Increase in urinary leukotriene LTE₄ levels in acute asthma: correlation with airflow limitation

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Background: Leukotrienes play a key role in the pathophysiology of chronic asthma. Activation of leukotriene pathways is accompanied by rises in detectable urinary levels of leukotriene E₄ (LTE₄). The relationship between urinary LTE₄ levels and factors associated with acute asthma has not been determined.

Methods: Adults aged 15–54 years presenting with moderate to severe acute asthma were evaluated at emergency departments in 16 US sites. Forced expiratory volume in 1 second (FEV₁) was measured during the first 60 minutes after arrival and at specified times until discharge or admission. Urine samples for measurement of LTE₄ levels were obtained either on arrival at the study site and/or before discharge. Patients were seen 2 weeks later for follow up, at which time repeat FEV₁ measurements and urine samples for LTE₄ were obtained.

Results: One hundred and eighty four patients were evaluated; LTE₄ results from both the acute and follow up periods were available for analysis in 146. Urinary LTE₄ levels were increased during asthma exacerbations compared with levels obtained 2 weeks later (geometric means 111.7 and 75.6 pg/mg creatinine, respectively, mean percentage change -32.3; 95% confidence interval (CI) for the mean percentage change -39.6 to -24.3, p<0.001). The correlation between improvement in FEV₁ and decline in LTE₄ over the 2 week interval was significant (p<0.001, r=0.43).

Conclusions: Activation of leukotriene pathways in acute asthma is correlated with the degree of airflow obstruction, and resolution of the asthma exacerbation is associated with a reduction in leukotriene levels.

METHODS

Patients

Sixteen US sites, primarily emergency departments affiliated with academic medical centres, participated in the study. Adults aged 15–54 years presenting with acute asthma were screened for enrolment in the study. Participants were required to have a history of asthma for at least 1 year, a history of tobacco use of less than 10 pack years, and no concomitant treatment with systemic corticosteroids, leukotriene modifiers, anticholinergic agents, or long acting β agonist bronchodilators. Patients with pneumonia, congestive heart failure, or other clinical explanations for dyspnoea were excluded, as were patients with significant co-morbid disorders requiring acute management. The study protocol was approved by each investigator’s respective Institutional Review Board and all patients gave written informed consent to participate.

Study design

The primary study examined the benefit of adding intravenous montelukast to standard treatment for adults with moderate to severe acute asthma; the benefit of intravenous montelukast in this setting has been reported elsewhere.21 Briefly, the study consisted of a screening period, active...
Patients included in the study received blinded treatment (intravenous montelukast or placebo) and, in addition, continued treatment with β agonists at the investigator’s discretion. When indicated, corticosteroids were administered at a standard dose (prednisone 60 mg orally). Serial spirometric tests were performed at selected times for up to 6 hours or until a decision was made for discharge or admission, whichever occurred first. All patients successfully discharged from the emergency setting were given a standard course of oral prednisone (50 mg/day for 5 days) and were scheduled for a follow up visit 14 (SD 3) days later, at which time the FEV<sub>1</sub> measurement was repeated.

**Urinary LTE₄ measurements**

As an exploratory objective of the main study, spot urine samples were obtained during the acute treatment period and at the follow up visit for those patients successfully discharged from the study site. Urine samples were placed on ice within 20 minutes, then frozen for analysis within 4 hours of collection. Urinary LTE₄ levels were analysed by reversed phase liquid chromatography after precolumn extraction combined with radioimmunoassay as described elsewhere. The results were normalised to the creatinine concentration determined in the same sample.

**Evaluation and statistical analyses**

Data on urinary LTE₄ levels were skewed so the analysis of urinary LTE₄ levels was performed after applying a log transformation. Geometric means and 95% confidence intervals (CI) were used to summarise back transformed data. Pearson coefficients of correlation between percentage predicted FEV<sub>1</sub> and LTE₄ levels (at entry and follow up) and between change in LTE₄ levels and change in percentage predicted FEV<sub>1</sub> were computed. Regression models including other explanatory variables (sex, age, race, smoking status, allergic rhinitis history, years since asthma diagnosis, and treatment during the acute treatment phase) were also fitted to the LTE₄ levels. Comparisons of LTE₄ levels by subgroup of patients based on their FEV₄ were performed using a t test.

**RESULTS**

A total of 274 patients were screened for enrolment; 201 were randomised for the study, 184 had LTE₄ measurements either during the acute or the follow up phases, and 146 had LTE₄ levels available for analysis from both phases. The major reason for exclusion was failure to meet spirometric criteria (57 of 73 patients (78%)). Of these, 49 were excluded because FEV₁ was >70% of the predicted value (before or after albuterol) and eight were excluded because FEV₁ (expressed as percentage predicted) increased by >20 percentage points following albuterol nebulisation.

Baseline characteristics of the patients are presented in table 1. Most patients enrolled in the study had moderate to severe asthma exacerbations (FEV₁ <50–60% of the predicted value).<sup>23</sup> The mean FEV₁ before the start of the study was 1.6 l, corresponding to 47% of the predicted value. It should be noted that the baseline value was determined after patients had received initial treatment with β agonists and/or oxygen, so the pre-study baseline value most probably overestimated the FEV₁ upon arrival at the study site, which was not measured at that time.

LTE₄ levels during the acute exacerbation or at the 2 week follow up visit were not significantly different between the group which received the single dose of intravenous montelukast (n = 123) and those who received placebo (n = 61; p = 0.36), a result that was not unexpected given that montelukast is a receptor antagonist and has no effect on leukotriene synthesis. Subsequent analyses were thus performed on pooled data between the treatment groups in order to explore the relationship between LTE₄ levels and other clinical measures associated with asthma exacerbations.

Urinary LTE₄ levels were increased during asthma exacerbations compared with levels obtained 2 weeks later (geometric means 111.7 and 75.6 pg/mg creatinine, respectively), a mean percentage change of −32.3% (95% CI −39.6 to −24.3), p<0.001 (fig 1). Regression analysis of LTE₄ levels and FEV₁ during the acute exacerbation showed that LTE₄ levels increased as FEV₁ decreased (fig 2); the coefficient of correlation was equal to −0.29 (95% CI −0.42 to −0.15). The median percentage predicted FEV₁ at baseline for all patients was 49%. During the acute phase LTE₄ levels were significantly higher (p<0.001) in patients with a baseline FEV₁ of

**Figure 1** Change in urinary LTE₄ levels during an acute asthma attack compared with levels at follow up for all patients with available data at both time points (n = 146). The difference between the two measurements was significant (p<0.001). Data are expressed as geometric mean (95% confidence intervals).

**Table 1** Demographic data and baseline characteristics of patients

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>184</td>
</tr>
<tr>
<td>Age (years)</td>
<td>35.4 (10.3)</td>
</tr>
<tr>
<td>Duration of asthma (years)</td>
<td>19.1 (12.8)</td>
</tr>
<tr>
<td>Current smokers (%)</td>
<td>29.9</td>
</tr>
<tr>
<td>Allergic rhinitis (%)</td>
<td>58.6</td>
</tr>
<tr>
<td>Baseline FEV₁ (l)</td>
<td>1.6 (0.6)</td>
</tr>
<tr>
<td>Baseline FEV₁ (%) predicted</td>
<td>46.7 (15.8)</td>
</tr>
</tbody>
</table>

FEV₁ = forced expiratory volume in 1 second

$^*$Baseline FEV₁ was defined as the measurement made before enrolment in the study, following initial treatment with oxygen and/or β agonists.
<49% of the predicted value than in patients with FEV$_1 \geq 49\%$ (table 2). At the 2 week follow up evaluation LTE$_4$ levels decreased in both groups while the median percentage predicted FEV$_1$ at the 2 week follow up increased to 66%. The coefficient of correlation between LTE$_4$ levels and FEV$_1$ at follow up was $-0.35$ (95% CI $-0.48$ to $-0.20$) (fig 3). LTE$_4$ levels were still significantly higher in the subpopulation of patients with greater airflow limitation (FEV$_1 < 66\%$) than in patients with less airflow limitation (FEV$_1 \geq 66\%$; p<0.001; table 2).

Regression analysis showed that the change in LTE$_4$ levels from acute to follow up correlated with the change in percentage predicted FEV$_1$ ($r = -0.43$ (95% CI $-0.55$ to $-0.28$), fig 4). The median change in percentage predicted FEV$_1$ from acute presentation to follow up was 18%. Patients with a change in FEV$_1$ of $>18\%$ from acute presentation to follow up had a significantly greater decrease in LTE$_4$ than patients with a change in FEV$_1$ of $<18\%$ (table 2).

In order to determine the influence of baseline characteristics on LTE$_4$ levels, regression analyses were performed using patient history in addition to pulmonary function measurements. Inclusion of sex, age, smoking status, allergic rhinitis history, or years since asthma diagnosis in the models described above did not increase the precision of the estimate of LTE$_4$ levels compared with models with predicted FEV$_1$ alone. Although one time treatment with intravenous montelukast was associated with a significant improvement in FEV$_1$ during the acute exacerbation compared with placebo, this did not translate into differences in the change in LTE$_4$ or FEV$_1$ over the 2 week follow up interval.

### Table 2 Urinary LTE$_4$ levels in acute asthma and at follow up by subgroup of percentage predicted FEV$_1$ ($<\geq$ median)

<table>
<thead>
<tr>
<th>LTE$_4$ levels</th>
<th>Acute period</th>
<th>Follow up period</th>
</tr>
</thead>
<tbody>
<tr>
<td>N Mean (95% CI)</td>
<td>N Mean† (95% CI)</td>
<td></td>
</tr>
<tr>
<td>FEV$_1$ [% predicted]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$&lt;\text{median}$</td>
<td>87</td>
<td>144.9 (120.3 to 174.5)</td>
</tr>
<tr>
<td>$\geq\text{median}$</td>
<td>87</td>
<td>88.2 (74.2 to 104.8)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Change in LTE$_4$ levels (acute to follow up)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in % predicted FEV$_1$</td>
</tr>
<tr>
<td>$&lt;\text{median}$</td>
</tr>
<tr>
<td>$\geq\text{median}$</td>
</tr>
</tbody>
</table>

†Geometric mean.

DISCUSSION

In this study acute exacerbations of asthma were accompanied by increased levels of LTE$_4$ in urine followed by a significant decrease during resolution. The degree of airflow limitation was correlated with levels of urinary LTE$_4$ during both the exacerbation and follow up periods. These data suggest that the leukotriene pathway is activated during acute asthma and that leukotrienes play an important role in the pathophysiology of acute asthma.

Previous studies have shown that individuals without asthma have a mean urinary LTE$_4$ concentration of approximately 80 pg/mg creatinine. In the current study the mean urinary LTE$_4$ concentration was 75.6 pg/mg creatinine at the follow up visit, which suggests that LTE$_4$ levels had normalised within 2 weeks of the asthma exacerbation. In contrast, urinary LTE$_4$ levels obtained during the exacerbation were substantially higher (111.7 pg/mg creatinine).

Our study included urinary LTE$_4$ levels from over 140 patients during acute asthma and after resolution. The findings confirm the results of previous studies in smaller numbers of patients which have also suggested that urinary leukotriene levels are raised during an asthma exacerbation. For example, Drazen and colleagues measured urinary LTE$_4$ levels in asthmatic patients presenting in the emergency department with acute asthma. Urinary LTE$_4$ levels were significantly increased in 16 patients whose peak flow increased after $\beta$ agonists and tended to be increased in...
12 patients who did not respond to β agonists. Oosaki and colleagues observed increased urinary LTE4 levels in both atopic and non-atopic asthmatics admitted to emergency departments with an acute asthma attack, suggesting that leukotrienes are important in the pathology of both types of asthma. In addition, they noted that LTE4 levels fell during recovery independent of steroid use. Children treated for acute asthma also have increased urinary levels of LTE4 and LTD4 compared with children without asthma. Urinary LTE4 levels have also been shown to be increased after antigen challenge in susceptible individuals.

Taken together, these data strongly support the notion that cysteinyl leukotrienes (CysLT) play a significant role in acute asthma, as has been previously shown in chronic asthma. Inflammatory cells increase in the airways of asthmatic individuals and studies have shown that these cells appear to have large pools of the CysLT precursor, arachidonic acid. In addition, eosinophils from asthmatic patients have increased activity of a key CysLT enzyme, LTC4 synthase. LTE4 is the extracellular metabolite of LTC4, the first active metabolite in the arachidonic acid/CysLT cascade and the only one synthesised and secreted by inflammatory cells, principally mast cells, basophils and eosinophils. Although it is possible that extrapulmonary production of CysLT could account for some of the increase in urinary LTE4 excretion, the correlation of urinary LTE4 excretion and pulmonary function observed in the current study, the demonstrated efficacy of a CysLT receptor antagonist in acute asthma and the previous data supporting the role of CysLT in chronic asthma make this possibility highly unlikely.

Two potential limitations of the current study deserve comment. Firstly, the clinical trial on which these analyses are based was designed primarily to determine whether a CysLT antagonist could be efficacious in patients with acute asthma. For this purpose, patients were enrolled whose response to treatment with β agonists was inadequate as determined by failure to achieve a strong improvement in post bronchodilator FEV1 or an FEV1 that was less than the commonly accepted threshold (70% of the predicted value). Patients with mild or easily reversible exacerbations were therefore excluded. In addition, the most severely ill patients (that is, those who required admission to hospital) were not evaluated in the follow up period and were thus excluded from the current analyses. Nevertheless, the study population would appear to be representative of moderate to severe acute asthma in adults.

The second limitation of the study is that patients were given standard treatment which included oxygen, β agonists and, at the investigator’s discretion, systemic corticosteroids consistent with current treatment guidelines. In fact, most (~80%) patients in the study received corticosteroids as part of treatment in the emergency department, and all patients were discharged with a standard 5 day course of oral prednisone. Nevertheless, a confounding effect of corticosteroid treatment on LTE4 levels cannot be excluded by the current data. In previous studies urinary levels of LTE4 were not altered by continued treatment with inhaled corticosteroids in children with moderate to severe asthma, or by treatment with corticosteroids in the emergency department in patients with acute asthma.

In conclusion, activation of leukotriene pathways in acute asthma is correlated with the degree of airflow obstruction, and resolution of the asthma exacerbation is associated with a reduction in leukotriene levels. The consistency of these data with those determined in patients with chronic asthma support the common pathophysiology of acute and chronic asthma and substantiate the important role of leukotrienes as key mediators in the clinical spectrum of asthma.
LUNG ALERT

Oral gefitinib produces symptomatic and radiological benefit in advanced NSCLC

Gefitinib, an epidermal growth factor receptor (EGFR) tyrosine kinase inhibitor, is one of the new biological treatments for lung cancer. EGFR mediates cancer cell growth, proliferation, invasion, and metastasis and inhibits apoptosis.

This was a multicentre trial of gefitinib in patients with symptomatic stage IIIb or IV NSCLC who had received first and second line chemotherapy. 221 patients were randomised to receive either 250 mg or 500 mg oral gefitinib for a median of 56 days (there was no placebo arm). Disease related symptoms improved in 43% of patients with 250 mg gefitinib and a 12% partial radiographic response rate was observed for a median of 7 months. Symptomatic improvement was associated with adenocarcinoma and a partial radiographic response, but responders had no identifiable characteristic features. There was no association between EGFR expression measured by immunohistochemistry and outcome after gefitinib treatment. Mild skin toxicity was seen in 62%, diarrhoea in 57%, and ocular toxicity in 19%. Similar outcomes were obtained for patients treated with 500 mg but there was a higher incidence of side effects.

In some patients with advanced NSCLC (particularly adenocarcinoma) unresponsive to chemotherapy, gefitinib provided a short term symptomatic and radiographic benefit. This study highlights the fact that new treatments derived from research into molecular mechanisms may be of potential use in improving outcomes in lung cancer.

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