Mucosal Immune Responses to Meningococcal Group C Conjugate and Group A and C Polysaccharide Vaccines in Adolescents

Q. ZHANG,* S. CHOO, J. EVERARD, R. JENNINGS, AND A. FINN

Sheffield Institute for Vaccine Studies, Division of Child Health, Children’s Hospital, and Division of Molecular and Genetic Medicine, University of Sheffield, Sheffield, United Kingdom

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Previous studies in children have shown that Haemophilus influenzae type b (Hib) polysaccharide conjugate vaccines can reduce nasopharyngeal carriage of H. influenzae and provide herd immunity and suggest that this effect is mediated through mucosal antibodies. As this phenomenon may operate in other invasive bacterial infections which are propagated by nasopharyngeal carriage, mucosal antibody responses to meningococcal C conjugate and A/C polysaccharide vaccines were investigated. A total of 166 school children aged 11 to 17 years were randomized to receive a single dose of either conjugate or polysaccharide vaccine in an observer-blind study. Before and at 1, 6, and 12 months after immunization, samples of unstimulated saliva were collected and assayed by enzyme-linked immunosorbent assay for group C polysaccharide-specific immunoglobulin A (IgA), IgA1, IgA2 and secretory component, IgG antibodies, and total IgG and IgA. A subset of serum samples were also assayed for specific IgA and IgG antibodies. The concentrations of specific IgA and IgG in saliva were expressed both as nanograms per milliliter and as nanograms per microliter of total IgA or IgG. One month after immunization, significant increases in antibody titers (both IgA and IgG) were observed in saliva in both groups. There were significant subsequent falls in antibody titers by 6 months. Anti-meningococcal C-specific secretory component and IgA antibody titers were closely correlated (r = 0.85, P < 0.001), but there was no significant correlation between salivary and serum IgA titers, suggesting that IgA antibodies are locally produced. Significant correlation was found between salivary and serum IgG titers (r = 0.52, P < 0.01), suggesting that salivary IgG may be serum derived. Compared with polysaccharide vaccine, the conjugate vaccine induced significantly higher salivary IgG responses (P < 0.05), although there were no significant differences between salivary IgA responses to the two vaccines. The conjugate vaccine induced greater salivary IgG responses than a polysaccharide vaccine. Both vaccines induced significant salivary IgA antibodies. Further studies are needed to establish the functional significance of these mucosal responses.

The increased incidence of septicemia and meningitis due to group C Neisseria meningitidis in recent years in the United Kingdom, particularly among older children and young adults, has created considerable public concern (30). Currently licensed polysaccharide vaccines against group C meningococcal disease do not induce immunological memory and are poorly immunogenic in children under the age of 2 years (4, 13, 21). New conjugate vaccines have been shown to induce greater immunoglobulin G (IgG) and bactericidal antibody responses (S. Choo, Q. Zhang, J. Everard, C. Goilav, E. Hatzmann, J. Zuckermann, and A. Finn, Arch. Dis. Child 80:A71, abstr. G207, 1999), to be immunogenic in infants, and to induce immunological memory (11, 22–24, 34).

Haemophilus influenzae type b (Hib) conjugate vaccines have been used successfully to prevent Hib-related invasive diseases (2, 3, 10) and have been shown to reduce nasopharyngeal carriage and to induce herd immunity (1, 27, 32, 33), while unconjugated polysaccharide (PS) vaccines have little effect on carriage (28). The reduction in Hib carriage suggests that the parenterally administered conjugate vaccine may induce significant local immunity and thus prevent colonization in the nasopharynx, while Kauppi et al. (17) have subsequently shown that salivary antibody responses are induced by administration of the vaccine. Studies by the same group have also shown that intranasally administered anti-Hib capsular PS antibodies can prevent nasopharyngeal colonization with Hib in an infant rat model (18, 19). These results suggest that mucosal anti-PS antibodies may play a role in the eradication of nasopharyngeal carriage. Like Hib, Neisseria meningitidis resides in the mucosa of the nasopharynx, and mucosal immune responses may therefore play a significant role in host defense against the development of invasive meningococcal infection. It is also possible that meningococcal conjugate vaccines, like Hib conjugate vaccines, may induce specific local immune responses and reduce rates of nasopharyngeal carriage.

Little information is available about the mucosal immune responses induced by conjugate meningococcal vaccines and how they compare with those induced by PS vaccines. Although both IgA and IgG antibodies can be detected in mucosal secretions, the relative functional importance of these two isotypes in the context of mucosal infections is largely unknown. In this study, we describe mucosal IgG and IgA antibodies to group C meningococcal PS in the saliva of adolescents given either a conjugate vaccine or a PS vaccine parenterally. We also report the correlation between mucosal and systemic immune responses to the two vaccines.

MATERIALS AND METHODS

Study subjects and vaccines. A total of 106 healthy schoolchildren aged between 11 and 17 years were recruited in one center (Sheffield) as part of a randomized controlled two-center phase II immunogenicity study. Subjects were randomized to receive a single dose of either a meningococcal C conjugate
were defrosted and immediately centrifuged at 10,000 g for 15 min at 4°C to pellet any debris. The supernatant was then added to 96-well flat-bottom microtiter plates (Nordic), or SC (1:5,000) (clone GA-1; Sigma), each diluted in PBS containing 10% FBS, were then added to the plates and incubated at RT for 2 h. Alkaline phosphatase-conjugated goat anti-mouse antibodies (Stratech) diluted 1:1,000 in PBS was added after washes and incubated for 2 h at RT. After further washes, p-nitrophenyl phosphate (PNPP; Sigma) substrate (1 mg/ml) dissolved in diethanolamine buffer (pH 9.8) (Sigma) was added, and the plates were incubated at 37°C. A sample was considered positive if the mean of the three sample ODs was within the range from 0.1 to 0.6 OD units.

Measurement of total salivary IgA and IgG. As salivary flow rates are known to vary among individuals and in the same individual under different conditions (9), total IgA and IgG were also measured, so that the ratio of anti-meningococcal C PS IgA to total IgA could be calculated for each individual subject as a method of compensating for dilution. Microtiter plates (Costar, Cambridge, Mass.) were coated with goat anti-human IgA or IgG (Dako, Glostrup, Denmark) in PBS (1:1,000 for IgG and 1:2,000 for IgA) and incubated overnight at 4°C. After washes (see the method described above), 100 μg/ml of meningococcal C PS antigens (20 μg/ml) was added, and the plates were incubated overnight at 4°C. After washes, PNPP substrate was added, and the plates were incubated at RT for 15 min. ODs were read at 405 nm, and the concentration of each sample was calculated against the standard curve.

Statistical analysis. For the purpose of statistical analysis, all antibody concentrations were initially logarithmically transformed (base 10). Tilers below the limit of detection were arbitrarily assigned to half the lower limit of detection for each assay. The lower limit of detection was determined from calculation of the lowest concentration in the standard curve derived from the reference standard using the DeltaSoft software, the OD value of which was at least 2 SDs above the mean OD value of PBS blank controls (three plates loaded with PBS solution were assayed three times instead of test samples) for each assay. The lower limits of detection were 8 ng/ml for specific IgG, 6 ng/ml for specific IgA, 3 U/ml for non-specific IgA, 1.5 μg/ml for total salivary IgA, and 0.6 μg/ml for total salivary IgG. When the specific salivary antibodies were

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**Immunoblot assay for serum anti-meningococcal C PS IgG and IgA antibodies.** Serum anti-meningococcal C PS IgG and IgA antibodies were also measured by immunoblot assay. The method was as described above for the salivary assay, except that the sample dilution used for the serum samples was 1:200 in PBS and all the incubations were done at RT.

**Definition of antibody positivity.** Ten immunization salivary samples with low levels (OD values not significantly different from background) of anti-meningococcal C PS-specific antibodies were adsorbed with the PS antigen (20 μg/ml) for 1 h at RT before being tested by the immunoblot in triplicate. After adsorption and immunoblot for the 10 samples, the OD values changed little compared with non-adsorbed samples, suggesting that these samples contain little or no meningococcal C PS-specific antibody. The mean and standard deviation (SD) of the mean OD of the 10 “negative” samples were then calculated. For each sample, a sample was considered positive if the mean of the three sample ODs was higher than the mean ± 2 SDs of the 10 preimmunization samples. Serum anti-meningococcal C PS IgG and IgA positivity was also determined as above but instead using 10 immunization serum samples with low antibody levels.

**Inhibition assay.** To confirm the specificity of the salivary IgG and IgA immunoblot assays, inhibition assays were performed as described by Carlone et al. (6). Briefly, three postimmunization saliva samples diluted 1:10 in PBS buffer containing 10% FBS were prepared, starting at the highest concentration of 100 μg/ml. An equal volume of each PS dilution was added to aliquots of each of the diluted saliva samples in tubes, which were subsequently incubated on a horizontal rotator for 1 h at RT. The mixture was then added in duplicate to a microtiter plate, and a standard immunoblot procedure was followed. The percent inhibition for the three samples, for both IgA and IgG, when 100 μg of meningococcal C PS per ml was added, was between 78 and 95%. The concentrations of meningococcal C PS needed for 50% inhibition of antibody activity for the three samples, for both IgA and IgG, were within the range from 0.1 to 1 μg/ml.

**FIG. 1.** GMC and 95% CIs of anti-meningococcal meningococcal C PS salivary IgA and IgG antibodies in adolescents before and after immunization with MC-conjugate vaccine (●) or MACPS vaccine (○).
expressed as a ratio to total IgA or IgG, samples with undetectable specific IgA or IgG but detectable total IgA or IgG were assigned a value of 0.15 ng/mg for IgA and 0.5 ng/mg for IgG, which were the lowest values found, respectively. Geometric mean concentrations (GMCs) and 95% CIs were calculated by the study group for each time point. Two group comparisons were made using a two-tailed Student’s t test. Serial measurements were analyzed using two summary measures: area under the curve (AUC) and the peak value (maximum concentration) for each subject during the time period of the study (25). The chi-squared test was used to compare positivity rates between groups. To assess correlations between two factors, Pearson’s correlation coefficients were computed after log transformation and assessed for significance. Statistical analysis was done using SPSS for Windows (version 9.0; SPSS Inc., Chicago, Ill.). Values of P, 0.05 were considered statistically significant.

RESULTS

A total of 106 adolescents aged between 11 and 17 years entered the study, of whom 53 were randomized to the MC-conjugate group and 53 were randomized to the MACPS group. There were no significant differences between the two groups with respect to age (median [ranges], 13 years [11, 17] and 12 years [11, 17], respectively) and gender (male-female ratio, 27:26 and 26:27, respectively). Saliva samples were available for analysis from all 53 subjects in each group both before vaccination and 1 month (range, 1.0 to 2.0 months) after vaccination; from 51 in the conjugate and 52 in the PS group at 6 months (range, 4.0 to 8.2 months), and from 51 in each group at 12 months (range, 10.1 to 14.2 months).

Salivary anti-meningococcal C PS-specific IgA responses. Anti-meningococcal C PS-specific IgA responses are shown in Fig. 1 and Table 1. The GMC of IgA in both vaccine groups increased 1 month after immunization and fell subsequently over the next 6 to 12 months. There were no significant differences between the MC-conjugate vaccine and the MACPS groups’ IgA responses when analyzed by summary measures either as peak values (P = 0.09) or as AUC (P = 0.08). The results were similar when analyzed using the ratio (nanograms per microgram) of the anti-meningococcal C PS-specific IgA to total IgA (Table 1) (P values, 0.24 and 0.18, respectively). The specific IgA positivity rates before vaccination were 42% (22 of 53) and 40% (21 of 53) for the conjugate and PS group, respectively (not significant [NS]). The equivalent data for the two groups 1 month after vaccination were 72% (40 of 53) and 85% (47 of 53) (NS).

To investigate whether the specific IgA detected was locally produced, we measured the anti-meningococcal C PS-specific SC (secretory IgA) concentrations in a randomly selected subgroup of subjects (28 in the MC-conjugate and 30 in the MACPS group) 1 month after immunization. There was a highly significant correlation between the anti-meningococcal C PS-specific IgA and the specific SC (secretory IgA) concentrations (r = 0.85) (Fig. 2). In contrast, there was no significant correlation between anti-meningococcal C PS-specific salivary IgA and the serum-specific IgA responses (r = 0.24; data not shown).

Anti-meningococcal C PS-specific IgA subclass (IgA1 and IgA2) concentrations were also measured in a randomly selected subgroup of subjects (24 per group) before and 1 month after immunization. Although the concentrations of both IgA1 and IgA2 subclass antibodies increased following immunization, there were no significant differences between the two vaccine groups in IgA1 and IgA2 concentrations or in the fold increase for the two subclasses (Table 2).

Table 1. Anti-meningococcal C PS-specific salivary IgA and IgG antibody concentrations in adolescents immunized with the MC-conjugate or MACPS vaccine

<table>
<thead>
<tr>
<th>Day</th>
<th>GMC (95% CI), ng/mg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IgA</td>
</tr>
<tr>
<td></td>
<td>MC-conjugate</td>
</tr>
<tr>
<td>0</td>
<td>0.30 (0.24, 0.38) (n = 53)</td>
</tr>
<tr>
<td>30</td>
<td>0.87 (0.63, 1.20) (n = 53)</td>
</tr>
<tr>
<td>180</td>
<td>0.40 (0.31, 0.52) (n = 51)</td>
</tr>
<tr>
<td>360</td>
<td>0.39 (0.30, 0.51) (n = 51)</td>
</tr>
</tbody>
</table>

FIG. 2. Correlation between salivary anti-meningococcal C PS-specific SC and specific IgA antibodies 1 month after immunization.
Salivary anti-meningococcal C PS-specific IgG responses. Anti-meningococcal C PS-specific IgG responses are shown in Fig. 1 and Table 1. Like IgA, salivary IgG concentrations rose at 1 month in both groups and then fell back towards baseline level at 6 to 12 months. The MC-conjugate vaccine induced significantly higher IgG response than the MACPS vaccine when summarized either as peak values \( (P < 0.001) \) or as AUC \( (P < 0.01) \). There was a significant correlation between salivary and serum IgG titers \( (r = 0.52, P < 0.01) \) (Fig. 3). The specific IgG positivity rates before vaccination were 13.2% (7 of 53) and 11.3% (6 of 53) for the conjugate and the PS group, respectively (NS); 1 month after vaccination, the specific IgG positivity rate for the conjugate vaccine group (79.2% [42 of 53]) was higher than that for the PS group (52.8% [28 of 53]) \( (P < 0.01) \).

Serum antibody responses. The MC-conjugate vaccine induced significantly higher serum IgG antibody levels than the MACPS vaccine (Table 3). However, there was no difference between the serum IgA responses to the two vaccines. Serum IgG positivity rates before vaccination were 18.2% (6 of 33) and 9.1% (3 of 33) for the conjugate and the PS group, respectively (NS). The equivalent data for the two groups 1 month after vaccination were 100% (33 of 33) and 90.9% (30 of 33) (NS). The equivalent data for serum IgA were 24.2% (8 of 33) and 21.2% (7 of 33), respectively, before vaccination (NS) and 97.0% (32 of 33) and 93.9% (31 of 33), respectively, after vaccination (NS) for the two groups.

DISCUSSION

The carriage of *N. meningitidis* in the nasopharyngeal mucosa in otherwise healthy humans has long been recognized. A close relationship between the carriage rate in a population and the onset of an epidemic (12) suggests that treatment of carriage may decrease the incidence of disease. Hib conjugate vaccines have been shown to reduce nasopharyngeal carriage (27, 32, 33), and it has been suggested that local mucosal antibodies may be important in the reduction of carriage (17–19). It is plausible that newly developed meningococcal conjugate vaccines, which are similar in design to Hib conjugate vaccines, may induce effective local mucosal immunity against *N. meningitidis* in the nasopharynx. If such responses occur and if they are able to reduce the rate of asymptomatic carriage, this could greatly enhance the effectiveness of vaccines of this type when used widely, by the induction of herd immunity.

This study is among the first to examine mucosal immune responses to meningococcal vaccines. Specific mucosal immune responses of both the IgA and IgG isotypes were observed in saliva following parenteral administration of both the conjugate and the PS meningococcal vaccines. The conjugate vaccine induced significantly greater IgG antibody responses, but IgA responses were quantitatively similar for the two groups. This pattern was also seen in serum responses in this study. The relative size of the responses to the two vaccines should be interpreted in the light of different group C PS doses in the PS (50 μg) and conjugate (10 μg) vaccines. Nevertheless, our data suggest that the conjugate vaccine, which contains a protein carrier, causes immunoglobulin class switching more towards the IgG than the IgA isotype. Salivary antibody responses after a single dose of either vaccine subsequently fell back considerably towards baseline levels after 6 to 12 months.

Our observation that salivary and serum IgG concentrations are significantly correlated suggests that the specific IgG in

![FIG. 3. Correlation between serum anti-meningococcal C PS-specific IgG and salivary specific IgG antibodies 1 month after immunization.](http://iai.asm.org/)
saliva may be serum derived, as suggested previously with Hib vaccines (17). However, some IgG may be produced locally as well, in some subjects the salivary and serum IgG antibodies were poorly correlated and the overall correlation coefficient was only 0.52. It is not known to what extent the rate of passive transudation of IgG from serum to mucosal surfaces varies between individuals or within individuals over time.

The close correlation between the anti-meningococcal C PS-specific SC (secretory IgA) and the specific IgA antibodies suggests that these IgA antibodies are secretory in form and thus locally produced. Poor correlation between salivary IgA and serum IgA antibodies suggests that the salivary IgA antibodies are less likely to be derived from serum than IgG and that their production may be regulated independently from serum responses following antigen stimulation. IgA exists as two subclasses, IgA1 and IgA2, which differ in their amino acid sequences and carbohydrate structures (15). The IgA1 protease produced by meningococcal strains may cleave IgA1, a mechanism which may facilitate bacterial colonization of mucosa by eliminating Fc-mediated functions of IgA1 antibodies (20). Due to the structural differences between IgA2 and IgA1, IgA2 is relatively resistant to this protease activity. This difference may provide some functional advantage for IgA2 in specific mucosal immune responses. As there are no standards for antimeningococcal-specific IgA1 and IgA2, we were unable to quantify IgA response in these two subclasses in absolute values. However, using reference sample standards, we show that both specific IgA1 and IgA2 levels were increased after immunization with both vaccines and that there were no significant differences between IgA subclass responses to the two vaccines. The GMC fold increase of IgA2 was slightly higher than that of IgA1 for both vaccines, but these differences were not significant.

The reported geometric mean quantities of specific IgG and IgA in the saliva of infants immunized with three doses of conjugate Hib vaccines, which are known to reduce nasopharyngeal carriage rates of that organism, vary between 14.4 and 31.0 ng/ml and between 20.0 and 43.6 ng/ml, respectively (17). This compares with similar values for salivary anti-meningococcal C PS antibodies observed after a single dose of the conjugate vaccine in adolescents in this study (IgG, 30.0 ng/ml; IgA, 21.4 ng/ml) (Fig. 1) and may suggest that this MC-conjugate vaccine could reduce nasopharyngeal carriage of this organism. The licensure and widespread use of conjugate meningococcal vaccines in the United Kingdom may provide an opportunity to directly observe effects on nasopharyngeal carriage rates.

It is not known how the intramuscularly injected vaccine antigens induce salivary responses. The induction and effector sites of these mucosal immune responses are unclear. It is possible that the PS antigen is absorbed into the body and transported to lymphoid tissue local to the upper respiratory tract, as injected Hib PS antigen has been shown to be desorbed in the body (8, 31). Another possibility is that B cells are stimulated in the lymphoid tissues near the antigen injection site and then migrate to the upper respiratory mucosa and produce IgA antibodies there (5, 7, 26). It has been shown that antigen-specific IgA-secreting cells that bear the mucosal homing receptor αβ can be detected in the circulation shortly after parenteral inoculation (16, 29), indicating that nonmucosal immunizations can induce effector B cells capable of homing to mucosal tissues. Further studies are needed to investigate these possibilities and the functions and mechanisms of action of these mucosal antibodies.

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REFERENCES


**TABLE 3. Serum IgG and IgA antibodies to meningococcal C PS before (day 0) and 1 month after (day 30) immunization with MC-conjugate or MACPS vaccine**

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Day 0</th>
<th>Day 30</th>
<th>Day 0</th>
<th>Day 30</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>IgG</td>
<td></td>
<td>IgA</td>
<td></td>
</tr>
<tr>
<td>MC-conjugate</td>
<td>33</td>
<td>0.43 (0.279, 0.682)</td>
<td>30.07 (21.61, 41.83)</td>
<td>0.26 (0.176, 0.39)</td>
<td>3.49 (2.249, 5.429)</td>
</tr>
<tr>
<td>MACPS</td>
<td>33</td>
<td>0.39 (0.26, 0.58)</td>
<td>10.25 (6.44, 16.32)</td>
<td>0.27 (0.20, 0.36)</td>
<td>2.93 (2.00, 4.29)</td>
</tr>
</tbody>
</table>

*p* Comparison between the two vaccine groups by a two-tailed Student’s *t* test.


