Outcomes Using a Conservative Versus Liberal Red Blood Cell Transfusion Strategy in Infants Requiring Cardiac Operation

Jill M. Cholette, MD, Michael F. Swartz, PhD, Jeffrey Rubenstein, MD, Kelly F. Henrichs, MT(ASCP), Hongyue Wang, PhD, Karen S. Powers, MD, L. Eugene Daugherty, MD, George M. Alfieris, MD, Francisco Gensini, MD, and Neil Blumberg, MD

Departments of Pediatrics, Surgery, Pathology and Laboratory Medicine, and Biostatistics, University of Rochester, Rochester, New York

Background. **The optimal hemoglobin for infants after cardiac operation is unknown. Red blood cells (RBCs) are commonly transfused to maintain high hemoglobin concentrations in the absence of a clinical indication. We hypothesized that infants can be managed with a postoperative conservative RBC transfusion strategy, resulting in lower daily hemoglobin concentrations, without evidence of impaired oxygen delivery (ie, lactate, arteriovenous oxygen difference [avO$_2$diff]), or adverse clinical outcomes.**

Methods. **Infants weighing 10 kg or less undergoing biventricular repair or palliative (nonseptated) operation were randomly assigned to either a postoperative conservative or liberal transfusion strategy. Conservative group strategy was RBC transfusion for a hemoglobin less than 7.0 g/dL for biventricular repairs or less than 9.0 g/dL for palliative procedures plus a clinical indication. Liberal group strategy was RBC transfusion for hemoglobin less than 9.5 g/dL for biventricular repairs or less than 12 g/dL for palliative procedures regardless of clinical indication.**

Results. **After the operation of 162 infants (82 conservative [53 biventricular, 29 palliative], 80 liberal [52 biventricular, 28 palliative]), including 12 Norwood procedures (6 conservative, 6 liberal), daily hemoglobin concentrations were significantly lower within the conservative group than the liberal group by postoperative day 1 and remained lower for more than 10 days. The percentage of patients requiring a RBC transfusion, number of transfusions, and volume of transfusions were all significantly lower within the conservative group. Despite lower hemoglobin concentrations within the conservative group, lactate, avO$_2$diff, and clinical outcomes were similar.**

Conclusions. **Infants undergoing cardiac operation can be managed with a conservative RBC transfusion strategy. Clinical indications should help guide the decision for RBC transfusion even in this uniquely vulnerable population. Larger multicenter trials are needed to confirm these results, and focus on the highest risk patients would be of great interest.**

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The potential adverse outcomes after a red blood cell (RBC) transfusion have been well described [1–3]. Despite these outcomes, infants after cardiac operation have historically been transfused based on "hemoglobin (Hb) thresholds or triggers," without consideration of their clinical status. Several studies have explored transfusion thresholds in children with congenital heart disease [4–6]. Unfortunately, children who may be most vulnerable to lower Hb concentrations (cyanotic neonates/infants and surgical palliations) were excluded from those studies.

The exclusion of children from large interventional trials stems from the concern that chronic hypoxemia, in conjunction with single ventricle physiology, could impair the ability to maintain adequate oxygen delivery [4–6]. In the immediate postoperative period, limiting RBC transfusions is thought unsafe because of bleeding, altered hemostasis, and myocardial depression. Our previous work compared a high with a low Hb transfusion strategy in children with single ventricle physiology during the immediate postoperative period and demonstrated no substantial difference in oxygen utilization [7].

The present trial was performed to assess the safety, frequency of RBC transfusion, daily Hb concentration,

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Address correspondence to Dr Cholette, Box 667 601 Elmwood Ave, Rochester, NY 14642; email: jill_cholette@urmc.rochester.edu.

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Abbreviations and Acronyms

avO_2diff	=	arteriovenous oxygen difference
CPB	=	cardiopulmonary bypass
CPDA	=	citrate-phosphate-dextrose-adenine
ECMO	=	extracorporeal membrane oxygenation
Hb	=	hemoglobin
LacTime2	=	arterial lactate concentrations $>$ 2 mmol/L
Lact4	=	arterial lactate concentration $\geq$ 4 mmol/L after previous value $<$ 4 mmol/L
PCICU	=	pediatric cardiac intensive care unit
RBC	=	red blood cell

and oxygen utilization between infants randomly assigned to either a conservative or liberal RBC transfusion strategy. We hypothesized that infants managed with a conservative transfusion strategy would receive fewer RBC transfusions, have a lower daily Hb concentration, while maintaining similar measures of oxygen utilization.

Material and Methods

After institutional review board approval and registration with ClinicalTrials.gov as NCT01484886, consecutive patients between March 2012 and July 2014 were screened, consented, and enrolled during the preoperative assessment. Inclusion criteria included congenital heart disease requiring operation, and weight of 10 kg or less for the consistent use of our infant cardiopulmonary bypass (CPB) circuit (further details in Supplement). Exclusion criteria included transition to extracorporeal membrane oxygenation (ECMO) from CPB, Hb greater than 17.5 g/dL, isolated patent ductus arteriosus, or non–English–speaking parent/guardian. Block randomization (block size = 8) divided patients to either a conservative or liberal transfusion strategy (stratified randomization). Patients were further divided into two strata based on the type of operation as follows: biventricular repair or palliative (nonseptated) procedure. Palliative procedure is defined as including all cases in which the heart is not septated or in which there continues to be intracardiac mixing.

The transfusion strategy was initiated at admission to the pediatric cardiac intensive care unit (PCICU) and was maintained until 1) transfer from PCICU service, 2) postoperative day (POD) 28, 3) decision to cannulate for ECMO, or 4) death. Transfusion thresholds for biventricular repairs were chosen based on previous clinical trials [4, 6]. The transfusion threshold chosen for palliated patients was based on a pretrial discussion with both the surgical and PCICU team members.

The conservative transfusion strategy for biventricular repairs was 10 mL/kg RBCs for Hb less than 7.0 g/dL and clinical indication, and for the palliation procedure it was 10 mL/kg RBCs for Hb less than 9.0 g/dL and clinical indication.

The liberal transfusion strategy for biventricular repairs was 10 mL/kg RBCs for Hb less than 9.5 g/dL regardless of clinical status, and for the palliation procedure it was 10 mL/kg RBCs for Hb less than 12 g/dL regardless of clinical status.

Hemoglobin concentrations were measured with each blood gas sample. For this work red cell transfusion is defined as an infusion of 10 mL/kg RBCs, over a defined time, as determined by the attending physician. Red cell transfusion was ordered immediately on breaching the Hb threshold in the liberal arm. In contrast, the combination of both breaching the Hb threshold in conjunction with a clinical indication as determined by the attending physician was required for transfusion in the conservative group. "Clinically indicated" transfusions were based on the judgment of the PCICU attending physician (ie, hypotension, tachycardia). Protocol violations and transfusions above the Hb threshold were at the discretion of the attending physician. However, after transfusion, subsequent management was according to the patient's designated transfusion group. All other aspects of care remained standard for all patients (Supplement).

All blood was prestored, leukoreduced, irradiated (CIS-US IBL 437 at 2,500 cg), ABO identical, and Rh matched. A volume-depleted protocol was used except in rare emergent cases when time does not allow for volume depletion methods and citrate-phosphate-dextrose-adenine (CPDA)-1 red cells of the patient's blood type are not available. Volume depletion was accomplished by centrifugation to remove additive solution, washing with normal saline, or using CPDA-1 red cells that do not have an additive solution. All RBCs were stored for less than 14 days and platelets for 3 to 5 days, and transfusion was initiated within 60 minutes of breaching the Hb threshold.

Blood bank staff (KH) tracked every RBC transfusion and its preceding Hb concentration for protocol compliance. Transfusion in a conservative group patient above the transfusion threshold was determined to be nonadherence to the conservative RBC transfusion strategy. In each case the indication for RBC transfusion was communicated to the primary investigator from the prescribing attending physician at the time of transfusion.

Elevated lactate concentrations and poor lactate clearance predict increased risk for death and morbidity after cardiac operation and can suggest possible impaired oxygen utilization [8, 9]. Arterial blood panels are obtained with every arterial blood gas (collected every 30 minutes from PCICU admission and spaced as clinically able) and include arterial lactate concentrations. All lactate concentrations from time of PCICU admission until the arterial line was removed (at discretion of the PCICU attending physician) or on POD 28 were included in the analysis. Daily mean and peak lactate concentrations were calculated, and the fraction of time the arterial lactate concentrations was greater than 2 mmol/L

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