

Construction of nonpolar espF mutations. The EHEC 85–170 and C. rodentium espF mutants were constructed by using a modification of the one-step method (9). In each case, a part of the gene and the flanking regions from both sides were amplified from the wild-type genomic DNA by PCR using the following pairs of primers (Table 2): for the EHEC mutant, EHEC-espF-flank-1 plus EHEC-espF-flank-r1 (fragment 1) and EHEC-espF-flank-l2 plus EHEC-espF-flank-r2 (fragment 2). For each mutant, the two PCR fragments (fragment 1 and fragment 2) were digested with BamHI, ligated to each other, and cloned into the cloning vector pGEMT. Then, in order to inactivate the gene and facilitate mutant strain identification, the nonpolar aphT cassette (14) conferring kanamycin resistance was inserted between the fused fragments (1 and 2) contained in pGEMT, at the BamHI site.

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The EPEC E2348/69 espF mutant was constructed by using the one-step method (9). Briefly, a PCR product was generated by amplifying pKD4 template plasmid using long primers (EPEC-espF-pKD4-l and EPEC-espF-pKD4-r) that
corresponded to 20 nucleotides of pKD4 and 50 nucleotides of flanking DNA regions homologous to the 5′ and 3′ ends of the esp1 gene. The PCR product contains a kanamycin resistance gene (derived from pKD4) flanked by 50-bp sequences located upstream and downstream of the esp1 gene. The PCR product was then transformed by electroporation into EPEC E2348/69 containing the pKD46 plasmid. Clones were grown on LB medium containing kanamycin to select for kanamycin resistance. pKD46 was cured by growth at 42°C. Mutation was verified by PCR.

**FAS test and IVOC assay.** Fluorescent actin staining (FAS) testing was performed on infected Hep-2 cells as described by Knutton et al. (25). For the human intestinal in vitro organ culture (IVOC) assay, tissue was obtained with fully informed parental consent and local ethical committee approval using grasp forceps during routine endoscopic (Fujinon EG-E4 pediatric endoscope) investigation of intestinal disorders. Terminal ileal mucosal biopsy specimens from the Peyer’s patch region that appeared macroscopically normal were taken for organ culture experiments. Light microscopy subsequently showed no histological abnormality. IVOC infections were performed as described previously (19). 85–170 μl of ESP1 (ICC188) was examined using tissue from three patients (aged 46, 110, and 141 months). In each experiment, an unoinoculated sample (to exclude endogenous bacterial adhesion) and a positive control (IVOC with the EPEC-espJ-pKD4-r region homologous to the 5′-lactamase and the detection of TEM-1 activity) were included. Samples were fixed with 2.5% glutaraldehyde, postfixed in 1% aqueous osmium tetroxide, and processed for viewing by a JOEL JSM 5300 scanning electron microscope.

**Mouse.** Two murine models that differ in their susceptibility to *C. rodentium* were used in this study. Female 6- to 8-week-old C57BL/6J mice and male 5- to 6-week-old C3H/HeJ mice were purchased from Harlan Olac (Bicester, United Kingdom) and came from specific-pathogen-free stocks. During the course of these studies, sentinel animals were screened for common murine pathogens every 2 months. All animals were housed in individually HEPA-filtered cages with sterile bedding and free access to sterilized food and water.

**Oral infection of mice.** Mice were orally inoculated using a gavage needle with 200 μl of bacterial suspension (≈10⁸ CFU for C57BL/6J mice (46) and ≈2 × 10⁸ CFU for C3H/HeJ mice (34). The viable count of the inoculum was determined by retrospective plating on LB agar containing the appropriate antibiotic. Independent experiments were performed at least twice using groups of at least four mice per strain. Stool samples were recovered aseptically at various times after inoculation, and the number of viable bacteria per gram of stool was determined by plating the stool onto LB agar containing the appropriate antibiotic. At selected times postinfection, mice were killed by cervical dislocation. The colon and cecum were aseptically removed and weighed after the removal of fecal pellets and cecal contents. The organs were then homogenized mechanically in 5 ml of sterile PBS using a Seward (London, United Kingdom) 80 stomacher, and the number of viable bacteria per gram of organ homogenate was determined by plating the homogenate onto LB agar containing the appropriate antibiotics.

**Oral inoculation of sheep.** Ten 6-week-old crossbred lambs were randomly divided into two equal groups, supplied with food and water ad libitum, and confirmed to be free of EHEC O157 by enrichment and O157 immunomagnetic separation. All of the lambs were housed in bioscience containment level 2 accommodations. Each group was housed in a separate room with its own air handling. The animals were visited only by experienced staff, who changed clothing between groups. Five lambs were each dosed orally with either 10⁹ CFU of 85–170 Nalr or 85–170 Δesp1-Kanr resuspended in 10 ml of PBS (pH 7.4). Approximately 2 h after the dosing, and as required thereafter for up to 27 days, rectal fecal samples from each lamb were collected for direct plating onto sorbitol-MacConkey (Oxoid) plates supplemented with either 15 μg of nalidixic acid/ml or 25 μg of kanamycin/ml (Sigma). Samples that were negative on direct plating were enriched in buffered peptone water for 6 h at 37°C and then plated onto sorbitol-MacConkey plates supplemented with the appropriate antibiotic. Representative colonies were confirmed to be *E. coli* O157 by latex agglutination (Oxoid). All animal experiments were performed in accordance with the Animals Scientific Procedures Act (1986) and were approved by the local ethical review committee.

**Statistics.** The unpaired Student t test was used to compare normally distributed values from groups of animals. The nonparametric Mann-Whitney and Kruskal-Wallis tests were used to compare nonnormally distributed values.

**RESULTS**

**Z3071 is present in EHEC, EPEC, and **C. rodentium,** and its product is similar to HopF, an effector protein of *P. syringae.** Z3071 (Ecs2714) is located within the 5′ end of the cryptic prophage CP-933U in EDL937 (33) and RIMD 0509952 Sakai (18), two clinical EHEC O157:H7 isolates that were recently sequenced. Z3071 is also present in EPEC O127:H6 strain E2348/69 (http://www.sanger.ac.uk/projects/Escherichia _Shigella) and *C. rodentium* (http://www.sanger.ac.uk/Projects/C_rodentium), but not in the *E. coli* K-12 genome (3), with 79.3 and 75.1% identity at the amino acid level, respectively. Z3071 encodes a 217-amino-acid protein with unknown function and is located upstream of Z3072 (tcpP/espF), encoding an EHEC type III effector protein that is required for EHEC-induced actin polymerization (5, 15). Similar to tcpP and most of the LEE-located genes, Z3071 is also down-regulated in bacteria closely attached to plasma membranes (8). Importantly, a search of the database revealed that Z3071 has 22% identity with HopF, an effector protein of *P. syringae* (http://ca.expasy.org; 43). The data suggested that Z3071 might be a virulence factor of EHEC, EPEC, and *C. rodentium,* and it was therefore chosen for further investigation.

**Z3071 is translocated into epithelial cells.** To determine whether Z3071 is translocated into epithelial cells, the novel TEM-1 translocation assay was applied (6). The system is based on a translational fusion of effector proteins with a mature TEM-1 β-lactamase and the detection of TEM-1 activity within eukaryotic cells by using the fluorescent β-lactamase substrate CCF2/AM. If translocation occurs, the translational fusion will be present in the eukaryotic cells, and the cells will appear blue. If translocation does not occur, the cells will appear green.

HeLa cell monolayers were infected with wild-type and ΔescF (ICC171) mutant (47) EPEC strains carrying the pICC283 plasmid encoding the TEM-1 fusion with Z3071. In addition, cells were infected with EPEC containing pCX340 (empty vector; negative control) or pCX327 (containing the
first 16 residues of Cif; positive control) (6). Cells infected with EPEC(pCX340) appeared green (data not shown), indicating a lack of TEM-1 activity in these cells. Cells infected with EPEC(pCX327) appeared blue (data not shown), indicating that TEM-1 was translocated into the host cells. Cells infected with EPEC carrying the translation fusion Z3071–TEM-1 also appeared blue, indicating that Z3071 is a new translocated effector (Fig. 1A). The translocation of Z3071 was dependent with EPEC carrying the translation fusion Z3071–TEM-1 also appeared blue, indicating that Z3071 is a new translocated effector (Fig. 1A). The translocation of Z3071 was dependent.

**EspJ is not required for the formation of A/E lesions in vitro.** In order to characterize the EspJ function, an espJ mutant was generated in EHEC O157:H7 strain 85–170, EPEC strain E2348/69, and C. rodentium ICC169 by deleting the open reading frame. The resulting mutant strains were analyzed for growth in vitro in both rich and minimal media and were found to have growth rates identical to those of the parental strains, as measured by optical density (data not shown).

An espJ mutant and the wild-type EHEC and EPEC strains were assessed for A/E lesion formation in vitro. Infecting HEp-2 cells with the mutant and the wild-type strains and employing the FAS test (25) revealed actin-rich pedestals under adherent EHEC ∆espJ (strain ICC188) (Fig. 1C) and EPEC ∆espJ (strain ICC190) (data not shown) that were indistinguishable from those formed by the wild-type strains (Fig. 1D), indicating that espJ is not required for this activity in vitro.

EspJ is not required for the formation of A/E lesions ex vivo. The IVOC adhesion assay is based on the infection of human intestinal biopsy specimens with pathogens and offers a more physiological model for EHEC-EPEC infection. Using this model, Phillips et al. demonstrated that EHEC O157:H7 binds to the follicle-associated epithelium of Peyer's patches (39). In order to assess the contribution of EspJ to the colonization of human intestinal explants, ∆espJ (ICC188) and 85–170 wild-type strains were used to infect terminal ileal mucosal biopsy specimens, which contained both villous and lymphoid follicular areas. Bacterial adhesion was not seen on the un inoculated negative control samples (Fig. 1E). The infection showed that the ∆espJ mutant attaches to and causes A/E lesions on the follicle-associated epithelium of distal ileal samples (Fig. 1F), but not on ileal villous surfaces, a phenotype identical to that of the parent strain, 85–170 (data not shown). Therefore, EspJ is not required for A/E lesion activity ex vivo.

**Contribution of EspJ to colonization of C3H/HeJ mice.** Infection experiments were performed in the murine model to determine the level of virulence of a C. rodentium ∆espJ mutant. The ability of the mutant strain to establish itself and expand in mice was investigated by monitoring the viable counts recovered from stools. In the sensitive C3H/HeJ mouse strain, the ∆espJ C. rodentium mutant (ICC189) produced the classic growth curve previously reported for the wild-type strain (1); however, the size of the challenging population increased steadily to peak at ca. 10^{9} to 10^{10} CFU g of stool^{-1} at day 8, significantly higher than the levels for the wild-type strain (P = 0.019) (Fig. 2). Ten days postinfection, the mice had become too ill for us to continue (as determined by weight loss, piloerection, and lack of mobility), so the experiment was terminated. The pathogen burdens of the organs of C3H/HeJ mice (n = 12) infected with the wild type and with ICC189
(ΔespJ) were determined, as were the abilities of the strains to cause hyperplasia. Mice infected with ΔespJ had significantly higher pathogen burdens in the colon than mice infected with wild-type bacteria \((6.86 \times 10^9 \pm 1.96 \times 10^9\) compared to \(4.32 \times 10^9 \pm 1.92 \times 10^9\) CFU g of organ homogenate\(^{-1}; P = 0.007\)) but similar burdens within the cecum \((2.70 \times 10^9 \pm 1.67 \times 10^9\) compared to \(2.01 \times 10^9 \pm 1.13 \times 10^9\) CFU g of organ homogenate\(^{-1}; P = 0.273\)) (Fig. 2). However, there was no significant difference between the induced levels of colonic hyperplasia, as indicated by increased colon weight (data not shown).

**Dynamics of clearance of C. rodentium ΔespJ in C57BL/6J mice.** Since C3H/HeJ mice infected with ΔespJ and wild-type bacteria became too ill for us to follow the clearance of the pathogens, the more resistant C57BL/6J strain was used to follow the dynamics of colonization and clearance after infection \((n = 10)\). The ability of the ΔespJ mutant strain (ICC189) to establish itself and expand in mice was investigated by monitoring the viable counts recovered from stools. For the first 10 days postinfection, the ΔespJ mutant produced the classic growth curve previously reported for the wild-type strain (46), with the size of the challenging population increasing steadily to peak at \(10^9\) CFU g of stool\(^{-1}\) on day 10 (Fig. 3A). Fourteen days postinfection, the pathogen burdens of the organs of infected mice were determined, as were the abilities of the strains to cause hyperplasia. Mice infected with ΔespJ bacteria had significantly higher pathogen burdens in the colon than mice infected with wild-type bacteria \((2.18 \times 10^8 \pm 1.22 \times 10^8\) compared to \(4.80 \times 10^7 \pm 5.73 \times 10^7\) CFU g of organ homogenate\(^{-1}; P = 0.05\)). Although the pathogen burdens within the cecum were higher for mice infected with ΔespJ bacteria, this difference was not significant \((9.73 \times 10^7 \pm 1.13 \times 10^7\) compared to \(1.19 \times 10^8 \pm 1.34 \times 10^8\) CFU g of organ homogenate\(^{-1}; P = 0.163\)) (Fig. 3B). Twenty days postinfection, mice infected with wild-type bacteria had completely cleared infection in both the cecum and colon, while three of five and four of five mice infected with ICC189 still had bacteria present within the colonic mucosa (ranging from \(1.79 \times 10^3\) to \(2.27 \times 10^7\) CFU g of organ homogenate\(^{-1}\)). In addition, four out of five mice infected with ΔespJ still had bacteria present within the cecum (ranging from \(1.41 \times 10^3\) to \(1.42 \times 10^7\) CFU g of organ homogenate\(^{-1}\)) (Fig. 3B). However, there was no significant difference between the induced levels of colonic hyperplasia, as indicated by increased colon weight (data not shown), on either day 14 or day 20 postinfection.

**The contribution of EspJ to the colonization of conventional 6-week-old lambs.** Infection experiments were performed in the conventional 6-week-old lamb model to determine the persistence of *E. coli* O157:H7 strain 85–170 and an espJ mutant. The abilities of the isolates to establish themselves and persist in lambs were investigated by monitoring the viable counts recovered in stools collected per rectum. Typically, wild-type EHEC produced the classic shedding pattern (48), persisting in relatively high numbers in the early stages of infection and then declining until it became detectable in only one lamb by day 9 postinfection (Fig. 4). EHEC was then undetectable by direct plating or enrichment for the duration of the study (27 days). In contrast, while EHEC ΔespJ behaved like the wild type in the early stages of infection, three lambs still had detectable EHEC ΔespJ on day 9 postinfection (Fig. 4) and one lamb continued to shed bacteria (as detected by enrichment) until the end of the study 27 days postinfection (data not shown). However, these differences were not statistically significant at any of the time points.

**DISCUSSION**

Using a DNA microarray specifically designed for *E. coli* O157:H7, we have recently identified two novel genes (Z3071 and Z3072) implicated in virulence that are located adjacent to each other within prophage CP-933U and are absent from the *E. coli* K-12 genome (8). Further studies demonstrated that Z3072 (TccP/EspF\(_1\)) is a type III effector protein that has an Nck-like activity following translocation, recruiting N-WASP,
Arp2/3 complex, and actin to the site of bacterial adhesion (5, 15). The purpose of this study was the characterization of the role of Z3071 (EspJ) in virulence.

Of particular interest is the fact that, while espJ is found in the genomes of EHEC O157:H7, EPEC, and C. rodentium, the gene downstream, tccP/espF, is found only in EHEC O157:H7. Selective evolutionary pressures must have operated on espJ and tccP/espF in the genetic backgrounds of EPEC and EHEC once prophage CP-933U was introduced which maintains espJ and tccP/espF in EHEC O157:H7, EPEC, and C. rodentium and espF/tccP in EHEC O157:H7 only.

In this study, we have demonstrated, by employing the TEM-1 reporter system, that EspJ is translocated into HeLa cells (6). Therefore, espJ encodes the fourth identified TTSS effector protein outside the LEE, after Cif (30), NleA/EspI (16, 34), and TccP/EspF (5, 15). In addition, by carrying out effector protein outside the LEE, after Cif (30), NleA/EspI and EspJ, the genomes of EHEC O157:H7, EPEC, and C. rodentium, the Arp2/3 complex, and actin to the site of bacterial adhesion (5, 15). The purpose of this study was the characterization of the role of Z3071 (EspJ) in virulence.

An unexpected effect of EspJ on virulence was revealed in vivo. In the murine model of infection, higher levels of colonization by the ΔespJ mutant (ICC189) were found in the gastrointestinal tract sites than for the wild-type strain in both susceptible and more resistant mouse strains. As infection of C3H/HeJ mice rendered the animals too ill to be followed for extended periods, the dynamics of colonization by and clearance of ΔespJ were studied in the more resistant C57BL/6J mice. This model indicates that the dynamics of clearance of the ΔespJ mutant and the wild type are very different. While mice infected with wild-type bacteria had completely cleared infection at 20 days postinfection, C. rodentium was still recovered from the colon and cecum of mice infected with the ΔespJ mutant at the same time. It therefore appears that the ΔespJ mutant exhibits a more persistent colonization phenotype than the wild-type strain. It is worth noting that the wild-type and mutant strains grew equally well on LB and M9 minimal media, indicating that the phenotype obtained is not caused by a higher growth rate. In addition, for both the wild-type and ΔespJ mutant strains, the symptoms of disease, including levels of colonic hyperplasia, were identical. This suggests that the phenotype of the ΔespJ mutant may be due to a difference in the dynamics of clearance of the colonizing bacteria and not the initial inoculum or rates of progression of infection. Recently, the dynamics of colonization and the subsequent clearance of C. rodentium from orally infected mice were followed by using bioluminescence imaging. In this study, it was shown that the cecal patch is the first site to be colonized and the first to be cleared, followed by colonization and clearance of the colon. It has been suggested that this organ acts as a reservoir, shedding bacteria into the colon (46).

It is important to note that C. rodentium mutants with different colonization and clearance dynamics in the murine model have been previously reported (34). C. rodentium strains lacking the genes espJ (strain ICC179) and map (strains P6C6 and P10H2) exhibited a different colonization phenotype in mice than wild-type bacteria, with viable counts recovered from the stools over an extended period. However, these strains also differ in their initial colonization dynamics, with the mutant strains being slower to become established and hence reaching a peak several days behind that of the wild-type strain. In contrast, the rates of progression of colonization of mice were identical for ΔespJ and wild-type bacteria. In addition, the mutant map and espJ strains also produced lower levels of hyperplasia, whereas the level observed with the ΔespJ mutant was indistinguishable from that of the wild type. This strengthens the observation that the ΔespJ mutant exhibits a clearance defect phenotype unrelated to its in vivo growth rate.

Colonization of the cecum and the colon is also a characteristic of the infection of neonatal and weaned lambs with EHEC O157:H7. Although this infection is not associated with clinical disease, A/E lesions were detected in the cecum and rectum in 6-week-old lambs infected with EHEC O157:H7 (48). Previous studies of 6-week-old lambs have confirmed a
role for intimin in the persistence of EHEC O157:H7 in the ovine intestine (48). In order to confirm the findings observed in the murine infection model, we also injected 6-week-old conventional lambs with the wild-type or espJ mutant E. coli O157:H7 strain 85–170. In this model, the espJ mutant was found to behave like the wild type in the early stages of infection but was recoverable from three out of five lambs on day 9 postinfection and persisted for 27 days postinfection in one lamb, whereas the wild type was found in only one out of five lambs 9 days postinfection. These data strengthen the observation that the espJ mutant exhibits a clearance defect phenotype.

Here, we report a TTSS effector that possesses properties that influence the dynamics of clearance of the pathogen from the host’s intestinal tract in a novel manner. Our data indicate that the espJ mutant persists longer in mammalian hosts; hence, the espJ gene exhibits “antivirulence” properties. Antivirulence genes have been described in other pathogenes, including Salmonella enterica (33) and Streptococcus pyogenes (12), and two main hypotheses have been put forward for their existence: they may favor host survival and thereby aid pathogen transmission, or they may contribute to pathogen fitness in nonhost environments. Indeed, the Salmonella antivirulence gene pegL was found to be required for survival in nutrient-limited environments (33). However, we found no such requirement for espJ for growth in nutrient-poor media, and the presence of C. rodentium espJ in the organs of mice after the wild-type strain had been cleared suggests that in the case of espJ a role in host survival, and hence in aiding pathogen transmission, may be more likely.

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Here, we report a TTSS effector that possesses properties that influence the dynamics of clearance of the pathogen from the host’s intestinal tract in a novel manner. Our data indicate that the espJ mutant persists longer in mammalian hosts; hence, the espJ gene exhibits “antivirulence” properties. Antivirulence genes have been described in other pathogenic enteropathogenic and enterohemorrhagic Escherichia coli O157:H7 and genomic comparison with a laboratory strain K-12. DNA Res. 28:11–22.


