Nursing Considerations for Children Undergoing Delayed Sternal Closure After Surgery for Congenital Heart Disease

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Congenital heart disease (CHD) has an estimated prevalence of 4 to 50 per 1000 live births, with more than 2 million Americans living with a congenital heart defect. Diagnosis usually occurs at birth or within the first few months of life; many of these children undergo palliative or corrective surgery in the first year of life. Many patients with complex CHD, such as hypoplastic left heart syndrome, undergo a series of complex surgeries before final palliation or repair is achieved. Surgical and technological advances have resulted in markedly improved survival and life expectancy in patients with CHD since the first surgery for CHD (ligation of a patent ductus arteriosus) was performed in 1938. Postoperative recovery of these children can be one of the most technical and rewarding challenges confronted by critical care nurses.

Open sternotomy and delayed sternal closure (DSC) is a surgical technique that has been used in children for the past 20 years that facilitates postoperative recovery in the intensive care unit (ICU). Few nursing publications describe or address the care of children undergoing open sternotomy and DSC. This article describes the pathophysiology and clinical rationale for the surgical technique and use of open sternotomy and delayed sternal closure.

CE Continuing Education

This article has been designated for CE credit. A closed-book, multiple-choice examination follows this article, which tests your knowledge of the following objectives:

1. Identify 3 complications that may occur after delayed sternal closure in children
2. Describe the pathophysiology and clinical rationale for the surgical technique and use of open sternotomy and delayed sternal closure
3. Discuss 3 nursing considerations for a child undergoing an open sternotomy

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PRIME POINTS

- Delayed sternal closure is used in children after surgery for congenital heart disease.
- Caring for a patient with an open sternum can be challenging but very rewarding for critical care nurses.
- The nursing care that may be provided by a critical care nurse for these specialized patients include respiratory, cardiac, endocrine, and preventive interventions.
using a systems approach for critical care nurses.

**Pathophysiology**

The last surgical step in the operating room after cardiac surgery is to close the median sternotomy by approximating the sternum, subcutaneous tissues, and skin.

Following palliative or reparative cardiac surgery, patients may not be able hemodynamically to tolerate sternal closure. Surgical manipulation of the heart can lead to swelling in the pericardium and/or the pericardiomediastinal space. Cardiac compression, which may occur at the time of sternal closure, can lead to decreased cardiac output and elevated pulmonary venous pressure due to decreased ventricular compliance and filling. This ongoing state of cardiac compression can cause a state of progressive low cardiac output that leads to hemodynamic instability and compromise. This clinical situation of low cardiac output has been described in the adult and pediatric literature by different terms: typical tamponade, atypical tamponade, tight mediastinal syndrome, and cardiac compression.

Clinical surgical experience and documented medical literature support leaving the sternum open postoperatively for the following clinical situations: hemodynamic instability, myocardial edema, cardiac dilatation, intractable bleeding and coagulopathy, dysrhythmias, respiratory compromise, and mediastinal placement of a circulatory assist device.

Cardiac surgeons decide to leave the sternum open and use DSC in a variety of clinical scenarios, including but not limited to electively in the operating room after complex neonatal repairs, in the operating room after attempting primary closure that resulted in hemodynamic compromise, after cannulation and/or decannulation from a mediastinal circulatory assist device, or emergently reopening the chest in the ICU at the time of cardiac arrest after primary closure. After the child achieves hemodynamic stability and recovery, he or she will undergo DSC either in the ICU or after a return trip to the operating room. The time frame for which DSC is used in the critical care unit depends on the patient, but it is usually within the first 24 to 72 hours of the recovery phase postoperatively. Riphagen et al reported that DSC was performed at a median of 21 hours (range, 18-40 hours) after surgery. In some clinical situations, such as mediastinitis or implantation of a mechanical support device through the open sternum, the sternum must remain open for longer than 72 hours.

### Pediatric Experience

Use of DSC after cardiac surgery was described in the adult cardiac literature as early as 1975 by Riahi and colleagues. In 1978, Ott et al reported one of the first pediatric cases of DSC, in a 2-month-old who had undergone surgical repair of d-transposition of the great vessels. Since then, the use of open sternum followed by DSC in neonates and children has been well documented to be helpful in managing these critically ill children in the early postoperative phase of recovery after surgical palliation or repair of CHD. Table 1 provides an extensive and exhaustive literature review of the surgical use of DSC in children.

Use of DSC has become routine in many centers as part of the postoperative management strategies for complex neonatal palliations such as Norwood stage I for hypoplastic left heart syndrome.

### Surgical Dressings and Devices

Once the surgical decision is made to leave the sternum open, a sterile occlusive dressing (Figure 1) is put in place by the surgeon. The choice of sterile dressing is based on the surgeon’s preference and experience. Different strategies and techniques have been used for sterile mediastinal dressings. McElhinney et al described the use of a Silastic sheet (Dow Corning, Midland, Michigan) cut into the shape of the open mediastinal cavity, attached to the external skin via sutures, and covered with an occlusive sterile dressing. Cardiac compression may not be alleviated by open sternotomy alone. The sternal edges may have to be physically...
<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Sample size</th>
<th>Method</th>
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<tr>
<td>Ott et al</td>
<td>1978</td>
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<td>Gangahar et al</td>
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<td>Retrospective review of pediatric patients who had undergone DSC</td>
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<tr>
<td>Jogi and Werner</td>
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<td>8</td>
<td>Clinical measurement of intravascular and airway pressures, cardiac output, and changes in intrathoracic blood volume after sternum closure</td>
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<td>Kay et al</td>
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<td>Clinical study</td>
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<td>Odim et al</td>
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<td>Ziener et al</td>
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<td>Elami et al</td>
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<td>Hakimi et al</td>
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<td>55</td>
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<td>Alexi-Meskishvili et al</td>
<td>1995</td>
<td>113</td>
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<td>Iyer et al</td>
<td>1997</td>
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<td>Tabbutt et al</td>
<td>1997</td>
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<td>1997</td>
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<td>Abstract presentation</td>
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<tr>
<td>McElheinney et al</td>
<td>2000</td>
<td>128</td>
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<td>Walker et al</td>
<td>2000</td>
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<td>Case study</td>
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<tr>
<td>Main et al</td>
<td>2001</td>
<td>17</td>
<td>Measurement of respiratory function before and after DSC</td>
</tr>
<tr>
<td>Samir et al</td>
<td>2002</td>
<td>119</td>
<td>Retrospective review of pediatric patients who had undergone DSC</td>
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<tr>
<td>Riphagen et al</td>
<td>2005</td>
<td>66</td>
<td>Retrospective review of pediatric patients who had undergone DSC</td>
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### Findings

<table>
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<tr>
<th>Patient series</th>
<th>Description</th>
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<tr>
<td>3 adult patients and 1 infant patient</td>
<td>Reviewed the use of DSC for cases of cardiac compression or risk of cardiac tamponade due to excessive bleeding.</td>
</tr>
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<td>9 patients who had undergone cardiac surgery for congenital heart disease</td>
<td>7 of the 9 patients survived with no wound infection or sternal dehiscence.</td>
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<td>100 patients over a 1-year period</td>
<td>Reviewed the use of DSC.</td>
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<tr>
<td>854 patients between July 1986 and June 1991</td>
<td>Demonstrated that sternum closure may compress the heart and cause a shift in the relationship between ventricular end-diastolic pressure and end-diastolic volume.</td>
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<tr>
<td>100 patients</td>
<td>Clinical study that described pericardial pressure measurements in infants after ventricular septal closure.</td>
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<td>5 (61.8%) underwent primary elective open sternum</td>
<td>Patient series: 89 patients reviewed.</td>
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<tr>
<td>Mortality 11 (20%)</td>
<td>Indications: low cardiac output.</td>
</tr>
<tr>
<td>Ages ranged from 1 day to 15 years</td>
<td>Prolonged open sternotomy used in 113 pediatric patients (9%).</td>
</tr>
<tr>
<td>Incidence of infection was 5.6% or 2 of the 36</td>
<td>Indications: low cardiac output.</td>
</tr>
<tr>
<td>100 patients over a 1-year period</td>
<td>Patient series: 3718 patients reviewed.</td>
</tr>
<tr>
<td>Survival: 41 patients who underwent DSC</td>
<td>15 patients with minor wound infection.</td>
</tr>
<tr>
<td>36 children (32%) and 43 newborns (38%)</td>
<td>178 patients underwent DSC with an overall mortality rate of 19%.</td>
</tr>
<tr>
<td>Overall mortality 36.2%, (41 patients)</td>
<td>6.7% incidence of surgical site infection.</td>
</tr>
<tr>
<td>Incidence of mediastinitis 0.8% (1 patient)</td>
<td>3.9% incidence of mediastinitis.</td>
</tr>
<tr>
<td>15 patients with minor wound infection</td>
<td>Patient series: 585 infants &lt;1 year of age from 1992 to 1996.</td>
</tr>
<tr>
<td>No re-exploration for mediastinitis</td>
<td>Sternal infection rate &lt;1%.</td>
</tr>
<tr>
<td>6.7% incidence of surgical site infection</td>
<td>DSC dictates the need for ventilator changes.</td>
</tr>
<tr>
<td>119 underwent DSC</td>
<td>Concluded that respiratory function may be compromised after DSC, requiring ventilator changes at the time of closure.</td>
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<td>Risk factors found to be predictive of use of DSC: interruption of the aortic arch or total anomalous pulmonary venous drainage; age, 7 days; aortic clamping &gt;98 min; cardiopulmonary bypass time &gt;185 min; central venous saturation &lt;51% after bypass</td>
<td>Patient series: 585 children between January 2000 and December 2002: 66 (11.3%) underwent DSC. Safe practice with potential benefits of earlier extubation and discharge from the intensive care unit.</td>
</tr>
</tbody>
</table>
lifted off of the heart with some form of traction or splinted from touching the heart (Figure 2) by using surgical tools such as rib spreaders, stents, or struts. The splinting device is placed between the sternal edges before the sterile dressing is applied.

**Complications**

Potential complications that may occur with the use of open sternotomy and DSC include late sternal instability, bleeding, and sepsis. The rates of mediastinitis and bloodstream infection after median sternotomy are low. Long and colleagues recently reported that the incidence of mediastinitis was 1.4% in children who had undergone median sternotomy for surgical correction of a complex congenital heart defect. Organisms that were identified as being the cause of the mediastinitis included *Staphylococcus aureus*, coagulase-negative staphylococci, and *Pseudomonas aeruginosa*.

Different risk factors that may predispose children for mediastinitis, such as wound contamination at the time of surgical procedure, prolonged surgical times, younger age, use of deep hypothermia, and a higher American Society of Anesthesiologists score, have been reported. Kagan and colleagues looked at the risk factors for mediastinitis after median sternotomy in children. They demonstrated that an American Society of Anesthesiologists score of 4 or greater, duration of epicardial pacing wires greater than 3 days, and a known or a possible genetic syndrome or chromosomal abnormality were risk factors that were associated with the development of mediastinitis.

Samir et al reviewed 192 cases and reported that 6.3% of children who had undergone median sternotomy had a bloodstream infection develop after surgery. One limitation of their review was the timing of identification of the bloodstream infection and which came first, the bloodstream infection or mediastinitis. *Pseudomonas aeruginosa*, coagulase-negative staphylococci,
Pseudomonas fluorescens-putida, Staphylococcus aureus, Serratia marcescens, and Candida albicans were the different organisms found to have caused the infections.28

Nursing Care

Diligent nursing care of patients with an open sternotomy is essential in reducing morbidity and obtaining good outcomes for patients with early closure. Critical care nurses caring for a child with an open chest must constantly assess the patient’s physiological and hemodynamic status and communicate with the medical/surgical staff about patients’ changes and needed interventions. The following sections describe nursing care that may be provided by a critical care nurse for these specialized patients by using a systematic approach. An overview of nursing care for these patients is provided in Table 2.

Respiratory

All patients with an open chest require endotracheal intubation and mechanical ventilatory support. Hourly respiratory assessments are essential and should include the presence and quality of breath sounds with evaluation of chest expansion. The bedside nurse is responsible for ensuring that the artificial airway is intact with a securement device and patent as clinically warranted by sterile suctioning technique. Monitoring of arterial blood gas measurements, mean airway pressure, ventilator parameters and settings, arterial saturations, and chest radiographs provides additional assessment data on which to base nursing interventions and/or notify members of the medical/surgical team of possible problems in order to prevent respiratory complications. Safety measures include proper securing of the artificial airway, maintaining patency of the artificial airway, keeping the correct size mask and bag for the patient available at all times, and using medically necessary restraints with a physician’s order to prevent inadvertent extubation.

Cardiac

Patients with an open sternotomy and low cardiac output require inotropic support in the form of intravenous infusions. Nurses must be familiar with the patient’s available intravenous access and ensure that all intravenous catheters, infusions, and pumps are working properly. Correct dosing of inotropic infusions should be a priority at all times. Assessments of patients should be ongoing to determine whether the patient is therapeutically responding to the inotropic infusions and management. The following specific hemodynamic parameters should be monitored: heart rate; blood pressure; cardiac parameters such as central venous pressure, right atrial pressure, left atrial pressure, or pulmonary artery pressure; and perfusion (central and peripheral).

Near infrared spectroscopy (NIRS) monitoring initially was used by pediatric anesthesiologists to monitor cerebral perfusion of infants undergoing cardiopulmonary bypass.30 NIRS is now used in the pediatric critical care environment after cardiac surgery and for other pediatric ICU patients with low cardiac output. NIRS, an optical technology, measures the oxyhemoglobin saturation and regional perfusion. Cerebral and renal perfusion may be monitored.30 Changes in cardiac output and regional perfusion are reflected in the NIRS trend values. Critical care nurses must monitor for changes or negative trends in the patient’s NIRS and communicate these parameters to the multidisciplinary team that is managing the patient.

Fluid/Renal/Electrolytes/Nutrition

Children who have undergone surgical repair with the use of cardiopulmonary bypass develop a capillary leak syndrome and experience fluid shifts with generalized tissue edema. These changes are due to a systemic endotoxemia, produced through the use of cardiopulmonary bypass, that produces an inflammatory response with activation of the complement cascade and cytokines.31 Fluid intake and output should be closely monitored and documented in patients with an open sternotomy. Intake measurements include medication dilutions, flushes, volume administration, nutritional source, and all intravenous infusions. Output measurements include urine output, chest tube loss, and any other source of fluid loss for the patient.

Urine output should be measured hourly via an indwelling catheter. A minimal urine output goal for children is 1 mL/kg per hour. Patients with decreased cardiac output can have decreased renal function that results in poor fluid removal and thus compounds the development of postoperative edema. A 24-hour goal for fluid intake versus output should be an even balance or a slightly negative balance. A continual daily positive
<table>
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<th>Type</th>
<th>Description</th>
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| Respiratory             | Hourly respiratory assessment to include presence of bilateral breath sounds, quality of breath sounds, and evaluation of bilateral chest expansion  
Monitor oxygenation and ventilation through arterial blood gas measurements and pulse oximetry  
Monitor ventilator settings, parameters, and mean airway pressure measurements  
Ensure proper securement of artificial airway per institutional protocol  
Maintain patency of the artificial airway per institutional protocol  
Ensure provision of ordered respiratory treatments  
Obtain chest radiographs as ordered                                                                                                                                                                                                                     |
| Cardiac                 | Ongoing assessment of hemodynamic parameters: heart rate, blood pressure, and cardiac parameters (right atrial pressure, central venous pressure, left atrial pressure, or pulmonary artery pressure)  
Ongoing assessment of markers of cardiac output: near infrared spectroscopy readings, urine output, level of consciousness, central and peripheral perfusion, capillary refill, and quality of pulses  
Monitor and maintain intravenous access for inotropic infusions  
Ensure correct administration of inotropic infusions and monitor for patient’s response to inotropic infusions                                                                                                                                               |
| Fluid, renal, and electrolytes | Strict, hourly intake and output measurements with cumulative 24-hour totals  
Monitor and document urine output hourly: notify medical team of decrease in output (<1 mL/kg per hour)  
Obtain samples for and monitor results of laboratory chemistries ordered  
Notify medical management team of abnormal electrolyte results such as hyperkalemia  
Replace electrolytes (eg, sodium, potassium, calcium, or magnesium) as ordered  
Provide renal replacement therapy (hemofiltration or peritoneal dialysis) as ordered                                                                                     |
| Nutrition               | Administer parenteral or enteral nutrition as ordered  
Obtain samples for and monitor results of laboratory chemistries (eg, albumin levels) for markers of nutritional status  
Monitor tolerance of enteral feedings: stool output, emesis, abdominal distention, and metabolic laboratory values                                                                                                                                 |
| Hematology              | Monitor and report postoperative bleeding such as chest tube output (>5 mL/kg per hour)  
Obtain, monitor, and notify surgical team of abnormal coagulation laboratory values                                                                                                                                                                                                                   |
| Infectious disease      | Monitor physical assessment findings that are indicative of signs/symptoms of infection  
Monitor daily complete blood cell count for trends  
Maintain strict sterile surgical procedure and full barrier precautions for all patient procedures  
Administer antibiotics as ordered by the medical team  
Obtain samples for and monitor results of surveillance cultures as ordered                                                                                                                                                                                      |
| Endocrine               | Obtain and report abnormal laboratory findings consistent with hypothyroidism, adrenal insufficiency, and/or hyperglycemia/hypoglycemia  
Maintain glycemic control in the form of insulin infusion as ordered by the medical team  
Obtain glucose measurements hourly when patient is receiving an insulin infusion and titrate according to medical team orders and parameters (eg, glucose goal of 100-150 mg/dL)                                                                 |
| Pain control and sedation | Assess and monitor the patient for adequate pain control and sedation  
Administer opioids in the form of infusions and as-needed boluses for pain management as ordered  
Administer sedation in the form of infusions and as-needed boluses as ordered  
Notify medication team for needed patient changes in pain management and sedation  
Provide a daily paralytic holiday if the patient is undergoing chemical paralysis in the form of an infusion to provide for an adequate neurological assessment after clearance of the paralytic agent                                                                 |
| Preventive interventions | Pressure sore: Ongoing shift assessments with appropriate skin assessment tools  
Use pressure-relief devices  
Turn patient every 2 hours when hemodynamically stable  
Notify medical team of skin changes associated with development of pressure sores  
Eye care: Monitor and prevent corneal abrasions with an ordered preventive lubricant and complete eyelid closure if patient undergoing chemical paralysis                                                                                                                     |
| Parent interventions     | Provide ongoing clinical updates on child’s status  
Provide referrals for parental support such as child life specialists, social workers, chaplains, and palliative care as needed  
Use a patient care delivery model such as Family-Centered Care to meet the needs of each family individually and promote good outcomes                                                                                                           |
balance over multiple days in the early postoperative period may lead to an extremely edematous patient, which makes future sternal closure surgically difficult.

The incidence of postoperative acute renal failure (ARF) and/or dysfunction in children after surgical repair for a CHD has been reported to be as high as 32.8%. Risk factors for pediatric ARF after cardiac surgery include, but are not limited to, young age, repair of complex cardiac lesions, duration of cardiopulmonary bypass, circulatory arrest, and low cardiac output postoperatively. Postoperative renal management by critical care nurses may include the administration of different diuretic medications and/or the use of renal replacement therapies such as hemofiltration or peritoneal dialysis.

Electrolytes such as sodium, potassium, calcium, and magnesium should be maintained within normal limits to ensure optimal cardiac function; therefore, laboratory values should, for example, be assessed every 4 hours to ascertain if additional supplementation is necessary. Frequency of laboratory assessment of chemistry panels will be dictated in abnormal electrolyte states such as hyperkalemia.

Patients with an open chest will need adequate nutrition to enhance wound healing and improve overall physiological status. Adequate nutrition can be achieved via parenteral nutrition or enteral feedings via either a transpyloric or nasogastric tube. The bedside nurse will need to assess placement of any feeding tubes or ensure that intravenous access is appropriate for infusing parenteral nutrition. Tolerance of feedings should be evaluated by monitoring stool output, emesis, trends in serial measurements of abdominal girth, and serial measurements of metabolic laboratory values such as liver function tests.

**Hematology**

Bleeding in the clinical state of coagulopathy can become an issue in patients with an open sternotomy after cardiac surgery and cardiopulmonary bypass. The dressing over the open chest should be assessed for oclusiveness, fullness, and any drainage, particularly at the top edge around the patient’s neck. Chest tubes and other drains should be assessed hourly to ensure they are draining appropriately and to document the amount of blood loss or body fluid loss correctly. Chest tube loss greater than 5 mL/kg per hour and abnormal laboratory values such as prolonged clotting times and decreasing hematocrit should be communicated to the managing surgical/medical team.

**Infectious Disease**

Patients with an open sternotomy are at an increased risk of infection. Prevention of infection for these patients takes high priority in the patient’s management goals. Sterile surgical technique and full barrier precautions should be used with every procedure involving the open sternum and patient. The medical team should use all precautions necessary to prevent a nosocomial infection. The cardiac postoperative recovery process has long included routine use of prophylactic antibiotics, although such use varies among institutions and surgeons. Daily monitoring of a complete blood cell count, routine surveillance cultures of the mediastinum, and ongoing physical examinations focused on potential clinical signs and symptoms that indicate sepsis are necessary for early detection of infection and/or sepsis. Once an infection is suspected, pan culturing of the patient’s blood, urine, endotracheal secretions, mediastinal wound, and any area of suspected infection should be undertaken and administration of broad-spectrum antibiotics should be started. After the organism has been identified, the antibiotic treatment should be narrowed on the basis of sensitivities in an effort to prevent microbial resistance in the ICU.

**Endocrine**

Alterations in thyroid hormone metabolism occur in children after cardiac surgery, with those undergoing DSC having a longer period of depression and delayed recovery. Laboratory studies of thyroid function such as measurement of serum levels of thyroxine and thyroid-stimulating hormone should be monitored routinely and supplemental thyroid hormone (eg, Synthroid), should be administered when the clinical situation warrants. Monitoring for adrenal insufficiency with corticotropin stimulation testing and the role of hydrocortisone replacement therapy is a current topic of interest in pediatric critical care medicine. Souminen and associates reviewed the use of hydrocortisone in neonates with low cardiac output syndrome after cardiac surgery. They demonstrated that the administration of low-dose hydrocortisone in hemodynamically compromised neonates normalized cardiovascular functions.
Diligent nursing care of patients with an open sternotomy is essential in reducing morbidity and obtaining good outcomes for patients with early closure.

status and decreased inotropic requirements.

The role of glycemic control to prevent hyperglycemia or hypoglycemia in pediatric ICUs is currently being reviewed. Treatment of hyperglycemia in critically ill children has been associated with poor outcomes. Critical care nurses should carefully monitor the patient’s glucose levels, use titration skills for patients who are receiving an insulin infusion to prevent hypoglycemia or hyperglycemia, and maintain an open line of communication with the managing team for concerns with glycemic control.

Pain Control and Sedation

Pain control is an area of very important focus for critical care nurses and children with an open sternotomy. The patient is usually on a continuous infusion of an opioid such as morphine for pain control. In addition, sedation, in the form of a benzodiazepine infusion, may be used concurrently with the opioid infusion. Nursing responsibilities include assessing for appropriate pain control, while using a developmentally appropriate pediatric assessment tool, adequate sedation, and safety measures.

A paralytic agent in the form of bolus or continuous infusion may be used to decrease the patient’s cardiac output demands by limiting energy expenditure and activity. A daily holiday, in which the paralytic medication is withheld, is mandatory in children undergoing chemical paralysis by infusion. During the holiday, the patient should be carefully monitored for timing and length of clearance of the prescribed medication, and a detailed neurological assessment should be done after the patient demonstrates medication clearance and resumes spontaneous movement. If prolonged clearance of the paralytic medication is assessed or if any abnormal neurological findings are found on assessment, the medical team should be notified immediately. Appropriate eye care is mandatory. Nursing interventions may include administering an ordered preventive lubricant (eg, Lacrilube), ensuring complete eyelid closure, and ongoing ocular assessments to prevent and detect corneal abrasions in patients undergoing chemical paralysis.

Preventive Interventions

Patients with an open sternotomy and limited cardiac output after cardiac surgery are vulnerable to development of pressure sores due to immobility, low cardiac output, and altered nutritional states. Preventive measurements include ongoing skin assessments from shift to shift with appropriate tools such as the Braden Q Scale and use of pressure-relief devices such as commercial air beds or mattresses.

Postoperatively, these patients are usually positioned supine until hemodynamic stability allows careful turning every 2 hours in a positioning rotation from side to supine to side and the provision of passive range-of-motion exercises to extremities and joints. After a skin abrasion, shear, tear, or pressure ulcer begins to develop, meticulous ongoing assessments of the patient’s pressure points with an assessment tool such as the Pressure Ulcer Scale for Healing (PUSH) tool is a priority. Ongoing communication to the medical/surgical team must occur so that restorative measures may be instituted and healing goals promoted.

Surgical Procedures in the ICU

Cardiothoracic surgical procedures undertaken in the pediatric ICU may include, but are not limited to, emergent and/or routine mediastinal exploration, DSC, and emergent placement of an assist device. In nonemergent situations, the cardiovascular operating room team can be notified and preparations made for the planned procedure. In emergency situations, the ICU nursing staff must take the initial steps in responding to changes related to the patient and assisting the surgeon until the operating room team arrives.

Planning and preparation should be undertaken before surgical procedures are performed in the
Parent Interventions

Parents and family members of the child undergoing cardiac surgery are in a very emotionally stressful situation. An open sternotomy can increase this stress for many reasons, but specifically because their child does not look the way he or she did before surgery. The bedside nurse can help family members cope by explaining the use of all monitoring and medical equipment attached to their child and encouraging the family to ask any questions or express concerns that they may have. Preparing the patient for visitation, such as covering the open sternotomy with a clean, light cloth, may be appropriate during the family visits. Referrals to different services, such as child life specialists, social workers, and chaplains, for support may be necessary as the families make their way through this stressful period after surgery. Models of nursing care that focus on family-centered care and palliative care training will help critical care nurses meet the daily challenges encountered at the bedside and maintain an open line of communication with the child’s parents and family members.

Patient Recovery: After DSC

After stable cardiac output and hemodynamic stability have been achieved, DSC will be surgically undertaken. This surgical procedure may occur in the ICU or the operating room. The patient, after chest closure, must undergo a second postoperative recovery phase. The bedside ICU nurse must monitor for and anticipate the hemodynamic changes associated with chest closure such as decreased cardiac output and tamponade. Table 3 summarizes the hemodynamic changes that may occur with chest closure. Monitoring for signs and symptoms of tamponade (tachycardia, elevated central venous pressure, etc.) is crucial.

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### Table 3 Hemodynamic changes associated with chest closure

<table>
<thead>
<tr>
<th>Systemic</th>
<th>Change</th>
<th>Possible medical intervention</th>
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<tbody>
<tr>
<td>Blood pressure</td>
<td>No change or decrease</td>
<td>Administration of fluids&lt;br&gt;Initiation or titration of infusion(s) of inotropic medications&lt;br&gt;Monitor for signs and symptoms or markers of decreased cardiac output&lt;br&gt;Obtain echocardiogram to assess for function and tamponade</td>
</tr>
<tr>
<td>Mean systemic arterial pressure</td>
<td>No change or decrease</td>
<td>Administration of fluids&lt;br&gt;Initiation or titration of infusion(s) of inotropic medications&lt;br&gt;Monitor for signs and symptoms or markers of decreased cardiac output</td>
</tr>
<tr>
<td>Filling pressures</td>
<td>Increases</td>
<td>Monitoring for changes in preload&lt;br&gt;Administration of fluids&lt;br&gt;Administration of diuretic&lt;br&gt;Monitor for signs and symptoms of tamponade</td>
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Respiratory

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<thead>
<tr>
<th>Decreased chest wall compliance</th>
<th>Changes in ventilation</th>
<th>Manipulate minute ventilation by changing rate or tidal volume&lt;br&gt;Obtain follow-up arterial blood gas analysis to assess patient’s response</th>
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<td>Changes in oxygenation</td>
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<td>Manipulate with change in positive end-expiratory pressure or oxygen percentage&lt;br&gt;Obtain follow-up arterial blood gas analysis to assess patient’s response</td>
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*a Based on data from Main et al.24 and McElhinney et al.23

ICU. Surgical supplies should be available and stored in a central location, such as a heart cart or chest cart, in the ICU. Sterilized prepackaged supply packs, instrument trays, sutures, and other essential items should be stocked and maintained at all times.

Education of the ICU nursing staff should focus on operating room education such as the roles of the circulating registered nurse, scrub nurse, chest cart nurse, medication nurse, and runner; technique of asepsis; skin preparation; maintenance of the sterile field; scrub technique; and management of surgical instruments and supplies.39 Continuing education and mock patient simulations strengthen the skills of ICU nurses when confronted by these surgical emergencies and thus promote improved outcomes for patients and increased satisfaction among critical care nurses.39

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venous pressure or right atrial pressure, muffled heart sounds, pulsum paradoxus on the arterial catheter, diminished chest tube output, poor peripheral perfusion, and decreased urine output) must be done. Figure 3 illustrates cardiac compression due to tamponade.

Clinical reasons such as mediastinitis, poor wound healing, and/or edema may preclude complete surgical closure of the sternum and surrounding tissues. Vacuum-assisted closure for DSC is being used more in children. Salazard et al reported the use of vacuum-assisted closure in 3 different pediatric clinical cases which had a duration in the therapy from 12 to 21 days, a decrease in C-reactive protein levels over a 72-hour period after the start of vacuum-assisted closure, and a decrease in local purulence due to the mediastinitis. They thought that the vacuum-assisted closure technique assisted with wound healing and reduced rates of infection; thus vacuum-assisted closure has a role in postcardiectomy mediastinitis in children.

**Conclusion**

Pediatric cardiac care has continued to evolve medically and surgically. If the child’s sternum is left open after congenital heart surgery, he or she is able to achieve hemodynamic stability and optimal cardiac output. Use of open sternotomy and DSC will continue to be an important management strategy for some time, particularly with the trend toward earlier age for surgical repair or staged palliation. Published reports indicate that DSC is a safe, effective procedure for children who have had surgery for CHD. Caring for children who undergo open sternotomy and DSC can be challenging, but it can also be very satisfying for critical care nurses. CCRN 

**References**

Nursing Considerations for Children Undergoing Delayed Sternal Closure After Surgery for Congenital Heart Disease

Facts
Critical care nurses caring for a child with an open chest must constantly assess the patient’s physiological and hemodynamic status and communicate with the medical and surgical staff about the patient’s changes and needed interventions. Nursing care that may be provided for these patients include the following:

Respiratory
- Hourly respiratory assessment to include presence of bilateral breath sounds, quality of breath sounds, and evaluation of bilateral chest expansion
- Monitor oxygenation and ventilation through arterial blood gas measurements and pulse oximetry
- Monitor ventilator settings, parameters, and mean airway pressure measurements
- Ensure proper securing of artificial airway
- Maintain patency of the artificial airway
- Ensure provision of ordered respiratory treatments
- Obtain chest radiographs as ordered

Cardiac
- Ongoing assessment of heart rate, blood pressure, and cardiac parameters (right atrial pressure, central venous pressure, left atrial pressure, or pulmonary artery pressure)
- Ongoing assessment of near infrared spectroscopy readings, urine output, level of consciousness, central and peripheral perfusion, capillary refill, and quality of pulses
- Monitor and maintain IV access for inotropic infusions
- Ensure correct administration of inotropic infusions and monitor for patient’s response to inotropic infusions

Fluid, Renal, and Electrolytes
- Strict, hourly intake and output measurements with cumulative 24-hour totals
- Monitor and document urine output hourly; notify medical team of decrease in output (<1 mL/kg per hour)
- Obtain samples for and monitor results of laboratory chemistries ordered
- Notify medical management team of abnormal electrolyte results and replace electrolytes as ordered
- Provide renal replacement therapy (hemofiltration or peritoneal dialysis) as ordered

Nutrition
- Administer parental or enteral nutrition as ordered
- Obtain samples for and monitor results of laboratory chemistries for markers of nutritional status
- Monitor tolerance of enteral feedings: stool output, emesis, abdominal distention, and metabolic laboratory values

Hematology
- Monitor and report postoperative bleeding such as chest tube output (>5 mL/kg per hour)
- Obtain, monitor, and notify surgical team of abnormal coagulation laboratory values

Infectious Disease
- Monitor physical assessment findings that are indicative of signs/symptoms of infection
- Monitor daily complete blood cell count for trends
- Maintain strict sterile surgical procedure and full barrier precautions for all patient procedures
- Administer antibiotics as ordered by the medical team
- Obtain samples for and monitor results of cultures

Endocrine
- Obtain and report abnormal laboratory findings consistent with hypothyroidism, adrenal insufficiency, and/or hyperglycemia/hypoglycemia
- Maintain glycemic control in the form of insulin infusion as ordered by the medical team
- Obtain glucose measurements hourly when patient is receiving an insulin infusion and titrate according to medical team orders and parameters (eg, glucose goal of 100-150 mg/dL)

Pain Control and Sedation
- Monitor the patient for adequate pain control and sedation
- Administer opioids in the form of infusions and as-needed boluses for pain management as ordered
- Administer sedation in the form of infusions and as-needed boluses as ordered
- Notify medication team for needed patient changes in pain management and sedation
- Provide a daily paralytic holiday if the patient is undergoing chemical paralysis in the form of an infusion to provide for an adequate neurological assessment after clearance of the paralytic agent

Preventive Interventions
- Pressure sore: ongoing skin assessment; use pressure-relief devices; turn patient every 2 hours when hemodynamically stable; notify medical team of skin changes
- Eye care: monitor and prevent corneal abrasions with an ordered preventive lubricant and complete eyelid; closure if patient undergoing chemical paralysis

Parent Interventions
- Provide ongoing clinical updates on child’s status
- Provide referrals for parental support such as child life specialists, social workers, chaplains, and palliative care as needed
- Use a patient care delivery model such as family-centered care to meet the needs of each family individually and promote good outcomes
Learning objectives: 1. Identify 3 complications that may occur after delayed sternal closure in children. 2. Describe the pathophysiology and clinical rationale for the surgical technique and use of open sternotomy and delayed sternal closure. 3. Discuss 3 nursing considerations for a child undergoing an open sternotomy.

1. The hemodynamic profile during cardiac compression includes which of the following?
   a. Decreased cardiac output, decreased venous pressure, decreased ventricular filling pressure
   b. Decreased cardiac output, increased venous pressure, decreased ventricular filling pressure
   c. Increased cardiac output, increased venous pressure, increased ventricular filling pressure
   d. Increased cardiac output, decreased venous pressure, increased ventricular filling pressure

2. Which of the following is an indication for leaving the patient’s sternum open postoperatively?
   a. Hemodynamic stability
   b. Lack of circulatory assist device
   c. Cardiac construction
   d. Respiratory compromise

3. Interventions to alleviate cardiac compression may require which of the following?
   a. Lifting the sternal edges off of the heart with traction
   b. Applying an occlusive dressing
   c. Inserting a circulatory assist device
   d. Packing the wound with sterile gauze

4. Which of the following organisms was found to be the cause of mediastinitis?
   a. *Serratia marcescens*
   b. *Candida albicans*
   c. *Pseudomonas aeruginosa*
   d. *Streptococcus pneumoniae*

5. Risk factors for mediastinitis include which of the following?
   a. An American Society of Anesthesiologists score of 1
   b. Possible genetic syndromes
   c. Short surgical time
   d. Epicardial pacing wires left in for 4 days after surgery

6. Safety measures to protect the child’s airway following delayed sternal closure include which of the following?
   a. Perform hourly chest radiographs
   b. Restrain all patients receiving mechanical ventilation
   c. Store the appropriate-sized mask and bag at the bedside
   d. Assess breath sounds and chest expansion daily

7. Near infrared spectroscopy is useful for measuring which of the following?
   a. Blood pressure
   b. Airway pressure
   c. Cardiac output
   d. Oxyhemoglobin saturation

8. Risk factors for children with acute renal failure following delayed sternal closure include which of the following?
   a. Simple lesions
   b. Increased time on bypass
   c. Increased cardiac output postoperatively
   d. Older age when surgery was conducted

9. Which of the following is true about chest tubes during the immediate postoperative period?
   a. They should be assessed every 4 hours.
   b. They should have an output of less than 5 mL/kg per hour.
   c. They should be clamped periodically to slow the amount of drainage.
   d. They should be monitored in place of serial laboratory values.

10. A patient receiving paralytic therapy requires which of the following?
    a. Hourly paralytic holidays
    b. Administration of eye lubrication every 2 to 4 hours
    c. Propping open the eyelids for assessment
    d. Frequent neurologic assessments while paralyzed

11. Signs of cardiac tamponade include which of the following?
    a. Bradycardia
    b. Decreased cardiac output
    c. Increased chest tube output
    d. Muffled heart tones

Test answers: Mark only one box for your answer to each question. You may photocopy this form.

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