Factors influencing adsorption of Dermatophagoides siboney allergen extract into aluminum adjuvants

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ABSTRACT

Allergen-specific immunotherapy consists in periodic administration of allergen vaccines, particularly from House Dust Mites (HDM), for desensitization and amelioration of allergic symptoms. The mite Dermatophagoides siboney has been commonly found in house dust in the Caribbean and it is associated to allergic asthma. In order to obtain a HDM vaccine containing aluminum adjuvant that can satisfy the requirements of consistency and immunogenicity, a lyophilized allergen extract of D. siboney was adsorbed into aluminum hydroxide (AH) and aluminum phosphate (AP) gels, aiming to establish the parameters that determine the highest adsorption capacity. Allergen adsorption was measured by total protein assays and by Der s 1 allergen-specific MAb-ELISA. Immunological potency was assessed in BALB/c mice. The results showed that AH had better adsorption capacity when compared to AP. The best adsorption conditions using AH were: 0.9% NaCl at pH 8 in 30 min. Sodium phosphate - buffered solution had negative effect to the allergen adsorption into AH, when used during the process or added later. The within-batch consistency of the adsorption process in the absence of buffer was demonstrated as well as the immunogenicity of this formulation, regarding induction of allergen-specific IgG antibodies.

Keywords: Vaccine formulation, allergens, adsorption process, aluminum adjuvants, phosphate buffer

Introduction

House dust mites, including Dermatophagoides siboney have been causing serious allergic diseases worldwide, such as dermatitis, eczema and asthma. Allergen-specific immunotherapy (SIT) is the only etiologic treatment of allergic diseases available worldwide and capable of interfering the disease progress. [1] Allergen vaccines prepared from native allergen proteins, including House Dust Mites (HDM), in aqueous or adsorbed form are preferentially used for SIT.

Alum adjuvants, including Alum Phosphate (AP) and Alum Hydroxide (AH), are known to raise and modulate the immune response and are used for many human vaccines including allergen vaccines. Achieving a high degree of adsorption is known to be relevant for the adjuvant effect or antigen uptake, and therefore for vaccine efficacy [2]. Generally, the adsorption process is carried out by mixing the adjuvant and the antigen, at optimal pH, temperature, solution concentration, and appropriate stirring velocity in a defined time. There are three major interactions in the adsorption process of the antigens into alum adjuvants: electrostatic attraction, hydrophobic interaction and ligand exchange. Electrostatic attraction is the most important and occurs when the adjuvant and the antigen have opposite charges. It depends heavily on the isoelectric point (pI) of the antigen and the point of zero charge (PZC) of the adjuvant. Then, the adsorption process is best accomplished in the pH interval between these two values. AH has been identified as a poorly crystalline aluminum oxyhydroxide [3] with a PZC of 11, which favors adsorption of negatively charged proteins at neutral pH. In contrast, AP has been classified as an amorphous aluminum hydroxyphosphate with a PZC of 5 favoring adsorption of positively charged proteins. The allergen extract of D. siboney contains predominantly the major allergens.


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protein Der s 1 with a pl in the range of 5.9 - 6.8. Hence, theoretically, it would be readily adsorbed into AH, taking advantage of their opposite charges in contrast to AP. Figure 1 depicts the situation described before. Nevertheless, previous experience has shown that the adsorption process of Der s 1 into AH can be inconsistent and suboptimal. In fact, electrostatic attraction is only one among the three most important interactions of the adsorption process. Hydrophobic interactions and specially ligand exchange could also play a role in this process. In addition, salt ions, and particularly buffers containing phosphates, commonly used in vaccine formulation, could affect the adsorption capacity of alum adjuvants [5].

Hence, the aim of this work was to select the most suitable adjuvant from AH and AP in order to achieve consistently the highest adsorption values with a desired immunogenic effect and to determine the optimal conditions for the adsorption process.

Materials and methods
Vaccine formulation
A lyophilized allergen extract of HDM *D. siboney* (VALERGEN-DS, 100 000 BU) manufactured by BIOCEN, Cuba, was used as the antigen. Der s 1 content as measured by Mab-ELISA, was used as a concentration marker. AP 2% (Adjuphos) and AH 2% (Alhydrogel) were obtained from Brenntag Biosector (Frederiksvaund, Denmark). The vaccine was formulated at a final Der s 1 concentration of 10 µg/mL, 1 mg/mL of either AP or AH and 0.05% of thiomersal. Different buffers were used depending on the experimental design: Tris-(hydroxymethyl)-aminomethane (Alhydrogel) were obtained from Brenntag Biosector (Frederiksvaund, Denmark). The vaccine was formulated at a final Der s 1 concentration of 10 µg/mL, 1 mg/mL of either AP or AH and 0.05% of thiomersal. Different buffers were used depending on the experimental design: Tris-(hydroxymethyl)-aminomethane (Sigma-Aldrich) diluted to pH 7.2 which includes di-sodium hydrogen phosphate 8.4 mmol/L, sodium dihydrogen orthophosphate 4 mmol/L and sodium chloride 136 mmol/L. For the last experiment design the NaCl 0.9% unbuffered solution was used at adjusted pH values of 7.0 or 8.0, using NaOH or HCl. Water for injection was used in all the experiments.

Analytical methods
The adsorption of the antigen onto the adjuvant gel was assessed by measuring protein or allergen content in the vaccine’s supernatant, i.e. after a brief centrifugation separating the gel from the buffer solution. The major allergen Der s 1 content was assayed by using indirect ELISA. Nunc Maxisorp microplates were coated with 1 µg/well of the lyophilized *D. siboney* allergen extract (BIOCEN) in sodium carbonate-bicarbonate at pH 9.6. After incubation overnight at 4 °C and washing out with PBS-T, blocking was performed with BSA 1% for 1 hour at 37 °C. After washing with PBS-T, 100 μL of each mouse sera were added into each well, diluted in 1:100 in BSA 1%, and incubated for 2 hours at 37 °C with slow agitation. Following the washing step, 100 µL of the antimouse-IgG biotin conjugate (SIGMA, USA) were applied into each well at a 1:1000 dilution, and incubated for 1 hour at 37 °C with slow agitation. Finally, after washing, 100 μL of streptavidine peroxydase (SIGMA, USA, 1:5 000 dilution) was added and incubated for 30 minutes at room temperature. The reaction was developed adding a tablet of substrate mixture (Urea/H2O2 and ortophenilendiamine, OPD, SIGMA, USA) and stopped with sulfuric acid 2.5 mol/L. Color intensity was assessed by measuring the absorbance at 450 nm using a microplate reader (Multiskan MS). The results are expressed in optical density (OD) units.

Immunogenicity study in a murine model
Immunogenicity of vaccine formulation variants was tested by injecting two doses (10 μg Der s 1) into BALB/c mice (CENPALAB, Cuba) with a 10 day-interval by subcutaneous route. Mice were randomly allocated in 4 groups with 6 mice in each group (3 males and 3 females). Groups A, B and C were administered with three consecutive pilot batches of the vaccine variant formulated with AH in saline solution (without buffer). Group D was immunized with the negative control (AH adjuvant in saline solution). Blood was extracted at days 0 and 17 and mice were sacrificed at day 17. Serum allergen specific antibodies were evaluated by ELISA as described before.

Statistical design and analysis
The design of the second adsorption experiment and all the analyses were performed using Statgraphic Centurion XVII software (StatPoint, Inc).

<table>
<thead>
<tr>
<th>pH 1</th>
<th>Der s 1</th>
<th>AH</th>
</tr>
</thead>
<tbody>
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<td>6</td>
<td>7</td>
<td>11</td>
</tr>
<tr>
<td>pH 1</td>
<td>Der s 1</td>
<td>pH 1</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>7</td>
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Figure 1. Relationship between pl values of allergen protein and PZC values of alum adjuvants. AH: Alum Hydroxide. AP: Alum Phosphate.


of the 3 experimental factors: pH, time and NaCl concentration in unbuffered solution. All these parameters were randomly ordered with one replicate to form the 16 runs experiment design. Experimental results were later processed to determine each optimal response. Finally, the multiple response optimization were used to find out the best formulation conditions.

Comparing groups in the immunization experiment was performed by using two-way analysis of variance (ANOVA) with multiple sample comparisons. Multiple range test was used to arrange the samples into homogenous groups with no statistical difference between their means.

**Results**

A preliminary experiment was carried out to choose the best adjuvant between AP and AH for the adsorption process and to define the best formulation solution selecting buffers among sPBS, Tris and unbuffered NaCl. As shown in figure 2, the Der s 1 adsorption values of AH for all buffer solutions were higher than those of AP. Thus, AH was chosen as the best option for next experiments. Among the results of AH, the adsorption process using Tris (pH 8.8) and NaCl rendered the highest adsorption percentages: 96.55% and 95.63%, respectively; meanwhile, the lowest value was shown with sPBS. Although Tris buffer showed the highest adsorption value, NaCl solution was chosen for further experiments due to its well-established compatibility for the injectable route of administration, from the lack of toxicity point of view.

Since AH was the best adsorptive adjuvant, a second adsorption experiment was performed to define the optimal conditions for the adsorption process using AH. The screening experimental design was carried out with 3 factors (adsorption time, NaCl concentration and pH) at 2 levels (low and high) with one replicate. NaCl solution was utilized at eight different conditions: concentrations 0.45% and 0.9%, adjusted at pH 7 or 8, and time intervals of 0.5 and 1 hour, in order to determine the effect of these variables on the adsorption process. No changes of the NaCl values were detected during the formulation process.

Main Effect plots of the three variables, regarding their influence on adsorption of the Der s 1 allergen and total protein are shown in figure 3. Regarding Der s 1 adsorption (the main quality parameter), the variable with the greater (significant) effect was the NaCl concentration (Figure 3B): increasing this concentration from 0.45 to 0.9% significantly decreased the amount of target antigen in the supernatant, i.e. increased the adsorption effect (Figure 3A). The influence of the other variables (time and pH) was not significant regarding adsorption of total proteins, as measured by the Bradford technique. Unexpectedly, increasing time from 0.5 to 1 hour decreased protein adsorption values. On the other hand, increasing pH from 7.0 to 8.0 significantly improved total protein adsorption (Figure 3C). The interaction between time and saline concentration was significant according to Pareto analysis (Figure 3D). Taking into account these apparently contradictory results a multiple response optimization was performed (The results are shown in table 1). According to this approach, the optimal variant chosen for further experiments was a saline concentration of 0.9% (corresponding to physiological level), 0.5 hour of adsorption time and a pH value of 8.0.

Using fixed optimized conditions, a third experiment was performed in order to check if the addition of buffer (sPBS) would, in fact, affect the adsorption process, as seen in the first preliminary experiment. AH adjuvant was used as before, to adsorb the allergen into NaCl formulation solution in presence or absence of sPBS buffer.

The results of this experiment confirmed the deleterious effect of phosphate buffer on Der s 1 adsorption. The highest adsorption values (more than 99%) were obtained by the variants without sPBS (runs 1 and 2; Figure 4). Adding sPBS either during the adsorption process (run 3) or at the end of this process (runs 1B and 2B), resulted both in lower and insufficient adsorption values, ranging from 63% to 65%.

The consistency of quality parameters is a requisite of Good Manufacturing Practices (GMP) for pharmaceutical products. After confirming the negative effect of the phosphate containing buffer in the adsorption process, a fourth experiment was carried out in order to test the between-batch consistency of the adsorption process following optimal conditions, in absence of buffer.

The Der s 1 adsorption values of three consecutive pilot scale batches prepared in aseptic conditions are shown in figure 5. The obtained adsorption values were 98.7% as an average, and significantly higher than the poor adsorption reported by a batch prepared with sPBS, in aseptic conditions as well. The consistency between batches can also be appreciated in figure 5, where error bars overlap each other, indicating...
that there were no significant differences between the means ($p < 0.05$).

For testing the immunogenicity of the GMP pilot batches, as the ultimate quality criterion, an immunization schedule was performed in mice. As can be noted in figure 6 and by using the statistical multiple range test, IgG antibody titers were defined to be significantly higher at day 17 (one week after the last injection) as compared to day 0 for all groups that received the vaccine, indicating that the vaccine evidently induced the expected allergen-specific antibody response. Furthermore, the multiple sample ANOVA comparisons demonstrated that the differences between batches at day 17 were statistically not significant, thus confirming the consistency of quality parameters.

Table 1. Multiple response optimizations for the second adsorption experiment

<table>
<thead>
<tr>
<th>Factor</th>
<th>Low</th>
<th>High</th>
<th>Optimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
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<td>1.0</td>
<td>0.5</td>
</tr>
<tr>
<td>NaCl concentration</td>
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<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>pH</td>
<td>7.0</td>
<td>8.0</td>
<td>8.0</td>
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Figure 3. Main Effect Plots and Pareto Charts for Der s 1 concentration (A and B) and for Total Protein (C and D), referred to the factorial experimental design, regarding time, NaCl concentration and pH.
Discussion

According to the first adsorption experiment, confirmed later by the third experiment, phosphate containing solution affected the adsorption process, or even desorbed already adsorbed allergen proteins. Such effect has been reported previously for other vaccine formulations containing certain proteins [8, 9] or oligonucleotides [10]. In agreement with this result AP showed decreased adsorption capacity as compared to AH. Taken together, these results suggest that electrostatic attraction could be the main mechanism of adsorption of Der s 1 to alum adjuvants, since AP and Der s 1 would have the same charge at neutral pH. One possible explanation of a decreased adsorption in presence of phosphate ions, would be the displacement of hydroxyl groups by phosphate ions, leading to the partial transformation of AH into aluminum hydroxyphosphate [8, 9], leading to a decrease of the PZC, and therefore, decreasing the ability to adsorb Der s 1.

According to the last adsorption experiment and the immunization schedule, the results obtained using non-buffered saline solutions showed high and consistent adsorption levels and the vaccine showed to be immunogenic in mice. Buffers are commonly used in vaccine formulations in order to maintain the pH unchanged, assuring thus, the chemical stability of the formulation. Particularly, for injectable drug products buffers should be compatible with physiological medium. In contrast, our results showed no advantage in using phosphate buffered saline, a very common buffer used for human vaccines. Nevertheless, real time stability studies should be performed later in order to look for possible changes in pH values. Another possibility would be to investigate other buffers compatible for the injection route.

Adsorption values found in our work (over 98%) are regarded as very suitable as compared to quality specifications of marketed allergen vaccines, which usually establish a limit of at least 90% adsorption [11]. The efficacy of this formulation could be judged by the immunogenicity in terms of allergen-specific IgG production, using only two injections.

Conclusions

It is concluded that the main mechanism of the adsorption process of Der s 1 into aluminum adjuvants is the electrostatic attraction. Therefore, AH showed advantage over AP regarding the adsorption level. NaCl solution was suitable for this adsorption process, while PBS buffer showed a negative effect to the adsorption of Der s 1 allergen. The consistency of the adsorption process and vaccine immunogenicity in mice, in absence of phosphate buffer, was clearly demonstrated.

Acknowledgement

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References