Treatment with epoprostenol reverts nitric oxide non-responsiveness in patients with primary pulmonary hypertension

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Abstract
Objective—To assess whether long term treatment with epoprostenol might restore primary non-responsiveness to nitric oxide (NO) in patients with primary pulmonary hypertension.

Methods—Seven patients with primary pulmonary hypertension receiving intravenous epoprostenol continuously because of failure of NO to influence pulmonary haemodynamics during initial testing were followed over a period of 13–29 months. Afterwards, acute vascular reactivity towards NO was tested again during right heart catheterisation.

Results—Administration of NO after continuous epoprostenol treatment for a mean period of 18 months improved arterial oxygen saturation (p < 0.01) and cardiac index (p < 0.05), and decreased mean pulmonary artery pressure (p < 0.01) and total pulmonary vascular resistance (p < 0.01) in patients previously unresponsive to NO.

Conclusions—Long term treatment with epoprostenol reverts initial refractoriness to NO in patients with primary pulmonary hypertension. Thus the addition of NO to epoprostenol treatment might cause further improvement in the course of the disease.

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Keywords: primary pulmonary hypertension; epoprostenol; vascular reactivity

Primary pulmonary hypertension is a rare disease of unknown aetiology leading to the development of severe precapillary pulmonary hypertension characterised by impaired regulation of both pulmonary haemodynamics and vascular growth. The responsiveness to vasodilator treatment in patients with this disorder varies considerably. Some affected individuals respond initially to the pulmonary vasodilator nitric oxide (NO) but lose the ability to respond for unknown reasons during the further development of the disease. Others are non-responders from the start and require treatment with epoprostenol. Continuous intravenous administration of epoprostenol has been shown to improve both pulmonary haemodynamics and survival in patients with primary pulmonary hypertension. Nevertheless, long term treatment with epoprostenol may cause tolerance phenomena and does not normalise haemodynamics in all affected individuals, despite the use of a sometimes rather aggressive therapeutic strategy.

Importantly, however, it has been found that long term treatment with epoprostenol causes a reduction in pulmonary vascular resistance far exceeding that expected from the extent of the acute vasorelaxation. This suggests that epoprostenol may have additional effects on the pulmonary vasculature. As both epoprostenol and NO decrease pulmonary vascular tone by hyperpolarisation of pulmonary smooth muscle cells, we hypothesised that the partial recovery of pulmonary vascular function in primary pulmonary hypertension caused by long term treatment with epoprostenol might restore the responsiveness to NO.
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artery pressure; PCWP, pulmonary capillary wedge pressure; PVRI, pulmonary vascular resistance index; SaO₂, systemic arterial oxygen saturation; APm, mean arterial pressure; CI, cardiac index; NYHA, New York Heart Association functional class; PAPm, mean pulmonary artery pressure; PCWP, pulmonary capillary wedge pressure; PVRI, pulmonary vascular resistance index; SaO₂, systemic arterial oxygen saturation; SvO₂, mixed venous oxygen saturation.

Nitric oxide was inhaled from a portable system providing pulsed, inspiration triggered delivery of the gas (NOXXI, Messer Austria, Gumpoldskirchen, Austria). The concentration of nitric oxide at the nasal cannulae was between 10 and 20 ppm corresponding to 2-3 ppm in the lower airways as assessed by intrabronchial monitoring. The concentration of NO and NO₂ was permanently controlled by continuous measurement using a chemoluminescence detector (Ecophysics, Zurich, Switzerland) included into the NO delivery system.

Epoprostenol (Flolan, Glaxo Wellcome) was permanently delivered into the subclavian vein as been previously described, using a portable pump system (CADD-1, Pharmacia-Upjohn, Austria) in a dose ranging from 11 to 21 ng/min/kg. The dose was adjusted as required on the basis of the clinical symptoms or from assessment of haemodynamics by echocardiography or clinical examination, carried out every month. The maximum dose of epoprostenol was 21 ng/min/kg (mean, 16 ng/min/kg). In addition, the patients received conventional treatment, including diuretics and anticoagulation with phenprocoumon to sustain an INR (international normalised ratio) of 1.5 to 2.5. Observations were carried out over a mean period of 18 months (range 13 to 28 months), with both clinical and echocardiographic assessment of pulmonary hypertension. Following at least 13 months of continuous treatment with epoprostenol, assessment of acute vasoreactivity to NO was repeated.

### Results

Seven patients were enrolled in the study. Six were in New York Heart Association (NYHA) functional class III and one was in class IV when the treatment with epoprostenol was begun. Details of the characteristics and haemodynamics of the patients at baseline, before and after the administration of NO, are given in table 1. Throughout the observation period, the concentration of epoprostenol was increased at least twice in each patient because of worsening of systolic pulmonary artery pressure, assessed by echocardiographic measurement of tricuspid regurgitation. Treatment with epoprostenol was never discontinued, and there were no infectious complications or serious side effects of the treatment or delivery system.

At baseline (before start of epoprostenol treatment), the cardiac index was 2.4 (0.6) l/min/m² and the pulmonary vascular resistance index (PVRI) was 7.5 (1.5) U/m² (n = 7). PAPm was 53 (9) mm Hg and PCWP was 9 (1) mm Hg. Acute vasodilator testing with NO did not result in significant changes of pulmonary haemodynamics (table 1). Following inhalation of 20 ppm NO (as measured at the cannula), the cardiac index changed to 2.5 (0.7) l/min/m² and PVRI was nearly stable at 7.1 (1.1) U/m². PAPm and PCWP slightly increased to 55 (10) mm Hg and 10 (2) mm Hg, respectively. SvO₂ changed from 60 (5)% to 64.0 (5)% after NO (NS), and SaO₂ from 92 (1)% to 94 (1)%.

### Table 1  Patient characteristics and haemodynamics at baseline. Clinical characteristics, haemodynamic values of the pulmonary and general circulation, and arterial and mixed venous oxygen saturation before treatment with epoprostenol

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age (years)</th>
<th>Sex</th>
<th>NYHA</th>
<th>PAPm (mm Hg)</th>
<th>Pm (mm Hg)</th>
<th>PCWP (mm Hg)</th>
<th>CI (l/min/m²)</th>
<th>PVRI (U/m²)</th>
<th>SaO₂ (%)</th>
<th>SvO₂ (%)</th>
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<tbody>
<tr>
<td>Before inhalation of NO</td>
<td>25</td>
<td>M</td>
<td>III</td>
<td>63</td>
<td>87</td>
<td>10</td>
<td>2.7</td>
<td>5.7</td>
<td>93</td>
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<td>2</td>
<td>49</td>
<td>F</td>
<td>III</td>
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<td>71</td>
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<td>50</td>
<td>M</td>
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<td>F</td>
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<td>Mean (SD)</td>
<td>53 (9)</td>
<td>75 (6)</td>
<td>9 (1)</td>
<td>2.4 (0.6)</td>
<td>7.5 (1.5)</td>
<td>92 (1)</td>
<td>60 (5)</td>
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<tr>
<td>After inhalation of NO</td>
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<td>69</td>
<td>74</td>
<td>14</td>
<td>2.9</td>
<td>5.9</td>
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APm, mean arterial pressure; CI, cardiac index; NYHA, New York Heart Association functional class; PAPm, mean pulmonary artery pressure; PCWP, pulmonary capillary wedge pressure; PVRI, pulmonary vascular resistance index; SaO₂, systemic arterial oxygen saturation; SvO₂, mixed venous oxygen saturation.

Data are given as mean (SD). Statistical analysis was performed by determination of the variance for three repeated measurements using the Wilcoxon rank sum test. All p values are based on two sided tests; p < 0.05 was considered significant.

## STATISTICS

Data are given as mean (SD). Statistical analysis was performed by determination of the variance for three repeated measurements using the Wilcoxon rank sum test. All p values are based on two sided tests; p < 0.05 was considered significant.
were observed. PAPm, however, increased to a mean of 65 (11) mm Hg, probably as a result of the comparatively low doses of epoprostenol. In contrast to the first test with NO, the second test inhalation of 20 ppm NO caused an increase in cardiac index (fig 1B), by a mean of 0.5 l/min/m² (p < 0.05), and a decrease in PVRI (fig 1C), by 1.1 U/m² (p < 0.01) in all patients. PAPm decreased by 5.6 mm Hg (p < 0.01) (fig 1A). SaO₂ rose by 3.3% to 96.2 (2.8)% (p < 0.01) (fig 1D). Sv O₂ did not change significantly (+1.6% to 62 (6)% , p = 0.073) (table 2). Neither PCWP nor mean arterial pressure changed significantly (+0.2 mm Hg, p = 0.603, and +4.3 mm Hg, p = 0.135, respectively) (table 2).

Discussion

In seven patients with primary pulmonary hypertension who were primary non-responders to inhaled nitric oxide, intravenous long term administration of epoprostenol abolished the lack of responsiveness to NO, causing significant improvement in pulmonary haemodynamics. In addition, we observed an increase in arterial oxygen saturation, though mixed venous oxygenation showed only a small and non-significant increase during acute testing, probably owing to the small numbers in our sample. It is currently thought that primary pulmonary hypertension becomes a “fixed” defect, with decreased reactivity to various vasodilators. Nonetheless, during long term administration of epoprostenol, most patients show improved pulmonary haemodynamics,
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while initially failing to respond to NO. 

Usually, this improvement, which is never complete, is observed after hours or even days, suggesting a partial restoration of the normal contractility of the pulmonary vascular smooth muscle cells. Our results indicate that this long term effect of epoprostenol involves cellular mechanisms that account for an increase in responsiveness to the most effective pulmonary vasodilator, nitric oxide.

NO has been shown to decrease intracellular free calcium concentration, $[\text{Ca}^{2+}]_i$, in pulmonary artery smooth muscle cells, leading to relaxation of arterial tone, possibly by mechanisms involving the activation of voltage or calcium dependent membrane potassium channels. A similar effect on $[\text{Ca}^{2+}]_i$, has been reported for prostacyclin. Although the underlying mechanism for desensitisation of pulmonary arterial tissue to NO in primary pulmonary hypertension is yet unknown, it is conceivable that changes of intracellular events regulating contractility, such as changes of intracellular calcium concentration, reflect the refractoriness to NO. In line with this, it has been reported that both NO and prostacyclin induce hyperpolarisation in vascular smooth muscle cells resulting in a decrease in intracellular calcium concentration. It is thus conceivable that a change in refractoriness of pulmonary arterial tissue to NO in primary pulmonary hypertension is achieved by changes in the electrophysiology of the cells.

If confirmed during continuous treatment with both epoprostenol and NO, these data suggest that the combined effects of the two drugs may further stabilise vascular contractility of the pulmonary arteries, leading to improvement in outcome in primary pulmonary hypertension.