Distribution and genetic location of Tn7 in trimethoprim-resistant *Escherichia coli*

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**Summary.** A series of 178 strains of *Escherichia coli*, highly resistant to trimethoprim, isolated from hospital patients and patients in the community between 1979 and 1983, was examined for the presence of Tn7 on a plasmid or on the chromosome only, by transposition to RP4 and restriction endonuclease digestion with *Hind* III. Of the isolates, 57% carried Tn7. Comparison of hospital isolates from 1979 to 1980 and 1982 showed that although the proportions that carried Tn7 were similar (63% and 57%) there had been a significant change in the genetic location of the transposon. The proportion of plasmid-mediated Tn7 had fallen from 62% to 30%, with a corresponding rise in Tn7 located exclusively on the chromosome from 38% to 70%. This change may be the result of continuing transposition of Tn7 from plasmids to the bacterial chromosome followed by plasmid loss. The consequent reduction in the mobility of trimethoprim-resistance genes may in turn lead to changes in the incidence of resistance.

**Introduction**

Transposon Tn7, which mediates high level resistance to trimethoprim and low level resistance to streptomycin, was first detected in Britain in IncI plasmids (Barth *et al.*, 1976; Barth and Datta, 1977). It has since been reported in plasmids of several other incompatibility groups including IncM, IncC and IncX (Datta *et al.*, 1981). Tn7 can transpose readily between replicons, including the *Escherichia coli* chromosome which has a ‘hot spot’, and with the continued use of trimethoprim, worldwide dissemination of the transposon has been predicted (Richards and Nugent, 1979). The transposon has recently been demonstrated in isolates from Finland and Sweden (Dornbusch and Hagelberg, 1983).

Recently, an increasingly large proportion of trimethoprim high level resistance in coliforms has been found to be non-transferable (Towner *et al.*, 1980; Kraft *et al.*, 1984). Towner *et al.* (1982) demonstrated transposition of trimethoprim resistance in *E. coli* isolates that lacked self-transmissible R-plasmids. These findings suggest that resistance may be carried on non-transferable (tra−) plasmids or be mediated by a transposable element inserted into the bacterial chromosome.

In the present study we have investigated the incidence of Tn7 in highly trimethoprim resistant *E. coli* strains isolated in the course of earlier studies from hospital patients and from patients attending general practitioners (Kraft *et al.*, 1983, 1984, 1985). The aim was to determine the proportion of high level resistance to trimethoprim coded for by Tn7 in a large series of isolates and to determine directly how many isolates carried the transposon exclusively in a chromosomal location and how many on a plasmid. We also investigated the possibility that a change had occurred in the relative proportions of isolates that carried Tn7 in these two locations during the period 1979–1982.

**Materials and methods**

**Design of the study**

Clinical isolates of *E. coli* highly resistant to trimethoprim (MIC > 1024 µg/ml) were collected during three earlier studies (see table I) and were divided into two groups: those which transferred trimethoprim resistance to *E. coli* K12 (TT) and those which failed to transfer resistance to the drug in a standard 24-h broth mating at 37°C (TNT). The aim was to determine the proportion of high level resistance to trimethoprim for by Tn7 in a large series of isolates and to determine directly how many isolates carried the transposon exclusively in a chromosomal location and how many on a plasmid. We also investigated the possibility that a change had occurred in the relative proportions of isolates that carried Tn7 in these two locations during the period 1979–1982.

**Media**

Cystine-Lactose-Electrolyte-Deficient (CLED) Agar (Mast) was used for growth and maintenance of orga-
Table I. Clinical isolates of *E. coli* included in the study

<table>
<thead>
<tr>
<th>Source of isolates</th>
<th>Number of isolates</th>
<th>Number of isolates studied with</th>
<th>Number of isolates transferable</th>
<th>Number of isolates non-transferable</th>
<th>Total</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hospital 1979-80</td>
<td>88</td>
<td>43*</td>
<td>26</td>
<td>69</td>
<td></td>
<td>Kraft et al., 1983</td>
</tr>
<tr>
<td>Hospital 1982</td>
<td>98</td>
<td>35†</td>
<td>54</td>
<td>89</td>
<td></td>
<td>Kraft et al., 1984</td>
</tr>
<tr>
<td>General practice 1981-83</td>
<td>32</td>
<td>11</td>
<td>17</td>
<td>28</td>
<td></td>
<td>Kraft et al., 1985</td>
</tr>
<tr>
<td>Total</td>
<td>218</td>
<td>89</td>
<td>97</td>
<td>186</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* 44 isolates tested—one transferred trimethoprim resistance to *E. coli* K12 but no plasmid DNA could be demonstrated in the transconjugant which was therefore excluded from the present study.
† 34 isolates tested—one transferred two trimethoprim resistance plasmids which differed in mol. wt and in resistance pattern.

Table II. Standard strains and plasmids

<table>
<thead>
<tr>
<th>Strain</th>
<th>Plasmid</th>
<th>Antibiotic resistance†</th>
<th>Source or reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>E. coli</em> K12 J62-2</td>
<td>None</td>
<td>Rif</td>
<td>Bachmann, 1972</td>
</tr>
<tr>
<td><em>E. coli</em> K12 J53-2</td>
<td>None</td>
<td>Rif</td>
<td>Bachmann, 1972</td>
</tr>
<tr>
<td><em>E. coli</em> K12 J62-1</td>
<td>None</td>
<td>Nal</td>
<td>Bachmann, 1972</td>
</tr>
<tr>
<td><em>E. coli</em> K12 J53-1</td>
<td>None</td>
<td>Nal</td>
<td>Bachmann, 1972</td>
</tr>
<tr>
<td><em>E. coli</em> K12 J62</td>
<td>RP4</td>
<td>Tc Cb Km</td>
<td>N. Datta*</td>
</tr>
<tr>
<td><em>E. coli</em> K12 J53</td>
<td>RP4</td>
<td>Tc Cb Km</td>
<td>N. Datta*</td>
</tr>
<tr>
<td><em>E. coli</em> K12 J62::Tn7</td>
<td>None</td>
<td>Tp Sm</td>
<td>H. Richards*</td>
</tr>
<tr>
<td><em>E. coli</em> K12 J62</td>
<td>RP4::Tn7</td>
<td>Tp Sm Tc Cb Km</td>
<td>This laboratory</td>
</tr>
<tr>
<td><em>P. aeruginosa</em> NCTC 10662</td>
<td>None</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Royal Postgraduate Medical School, Hammersmith Hospital, London.
† Rif—rifampicin, Nal—nalidixic acid, Tc—tetracycline, Cb—carbenicillin, Km—kanamycin, Tp—trimethoprim, Sm—streptomycin.

Antimicrobial sensitivity tests and test for colicin production

Antimicrobial sensitivity testing was performed as described previously (Kraft et al., 1983). To distinguish between intrinsic and high level resistance to trimethoprim in *P. aeruginosa*, 50 μl of trimethoprim (10-24 mg/ml) was added to a well in the sensitivity plate.

The production of clinical isolates of *E. coli* of colicins active against *E. coli* K12 was tested by the agar overlay method (Barth et al., 1978). The isolates were stabbed into NA plates and overlaid with 10 ml of 0.5% soft agar containing 10 μl of an overnight broth culture of *E. coli* K12. Clear zones in the indicator lawn after overnight incubation at 37°C were taken to indicate colicin-like activity.

Translocation of trimethoprim resistance into RP4

RP4 was transferred into the clinical isolates in a standard 24-h broth mating at 37°C, with trimethoprim and tetracycline, kanamycin or carbenicillin selection. The plasmid was then re-transferred to an appropriate strain of *E. coli* K12 with selection for trimethoprim resistance or for tetracycline resistance (control). When
indigenous plasmids co-transferred with putative RP4::Tn7 the latter was separated by transfer into P. aeruginosa and selection with trimethoprim and cetrimide, and then re-transfer to E. coli K12 and selection with trimethoprim and rifampicin. A surface mating method was used (Bradley et al., 1980).

Detection of plasmid DNA

Plasmid DNA was extracted, separated by gel electrophoresis and the mol. wt determined as described previously (Platt and Sommerville, 1981).

Restriction enzyme analysis

Organisms were grown in BHI or CM1. Plasmid DNA was extracted by the alkaline-SDS method of Birnboim and Doly (1979) as modified by Ish-Horowitz and Burke (1981). Furthermore the preparations were treated with 7.5 M ammonium acetate before ethanol precipitation. The plasmid DNA was digested with Hind III (BRL) in accordance with the manufacturer's instructions. The DNA fragments were separated by electrophoresis on horizontal 0.7% agarose gels in tris-borate buffer, pH 8.0, incorporating ethidium bromide 0.3 µg/ml. Gels were run at 18 mA for 16–18 h. Phage Lambda DNA (BRL) was included to provide mol. wt standards and RP4::Tn7 was run as a control.

TT group

E. coli K12 transconjugants into which trimethoprim-resistance plasmids from the TT group had been transferred were tested for the presence of Tn7 by restriction endonuclease digestion with Hind III. When a transconjugant plasmid did not correspond in mol. wt to any plasmid in the original clinical isolate, plasmid DNA from the original isolate was also tested for the presence of a plasmid-coded Tn7.

TNT group

Plasmid DNA from all isolates in the TNT group was screened for the presence of Tn7 by digestion with Hind III to determine whether Tn7 was carried on tra-plasmids. The isolates were then screened for the presence of Tn7 in the bacterial chromosome by testing for translocation of trimethoprim resistance to RP4. Thirty two isolates resistant to tetracycline, kanamycin and carbenicillin were excluded from the TNT group, because it was not possible to select for incoming RP4. When trimethoprim resistance translocated to RP4, the resulting plasmids were tested for Tn7 by restriction endonuclease digestion with Hind III. This was to distinguish between isolates that lacked a plasmid-coded Tn7 and in which a Tn7 translocating to RP4 must have come from the bacterial chromosome, and isolates that carried a plasmid-coded Tn7, in which transposition to RP4 together with lack of transfer in earlier experiments suggested location of the transposon on a tra− plasmid.

Recognition of Tn7

For the purposes of the present study the following criteria have been taken as evidence of the presence of Tn7 or a similar transposon (after Datta and Richards, 1981): (i) Resistance to trimethoprim (MIC ≥ 1024 µg/ml) and to streptomycin; (ii) in TNT isolates, translocation of trimethoprim- and streptomycin-resistance determinants to RP4 or to an indigenous plasmid, accompanied by an increase in mol. wt of c. 10 × 10^6; (iii) after digestion of plasmid DNA with Hind III, the appearance of two characteristic fragments (mol. wt 1.4 × 10^6 and 1.7 × 10^6 respectively) which corresponded on gel electrophoresis to fragments from control RP4::Tn7.

Statistical analysis

A chi-squared 2 × 2 contingency test was applied, incorporating Yates' correction for continuity (Siegel, 1956).

Results

Plasmid-mediated Tn7

Analysis of 89 transferable (tra+) trimethoprim-resistance plasmids in E. coli K12 transconjugants showed that 46 carried Tn7. The plasmids analysed included 80, each of which corresponded in mol. wt to a plasmid in its respective clinical donor isolate (fig. 1); 37 of these carried Tn7. The remaining nine plasmids did not correspond in mol. wt to any plasmid in the donor isolate (fig. 2). The clinical isolates from which these were obtained were also examined for plasmid-mediated Tn7 to determine the original location of the transposon. Tn7 was present in all of these nine plasmids. However, in six of the nine isolates from which these plasmids had been transferred, Hind III digests of plasmid DNA failed to show the fragments characteristic of Tn7, indicating that the transposon was located on the

Fig. 1. Agarose (0.7%) gel electrophoresis of plasmid DNA in crude lysates: A and B—two E. coli K12 transconjugants; C—clinical E. coli isolate (GR150582).
bacterial chromosome. These nine isolates included four of the five isolates described previously (Kraft et al., 1984), in which the transconjugant plasmid had a mol. wt c. $10 \times 10^6$ larger than one of those in the clinical isolate and transposition of Tn7 from the chromosome was suspected. One transconjugant plasmid from strain GRI 1482 had a mol. wt $10 \times 10^6$ greater than the larger of the two plasmids present in the clinical isolate. This larger plasmid was transferable and carried ampicillin resistance (Kraft et al., 1984). The clinical isolate was found to carry plasmid-mediated Tn7, which indicated transposition from the smaller $tra^-$ plasmid to the larger $tra^+$ plasmid.

Forty of 89 (45%) $tra^+$ trimethoprim R-plasmids in the clinical isolates carried Tn7. A larger proportion of plasmids from the first (1979–80) hospital collection carried Tn7 than did those from the second (1982) collection: 25 of 43 (58%) and 13 of 35 (37%) respectively. This difference was not statistically significant ($p > 0.1$). Two of 11 plasmids from the community isolates carried Tn7 (18%).

**Isolates with non-transferable trimethoprim resistance**

RP4 was transferred successfully into 93 of 97 TNT isolates. From 82 of these 93 isolates RP4 was re-transferred to *E. coli* K12. By use of trimethoprim selection, 49 of these transconjugants were found to harbour RP4 that carried translocated trimethoprim and streptomycin resistance. These plasmids had a mol. wt of c. $46 \times 10^6$ and in all but two cases, digestion with *Hind* III showed the two restriction fragments characteristic of Tn7 (fig. 3). In the two remaining cases, the $1.7 \times 10^6$-mol. wt fragment was absent (fig. 4) although no change in the mol. wt of the plasmid was detected. However, an additional fragment of mol. wt $3.8 \times 10^6$ was seen in the digests of both plasmids. None of the TNT isolates showed the characteristic Tn7 fragments on *Hind* III digestion of their plasmid DNA confirming the chromosomal location of the transposon.
Table III. Trimethoprim-resistance plasmids transferred by clinical isolates of *E. coli* containing RP4

<table>
<thead>
<tr>
<th>Clinical isolate</th>
<th>Plasmid mean mol. wt (10⁶)</th>
<th>Resistance pattern</th>
<th>Self transferability</th>
<th>Presence of Tn7</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRI 10379</td>
<td>62</td>
<td>Tp Su Sm Tc Ap</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>GRI 1880</td>
<td>30</td>
<td>Tp Sm</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>GRI 3780</td>
<td>36</td>
<td>Tp Su Sm Ap</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>GRI 8281</td>
<td>50</td>
<td>Tp Sm Cm Km</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>GRI 13781</td>
<td>&lt;10</td>
<td>Tp Sm (Tc)*</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>GRI 3882</td>
<td>62</td>
<td>Tp Su Sm Ap</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>GRI 12682</td>
<td>62</td>
<td>Tp Su Sm Ap</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>GRI 183</td>
<td>46†</td>
<td>Tp</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>


* RP4 present in transconjugant; therefore it was not possible to determine if this plasmid carried Tc resistance.
† Tn7 apparently acquired from chromosome—see text.

In a further eight TNT isolates a donor plasmid that carried trimethoprim resistance was transferred. Five of these plasmids were found subsequently to be conjugative. The remainder appear to have been mobilised co-incidently by RP4 and none carried Tn7. The characteristics of these eight plasmids are shown in table III. One plasmid gave the *Hind* III fragments characteristic of Tn7 even though it conferred resistance to trimethoprim but not to streptomycin.

Of the 13 isolates that failed either to acquire or to re-transfer RP4, or to transfer an indigenous trimethoprim-resistance plasmid, eight showed colicin-like activity against *E. coli* K12.

**Changes in the genetic location of Tn7**

Of 218 highly trimethoprim resistant *E. coli* strains that had been collected, 173 (79%) of the clinical isolates or transconjugants derived from them were examined in the present study. (The 13 TNT isolates that failed either to acquire or to re-transfer RP4 or to transfer an indigenous trimethoprim-resistance plasmid were excluded from this total.) The strains examined represented 75% (66 of 88) and 84% (82 of 98) of the isolates from the 1979–80 and 1982 hospital collections respectively and 78% (25 of 32) of isolates from general practice. Since there was no significant difference between the

<table>
<thead>
<tr>
<th>Genetic location of Tn7</th>
<th>Hospital 1979–80</th>
<th>Hospital 1982</th>
<th>General practice 1981–83</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Tn7 located on bacterial chromosome</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demonstrated by Tn7 translocation to RP4</td>
<td>13</td>
<td>30</td>
<td>6</td>
<td>49</td>
</tr>
<tr>
<td>Inferred from Tn7 translocation to clinical plasmid</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Total (%)</td>
<td>16 (38)</td>
<td>33 (70)</td>
<td>7 (78)</td>
<td>56</td>
</tr>
<tr>
<td><em>Plasmid located Tn7</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tra⁰ plasmids</td>
<td>26</td>
<td>13</td>
<td>2</td>
<td>41</td>
</tr>
<tr>
<td>Tra⁻ plasmids</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total (%)</td>
<td>26 (62)</td>
<td>14 (30)</td>
<td>2 (22)</td>
<td>42</td>
</tr>
<tr>
<td>Total Tn7 (%)</td>
<td>42 (100)</td>
<td>47 (100)</td>
<td>9 (100)</td>
<td>98</td>
</tr>
</tbody>
</table>

Table IV. The genetic location of Tn7 in trimethoprim-resistant *E. coli*
proportion of isolates examined from each collection (p > 0.02) the proportions of isolates that carried Tn7 were compared and changes in the genetic location of the transposon analysed.

Of the 173 isolates examined 98 (57\%) contained Tn7. The proportions of isolates that harboured Tn7 in the two hospital collections were similar—42 (63\%) of the 1979–80 isolates and 47 (57\%) in those from 1982. The corresponding figure for isolates from general practice was 9 (36\%) but this difference was not statistically significant (p > 0.05). The genetic location of Tn7 in isolates from the three collections is shown in table IV. When the two hospital collections were compared, there was a highly significant difference in the proportions of plasmid and chromosomally-mediated Tn7. Between 1979–80 and 1982 the proportion of plasmid-mediated Tn7 had fallen from 62\% to 30\% with a corresponding rise in chromosomally-located Tn7 from 38\% to 70\% (p < 0.005) (table IV). Seven out of nine isolates from the community carried Tn7 on the chromosome and two on a plasmid. Although they resemble the proportions in the 1982 hospital isolates these numbers are too small to permit statistical comparison.

Discussion

The most notable finding was the significant change between 1979–80 and 1982 in the genetic location of Tn7 from a predominantly plasmid location to a location exclusively on the bacterial chromosome in isolates which did not carry Tn7 on a plasmid. This provides evidence in support of the earlier hypothesis that the increasing incidence of non-transferable, trimethoprim high level resistance is the result of transposition of Tn7 from plasmids to the bacterial chromosome followed by plasmid loss (Towner, 1982; Kraft et al., 1984). Among the isolates described here, Tn7 was found on a single tra- plasmid, although we cannot explain why such plasmids are not more common.

However, Tn7 accounted for only 57\% of the trimethoprim high level resistance observed. Resistance in the remaining isolates could be mediated by several different mechanisms. Some isolates may carry a defective Tn7 that either fails to transpose to RP4 or that, when plasmid mediated, lacks the Hind III restriction sites so that the characteristic fragments are not seen. We conclude that some of our isolates carried modified Tn7 because in two instances translocation occurred to RP4 of the appropriate resistance markers and a segment of DNA of appropriate mol. wt, but one of the characteristic fragments was missing and an additional larger fragment was seen. This probably arose by the insertion of a 2.1 × 10^6 mol. wt segment of DNA into the larger (1.7 × 10^6) Tn7 fragment. Furthermore, the characteristic restriction fragments were obtained from plasmids that lacked streptomycin resistance; these may carry a transposon resembling Tn78 (Datta et al., 1979). Alternatively, some of the plasmid-mediated resistance may be due to Tn402 which specifies trimethoprim resistance only (Shapiro and Sporn, 1977) and which does not transpose readily to other replicons in vitro (Datta and Richards, 1981). Other genetic mechanisms may also be involved, because at least three different trimethoprim-resistant dihydrofolate reductases have been described (Fling et al., 1982).

Although we were able to show in some clinical isolates that Tn7 was present in the chromosome but not in any of the plasmids, the converse could not be demonstrated. Thus, in isolates that carried Tn7 on a tra+ plasmid an additional copy may have been present in the chromosome. This situation might be maintained, without loss of the plasmid, if there was selection for plasmid resistance markers other than trimethoprim. Alternatively, plasmids that carry Tn7 could be maintained if there were genetic changes in the transposon that prevented transposition. Plasmids that carry other trimethoprim-resistance determinants may be retained in the population if these determinants do not transpose readily to the chromosome. Our results show that there was an increase between 1979–80 and 1982 in the proportion of plasmids that carried resistance determinants other than Tn7.

Our results indicate that in addition to transposition of Tn7 from plasmid to chromosome, the reverse also occurs. With some clinical isolates in which plasmid-mediated Tn7 could not be demonstrated, conjugation and trimethoprim selection allowed the isolation of a very small number of transconjugants that did carry plasmid-coded Tn7. The most probable sequence of events is acquisition of a Tn7 carrying plasmid, transposition of Tn7 to the chromosome, loss of the Tn7 carrying plasmid followed by transposition of Tn7 from the chromosome to another plasmid. Thus transposition to the chromosome, which stabilises the resistance (Serratt, 1982), retains the potential for transfer. Such strains, however, were rare in our collection and probably arose as a result of laboratory manipulation, but the process may have a parallel in vivo in conditions of trimethoprim selection.

Fewer isolates from the community carried Tn7 than did hospital isolates. However, in the community isolates, as in the second hospital collection,
exclusively chromosomal Tn7 predominated over plasmid-mediated Tn7, which suggests that the process of transposition to the chromosome and subsequent plasmid loss is occurring in community isolates also.

In conclusion, the present study showed that Tn7 accounted for over half the trimethoprim high level resistance detected. There was a significant change in the genetic location of Tn7 with an increasing tendency for the transposon to be located exclusively on the chromosome. This may result in a decrease in the mobility of Tn7 and thus to changes in the incidence of resistance.

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REFERENCES