Cost Variation Across Centers for the Norwood Operation

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*Background.* The Norwood operation is associated with substantial variability in Norwood costs across centers. However, specific factors driving this cost variation are unclear. We assessed center variability in Norwood costs and underlying mechanisms in a multicenter cohort.

*Methods.* Clinical data from the Pediatric Heart Network Single Ventricle Reconstruction trial were linked with cost data from the Children’s Hospital Association Inpatient Essentials database. Center variation was assessed by modeling Norwood costs adjusted for baseline patient characteristics, and the relationship with complications, length of stay (LOS), and specific cost categories was examined. Patients undergoing transplantation or stage 2 palliation during the Norwood admission were excluded.

*Results.* Nine centers (332 patients) were included. Adjusted mean cost/case varied 4.6-fold across centers (range: $50,559 to $230,851, p < 0.001). In addition, variation was found across centers in the adjusted mean number of complications/case (2.6-fold variation) and adjusted mean LOS/case (1.9-fold variation). Differences in complications explained 63% of the cost variation across centers. After accounting for complications, differences in LOS explained 66% of the remaining cost variation. Seven specific complications were found to occur more frequently at high-cost centers: pleural effusion, seizures, wound infection, thrombus, liver dysfunction, sepsis, necrotizing enterocolitis (all p < 0.001). With regard to types of cost, room and board/supplies and laboratory costs were the primary drivers of cost variation across centers.

*Conclusions.* This study identified several factors associated with center variation in Norwood costs, which may be targeted in subsequent initiatives aimed at both improving quality of care and reducing costs.

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In this era of rising health care costs, improved understanding of factors affecting resource utilization is increasingly important. Prior work has shown that patients with congenital heart disease account for the highest costs among all birth defects [1], and that hospital costs for this population are disproportionately high compared with other pediatric hospitalizations [2]. It is estimated that approximately $6 billion in inpatient costs annually are related to congenital heart disease [3].

Among all types of congenital heart disease, patients undergoing the Norwood operation for hypoplastic left heart syndrome and related single right ventricle anomalies have generally been reported to account for the greatest resource utilization [4]. Moreover, considerable variation across centers in costs related to the Norwood operation has been demonstrated [5]. However, the factors that influence this variation remain understudied. It is known that postoperative complications and prolonged length of stay (LOS) can have an important impact on hospital costs after congenital heart operation on a patient level; however, it is less clear how these factors, and specific complications, influence variation in costs across centers. A better understanding of these relationships may aid in informing the design of initiatives aimed at both improving patient outcomes and reducing costs of care across institutions. Therefore, the purpose of this study was to examine variation across centers in costs associated with the Norwood operation and to evaluate the relationship of postoperative complications, LOS, and other factors with this variation.

**Patients and Methods**

*Data Sources*

The Single Ventricle Reconstruction (SVR) Trial (NCT00115934), conducted by the Pediatric Heart Network, enrolled 555 infants across 15 centers undergoing the Norwood procedure for hypoplastic left heart syndrome or related single right ventricle anomalies from 2005 to 2008. Patients were randomized to receive either a modified Blalock-Taussig shunt or a right ventricle-to-pulmonary artery shunt [6].

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The Inpatient Essentials database (formally known as
the Case Mix database) is a large administrative database
maintained by Children’s Hospital Association (Lenexa,
KS). The database contains resource utilization and other
patient data from 90 US children’s hospitals [7]. In addi-
tion to daily line item utilization, these data are also
categorized as laboratory, imaging, pharmacy, and other
(supplies, clinical, room, and nursing).

This study that involved a retrospective analysis of de-
deidentified data was reviewed by the Medical University
of South Carolina Institutional Review Board and did not
meet qualifications for human subjects research.

**Linkage**

Clinical data from the SVR trial were merged at the pa-
tient level with cost data from the Inpatient Essentials
database for centers participating in both data sets during
the trial period as previously described [7]. Briefly,
probabilistic matching of indirect identifiers was used to
link records, including center, sex, date of admission (±1
day), date of discharge (±1 day), and date of birth (±1
day). These methods have been previously validated in
the congenital heart disease population [7, 8].

**Study Population**

As previously described, all patients enrolled in the SVR
trial were eligible for inclusion [7]. Patients undergoing
stage 2 palliation or heart transplantation during the
same hospital admission (n = 27) were excluded from
analysis, because this study focused on the Norwood
hospitalization, and it is known that these practices can
vary widely across centers. One center enrolling fewer
than 10 total patients was also excluded from this anal-
ysis, because their small sample size precluded mean-
ingful evaluation of center-level data. Of note, we did not
exclude patients who died during the hospitalization
because our prior work has shown that the inclusion/
 exclusion of survivors has little impact on overall center-
level cost variation in this population [9].

**Data Collection**

Detailed clinical information was obtained from the SVR
trial data set as previously described [7]. All serious
adverse events and other complications collected in the
trial were included, which comprised major complica-
tions in the cardiac, vascular, respiratory, neurologic,
gastrointestinal, infectious, renal, and hematologic sys-
tems [10].

Data on hospital costs and payor were obtained from
the Inpatient Essentials database [7]. Costs were esti-
mated from charges using hospital-specific cost-to-charge
ratios, adjusted for geographic region, using the Centers
for Medicare and Medicaid Services price wage index,
and were inflated to 2008 dollars using the medical
component of the consumer price index.

**Statistical Analysis**

Because of non-normal distributions, continuous vari-
ables were summarized with medians and interquartile
ranges, and categorical variables were depicted as
frequencies and percentages.

Center variation in costs, postoperative complication
rates, and postoperative LOS was examined using
generalized linear mixed effects models with a random
intercept for each hospital to account for within-center
clustering. Continuous outcomes were log-transformed
before modeling, and estimates were back-transformed
onto the original scale for ease of interpretability. As
described previously [7], models were adjusted for base-
line patient and operative characteristics found to be
associated with higher costs (p < 0.1) in univariate ana-
lyses, including preoperative intubation, pre-Norwood
pulmonary artery banding, pre-Norwood atrial septec-
tomy, presence of aberrant right subclavian artery,
number of pre-Norwood surgeries, number of pre-
Norwood complications, payor type, use of regional ce-
rebral perfusion, cardiopulmonary bypass time, deep
hypothermic circulatory arrest time, use of ultrafiltration,
and presence of open sternum. Of note, shunt type was
not found to be associated with cost in univariate analysis.

From the models, adjusted center-level costs, number
of postoperative complications, and postoperative LOS
were determined. To understand the proportion of vari-
ation in center-level costs explained by complications and
LOS, adjusted center-level costs were modeled by the
number of complications, and the percentage of variation
explained was determined using the coefficient of deter-
mination (R²). We then additionally adjusted center-level
costs by the number of complications and modeled this
measure with adjusted postoperative LOS.

To examine the specific types of complications that
occurred more frequently at high-cost centers, centers
were grouped into adjusted cost tertiles on the basis of
the distribution of the data, and the frequency of com-
plications was examined across these cost tertiles. We
only focused on those complications occurring in 5% or
more of our overall study cohort, because it is both
complications that are relatively common and that occur
more frequently at high-cost centers that may be the most
“high leverage” complications to target in initiatives
aiming to reduce cost variation. Specific categories of cost
were also assessed across centers (n = 8 for which data
were available). All analyses were performed using SAS
value less than 0.05 was considered statistically
significant.

**Results**

**Study Population**

Overall, 9 of 15 centers participating in the SVR trial also
participated in the Inpatient Essentials database and
enrolled more than 10 patients during the trial period.
From these nine centers, records on 332 of 350 eligible
patients were able to be matched between data sets
(overall linkage rate of 95%). The 18 unmatched patients
were distributed across four sites, with a range of 0 to 7
unmatched patients across these sites.
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