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Published By: American Association of Avian Pathologists


URL: http://www.bioone.org/doi/full/10.1637/0005-2086%282007%2951%5B771%3ACOASOT%5D2.0.CO%3B2
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Escherichia coli Isolate for Resistance to Serum Complement

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SUMMARY. Colibacillosis, caused by avian pathogenic Escherichia coli (APEC) is a major problem for the poultry industry resulting in significant losses annually. Previous work in our lab and by others has shown that the increased serum survival gene (iss) is a common trait associated with the virulence of APEC. This gene was first described for its contributions to E. coli serum resistance. However, recently published research has called the contribution of iss to this trait into question. In the present study, the level of serum resistance conferred on an E. coli isolate by iss is examined. Additionally, the contribution of h, bor gene to E. coli serum resistance is studied, as iss is thought to be derived from bor and bor occurs commonly among E. coli. To better understand the iss and bor contributions to serum resistance, a series of iss and bor mutants was generated. An iss deletion (iss−) mutant showed a significant drop in its resistance to serum. Similarly, a bor mutant showed a drop in serum resistance but not as drastic as that observed with the iss mutant, suggesting that iss contributes more to serum resistance than bor in this E. coli strain. Also, when iss was reintroduced into the iss− mutant the wild-type level of serum resistance was restored, confirming that the deletion of iss was responsible for the change in resistance seen in the mutant.

Key words: iss, bor, Escherichia coli virulence, avian colibacillosis, Escherichia coli, APEC, Bor, complement resistance, Iss, serum resistance

Abbreviations: APEC = avian pathogenic Escherichia coli; LB = Luria Bertani; PCR = polymerase chain reaction; PG = peptone glucose

Colibacillosis accounts for multimillion dollar losses in the poultry industry annually (1). Despite this fact, the basic mechanisms of virulence used by avian pathogenic Escherichia coli (APEC) to cause disease in poultry remain ill defined. However, the ability of avian E. coli to resist the bactericidal effects of serum complement appears to play a significant role in the development of colibacillosis in poultry (13,16,25,26,27,28,33,36,37). Serum resistance in E. coli has been related to several structural factors including a K1 antigenic capsule (10,22), a smooth lipopolysaccharide layer (11,14), and certain outer membrane proteins, including TraT, Iss, and OmpA (3,5,8,9,34). Recent work in our laboratory has shown that the presence of iss is strongly correlated with an APEC isolate’s ability to cause disease in poultry (29,30).

The increased serum survival gene, iss, first described for its role in the serum resistance associated with a ColV plasmid in a human E. coli isolate, increases the virulence of an E. coli isolate for day-old chicks 100-fold and its complement resistance over 20-fold (2,4,8,9). Iss, the protein product of iss, is thought to occur as a 10 to 11 kD lipoprotein in the bacterial outer membrane (3,15). iss may be a derivative of bor, a gene of bacteriophage λ (2,3,8,15). Bor, a lipoprotein of the cell envelope of E. coli λ lysogens, appears to confer complement resistance on these lysogens (2). Amino acid sequences of Iss and Bor are about 90% identical (15).

The iss gene has recently been localized to large plasmids that typify the APEC pathotype (17,20). To date, it is known that these iss-containing APEC plasmids may encode ColV or ColBM. Regardless
of the colicin encoded, these plasmids contain a pathogenicity island characterized by possession of iss, several iron acquisition operons, and other genes (17). These plasmids are often conjugative and confer upon the recipient strain such traits as colicin production, aerobactin production, and increased serum resistance (17). Recently, Mellata et al. (24) questioned the role of iss/Iss in the ability of an APEC isolate to resist serum complement. In their study, strains that contained iss and traT genes but had lost their K1 or O serotype were not protected against the bactericidal effect of serum. However, these strains were less sensitive to serum than iss and traT negative control strains. Based on these results, the authors concluded that Iss plays a limited role in the serum resistance of the APEC strain they studied.

In an effort of clarify the role of Iss in *E. coli* complement resistance and to better understand the mechanisms of APEC virulence, a series of transconjugant iss and bor mutants of an APEC isolate were studied (23).

**MATERIALS AND METHODS**

**Bacterial strains.** Strains used in this study are summarized in Table 1 and include APEC-O2, an *iss* † virulent APEC strain isolated from the joint of a chicken with colibacillosis. APEC-O2 possesses pAPEC-O2-R, a 101-kb, multidrug-resistance–encoding plasmid (19), and pAPEC-O2-ColV, a 180-kb, ColV-encoding plasmid (20). pAPEC-O2-ColV contains a 93-kb cluster of putative virulence genes, which includes *iss* (20). Both plasmids are transmissible by conjugation (19,20). Also, *E. coli* DH5α (7), a plasmidless, avirulent K12 strain that is *iss* † and *bor* †, and a series of mutants previously created (23) were used in this study. Knockout mutants were created by deletion of *iss* from pAPEC-O2-ColV in APEC-O2 and deletions of *bor* from the chromosome of *E. coli* DH5α by a one-step inactivation method using λ-derived recombination proteins and polymerase chain reaction (PCR) products. Transconjugants were generated using an APEC-O2 or APEC-O2Δiss as the plasmid donor and *E. coli* DH5α or DH5αΔbor as the plasmid recipients (23). When not in use, these organisms were stored at −70°C in brain heart infusion broth (Difco Laboratories, Detroit, MI) with 10% glycerol. When in use, these organisms were grown on either MacConkey or Luria Bertani (LB) agar (Difco) overnight at 37°C.

**Fig. 1.** Growth in PG broth.
and viewed under UV light. A 720-bp band, corresponding in size to the predicted \textit{iss} amplicon, was excised from the gel and purified from the agarose using MiniElute Gel Extraction Kit (Qiagen, Valencia, CA). \textit{Nsi}I- and \textit{Sac}II-digested \textit{iss} was ligated into pZC320 using standard procedures (32) to form pZCiss. Ligations were transformed in \textit{E. coli} BL21 (DE3) using the calcium chloride method (31). Transformants were selected on LB agar containing ampicillin (100 \mu g/ml).

**Serum resistance assay by microtiter method.** Strains were assessed for their ability to resist the bactericidal effects of complement by a microtiter plate method previously described (21). Briefly, 2-hr cultures of isolates grown in LB broth were diluted to $10^3$ colony-forming units (CFU)/ml in peptone glucose (PG) broth. One hundred microliters of these cultures was inoculated into flat-bottomed 96-well microtiter plates. A 100-\mu l amount of 50\% chicken serum diluted in phosphate-buffered saline (PBS) was added to each well. Medium and culture controls were also included. Plates were monitored for growth using a microplate reader set at 490 nm. Plates were incubated at 37 C and read every 30 min for 4 hr.

**Serum resistance assay by plate count method.** Strains were assessed for their ability to resist the bactericidal effects of complement by a plate count method previously described (21) in order to verify the results of the microtiter method. The strains were grown overnight in a 2-ml culture of LB broth. The next day, cell densities were calculated by spectrophotometry, and cultures were diluted in LB with 25\% chicken sera to a starting concentration of $10^3$ CFU/ml, which was confirmed by viable counts. Mixtures were incubated at 37 C with shaking. Samples were taken every hour for 6 hr and plated on MacConkey agar to determine viable counts. Results shown are the average of three trials. The experiment was repeated using LB with no serum as a medium control.

**Biostatistics.** All growth rate data for the strains were analyzed using linear regression analysis (Systat, Evanston, IL). The growth rates of each \textit{E. coli} strain were determined as previously described by Broughall \textit{et al.} (6). Briefly, all data were included from the point at which the cell concentration had increased to 150\% of the inoculated concentration to the point where the population density ceased to increase. Specific growth rates were calculated from the slopes of the generated regression lines as described by Duffy \textit{et al.} (12). A one-way ANOVA was used to test the null hypothesis of equal mean growth rates among the strains. A post hoc test, Fisher LSD, was used to identify differences between specific strains with a Type I error rate of 5\% ($\alpha = .05$) for all tests.

### Results

Previously, a series of \textit{iss} and \textit{bar} transconjugant mutants were created (23). In order to complement \textit{iss} transconjugant mutants, pZCiss was produced. The \textit{iss} gene was first amplified and cloned into pGEM-T Easy cloning vector. \textit{iss} was then cleaved from pGEM-T Easy and successfully cloned into pZC320. The construct was termed pZCiss. This construct was successfully transformed into \textit{iss} transconjugant mutants and selected on ampicillin-containing LB agar.

Growth rates amongst all the strains for the microtiter test, including wild types, mutants, and complemented mutants, were not statistically different in PG broth (Fig. 1). However, differences were observed when strains were grown in serum. Deletion of \textit{iss} from pAPEC-O2-ColV significantly decreased the growth of the transconjugants in chicken serum (Table 2, Fig. 2). Deletion of \textit{bar} from the chromosome of the transconjugants also significantly decreased their growth in chicken serum (Table 2, Fig. 2). TC4 \textit{bar} had a growth rate in chicken serum significantly higher than DH5\textalpha, TC4 \textit{iss}, and TC4 \textit{bar} \textit{iss} ($p < .05$ for all) but did not attain the growth rate of TC4. TC4 \textit{iss} grew at a rate statistically indistinguishable from TC4 \textit{bar} \textit{iss}. Transconjugants with \textit{iss} deletions that were complemented with pZCiss attained wild-type
levels of serum resistance. That is, TC4 Δiss + pZCiss grew at a rate statistically indistinguishable from TC4, and TC4 Δbor Δiss + pZCiss grew at a rate statistically indistinguishable from TC4 Δbor.

Growth rates of the strains using the plate count method showed similar results. Growth rates for all strains was not significantly different in LB broth (results not shown), while differences in growth rates were seen when grown in serum (Table 3, Fig. 3).

**DISCUSSION**

Previously we have found that the acquisition of pAPEC-O2-ColV by *E. coli* DH5α increased its serum resistance, but the gene or genes on the ColV plasmid responsible for the serum resistance phenotype were not identified. Since *iss*, which has been associated with serum resistance (4,5,8,9), has been localized to pAPEC-O2-ColV (17) and pAPEC-O1-ColBM (18), and since these plasmids typify the APEC pathotype (30), it seems likely that *iss* would contribute to the increased serum resistance conferred by the ColV plasmid. However, since genes other than *iss*, such as *traT*, which is thought to contribute to serum resistance, occur on ColV plasmids, we cannot be sure if increased serum resistance is due to the possession of *iss* alone. Therefore, this study sought to determine the level of serum resistance conferred on an isolate by possession of *iss* using a series of previously created isogenic mutants (23). Also, since *iss* and *bor* share about 90% homology (15), we wished to compare the levels of serum resistance conferred on an *E. coli* strain by the possession of *bor* and *iss*.

Transconjugants containing pAPEC-O2-ColVΔiss were significantly less resistant to serum than the wild-type transconjugant. Indeed, the mutant’s ability to grow in serum was so impaired that there was almost no growth at all. When *bor* was deleted from the chromosome of DH5α, a significant decrease in serum resistance, as compared to the wild-type transconjugant, was observed. However, this decrease was not as large as that seen in the *iss*− mutant, suggesting that *iss* contributes more to the serum resistance of TC4 than does *bor*. When *iss* was reintroduced into the *iss*− mutants, the serum resistance of the mutant was restored to the wild-type transconjugant level, confirming that the mutation of *iss* was responsible for the change in the mutant’s complement sensitivity. These results are interesting and seem to confirm the role of *iss* in the complement resistance associated with ColV plasmids. Considering that *iss* is found significantly more often in APEC isolates than in avian commensal *E. coli* isolates (29,30), whereas *bor* is found in the chromosome of most *E. coli* isolates. Since Iss and Bor both occur on the outer membrane of the bacterium (23), are involved in serum resistance (3,4,5,8,9), and have about 90% amino acid homology (15), the difference in their contribution to serum resistance could be due to the level of expression of the genes, with *iss* being up-regulated over *bor*, or due to difference in protein structure. Currently, research in our lab is focused on determining the levels of gene expression by reverse transcriptase PCR to help answer this question.

**Table 3.** Growth in normal serum using plate count method method.

<table>
<thead>
<tr>
<th>Isolate</th>
<th>Growth rate mean</th>
<th>Growth rate class</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC4</td>
<td>1.09</td>
<td>A</td>
</tr>
<tr>
<td>TC4Δiss + pZCiss</td>
<td>1.04</td>
<td>A</td>
</tr>
<tr>
<td>TC4 Δbor</td>
<td>0.87</td>
<td>B</td>
</tr>
<tr>
<td>TC4 Δbor Δiss + pZCiss</td>
<td>0.85</td>
<td>B</td>
</tr>
<tr>
<td>TC4 Δiss</td>
<td>0.61</td>
<td>C</td>
</tr>
<tr>
<td>DH5α</td>
<td>0.54</td>
<td>C</td>
</tr>
<tr>
<td>TC4 Δbor Δiss</td>
<td>0.55</td>
<td>C</td>
</tr>
</tbody>
</table>

*Growth rates with the same letter are not significantly different (P > .05), calculated using a one-way ANOVA.*

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![Fig. 3.](image_url) Growth in chicken serum (plate count method). Growth in chicken serum of DH5α, the transconjugant and corresponding mutants, and the *iss*-complemented mutants. Growth curves were determined by the plate count method and reflect an average of three trials for each strain.
The results from the plate count method verify the results of the microtiter method. That is, we were able to arrange strains in groups whose growth rates were not statistically different from each other. It is interesting to note that while the groupings were the same between the two methods, the growth rates were different using the two methods. Using the microtiter method, strains TC4 Δiss, DH5α, and TC4 Δbor Δiss showed little to no growth, but showed considerable growth using the plate count method. While the microtiter method is a fast and easy method to determine growth rates, it may not be as accurate as a plate count method.

Recently, Mellata et al. (24) stated that Iss and TraT played a limited role in complement resistance due to the fact that strains containing iss and traT genes, but had lost the K1 or O serotype were not protected against the bactericidal effect of serum. However, these strains were less sensitive than iss and traT− control strains. While certainly there may be other chromosomal factors that contribute to serum resistance, iss appears to play the major role in the serum resistance associated with pAPEC-O2-ColV.

In summary, a series of iss and bor mutants were generated to study the contributions of each gene to serum resistance. Deletion of iss in a strain conferred a significant drop in its resistance to serum. Similarly, a bor mutant showed a drop in serum resistance but not as drastic as that observed with the iss mutant. Also, when iss is reintroduced into the iss− mutant, the wild-type level of serum resistance was restored, confirming that the deletion of iss was responsible for the change in resistance seen in the mutant.

REFERENCES


**ACKNOWLEDGMENTS**

This project was funded by Iowa State University’s Biotechnology Council, Provost’s Office, and College of Veterinary Medicine Dean’s Office.