ASSOCIATION BETWEEN *Bordetella pertussis* AGGLUTINOGEN 2 AND FIMBRIAE

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**SUMMARY.** Fimbriae have been demonstrated on strains of *Bordetella pertussis* that possess agglutinogen 2 (types 1, 2, 3 and 1, 2), but not on those that lack it (types 1, 3 and 1). This correlation between fimbriation and the presence of agglutinogen 2 has been found with fresh isolates from children and with laboratory strains that are virulent for mice. If fimbriae enhance the attachment of bacteria to mucosal cells, these findings offer an explanation for the predominance of serotypes 1, 2, 3 and 1, 2 in non-vaccinated communities. The findings also suggest that agglutinogen 3 is not a fimbrial antigen, and because this is an essential component of fully effective whole-cell vaccine, a subcellular vaccine prepared from fimbriae alone may be inadequate.

**INTRODUCTION**

The role of fimbriae in the attachment of pathogenic bacteria to mucosal surfaces is well recognised (Sawyer and Rosenthal, 1978; Wilson, Miles and Parker, 1983). Moreover, there have been many reports of the presence of fimbriae on strains of *Bordetella pertussis*, but these have not included studies of the serotypes of the strains examined (e.g., Morse and Morse, 1976; Blom, Hansen and Poulsen, 1983).

We have investigated the relationship between fimbriation and serotype of strains isolated from patients with whooping cough, and also of the unusual laboratory strains that are virulent for mice.

**MATERIALS AND METHODS**

*Strains of Bordetella pertussis.* During the 1977–79 epidemic of whooping cough, isolates of *B. pertussis* were sent from many parts of Britain to our reference laboratory for serological typing. The present investigation included 17 of these cultures from patients aged 2 months to 11 years. Apart from one strain that came from Kettering General Hospital and one from Monsall Hospital, Manchester, all were received from Public Health Laboratories (see table I).

A culture that had been isolated in Coventry in 1967 was of particular interest because it had been found to contain all four *B. pertussis* serotypes (Stanbridge and Preston, 1974); these have since been preserved in our laboratory as freeze-dried cultures.

Six strains virulent for mice have been in our collection for many years. Strain GL353, and its derivative (353/Z) of enhanced mouse-virulence, are both of serotype 1 (Preston, 1966). Strain W.18-323 is the Kendrick challenge strain, which in our laboratory tests is of serotype 1.

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### Table I

**Serotype, fimbriation and source of strains of B. pertussis**

<table>
<thead>
<tr>
<th>Bacterial strains</th>
<th>Serotype 1,2,3 Fimbriate</th>
<th>Serotype 1,2 Fimbriate</th>
<th>Serotype 1,3 Non-fimbriate</th>
<th>Serotype 1 Non-fimbriate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Place of isolation</td>
<td>Strain designation</td>
<td>Place of isolation</td>
<td>Strain designation</td>
<td>Place of isolation</td>
</tr>
<tr>
<td>Strains isolated in 1978 from children aged 2 months to 11 years</td>
<td>Kettering K 19587</td>
<td>Leicester 39424</td>
<td>Guildford 36379</td>
<td>...</td>
</tr>
<tr>
<td>Newcastle upon Tyne</td>
<td>57871/1*</td>
<td>Maidstone 48371</td>
<td>Leeds A36752</td>
<td>...</td>
</tr>
<tr>
<td>Plymouth</td>
<td>83133</td>
<td>Manchester 71333</td>
<td>Newcastle upon Tyne 57871/8*</td>
<td>...</td>
</tr>
<tr>
<td>Preston</td>
<td>18335</td>
<td>Plymouth 85068</td>
<td>Nottingham 220822</td>
<td>...</td>
</tr>
<tr>
<td>Shrewsbury</td>
<td>183880</td>
<td>Portsmouth 8002</td>
<td>Plymouth 84455</td>
<td>...</td>
</tr>
<tr>
<td>Swansea</td>
<td>28771/6†</td>
<td>Preston 22314</td>
<td>Plymouth 85248</td>
<td>...</td>
</tr>
<tr>
<td>Strain isolated from child in 1967 Mouse-virulent strains</td>
<td>Coventry 41633/S/8‡</td>
<td>Coventry 41633/11/9‡</td>
<td>Coventry 41633/11/10‡</td>
<td>Coventry 41633/S/2‡</td>
</tr>
<tr>
<td>...</td>
<td>9797</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>CN1262</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>CN1262C</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>W.18-323</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>GL353</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>353/Z</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

* Two single-colony subcultures from the original isolate 57871.
† Two single-colony subcultures from the original isolate 28771.
‡ Four single-colony subcultures from the original isolate 41633.
Three other strains are probably derivatives of the Kendrick strain: 9797 which came to us from Switzerland (type 1,2,3), CN1262 from Wellcome Research Laboratories (type 1,2), and CN1262C from Copenhagen (type 1,3).

**Serotyping of B. pertussis cultures.** Slide agglutination with our own monospecific antisera (Preston, 1970) gave a roughly quantitative comparison of the agglutinability of bacterial suspensions: ++ + = rapid formation of large agglutinates, complete within 3 min; + + = agglutination visible within 3 min and complete within 5 min; + = slow formation of small agglutinates, incomplete within 5 min; - = no agglutination visible to the naked eye within 5 min.

**Electron microscopy.** Bacteria were grown for 2–3 days at 36°C on Charcoal Blood Agar (Oxoid) in Petri dishes. The organisms were then suspended in distilled water and washed three times by centrifugation and re-suspension. A drop of the washed bacterial suspension was transferred to a formvar-coated grid, allowed to dry, and then shadowed with platinum at an angle of 19° in a 300S coating unit (Nanotech Scientific Ltd, Prestwich, Manchester M25 8WD).

For negative staining, formvar-coated grids were coated with carbon which was ionised by the plasma glow technique in the 300S unit. A drop of the washed bacterial suspension was placed on the grid, and a drop of 1% methylamine tungstate (Emscope Laboratories Ltd, Ashford, Kent TN23 2LN) was added. After removal of excess liquid with filter paper, the specimen was allowed to dry; subsequent examination was confined to areas showing an even spread of stain.

Electron microscopy was performed at 100 kV with an Hitachi H600 microscope. Photographic negatives were obtained on 9 × 12 cm Ilford "Line" film.

**RESULTS**

**Strains of B. pertussis isolated in 1978**

Strains of each serotype of *B. pertussis* (1,2,3; 1,2; 1,3) were randomly selected from many hundreds of isolates received from different parts of the country. The usual patterns of agglutination with the three monospecific typing sera are shown in table II; most of the strains listed in table I reacted in that manner.

However, strain 28771 reacted in an unusual manner (+ +, + +, + + +, with antisera 1, 2 and 3 respectively). Single colony subcultures of this strain showed that it was a mixture of type 1,2,3 (designated strain 28771/6) and type 1,3 (designated strain 28771/4); these subcultures reacted in the characteristic manner (+ + +, + + +, + + +, and +, −, + + +, respectively). Such mixtures of serotype are not uncommon amongst fresh isolates from patients (Preston and Stanbridge, 1972).

**Table II**

*Characteristic agglutination patterns of the serotypes of B. pertussis*

<table>
<thead>
<tr>
<th>Serotype</th>
<th>Degree* of agglutination with monospecific serum for no serum factor 1 factor 2 factor 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,2,3</td>
<td>+++  +++  +++  +++  −</td>
</tr>
<tr>
<td>1,2</td>
<td>+ + +  +++  −</td>
</tr>
<tr>
<td>1,3</td>
<td>+ or + +  +++  −</td>
</tr>
<tr>
<td>1</td>
<td>+ or + +  −  −  −</td>
</tr>
</tbody>
</table>

*See Materials and Methods.
Electron microscopy showed that all strains that reacted with factor-2 serum (type 1,2,3 or type 1,2) possessed fimbriae, whereas those that did not react with factor-2 serum (type 1,3) were non-fimbriate (table I and fig. 1). In most of the fimbriate strains, >90% of the cells had fimbriae; but, with the mixed serotype culture (strain 28771), only about half of the cells had fimbriae. However, in its type 1,2,3 derivative (strain 28771/6) >90% of the cells had fimbriae, but in its type 1,3 derivative (strain 28771/4) no fimbriae were found.

Although strain 57871 agglutinated in the usual manner for a type 1,2,3 strain—strong reaction with all three monospecific antisera—little more than half of the cells exhibited fimbriae. Single colony subcultures revealed that this culture, too, was a mixture (table I): strain 57871/1 agglutinated as a type 1,2,3 culture and had a
very high proportion of fimbriate cells; strain 57871/8 agglutinated as a type 1,3 culture (table II) and possessed no fimbriae.

In shadowed preparations (fig. 1), fimbriate bacteria were found to have about 5–15 fimbriae per cell. With negative staining (fig. 2), about twice as many fimbriae were seen on fimbriate cells, though many of these were shorter than those seen by shadowing. It seemed likely that the fimbriae seen by shadowing corresponded to the longer ones seen by negative staining. With type 1,3 cells, no fimbriae were seen even with negative staining (fig. 2b).

**Strain of *B. pertussis* isolated in 1967**

Stanbridge and Preston (1974) gave a detailed account of an isolate in which an unusual range of serotypes was demonstrated by single colony subculture: the three serotypes described above (1,2,3; 1,2; 1,3), and also the degraded form of the organism (type 1) which is rarely recovered from the human nasopharynx and only then as a minority component of a mixed-serotype culture (Preston and Stanbridge, 1972).

We thought that these four serotypes would make an interesting comparative study in fimbriation, because they were likely to be variants of a single serotype with which the child was originally infected. The serotypes which were agglutinated with factor 2 serum (41633/S/8 and 41633/11/9) were found to possess fimbriae, whereas those which were not agglutinated with this serum (41633/11/10 and 41633/S/2) had no fimbriae (fig. 3).
Strains of *B. pertussis* virulent for mice

Strains of *B. pertussis* freshly isolated from children are not virulent for mice, but a few laboratory strains produce a lethal infection when injected intracerebrally (Preston, 1966). These include the Kendrick challenge strain, W.18-323, which in our laboratory tests is of serotype 1. Our collection also includes three other strains (9797, CN1262 and CN1262C) which were received from different laboratories, and which
are probably derivatives of the Kendrick strain (see Materials and Methods). They are of type 1,2,3, type 1,2 and type 1,3 respectively (table I).

However, strains 9797 and CN1262 did not give characteristic patterns of agglutination (table II), reacting only weakly with factor-2 serum. Moreover, the weak reactions were not caused by mixed populations in which some cells produced agglutinogen 2 and others did not; single colony subcultures were all found to give the same weak reaction with factor-2 serum.

Consistent with this finding was the appearance of these two strains by electron microscopy: most cells were fimbriate, although they had less than five fimbriae per cell. The strains of type 1,3 and type 1 virulent for mice (CN1262C and W.18-323 respectively) had no fimbriae. Nor did two other strains of type 1 (GL353 and 353/Z) that were virulent for mice.

**DISCUSSION**

Strains of *B. pertussis* that are isolated from children with whooping cough possess a common agglutinogen (factor 1) together with either, or both, of two other agglutinogens (factors 2 and 3). They are designated type 1,2,3, type 1,2 or type 1,3, according to the combination of these antigens that they possess. Type-1 organisms, devoid of antigens 2 and 3, do not cause whooping cough, though they may be virulent for mice.

We have shown a complete correlation between fimbriation and the possession of agglutinogen 2 for isolates from children and for strains virulent for mice: type 1,2,3 and type 1,2 strains were fimbriate, whereas type 1,3 and type 1 were not. We deduce from these observations that agglutinogen 2 is a fimbrial antigen, but that agglutinogen 3 is not—unless it is associated with fimbriae that were not revealed by our techniques. We intend to investigate the locations of these antigens more fully with labelled antibody. However, our repeated experience of mixed serotypes, even in fresh isolates from children, emphasises the need for such studies to be linked with a simultaneous demonstration of the serological purity of the cultures (Preston, Surapatana and Carter, 1982).

The role of fimbriae in the attachment of bacteria to mucosal epithelium may well explain the predominance of strains that possess factor 2 (types 1,2,3 and 1,2) in non-vaccinated communities (Preston, 1976). In the past, many countries have used vaccine that was rich in factor 2 but deficient in factor 3, and they have experienced a vast predominance of infections with type-1,3 strains (Preston, 1976). These organisms are normally at a disadvantage because of their lack of fimbriae, but they are sufficiently pathogenic to cause whooping cough in partially immunised children.

Britain was one such country in the 1960s. However, the recent low levels of vaccination have left a large population of children who are susceptible to fimbriate strains (types 1,2,3 and 1,2) and these have again replaced type-1,3 strains as the predominant serotypes (Preston, 1983).

Whole-cell vaccine containing all three agglutinogens offers complete protection against whooping cough (Preston, 1983). However, if we wish to develop a subcellular vaccine (Preston, 1982), we must ensure that it includes agglutinogen 3. The present study suggests that fimbriae alone may be inadequate.
We are grateful to the staff of the many laboratories throughout Britain from whom we received *B. pertussis* cultures for serotyping. We also thank Dr P. S. Handley and Mr L. M. Hill for their advice on the electron microscopy, and Mrs S. M. Craigen for secretarial assistance.

REFERENCES


