Pulmonary arterial hypertension (PAH) associated with chronic lung disease of infancy can be a life-threatening disease affecting an increasing number of former premature infants. There is a need for improved delivery of targeted PAH therapies for this subgroup of patients who have severe and persistent PAH despite standard respiratory care for chronic lung disease. Currently infants who have severe PAH despite oral or inhaled therapy receive continuous intravenous prostanoid therapy (mostly epoprostenol), which is complicated because of the need for central venous access and associated catheter-related complications. We present a series of 5 infants who were successfully treated with a continuous infusion of subcutaneous treprostinil, which is a longer-acting prostanoid with similar hemodynamic effects. There were improvements in echocardiographic assessment of right ventricular function and estimated pulmonary hypertension, and in respiratory support required within weeks of therapy. Unlike commonly in adults, these 5 infants had no instances of severe site erythema, bleeding, bruising, or infection. In our experience with 5 former extremely preterm infants who had PAH associated with chronic lung disease, subcutaneous treprostinil was safe, efficacious, and well tolerated. We believe that subcutaneous treprostinil can be beneficial in a select group of former premature infants who have chronic lung disease and severe pulmonary arterial hypertension who have not responded adequately to conservative therapies. Pediatrics 2014;134:e274–e278

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KEY WORDS
extreme prematurity, pulmonary arterial hypertension, chronic lung disease of infancy, treprostinil

ABBREVIATIONS
iNO—inhaled nitric oxide
IV—intravenous
PAH—pulmonary arterial hypertension
PAH-CLD—pulmonary arterial hypertension associated with chronic lung disease
RV—right ventricle
SC—subcutaneous
SCTre—subcutaneous treprostinil

Dr Krishnan conceptualized and designed the case study, supervised the treatment protocols, and reviewed and revised the final manuscript; Dr Rosenzweig conceptualized and designed the case study, supervised the treatment protocols, and reviewed and revised the final manuscript; Dr Ferdman drafted the initial manuscript and collected the data; Dr Zuckerman supervised the treatment protocols and reviewed and revised the manuscript; and all authors approved the final manuscript as submitted.

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Pulmonary arterial hypertension (PAH) is a life-threatening disease of progressive pulmonary vasoconstriction and vascular remodeling, leading to right ventricular (RV) failure. PAH associated with chronic lung disease (PAH-CLD) of infancy (formerly known as bronchopulmonary dysplasia) is thought to have elements of both Group I (PAH) and Group III (lung disease-related) pulmonary hypertension. Initial treatment includes adequate respiratory management, treatment of aspiration and reactive airway disease, and control of exacerbating factors, such as systemic hypertension and left ventricular diastolic dysfunction. Despite these measures, however, some patients may require targeted pulmonary vasodilator therapy to demonstrate clinical improvement, either oral medications used alone or in combination with prostanoids. Continuous intravenous (IV) epoprostenol is added in severe and refractory PAH, but this is complicated in infants and small children owing to the need for central venous access and associated catheter-related complications, including infections, catheter breakage, loss of venous access, and thrombosis. Furthermore, the short half-life of epoprostenol increases the risk associated with infusion interruptions attributable to line breakage or inadvertent bolus, especially in young children. There is a need for an alternate delivery system to potentially reduce these complications. Treprostinil is an alternative prostanoid formulation delivered either IV or subcutaneously (SC), has a longer half-life (4 hours) than epoprostenol (minutes), and is stable at room temperature. In the past, pediatric PAH specialists were reluctant to use subcutaneous treprostinil (SCTre) in young children because of the significant infusion site pain described in older patients. This is the first reported use of SCTre in select infants who have PAH-CLD.

PATIENT CHARACTERISTICS

Five patients were identified as appropriate for SCTre therapy at our institution in the past year. All were former premature infants, born at a gestational age of 23 to 26 weeks, birth weight of 470 to 653 g (Table 1), and who had already required the addition of targeted PAH treatment to conservative management for PAH-CLD. Patients 1 to 4 were younger than 1 year of age when started on SCTre, after failure of oral and inhaled therapies. Patient 5 was already on IV epoprostenol via an indwelling catheter and was electively transitioned to SCTre because of multiple hospitalizations for line breakages and infection. All the infants required prolonged respiratory support and had multiple gut and respiratory infections. Patients 1 through 4 had multiple brief cardiorespiratory arrests secondary to PAH crises needing resuscitation and inotropic support during their hospital stay. None of the patients had systemic hypertension at the time of SCTre initiation; rather, several continued to require inotropes for hypotension. Echocardiograms done because of increasing need for respiratory support revealed severe pulmonary hypertension, RV dysfunction, and right-to-left atrial and ductal shunts. Cardiac catheterization was performed in 4 patients under general anesthesia (Table 1). Because of severe desaturation, 3 infants needed oxygen and/or inhaled nitric oxide (iNO) during their baseline hemodynamics. Patient 2 had a concern for pulmonary vein stenosis on echocardiogram and so underwent angiography of all 4 pulmonary veins demonstrating a mild narrowing of the left lower pulmonary vein with the remainder unobstructed.

OUR TREATMENT PROTOCOL

At initial presentation of acute PAH crises, iNO was started along with milrinone infusion to support the failing RV. Oral (or IV) sildenafil (followed by bosentan in patients 1 and 5) was added to the therapy, with attempts at weaning iNO. In patients 1 through 4, inhaled iloprost was initiated at 1 to 5 (median 3) mcg every 1 to 4 (median 2) hours, before starting SCTre. Patient 5, who had been on IV epoprostenol, was initially transitioned to IV treprostinil and subsequently converted to SCTre. SCTre was initiated at 1.25 ng/kg/min via an in-house pump at a concentration of 0.1 mg/mL. The dose was titrated up by 1.25 ng every 12 to 48 hours as tolerated. They were monitored closely for adverse effects, including increasing oxygen requirement or ventilator support, hypotension, irritability, feeding intolerance, and diarrhea. Patients 1 through 4 were already receiving sedation owing to their ventilator support and did not require additional medication. Patient 5 did not require any use of analgesic medication. Once the target dose of 20 ng/kg/min was reached, the increase was slowed to 1.25 ng/kg/once weekly until discharge or side effects. Concentration was increased as needed up to 1 mg/mL. Patient caregivers were trained on medication preparation, sterile techniques, pump use, and subcutaneous delivery, and educated on the side effects. Patients were discharged only after training was complete. As outpatients, the dose titration is every 3 to 4 weeks, with the assistance of specialty pharmacy and home nursing. There were no local reactions, evidence of pain or tenderness at the infusion site (Fig 1A and B), and no systemic side effects. The infusion sites were changed every 2 to 4 weeks to prevent local reactions or if the infusion cannula inadvertently came off. Infusion sites included the back of the arms, over the thighs, and abdomen.

FOLLOW-UP DATA

All patients had improvements in respiratory and inotropic support and echocardiogram parameters after SCTre initiation (Table 2). They were monitored...
for ventilation perfusion mismatch and none had worsening of respiratory status acutely or throughout treatment initiation. Patients 1 and 2 were both ventilator-dependent initially and now are home breathing room air. Patient 3 had ongoing necrotizing enterocolitis and sepsis, and although he initially improved hemodynamically, he died of septic shock 3 weeks after starting SCTre. Patient 4 was discharged to a chronic care facility on 35% FiO2 (via tracheostomy) after 4 months on SCTre. Patient 5 had been on 1/2 L oxygen via nasal cannula at home. Soon after transition from IV epoprostenol to SCTre she was weaned to room air with no right-to-left shunting at the patent ductus arteriosus. iNO was weaned off 3 weeks after SCTre initiation in patients 1 and 2, and by 6 weeks in patient 4. Patients 2 and 4 were on inhaled iloprost, and were weaned off within 2 weeks after initiation.

**DISCUSSION**

Very low birth weight infants are at risk for severe lung injury and CLD, secondary to hypoalveolarization and prolonged ventilation. A subset of these patients develop associated PAH. When PAH becomes severe, these infants are at high risk for death. Currently no clear guidelines exist for the treatment of these infants. Targeted PAH therapies available include endothelin-receptor antagonists, phosphodiesterase type-5 inhibitors, and prostanooids. Often patients who have severe PAH are on a combination of drugs from multiple categories. Although none of these therapies are FDA-approved for use in infants and children, PAH specialists judiciously use these therapies in managing sick children.

Aside from iNO, intravenous prostacyclin (epoprostenol), was the first targeted

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**TABLE 1** Baseline Patient Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Case No.</th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Birth weight (g)</td>
<td>653</td>
<td>470</td>
<td>480</td>
<td>560</td>
<td>640</td>
</tr>
<tr>
<td>Gestational age (wk)</td>
<td>26</td>
<td>23</td>
<td>23</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Gender</td>
<td>F</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>F</td>
</tr>
<tr>
<td>Age at PAH diagnosis (wk)</td>
<td>15</td>
<td>31</td>
<td>13</td>
<td>30</td>
<td>24</td>
</tr>
<tr>
<td>Diagnostic catheterization</td>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (wk)</td>
<td>20</td>
<td>38</td>
<td>36</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td>Baseline rest state</td>
<td>FiO2 35%</td>
<td>iNO 4 ppm</td>
<td>FiO2 60%</td>
<td>iNO 16 ppm</td>
<td>FiO2 21%</td>
</tr>
<tr>
<td>SAPm (mm Hg)</td>
<td>69</td>
<td>58</td>
<td>69</td>
<td>58</td>
<td>69</td>
</tr>
<tr>
<td>PCWPm (mm Hg)</td>
<td>9</td>
<td>8</td>
<td>9</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Mean RAP (mm Hg)</td>
<td>6</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>CI (L/min/m²)</td>
<td>3.09</td>
<td>3.8</td>
<td>3.5</td>
<td>0.8</td>
<td>0.82</td>
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<tr>
<td>Qp:Qs</td>
<td>1.1</td>
<td>1.21</td>
<td></td>
<td>11</td>
<td>15</td>
</tr>
<tr>
<td>PVRI (WU/m²) on AVT</td>
<td>7.8</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atrial septal defect</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>ASD</td>
<td>PDA</td>
</tr>
<tr>
<td>Comorbidities</td>
<td>CLD</td>
<td>CLD, NEC</td>
<td>CLD, NEC, recurrent sepsis</td>
<td>CLD, intestinal perforation</td>
<td>CLD, NEC</td>
</tr>
<tr>
<td>H/o cardiopulmonary arrest</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>
| ASO, atrial septal defect; AVT, acute vasoreactivity testing with iNO 80 PPM; CI, cardiac index; CLD, chronic lung disease; NEC, necrotizing enterocolitis; Fap, right atrial pressure; PAPm, mean pulmonary artery pressure; PCWPm, mean pulmonary capillary wedge pressure; PDA, patent ductus arteriosus; PVRI, pulmonary vascular resistance index Qp/Qs, ratio of pulmonary to systemic blood flow; SAPm, mean systemic artery pressure; WU, Woods units.

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**FIGURE 1**

Infusion sites over the A, thigh and B, arm in patient 1.
PAH therapy with demonstrated efficacy in children; however, there are many potential complications of continuous intravenous therapy. Adult data have shown the effectiveness of SCTre. Transition from IV epoprostenol to SCTre has been reported without clinical deterioration in adults and children. Adverse effects of the SC infusion include site pain in 89% to 92% of adults, and site reactions in 81% to 100%. In adults, 23% discontinued SCTre owing to severe site pain. Levy et al. reported on 8 children (ages 1.5 to 10 years, median 4 years) who were started on SCTre after failure of oral medications. A total of 58 patients had congenital heart defects and 2 had idiopathic PAH. All had suprasystemic pulmonary artery pressure. There was no mention of prematurity in any patient. Follow-up ranged from 6 to 18 months, at least follow-up 6 improved patients, 2 died. Unlike our experience, they had significant local pain requiring analgesics. One child required narcotics and transitioned to IV epoprostenol after 6 months of SC therapy. In our single-center experience, all 5 patients tolerated initiation of SCTre and demonstrated clinical and echocardiographic improvement (Table 2). Inotropic support was required for the intensive care nursing staff. There were no instances of severe site erythema, bleeding, bruising, or infection. The patients were not irritated or noticed to withdraw the limb from the infusion site. The patients were not irritable or noted to withdraw the limb from the infusion site. Even when the limb was examined or handled, it was not examined or handled. The patients were not irritable or noticed to withdraw the limb from the infusion site. Even when the limb was examined or handled, it was not examined or handled. The patients were not irritable or noticed to withdraw the limb from the infusion site. Even when the limb was examined or handled, it was not examined or handled. The patients were not irritable or noticed to withdraw the limb from the infusion site. Even when the limb was examined or handled, it was not examined or handled.

<table>
<thead>
<tr>
<th>Case No</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at initiation (wk)</td>
<td>28</td>
<td>39</td>
<td>20</td>
<td>52</td>
<td>128</td>
</tr>
<tr>
<td>Follow-up time (wk)</td>
<td>30</td>
<td>21</td>
<td>3*</td>
<td>12</td>
<td>18</td>
</tr>
<tr>
<td>Last dose (ng/kg/min)</td>
<td>47</td>
<td>50</td>
<td>20</td>
<td>37.5</td>
<td>50</td>
</tr>
</tbody>
</table>

### TABLE 2 Patient Characteristics at Initiation of SCTre and Latest Follow-Up

<table>
<thead>
<tr>
<th>Echo parameters</th>
<th>Case No</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>RV systolic dysfunction</td>
<td>Moderate</td>
<td>Normal</td>
<td>Severe</td>
<td>Normal</td>
<td>Moderate</td>
<td>Mild</td>
</tr>
<tr>
<td>Estimated PH</td>
<td>Severe</td>
<td>Mild</td>
<td>Severe</td>
<td>Mild</td>
<td>n/a*</td>
<td>n/a</td>
</tr>
<tr>
<td>TR jet (mm Hg)</td>
<td>64</td>
<td>60</td>
<td>n/a</td>
<td>52</td>
<td>128</td>
<td>81</td>
</tr>
<tr>
<td>Inotropic support</td>
<td>Epinephrine</td>
<td>None</td>
<td>Dopamine</td>
<td>None</td>
<td>Milrinone</td>
<td>Milrinone</td>
</tr>
<tr>
<td>Other PAH meds</td>
<td>Bosentan</td>
<td>Sildenafil</td>
<td>Iloprost iNO</td>
<td>Sildenafil</td>
<td>Iloprost iNO</td>
<td>Sildenafil</td>
</tr>
<tr>
<td>Respiratory support</td>
<td>Ventilator</td>
<td>Room air</td>
<td>Ventilator</td>
<td>Room air</td>
<td>Ventilator</td>
<td>Ventilator</td>
</tr>
<tr>
<td>Oxygen</td>
<td>80%</td>
<td>21%</td>
<td>40%</td>
<td>21%</td>
<td>80%</td>
<td>n/a</td>
</tr>
</tbody>
</table>

Epoprostenol (Epo), patent ductus arteriosus (PDA), pulmonary hypertension (PH), right ventricular (RV), tricuspid regurgitation (TR), doppler gradient (n/a).

* Patient died 3 weeks after initiation.

- Estimate of PAH made by posterior bowing of ventricular septum, RV hypertrophy, PDA direction, RV dysfunction and size.
- Insufficient tricuspid regurgitation to obtain an accurate TR gradient estimate.

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**CASE REPORT**

PEDIATRICS Volume 134, Number 1, July 2014

e277

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been the experience with other centers managing these patients as well. This suggests pain perception and development of local inflammation may be different in the premature infant compared with the term infant, and certainly is different than in adults. Preterm infants’ immature cortical nociceptive response circuitry make them better suited to tolerate SC infusions than older patients. Anand et al suggest that preterm infants who undergo multiple painful procedures earlier on have a higher pain threshold and dampened responses to pain in later infancy and childhood. Additionally, the soft and loose subcutaneous tissue in infants may prevent the local accumulation and reaction seen in adults. This makes this subgroup of former preterm infants who have PAH-CLD ideal candidates for SCTre therapy if indicated.

As neonatal intensive care centers are becoming more skilled at caring for extremely premature infants who have improved overall survival, the population who have severe PAH-CLD may increase. Currently there are no long-term, randomized, controlled studies involving targeted PAH therapies for these patients. In our experience, SCTre was safe, efficacious, and well tolerated, and may enable safer delivery of a prostanooid to critically ill infants. As with any systemic pulmonary vasodilator, monitoring is critical for ventilation-perfusion mismatch in children who have lung disease, and therapy must be altered appropriately. We suggest this therapy should be considered for early use in infants who have severe PAH in centers with experience in the use of SCTre. Further study of SCTre is warranted in larger pediatric cohorts.

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REFERENCES


Subcutaneous Treprostinil for Pulmonary Hypertension in Chronic Lung Disease of Infancy
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