Original Article

Outcomes and hospital costs associated with the Norwood operation: beyond morbidity and mortality

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Abstract
Background: Although much is known about morbidity and mortality, there are limited data focusing on the financial aspect of the Norwood operation. Our objective is to characterise the hospitalisation and detail the hospital costs.

Methods: We retrospectively studied 86 newborns with hypoplastic left heart syndrome who underwent Norwood palliation between 2008 and 2012. Clinical and financial data were collected. Financial data have been reported for 2011–2012.

Results: At surgery, median age and weight of the patients were 4 days (range 1–13) and 3 kg (range 2–4.8), respectively. The median time from admission to surgery was 4 days (range 1–10), with the postoperative ICU stay and total length of stay at the hospital being 10 days (range 4–135) and 16 days (range 5–136), respectively. Discharge mortality was 14/86 (16%) patients.

For patients operated on between 2011 and 2012 (n = 40), median hospital costs, charges, and collections per patient were $117,021, $433,054, and $198,453, respectively, and mean hospital costs, charges, and collections per patient were $322,765, $1,109,500, and $511,271, respectively.

A breakdown of total hospital costs (direct and indirect) by department showed that the top four areas of resource utilisation (excluding physician fees) were as follows: the cardiac ICU (35%), laboratory (12%), pharmacy (12%), and operating room (7%). Interestingly, point-of-care laboratory evaluations accounted for almost half of the laboratory total (5%). Extracorporeal membrane oxygenation, although only utilised in eight patients between 2011 and 2012, accounted for 7% of utilisation. General radiology only accounted for 2%, despite numerous radiographs.

Conclusions: Limited data are available that detail the hospitalisation and costs associated with the Norwood operation. We hope that this analysis will identify areas for quality and value improvement from both system and patient perspectives.

Keywords: Norwood; outcomes; hospital costs

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Systems Database, Pasquali et al\textsuperscript{3,4} established benchmarks for hospital costs for common congenital heart operations, including the Norwood operation. In addition, the analysis demonstrated wide variability across hospitals related in part to differences in length of stay and complication rates.\textsuperscript{3,4} Interestingly, Mishra et al,\textsuperscript{5} using a prospective cost analysis model, showed that in Norway reimbursement received for the Norwood sequence of operations was less than one-third of the recorded costs. On the other hand, our current analysis in the United States demonstrated that the median reimbursement received for the hospitalisation associated with the Norwood operation alone exceeded the recorded median hospital costs by $81,432 per case, and the mean reimbursement received for the hospitalisation associated with the Norwood operation alone exceeded the recorded mean hospital costs by $188,506 per case.

Our objectives are to characterise our Norwood hospitalisation and break down the hospital costs by department, in order to guide future quality initiatives.

Methods

We retrospectively studied 86 newborns with hypoplastic left heart syndrome who underwent Norwood palliation within the first 2 weeks of life between 2008 and 2012, inclusive, at a single institution. Clinical data collected included demographics, postoperative timeline, postoperative diagnostic studies and interventional procedures, and discharge medicine and feeding regimens. Financial data collected include total hospital costs (direct and indirect), charges and collections for those patients operated on between 2011 and 2012. We do not have comparable data for the years between 2008 and 2010 because of different methodologies that were used at that time. Data were collected using an internal cost accounting module (StrataJazz\textsuperscript{TM}, Strata Decision Technology, Chicago, Illinois, United States of America). Costs were calculated on the basis of relative value units. Physician fees were excluded, allowing us to focus solely on the hospital-based impact. A descriptive analysis is reported throughout.

Institutional Review Board approval was obtained to perform this retrospective study, and individual patient consent was waived.

Results

Population summary statistics

At surgery, median age and weight of the patients were 4 days (range 1–13) and 3 kg, respectively (range 2–4.8). The majority of operations (83/86) were performed using a Sano shunt to provide pulmonary blood flow. The median time from admission to surgery was 4 days (range 1–10), with the postoperative ICU stay and total length of stay at the hospital being 10 days (range 4–135) and 16 days (range 5–136), respectively (Fig 1). Survivorship, defined as survival up to hospital discharge and 30 days following surgery, was 72/86 (84%) patients.

Postoperative diagnostics

(Table 1) Postoperative imaging modalities included routine chest and abdominal radiography, ultrasound, fluoroscopy, MRI, and computed tomography. The entire cohort underwent a total of 3171 routine radiographs (per patient: median 26, range 10–185), 306 ultrasounds (median 2, range 1–14), 33 fluoroscopy studies (median 0, range 0–3), 34 MRI studies (median 0, range 0–6), and nine computed tomograms (median 0, range 0–2). Advanced imaging included echocardiography and diagnostic cardiac catheterisation. The cohort underwent 476 echocardiograms (median 4, range 1–24) and eight diagnostic cardiac catheterisations (median 0, range 0–1).

For the entire cohort, there were 108 different types of laboratory blood tests ordered, 15 of which were point-of-care blood tests performed at the bedside. The median total number of blood tests ordered per patient per day was 45 (range 9–131), 37 of which were point-of-care tests (range 4–109) and eight of which were sent to the hospital laboratory (range 4–22).

Postoperative interventions

(Table 2) Occasionally, patients required unplanned postoperative interventions, including interventional cardiac catheterisations, repeat cardiac surgery, and/or non-cardiac surgery. The majority of interventional...
Cardiac catheterisations were performed to address the shunt\(^4\) or the branch pulmonary arteries.\(^5\) The majority of unplanned cardiac operations were performed to address haemodynamic compromise with extracorporeal membrane oxygenation\(^1,2\) or the shunt.\(^3\) The majority of non-cardiac operations were performed to address gastro-oesophageal reflux by Nissen fundoplication/G-tube.\(^7\)

Of note, in those patients requiring either an unplanned interventional cardiac catheterisation or an unplanned cardiac re-operation, hospital length of stay was longer (38 versus 18 days) and mortality was high (11 of 18 patients, 61%). In those patients requiring extracorporeal membrane oxygenation support, survival was 25% (three of 12 patients).

**Discharge status**

(Table 3) Of the 72 survivors, patients were discharged on a median of four medications (range 2–10), three of which were cardiac medications. Cardiac medications included aspirin, furosemide, chlorothiazide, spironolactone, metolazone, captopril, lisinopril, digoxin, inderal, propafenone, carvedilol. Discharge feeding regimens varied between oral, nasogastric, or a combination thereof, as well as between intermittent bolus and continuous regimes. In addition to post-discharge cardiac surgical and cardiology follow-up, patients had a median of two (range 1–4) additional appointments with non-cardiac subspecialists. These included haematology, gastroenterology, ophthalmology, neurology, nephrology, general surgery, urology, endocrinology, otolaryngology, hepatology, and genetics appointments.

**Financial data**

(Tables 4 and 5) Looking specifically at the financial data from 2011 to 2012 (n = 40), median hospital cost, charges, and collections per patient were $117,021, $443,054, and $198,453, respectively, and mean hospital costs, charges, and collections per patient were $322,765, $1,109,500, and $511,271, respectively. The cost analysis included direct (64%) and indirect (34%) costs (Table 4).

A breakdown of total hospital costs by department showed that the top four areas of resource utilisation (excluding physician fees) were the cardiac ICU (35%), laboratory (12%), pharmacy (12%), and operating room (7%). Interestingly, point-of-care laboratory evaluations accounted for almost half of the laboratory total (5%). Extracorporeal membrane oxygenation, although only utilised in eight patients between 2011 and 2012, accounted for 7% of utilisation. Despite numerous radiographs, general radiology only accounted for 2% (Table 5).
Discussion

Many patients require expensive and extensive care during the postoperative period to enable their recovery. The postoperative course is sometimes complicated by a sudden deterioration requiring mechanical circulatory/respiratory support, sub-optimal or technically challenging repair with residual haemodynamically significant lesions, feeding difficulties, and the need for numerous and frequent radiographic and laboratory evaluations. The services required to address these issues can substantially increase the cost of care delivery. An increased understanding of hospital costs may facilitate developing strategies of improved resource allocation. Opportunities for improvement include strategic implementation of mechanical cardiopulmonary support, identifying means to lower the risk associated with genetic and non-cardiac lesions, technical performance enhancement to minimise complications, institution of feeding protocols, and streamlined ordering of diagnostic tests.

Extracorporeal membrane oxygenation

The increased success of extracorporeal membrane oxygenation in patients who suffer cardiac arrest following congenital cardiac surgery has led to expansion of this technology to patients who were previously considered poor candidates. Patients who are decompensating after a Norwood operation fall into this category and are not uncommonly placed on extracorporeal membrane oxygenation during active resuscitation.6

In a large analysis of the Society of Thoracic Surgeons Congenital Heart Surgery Database (2000–2010), mechanical support was utilised in 2287 (2.4%) patients.7 Extracorporeal membrane oxygenation support accounted for >95% of the instances of postoperative support.7 The greatest postoperative rate of mechanical cardiac support was observed for the Norwood operation (17%).7 Mortality was 57% in patients with mechanical support and 13% among those without support (unadjusted odds ratio 8.7, p < 0.0001).7 Using data from the Extracorporeal Life Support Organization (2000–2009), the survival to hospital discharge for 738 neonates supported with extracorporeal membrane oxygenation specifically after Norwood operation for hypoplastic left heart syndrome was 31%.8

The application of extracorporeal membrane oxygenation to postoperative patients may be an area

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Table 4. Financial summary.

<table>
<thead>
<tr>
<th>Payor mix</th>
<th>n</th>
<th>Value</th>
<th>Interquartile range</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medicaid</td>
<td>21</td>
<td>$117,021</td>
<td>($75,826–$251,731)</td>
<td>53</td>
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<tr>
<td>Managed care</td>
<td>15</td>
<td>$198,453</td>
<td>($87,067–$422,184)</td>
<td>37</td>
</tr>
<tr>
<td>Commercial</td>
<td>4</td>
<td>$433,054</td>
<td>($307,257–$871,868)</td>
<td>10</td>
</tr>
</tbody>
</table>

Median finances

| Costs/patient   | $322,765 |
| Direct ($205,464 – 64%) | $205,464 |
| Indirect ($117,302 – 34%) | $117,302 |
| Charges/patient | $1,109,500|
| Collections/patient | $511,271 |

Table 5. 2011–2012 Hospital cost data.

<table>
<thead>
<tr>
<th>Area of hospital resource utilisation</th>
<th>% of total Norwood hospital costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anaesthesia</td>
<td>0.6</td>
</tr>
<tr>
<td>Cardiac catheterisation laboratory</td>
<td>2.6</td>
</tr>
<tr>
<td>Cardiac stepdown unit</td>
<td>2.5</td>
</tr>
<tr>
<td>Cardiac ICU</td>
<td>35.1</td>
</tr>
<tr>
<td>ECMO</td>
<td>6.9</td>
</tr>
<tr>
<td>Laboratory</td>
<td>11.7</td>
</tr>
<tr>
<td>Non-invasive imaging</td>
<td>1.5</td>
</tr>
<tr>
<td>Operating room</td>
<td>7</td>
</tr>
<tr>
<td>Perfusion</td>
<td>2.9</td>
</tr>
<tr>
<td>Pharmacy</td>
<td>12.4</td>
</tr>
<tr>
<td>Radiology</td>
<td>2.0</td>
</tr>
<tr>
<td>Respiratory</td>
<td>11.3</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>3.5</td>
</tr>
</tbody>
</table>

ECMO = extracorporeal membrane oxygenation
n = 40
Nutrition and feeding

Following neonatal congenital cardiac surgery, one of the factors impacting patient recovery is feeding difficulty. Specifically after the Norwood operation, during which there is potential for recurrent laryngeal nerve injury and resultant vocal cord paralysis, the problem may be compounded. A study looking specifically at this population showed an incidence of vocal cord paralysis of 35%, along with abnormal oral feeding evaluations in 70% and abnormal modified barium swallows in 82%. Only 18/50 (36%) patients were tolerating full oral feeds at discharge. In our series, none of the patients were discharged on full oral feeds – 72% were discharged on oral feeds with supplemental tube feeds and 28% were discharged solely on nasogastric or gastrostomy tube feeds. Unfortunately, the swallowing dysfunction observed following the Norwood operation translates into a prolonged hospital stay (31 versus 23 days).

The application of standardised feeding algorithms may be a means of improving resource utilisation. A total of three studies have looked at the benefits of such algorithms following the Norwood procedure. The studies demonstrated increased survival, decreased incidence of necrotising enterocolitis, and decreased median time to recommended daily allowance of calories. The first study showed that, after implementation of a standardised feeding protocol, duration of total parenteral nutrition (51 versus 116 hours, p = 0.03) and days to achieve daily calories (9 versus 13 days, p = 0.01) both decreased. The second study showed a significant decrease in the incidence of necrotising enterocolitis (p = 0.01) after introduction of a feeding protocol. A third study, which included both perioperative and postoperative management techniques, showed increased survival to discharge from 70 to 95% (p = 0.003). Combining the studies, the average length of stay was reduced from 31 days in the pre-protocol groups to 24.5 days in the post-protocol groups. Measures directed at reducing the incidence of gastrointestinal complications may improve outcomes and reduce hospital costs in this population.

Genetic and non-cardiac lesions

The presence of genetic and non-cardiac lesions contribute to adverse outcomes following the Norwood operation. In the Society of Thoracic Surgeons Database, stage 1 in-hospital mortality (26 versus 20%, p = 0.04) and mean postoperative length of stay (42 versus 31 days, p < 0.0001) were greater, and postoperative complications were significantly more prevalent in infants with genetic and non-cardiac defects. In the Congenital Heart Surgeons’ Society database, genetic and non-cardiac defects were present in 55 (8%) patients. Early hazard for death after the Norwood surgery was significantly worse in infants with non-cardiac defects/syndromes (p = 0.008). For chromosomal defects (n = 14), outcomes were highly unfavourable and the risk of death was doubled (10-year survival 25 ± 9 versus 54 ± 2%, p = 0.005).

Owing to the fact that survival after the Norwood operation has increased, debate continues as to whether a non-operative option should even be offered to neonates with hypoplastic left heart syndrome. This debate becomes more complicated in the presence of high-risk lesions that increase morbidity and mortality. The variable penetrance and unknown outcomes of many of these associated lesions have led us to continue to offer surgical palliation. While we continue to support an operative approach, we also look for strategies to mitigate these factors in order to improve outcomes and reduce hospital costs. Although it may be a result of differing methodologies between the databases, outcomes in children with non-cardiac and genetic defects have improved over time, hinting that strides have already been made to minimise the deleterious effects of these associated conditions. Certainly, progress in this high-risk population will reduce morbidity and mortality and improve resource utilisation.

Technical performance, postoperative complications, and re-interventions

Postoperative re-interventions contribute significantly to outcome and increase hospital costs. A study showed a postoperative re-intervention rate of 27% (36 of 135 patients). Postoperative re-intervention was defined as the need for cardiac catheterisation laboratory- or operating room-based procedures that include balloon dilation or repair of arch obstruction, shunt revision, reoperations for bleeding, and extracorporeal membrane oxygenation support. In our series, 18 individual patients required re-intervention – 10 patients who underwent surgical re-intervention, three patients who underwent catheter-based re-intervention, and five patients who underwent both surgical and catheter-based
re-intervention. The length of hospital stay was longer (38 versus 18 days) and mortality was high (11 of 18 patients, 61%) in those patients requiring re-intervention.

Multiple recent studies have examined the role of technical performance on outcomes, particularly for the Norwood operation. These studies have shown that technical scores can be measured after the Norwood operation; these scores correlate with early outcomes; optimal technical performance can attenuate the effects of poor preoperative physiologic status and high case complexity; and inadequate technical performance can result in poor outcomes regardless of the preoperative status.22,23

A system to improve technical performance (simulation, dedicated Norwood surgeons, etc.) and reduce postoperative morbidity may result in clinical and economic benefit.24

**Diagnostic testing**

An enormous number of diagnostic tests are obtained during the Norwood operation hospitalisation. These include radiographs (general, ultrasonic, fluoroscopic, computed tomographic, and magnetic resonance images), echocardiograms, diagnostic cardiac catheterisations, and laboratory tests. During the median 16-day postoperative length of stay in our series, each patient underwent a median of 26 (range 10–185) plain radiographs and 868 (range 188–6808) individual blood tests. Of the blood tests, 685 (range 111–5668) were obtained as point-of-care laboratory tests at the patient’s bedside in the cardiac ICU.

Streamlining the diagnostic testing may be beneficial from a patient care and cost perspective. In recent years, several studies have focussed on the feasibility of lowering the number of bedside chest radiographs performed in the ICU, favouring an on-demand prescription strategy rather than daily routine imaging.25–27 A meta-analysis carried out included nine studies comparing routine and selective chest radiograph approaches in critically ill adults and children.26 Pooled data showed no evidence of effect of a restrictive approach on ICU mortality (RR 1.04, 95% CI 0.84–1.28, p = 0.72), hospital mortality (RR 0.98, 95% CI 0.68–1.41, p = 0.91), length of ICU stay (difference −0.86 days, 95% CI −2.38 to 0.66 days, p = 0.27), length of hospital stay (difference −2.50 days, 95% CI −6.62 to 1.61 days), or duration of mechanical ventilation (difference −0.30 days, 95% CI −1.48 to 0.89 days, p = 0.62).26 A study extended the efforts in order to reduce routine ordering of biological samples in addition to radiographs.27 Ordering of routine samplings was discouraged, whereas ordering targeted samplings was encouraged. A portion of the reduction in annual expenses was due to a decreased orderings of biological samples by 30%, with no change in clinical outcomes.27

Streamlining in both areas may be beneficial, although the influence may be greatest in the laboratory area, given the difference in overall resource utilisation between radiography (2%) and laboratory (12%) in our series.

**Conclusion**

Although the Norwood operation remains one of the more challenging operations, survival has improved and the analysis of outcomes after the Norwood operation must include multiple domains in addition to operative mortality. Despite being surgical survivors, many patients require expensive and extensive hospital-based services during the perioperative period to enable their convalescence. By better delineating the postoperative course, numerous strategies can likely be employed to improve patient care and reduce resource utilisation in this complex patient population. We hope that this analysis will allow us to identify areas for quality and value improvement from both system and patient perspectives.

**Acknowledgements**

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**Conflicts of Interest**

None.

**Ethical Standards**

Institutional Review Board approval was obtained to perform this retrospective study, and individual patient consent was waived.

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