PENICILLINASE PRODUCTION BY STAPHYLOCOCCUS AUREUS STRAINS FROM OUTBREAKS OF FOOD POISONING

BY

M. T. PARKER AND S. P. LAPAGE

From the Public Health Laboratory, Manchester

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In the course of the routine examination of strains of Staphylococcus aureus isolated from outbreaks of staphylococcal food poisoning in north-west England, we were surprised to find that most of them were penicillin resistant. Nine of 11 strains, all present in large numbers in foods that had caused clinically typical outbreaks of vomiting and diarrhoea, were penicillin resistant. None of the outbreaks had occurred in a hospital. This finding was particularly interesting because, when penicillin-resistant staphylococci first became common in hospitals, the resistant strains were found to be mainly members of phage group III, the group to which most enterotoxigenic staphylococci also belong.

There are several scattered references to the incrimination of penicillin-resistant staphylococci as the cause of outbreaks of food poisoning in the years before penicillin had come into general therapeutic use. Rutherford and Crowson (1945) described an outbreak of food poisoning in Canada in 1945, in which the organism responsible was resistant to 12.5 units of penicillin in a tube test. Mason (1945) examined six "well-known" food-poisoning strains obtained from other workers and found that three of them were completely resistant when tested by the cylinder plate method. Segalove (1947) tested a collection of 15 well-authenticated enterotoxigenic strains from the collection maintained at the University of Chicago. All were known to have had no previous contact with penicillin in the laboratory, and most had been isolated before 1941. He used a tube dilution test with an inoculum of 0.1 ml. of a 1/10 dilution of a 24-hour culture in a semi-synthetic liquid medium. Seven of the strains were inhibited by 0.1 unit per ml. of penicillin or less, and eight required 10 units or more for inhibition.

Allison (1949) first noted the common association with outbreaks of food poisoning of Staph. aureus strains lysed by certain phages. He examined 47 cultures, including 26 isolated in this country and 21 from the United States, Canada, Egypt, and the Sudan, and found that 38 of them were lysed by phages of the "6/47" group (including phage 42D). Others (Saint-Martin, Charest, and Desranleau, 1951; Williams, Rippon, and Dowsett, 1953; Parker, 1953) subsequently confirmed these findings. In 1953 Williams et al. proposed the classification of Staph. aureus into three broad phage groups, and included in group III strains lysed by one or more of the phages 6, 7, 47, 53, 54, 70, 73, 75, 77, 42D, and 42E. The association of strains of group III so defined with food poisoning has become even closer than that of Allison's "6/47 group" since the inclusion of further group III phages in the typing scheme and the introduction of the practice of testing apparently non-typable cultures with phage at 1,000× the routine test dilution.

Members of phage group III form a considerable proportion of all strains isolated from human sources—between 10% and 50% according to the type of material sampled—but few of them react with phage 42D, and strains lysed only by 42D at the routine test dilution are quite rare. For example, we encountered only one "pure" 42D strain in a series of 1,494 human cultures. Such strains are, however, common in material of bovine origin and appear to be a frequent cause of mastitis of cattle (Macdonald, 1946; Smith, 1948; Price, Neave, Rippon, and Williams, 1954). It has, therefore, been proposed (see Rippon, 1956) that "type 42D" strains should be removed from phage group III to a new provisional group IV.

Materials and Methods

Strains.—The authors were fortunate in being able to secure, through the kindness of Professor G. M. Dack and Dr. M. Bergdoll, of the Food Research
Institute of the University of Chicago, a collection of 12 strains of American food-poisoning staphylococci from outbreaks before 1941. All of them had been included in the series examined by Segalove and had also been tested for enterotoxin production either in monkeys or in human volunteers. Three early American strains were also obtained from Dr. S. T. Cowan, of the National Collection of Type Cultures. The information available with two of them indicated that they should be identical with two of Professor Dack’s strains, and, in fact, they proved to be culturally indistinguishable from them: the third strain appeared not to be represented in the Chicago collection. Dr. R. E. O. Williams, of the Staphylococcal Reference Laboratory at Colindale, also provided two collections of strains from fairly recent well-investigated outbreaks, mainly in Great Britain. The origins of the 37 separate strains are shown in Table I.

### Methods

The strains were first shown to be coagulase positive by the slide method of Cadness-Graves, Williams, Harper, and Miles (1943). They were then phage typed by the method of Wilson and Atkinson (1945) as modified by Williams and Rippon (1952), using the "basic set” of 20 phages listed by Williams et al. (1953), omitting phage 44, but with the addition of phages 71 and 80. Strains were allotted to the three main phage groups described by Williams et al., except that strains lysed only by phage 42D at routine test dilution were placed in provisional group IV. Sensitivity to five antibiotics (penicillin, streptomycin, chloramphenicol, chlorotetracycline, and erythromycin) was tested on a single plate of blood agar. Plates were flooded with overnight broth cultures of staphylococci, and antibiotic tablets (Evans’ “sentest”) were placed on the surface after drying. Strains were considered resistant when growth occurred to within 1 mm. of a tablet after 18 hours at 37° C. The tablets contained the following quantities of antibiotic: penicillin 0.5 unit, streptomycin 20 μg., chloramphenicol 40 μg., chlorotetracycline 10 μg., erythromycin 10 μg. Each culture was also tested for penicillan production by the method based on that of Bondi and Dietz (1944). Agar plates were flooded with an overnight broth culture of the Oxford staphylococcus (N.C.T.C. 6571) and, after drying, porcelain cylinders (Heatley, 1944) were placed on the surface of the medium. Equal quantities of a penicillin solution, containing 2 units/ml., and of an overnight broth culture of the staphylococcus being tested were placed in a cylinder. A control cylinder containing an equal volume of penicillin and of uninoculated broth was included on each plate. Complete absence of inhibition of growth around the test cylinder after overnight incubation at 37° C. was taken as evidence of penicillan production.

### Results

#### Phage-typing

All of the 37 strains were lysed by one or more of the phages of group III as originally defined by Williams et al. (1953). Only 34 of them conformed to the more strict definition of group III, since three were lysed only by phage 42D at the routine test dilution and were therefore placed in provisional group IV. The fact that all three of the group IV strains were among the earliest in the series is fortuitous: a small proportion of similar strains has been noted in several other series of cultures. Allison found four among 21 British strains isolated before 1949, Williams et al. two out of 40 from outbreaks in 1950 and 1951, and Saint-Martin et al. two among 15 Canadian strains. It is unfortunate that no

### Table I

**SUMMARY OF INFORMATION ABOUT 37 STRAINS OF STAPHYLOCOCCUS AUREUS CONSIDERED THE CAUSE OF ENTEROTOXIC FOOD-POISONING OUTBREAKS**

<table>
<thead>
<tr>
<th>No.</th>
<th>Identification of Culture</th>
<th>Location of Outbreak</th>
<th>Year</th>
<th>Food Responsible</th>
<th>Phase Group Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>D 1 (also NCTC 4135)</td>
<td>Chicago</td>
<td>1929</td>
<td>Christmas cake</td>
<td>IV</td>
</tr>
<tr>
<td>2</td>
<td>D 8</td>
<td>Milwaukee</td>
<td>1930</td>
<td>Cake</td>
<td>IV</td>
</tr>
<tr>
<td>3</td>
<td>D 9 (also NCTC 4134)</td>
<td>Portland</td>
<td>1931</td>
<td>Chicken gravy</td>
<td>III</td>
</tr>
<tr>
<td>4</td>
<td>D 47</td>
<td>Jersey City</td>
<td>1931</td>
<td>Cake</td>
<td>IV</td>
</tr>
<tr>
<td>5</td>
<td>NCTC 4136</td>
<td>Chicago</td>
<td>1932</td>
<td>Not known</td>
<td>III</td>
</tr>
<tr>
<td>6</td>
<td>D 47</td>
<td>Tennessee</td>
<td>1933</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>D 161</td>
<td>Indianapolis</td>
<td>1935</td>
<td>Sandwiches</td>
<td>III</td>
</tr>
<tr>
<td>8</td>
<td>D 169</td>
<td>U.S.A.</td>
<td>1938</td>
<td>Chocolate eclair</td>
<td>III</td>
</tr>
<tr>
<td>9</td>
<td>D 170</td>
<td>...</td>
<td>1938</td>
<td>Beef</td>
<td>III</td>
</tr>
<tr>
<td>10</td>
<td>C 171</td>
<td>Obese</td>
<td>1939</td>
<td>Chipped beef</td>
<td>III</td>
</tr>
<tr>
<td>11</td>
<td>D 177</td>
<td>Baltimore</td>
<td>1939</td>
<td>Chicken</td>
<td>III</td>
</tr>
<tr>
<td>12</td>
<td>D 178</td>
<td>Cook County, Ill.</td>
<td>1939</td>
<td>Ham</td>
<td>III</td>
</tr>
<tr>
<td>13</td>
<td>D 196</td>
<td>U.S.A.</td>
<td>1940</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Identification: D, Food Research Institute, University of Chicago. C, Staphylococcal Reference Laboratory, Colindale, London. NCTC, National Collection of Type Cultures. M, Manchester Public Health Laboratory.

recent group IV strains from outbreaks of food poisoning were available for testing.

Penicillin Resistance and Penicillinase Production.—Eight of the strains were sensitive to penicillin and failed to produce penicillinase: the remaining 29 were completely resistant in the plate test and all of them produced penicillinase. Eight of the 13 American strains isolated before 1941 were penicillin resistant: these included eight of the 10 members of group III but none of the group IV strains. A comparison of these results with those obtained by Segalove nine years previously revealed one discrepancy. No. 169 was sensitive to 0.1 unit of penicillin when tested by tube dilution in 1947, but was examined in this laboratory was resistant in the plate test and produced penicillinase. However, the inoculum used by Segalove was rather small, and it is possible that a weak penicillinase producer might have appeared to be sensitive to 0.1 unit under these conditions. Among the more recently isolated strains, all members of group III, 21 of 24 (88%), were penicillin resistant.

Although the number of strains available for study was small, the results suggest that at least three-quarters of all enterotoxigenic staphylococci are penicillin resistant and produce penicillinase. Whether it can be concluded that there has or has not been an increase in the proportion of penicillin-resistant strains in group III during the last 25 years will depend on whether the "type 42D" strains are separated from the "true" members of group III. Among group III strains of the sort usually found in human material, the percentage of resistant strains was of the order of 80% in the 1930s and is about the same to-day.

None of the strains was resistant to streptomycin, chloramphenicol, chlorotetracycline, or erythromycin.

Penicillin Resistance Among Group III Strains from Other Sources.—Records were available of 1,494 strains, isolated from human sources between September, 1953, and July, 1956, which had been phage typed and tested for penicillin resistance as part of another investigation. The proportion of penicillin-resistant strains and of penicillin-resistant group III strains from lesions of various sorts and from "normal" nose swabs is shown in Table II.

The material from which these strains were derived was very varied in its origin. The impetigo swabs were from cases in a number of different towns. The other specimens from patients treated at home were received from practitioners widely scattered throughout Lancashire and Cheshire. The "normal" nose swabs were from samples of children in three schools and one nursery. The material from hospital patients came from over 30 different hospitals in north-west England.

A little less than half (45%) of all the phage group III strains from sources other than hospitals were penicillin resistant, and there was no significant difference between the proportion resistant in the various types of lesion and in the nasal swabs. If the nasal swabs and the lesions other than impetigo from private cases were considered together, group III strains were more likely than other strains to be resistant (43% and 19% respectively). In the impetigo lesions, however, a smaller proportion of group III than of other strains were resistant (48% and 68% respectively) because of the preponderance of penicillin-resistant type 71 strains.

Eighty-six per cent. of group III strains from hospital patients were resistant. As is usually the case, the percentage of resistant strains from deep lesions in hospital patients was a little lower, presumably because some of the infections were acquired before admission to hospital.

It appears, therefore, that present-day enterotoxigenic group III strains, derived from sources unconnected with the hospital environment, are more likely to be penicillin resistant than strains from the noses and lesions of people outside hospital.

**TABLE II**

**PROPORTION OF PENICILLIN-RESISTANT STRAINS AND OF PENICILLIN-RESISTANT STRAINS IN PHAGE GROUP III IN 1,494 CULTURES OF STAPHYLOCOCCUS AUREUS ISOLATED BETWEEN SEPTEMBER, 1953, AND JULY, 1956**

<table>
<thead>
<tr>
<th>Population Not Treated in Hospital</th>
<th>Hospital Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Impetigo</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Other Superficial Lesions</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Deep Lesions</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Nose Swabs</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Infections of Newborn Infants</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Older Patients</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
</tr>
<tr>
<td>All strains</td>
<td></td>
</tr>
<tr>
<td>(66%)</td>
<td></td>
</tr>
<tr>
<td>382/578</td>
<td></td>
</tr>
<tr>
<td>33/97</td>
<td></td>
</tr>
<tr>
<td>16/80</td>
<td></td>
</tr>
<tr>
<td>33/182</td>
<td></td>
</tr>
<tr>
<td>321/377</td>
<td></td>
</tr>
<tr>
<td>90/110</td>
<td></td>
</tr>
<tr>
<td>51/70</td>
<td></td>
</tr>
<tr>
<td>926/1494</td>
<td></td>
</tr>
<tr>
<td>Phage group III</td>
<td></td>
</tr>
<tr>
<td>(48%)</td>
<td></td>
</tr>
<tr>
<td>30/62</td>
<td></td>
</tr>
<tr>
<td>14/31</td>
<td></td>
</tr>
<tr>
<td>6/10</td>
<td></td>
</tr>
<tr>
<td>6/10</td>
<td></td>
</tr>
<tr>
<td>83/94</td>
<td></td>
</tr>
<tr>
<td>57/64</td>
<td></td>
</tr>
<tr>
<td>13/19</td>
<td></td>
</tr>
<tr>
<td>209/291</td>
<td></td>
</tr>
</tbody>
</table>

| **Superficial Lesions**           |                   |
| **Deep Lesions**                  |                   |
| (62%)                             |                   |
| (72%)                             |                   |
Discussion

Naturally occurring strains of Staph. aureus are only resistant to penicillin if they produce penicillinase. Information about the prevalence of such resistant strains before the introduction of penicillin as a therapeutic agent is unfortunately scanty. There are a number of accounts of series of strains examined between 1942 and 1946, usually by a tube dilution test, but the importance of inoculum size was not generally appreciated at that time. It is difficult, therefore, to translate these results into a percentage of penicillinase-producing strains. Some undoubtedly resistant strains were encountered quite early in the period, though they were not common in supplicative lesions or wound infections in hospital. No large series of cultures from nasal swabs of normal people, from septic lesions outside hospital, or from superficial skin lesions appears to have been recorded.

The rapid increase in infections due to resistant strains in hospitals was first noted early in 1947 (Barber, 1947; Barber and Rozadowska-Dowzenko, 1948) and was correctly attributed to the widespread therapeutic use of penicillin. Barber's opinion that penicillin acted by selecting resistant strains which were subsequently spread from patient to patient by cross-infection has been generally accepted. Most of the penicillin-resistant strains examined by Barber and her colleagues during the next two years were members of phage group III (Barber and Whitehead, 1949), but soon afterwards a large outbreak in a maternity hospital due to resistant group I strains was recorded (Barber, Hayhoe, and Whitehead, 1949). Later a considerable proportion of group II strains was found to be resistant (Williams et al., 1953; Barber and Burston, 1955). These findings have been interpreted as evidence that phage group III strains yield antibiotic-resistant variants more readily than other strains of Staph. aureus, though the occurrence of such a mutation has never been observed. It is possible that the successive appearance of penicillin-resistant members in groups III, I, and II was only apparent. The series showing a predominance of resistant group III strains was obtained from a general hospital, and an excess of group I strains was only observed when outbreaks of infection among newborn infants were investigated. A similar preponderance of group I strains in neonatal infections and of group III strains in older hospital patients has been apparent in this area during the whole of the last three years. It is probable that similar considerations, together with certain changes in phage-typing techniques which have been introduced since 1949, would explain the apparent emergence of penicillin-resistant group II strains in the later years.

It is becoming clear that certain classes of staphylococci prevalent in populations unconnected with hospitals are predominantly penicillin resistant. Parker, Tomlinson, and Williams (1955) reported that over 90% of all strains of Staph. aureus type 71, which is associated with impetigo contagiosa, are penicillin resistant, and have also produced evidence which suggests that similar strains seen in impetigo lesions in 1941 may also have been resistant (see also Tomlinson and Parker, 1956). The results reported here indicate that most group III strains isolated from foods responsible for outbreaks of enterotoxic food poisoning in recent years are penicillin resistant, and that the percentage of resistant strains from this source exceeds that among group III strains in nasal swabs and septic lesions in the population not treated in hospital. Over half of a small series of enterotoxigenic staphylococci isolated over 15 years ago are also resistant. It will, however, not be possible to decide whether any increase of penicillin resistance among group III strains from outbreaks of food poisoning has taken place during the last 15 years until the status of "type 42D" has been settled and a larger series of strains has been examined.

Although resistant strains were uncommon among staphylococci causing suppuration in pre-penicillin days, it is now probable that they would have been found more frequently elsewhere if they had been looked for. There may well have been foci of resistant strains in other ecological "niches" which cannot now be identified. It is clear that the occurrence of mutation need not be invoked to explain the appearance of penicillin-resistant strains in hospitals in the last 10 years.

Summary

Twenty-one of 24 strains of Staph. aureus from recent outbreaks of enterotoxic food poisoning were found to be penicillin resistant and to produce penicillinase. All were members of phage group III.

A greater proportion of phage group III strains from food-poisoning incidents than from other sources outside hospital were penicillin resistant. Eight of a collection of 13 staphylococci causing food poisoning isolated before 1941 were penicillin resistant. All of these eight were members of phage group III. The five sensitive strains included two belonging to group III and three to group IV.
We wish to thank Professor G. M. Dack and Dr. M. Bergdoll, of the Food Research Institute, Chicago, and Dr. R. E. O. Williams, of the Staphylococcal Reference Laboratory, and Dr. S. T. Cowan, of the National Collection of Type Cultures, for providing us with cultures of staphylococci from food-poisoning outbreaks.

References

Wilson, G. S., and Atkinson, J. D. (1945). Ibid., 1, 647.