Effect of the oral endothelin antagonist bosentan on the clinical, exercise, and haemodynamic status of patients with pulmonary arterial hypertension related to congenital heart disease

S C Apostolopoulou, A Manginas, D V Cokkinos, S Rammos


Objective: To evaluate the clinical, exercise, and haemodynamic effects of chronic oral administration of the non-selective endothelin receptor antagonist bosentan on patients with pulmonary arterial hypertension (PAH) related to congenital heart disease (CHD).

Design: Prospective non-randomised open clinical study.

Setting: Cardiology tertiary referral centre.

Patients: 21 patients with a mean (SEM) age of 22 (3) years with chronic PAH related to CHD (15 with Eisenmenger’s syndrome). Patients were in World Health Organization (WHO) class II to IV with oxygen saturation 87 (2)%

Intervention: Patients underwent clinical, exercise, and haemodynamic evaluations at baseline and after 16 weeks of treatment.

Results: Bosentan improved (p < 0.01) WHO class, peak oxygen consumption from 16.8 (1.4) to 18.3 (1.4) ml/kg/min, exercise duration from 9.0 (0.8) to 10.7 (0.6) minutes during the treadmill test, walking distance from 416 (23) to 459 (22) m, and Borg dyspnoea index from 2.9 (0.2) to 2.0 (0.1) during the six minute walk test. Bosentan treatment improved (p < 0.05) mean pulmonary artery pressure from 87 (4) to 81 (4) mm Hg, pulmonary blood flow index from 3.2 (0.4) to 3.7 (0.5) l/min/m², pulmonary to systemic blood flow ratio from 1.2 (0.2) to 1.4 (0.2), and pulmonary vascular resistance index from 2232 (283) to 1768 (248) dyn·s·cm⁻². Two patients died, presumably of arrhythmic causes, who were in WHO class IV at baseline and who had improved during treatment.

Conclusions: Bosentan induces short and mid term clinical, exercise, and haemodynamic improvements in patients with PAH related to CHD. Larger studies with long term endothelin receptor antagonism are needed to assess the safety and possible treatment role of bosentan in this population.

PAH, pulmonary arterial hypertension; WHO, World Health Organization.

PATIENTS AND METHODS

Patient population

Patients in World Health Organization (WHO) functional class II to IV with severe PAH related to CHD with or without prior surgical repair and pulmonary vascular resistance index > 500 dyn·s·cm⁻² were enrolled in this study. At the time of enrolment, all patients had fixed increased pulmonary vascular resistance that precluded further surgical intervention. Care was taken to exclude other causes of pulmonary hypertension such as pulmonary arterial hypoplasia, hypoventilation, and lung or liver disease. Patients’ treatment regimens were not changed within the last month before enrolment and during the study period.

Abbreviations: CHD, congenital heart disease; CI, confidence interval; PAH, pulmonary arterial hypertension; WHO, World Health Organization.
with transposition of the great arteries physiology, where the small pulmonary arteriovenous oxygen content difference and the increased bronchial blood flow may render pulmonary artery flow and resistance calculations relatively unreliable,

Statistical analysis
The descriptive data are presented as the mean (SEM) with median and range as appropriate. Changes from baseline are reported with 95% confidence interval (CI). Significance of the differences from baseline to week 16 for the exercise and haemodynamic parameters was calculated with Student’s paired t test. Change in the WHO functional class from baseline to week 16 was analysed with Wilcoxon’s rank sum test. All p values were two tailed with the required level of significance p < 0.05.

RESULTS

Patients
Twenty one patients, 11 (52%) male and 10 (48%) female, aged 22 (3) years (range 6–43 years, median 19 years) with severe chronic PAH related to CHD were enrolled in this study. Table 2 describes the patients’ baseline clinical characteristics including diagnosis, sex, pulse oximetry, medications, and supplemental oxygen.

Patients 1 to 17 had PAH associated with uncorrected unrestricted communications at the ventricular or great artery level and no pulmonary stenosis allowing complete mixing and equal pressures in the pulmonary and systemic circulations. Of those, patients 13 to 17 additionally had transposition of the great arteries physiology and were thus excluded from the initial statistical analysis of the blood flow and resistance parameters. Patient 18 had unrestricted atrial level shunt with fixed increased pulmonary vascular resistance due to a > 35 mm atrial septal defect. Patients 7 to 10 had only left to right shunt at baseline and the rest had baseline right to left shunt and cyanosis, as in Eisenmenger’s syndrome. All patients with unrestricted communications had evidence of congestive heart failure during infancy, which disappeared gradually as pulmonary vascular resistance increased. Patients 19 to 21 were born with unrestricted ventricular and great artery level communications allowing complete mixing and systemic pulmonary hypertension; all their defects, except for an atrial septal defect in patient 21, had been surgically repaired. All patients were clinically evaluated and performed the six minute walk test. All patients except the two youngest (patients 8 and 21) and the adult patient with Down’s syndrome (patient 12) underwent treadmill exercise testing with oxygen consumption measurements. Haemodynamic parameters were assessed invasively in all patients except patients 11 to 14 and 21, who declined the assessment.

Baseline characteristics
Most patients (76%) were significantly symptomatic (12 patients in WHO functional class III and four patients in class IV) except for five patients less than 12 years of age who were in WHO class II (table 2). Most patients (71%) were cyanotic with pulse oximetry < 95% at rest in room air. Four patients with unrestricted mixing but absence of right to left shunt (patients 7 to 10) and the two patients with complete repair (patients 19 and 20) had normal baseline pulse oximetry (table 2). No patient had significant iron deficiency. All patients had severe right ventricular dilatation and hypertrophy on echocardiography with moderate to severe tricuspid regurgitation. Baseline maximum and submaximal exercise capacity and haemodynamic parameters were significantly impaired with median mean pulmonary artery

### Table 1: Bosentan dosing regimen according to body weight

<table>
<thead>
<tr>
<th>Body weight</th>
<th>Initial dose</th>
<th>Maintenance dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;40 kg</td>
<td>62.5 mg twice daily</td>
<td>125 mg twice daily</td>
</tr>
<tr>
<td>20–40 kg</td>
<td>31.25 mg twice daily</td>
<td>62.5 mg twice daily</td>
</tr>
<tr>
<td>10–20 kg</td>
<td>31.25 mg twice daily</td>
<td>31.25 mg twice daily</td>
</tr>
</tbody>
</table>

The descriptive data are presented as the mean (SEM) with median and range as appropriate. Changes from baseline are reported with 95% confidence interval (CI). Significance of the differences from baseline to week 16 for the exercise and haemodynamic parameters was calculated with Student’s paired t test. Change in the WHO functional class from baseline to week 16 was analysed with Wilcoxon’s rank sum test. All p values were two tailed with the required level of significance p < 0.05.
pressure 92 mm Hg (range 57–105 mm Hg), median systemic blood flow index 2.5 l/min/m² (range 1.6–3.8 l/min/m²), and median pulmonary vascular resistance index 2048 dyn·s·cm⁻² (range 762–4387 dyn·s·cm⁻²).

### Treatment effect

Figures 1 and 2 depict the changes from baseline observed after 16 weeks of bosentan treatment in the WHO classification, exercise tolerance, pulse oximetry, and haemodynamic status. At week 16, 13 patients had improved WHO functional class by one (the four patients in class IV improved to III and nine in class III improved to II), and two patients in class III and the five in class II remained stable (fig 1). All patients reported “feeling significantly better” during treatment and seven patients reported less cyanosis, especially during exercise.

Exercise evaluation showed, compared with baseline, an increase in peak oxygen consumption by 1.5 ml/kg/min (95% CI 0.4 to 2.5 ml/kg/min), in exercise capacity by 0.4 metabolic equivalents (95% CI 0.1 to 0.7), and in duration by 1.7 minutes (95% CI 1.1 to 2.3 minutes) during the Dargie treadmill protocol (fig 2). The ventilatory equivalent for carbon dioxide (minute ventilation/carbon dioxide production) at anaerobic threshold also decreased significantly (p < 0.05) from 59 (4) to 53 (4) (95% CI 1.4 to 10.3). During the six minute walk test, patients increased their walk distance by 42 m (95% CI 27 to 58 m) and reduced their Borg dyspnoea index by 0.6 (95% CI 0.5 to 1.1) (fig 2). The cyanotic patients also had increased (p < 0.05) pulse oximetry from 64 (3) to 69 (3)% (95% CI 0.4% to 10%) at test completion.

Pulse oximetry in room air improved in all 15 cyanotic patients by 4% (95% CI 1.1% to 6%) (fig 2). Haemodynamic assessment showed significant (p < 0.05) improvement, compared with baseline, in systolic pulmonary artery pressure by 7 mm Hg (95% CI 1 to 14 mm Hg), in mean pulmonary artery pressure by 6 mm Hg (95% CI 1 to 11 mm Hg), in transpulmonary pressure gradient by 8 mm Hg (95% CI 2 to 13 mm Hg), in mean aortic pressure by 6 mm Hg (95% CI 1 to 11 mm Hg), in pulmonary blood flow index by 0.6 l/min/m² (95% CI 0.1 to 1.0 l/min/m²), in pulmonary to systemic blood flow ratio by 0.2 (95% CI 0.02 to 0.35), and in pulmonary vascular resistance index by 464 dyn·s·cm⁻² (95% CI 189 to 738 dyn·s·cm⁻²) (fig 2). Right atrial pressure, systemic and effective blood flow, systemic oxygen delivery, systemic vascular resistance, and pulmonary to systemic vascular resistance ratio did not change significantly. Haemodynamic improvement was more pronounced in the four patients without baseline cyanosis (patients 7 to 10), whose pulmonary vascular resistance index decreased by 20–53% to 472–1120 dyn·s·cm⁻² and pulmonary to systemic vascular resistance ratio decreased to 0.3 to 0.5.

Analysis of the haemodynamic data including patients with transposition of the great arteries showed the same results as above except for an absence of change in the
pulmonary blood flow and pulmonary to systemic flow ratio, probably due to the inherent problems in flow calculations in this population. The effect observed did not differ significantly between the three patients who had undergone surgical intervention and the rest of the population.

Safety and tolerability

Flushing and dizziness were reported once each but resolved within two weeks without regimen changes. Abnormal hepatic function, interference with the international normalised ratio, and other adverse events were not observed in this population.
study. Haemoglobin concentration decreased significantly (p < 0.001) from 173 (6) to 160 (6) g/l. No patient required phlebotomy or red cell depletions during the study.

Two patients (patients 5 and 21) in this cohort died suddenly nine and five months, respectively, after starting bosentan treatment. Both deaths were observed, occurred after complaints of palpitations, and were presumably due to arrhythmia. Both patients had no previously documented arrhythmia and had moved from WHO class IV to class III with treatment reporting subjective improvement and return to daily activities (work and school, respectively) that they were unable to do before. Both had mildly increased their six-minute walking distance from 349 and 187 m to 366 and 207 m, respectively, at 16 weeks of treatment. Patient 21 had declined haemodynamic assessment; haemodynamic evaluation of patient 5 at 16 weeks of treatment showed stable pulmonary and aortic pressures with improved resting pulmonary blood flow index from 2.7 to 4.2 l/min/m², pulmonary to systemic blood flow ratio from 1.2 to 1.8, pulmonary vascular resistance index from 2248 to 1512 dyn·s·cm⁻⁵, and pulmonary to systemic vascular resistance ratio from 0.61 to 0.47. Postmortem examination showed generalised myocardial ischaemia as a recent terminal event consistent with possible arrhythmic death in the case of patient 5. Permission was not given to conduct a postmortem examination of patient 21.

The remaining 19 patients continued in stable clinical condition without changes in WHO functional class or exercise capacity on the same bosentan regimen during 1.3 (0.1) years (range 0.6 to 1.5 years) of follow up. Patient 1 reported disappearance of her bimonthly mild haemoptysis episodes and patient 18 was hospitalised once with her first moderate haemoptysis episode, which resolved with conservative treatment.

DISCUSSION

In this study, chronic oral administration of the non-selective endothelin receptor antagonist bosentan improved the clinical, exercise, and haemodynamic status of patients with PAH related to CHD. Factors affecting right ventricular performance, a key issue in PAH symptomatology, include increased afterload due to raised pulmonary pressure and vascular resistance, increased preload due to tricuspid regurgitation, and right ventricular ischaemia due to right ventricular hypertrophy and increased wall stress, which increase myocardial oxygen demand. Decreased right ventricular afterload may lead to improved right ventricular wall stress and performance, as manifested by the improved clinical and exercise status of our patients. This observation is in accordance with the improved right ventricular systolic function and size seen with bosentan in idiopathic PAH. Furthermore, the increased baseline pulse oximetry and blood oxygen content of our cyanotic patients may have contributed to the improved performance during exercise, a state of increased oxygen consumption.

The small number of studies showing benefit of endothelin antagonism in PAH enrolled only few patients with PAH due to CHD or administered endothelin A antagonists in the acute or chronic setting. The only previous study showing beneficial effect of bosentan in paediatric PAH included few patients with CHD, none with cyanosis and Eisenmenger’s syndrome. The present study is, to our knowledge, the first to examine in detail the clinical, exercise, and haemodynamic effects of chronic oral endothelin antagonism in patients with PAH associated with CHD, the majority of whom had Eisenmenger’s syndrome. It is unclear whether treatment of pulmonary vascular disease is beneficial in PAH related to CHD; therefore, management should probably address the clinical condition, exercise capacity, and quality of life of this population. Conventional treatment including digitalis, diuretics, supplemental oxygen, warfarin, and calcium channel blockers has limited benefit, and lung transplantation presents issues with donor availability, correct timing for listing, and increased perioperative risk in this older patient population. Only continuous intravenous epoprostenol has been shown to improve haemodynamic status, exercise capacity, and quality of life in patients with PAH related to CHD but is associated with considerable inconvenience and morbidity from the indwelling catheter. The orally active bosentan benefited patients with PAH related to CHD in this study and its effects were sustained over one year in patients with endocardial or autoimmune PAH. This treatment also prevented or reversed PAH and promoted pulmonary vascular remodelling in an animal model. PAH related to CHD possibly presents a novel indication for bosentan administration. Bosentan constitutes a promising treatment agent for a patient population with very limited treatment options. Further studies are warranted to assess whether bosentan will have long term effect and survival benefit in this population.

Two theoretical considerations arise with endothelin antagonism in PAH related to CHD. Firstly, in patients with left to right shunt, a decrease in pulmonary vascular resistance may lead to increased pulmonary blood flow and aggravation of congestive heart failure. This study included four such patients (patients 7 to 10), in whom clinical, exercise, and haemodynamic improvements were noted without need for additional anticoagulative treatment. More important, pulmonary vascular resistance index and pulmonary to systemic vascular resistance ratio decreased significantly in these patients to values close to those permitting surgical repair in young infants and toddlers, considered not to have fixed pulmonary vascular resistance. Partial closure of CHD communications may be considered for such young patients if further long term endothelin antagonism studies prove sustained and possibly augmented improvement in pulmonary haemodynamic function.

The second theoretical consideration in patients with fixed increased pulmonary vascular resistance, as in Eisenmenger’s syndrome, is whether endothelin antagonism would act only on the systemic vascular bed without affecting the pulmonary vascular bed resulting in decreased systemic vascular resistance and increased right to left shunt and cyanosis. In this study, endothelin receptor antagonism was probably more selective to the pulmonary than the systemic vascular bed, as shown by the increased aortic saturation of our cyanotic patients and the improved pulmonary blood flow, pulmonary to systemic blood flow ratio, and pulmonary vascular resistance without change in the systemic vascular resistance. Pulmonary to systemic vascular resistance ratio did not change significantly, possibly due to the small values of this parameter.

The two patients who died suddenly, probably of arrhythmic causes, were initially in WHO functional class IV with very poor prognosis. Interestingly, both patients had had subjective and objective clinical, exercise, haemodynamic, and quality of life improvements during treatment with bosentan. Arrhythmia has not been reported with bosentan treatment in the literature and endothelin antagonists may in fact block ischaemia induced arrhythmias in experimental models. The rest of our population did not report palpitations, nor did these two patients before their deaths. Although the role of increased activity of these two patients in their sudden death remains unclear, extreme caution should be exercised when applying novel treatments manipulating pulmonary and systemic haemodynamic function in this very sensitive population, especially in the case of patients in WHO functional class IV.
Study limitations

Limitations of this study include the lack of a placebo group, the relatively small sample size, and the age and diagnosis heterogeneity of the study population. Despite the lack of a placebo group, which may have influenced end points such as WHO functional classification, exercise performance, and Borg dyspnoea index, the observed effects were consistent and persisted over a significant follow up period, suggesting a true haemodynamic effect. Use of assumed oxygen consumption, especially for patients with PAH with possibly significantly increased measured values, may create problems in flow and resistance haemodynamic calculations but not their ratios. Against these limitations, this study reports in detail the clinical, exercise, and haemodynamic effects of the non-selective endothelin antagonist bosentan in the infrequently studied population of PAH related to CHD and especially Eisenmenger’s syndrome. It does not, however, definitely show reversibility of PAH leading to operability of patients with Eisenmenger’s syndrome.

In conclusion, this study shows that chronic oral administration of the non-selective endothelin antagonist bosentan induces clinical, exercise, and haemodynamic improvements in patients with chronic PAH related to CHD, including Eisenmenger’s syndrome. Additional larger detailed studies with long term endothelin antagonism in patients with PAH related to CHD are needed to assess safety and duration of the effect and whether there may be a treatment role of endothelin antagonism in this challenging patient population.

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There are no competing interests concerning this manuscript.

This study was conducted with approval of the Onassis Cardiac Surgery Centre Ethics Committee and after informed consent was obtained from the patients and their parents.

REFERENCES
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