PATENT DUCTUS ARTERIOSUS (PDA) SURGICAL CLOSURE - MANAGEMENT OF NEONATES - GCNIC - CHW

PRACTICE GUIDELINE ©

DOCUMENT SUMMARY/KEY POINTS

- Patent ductus arteriosus (PDA) is a common problem amongst infants born very preterm. Initial management of PDA includes pharmacotherapy, with surgical or transcatheter closure reserved for infants where medical treatment has been unsuccessful or contraindicated.
- Care should be taken to conduct a detailed assessment of clinical and echocardiographic markers of PDA suggesting the infant would benefit from having this surgically or device closed – this assessment is multidisciplinary, involving the Cardiology and Neonatology teams.
- 2 options exist for PDA closure: surgical ligation and transcatheter device closure (TCDC); the latter is performed in the cardiac catheterisation laboratory.
- Both procedures are possible for infants admitted to GCNIC, and the choice of procedure will be according to the Cardiology and Cardiac Surgery teams, following detailed assessment of each individual patient.
- Pre- and post-procedure care in GCNIC for surgical and TCDC is outlined.
- PDA closure is generally well-tolerated. Complications can occur with both interventions, though post-procedure cardiorespiratory instability appears to be less common with catheter closure.
- Infants are generally transferred back to their referring Neonatal Intensive Care Unit (NICU) the day following their procedure and are provided with ongoing Cardiology follow-up.

Approved by:	SCHN Policy, Procedure and Guideline Committee	
Date Effective:	1st July 2022	**Review Period:** 3 years
Team Leader:	Staff Specialist	**Area/Dept:** GCNIC - CHW

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CHANGE SUMMARY

- Not applicable as this is the initial version of this guideline.
- **12/04/23** Minor review: addition of clinician performed ultrasound utilisation to reflect current unit practice.

READ ACKNOWLEDGEMENT

- All nursing and medical clinicians working in The Grace Centre for Newborn Intensive Care, i.e. Registered Nurses, Clinical Nurse Specialists, Nursing Unit Managers, Clinical Nurse Educators, Registrars, Fellows and Neonatologists are to read and acknowledge they understand the contents of this document.

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Background

The ductus arteriosus (DA) is essential during foetal life as it diverts blood away from the lungs and out to the foetal systemic circulation[1]. The DA generally closes spontaneously within 72 hours of birth in healthy term neonates[2]. The DA may remain patent however in preterm infants beyond the first few postnatal days, with the incidence of a patent ductus arteriosus (PDA) inversely related to gestational age at birth[3]. Up to 65% of preterm neonates with extremely low birthweight (<1000 grams) are affected[4]. The predominant flow of blood through a PDA is generally (in the absence of congenital cardiac disease or significant pulmonary hypertension) from the aorta to the pulmonary artery, that is "left-to-right". See Figure 1 below.

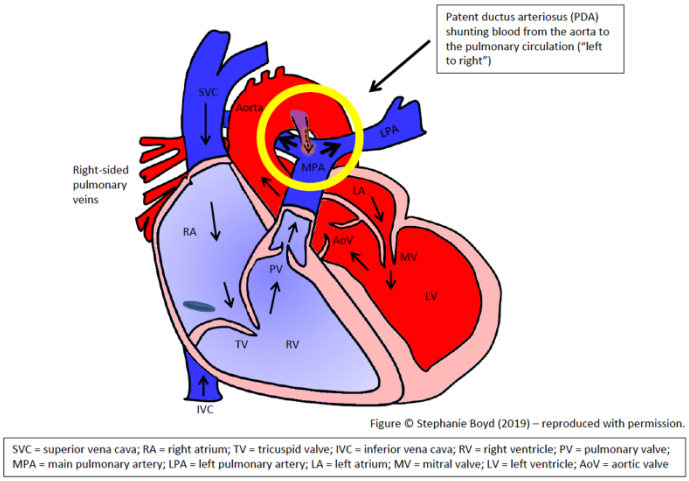

Figure 1: Patent ductus arteriosus with left-to-right shunt from systemic to pulmonary circulation

Significant "left-to-right" shunting of blood from the systemic to the pulmonary circulation can result in complications for preterm neonates. A PDA of this nature may be referred to as a haemodynamically significant PDA (hsPDA). In this setting, the infant may develop symptoms of pulmonary overcirculation (excessive pulmonary blood flow) and/or systemic hypoperfusion (inadequate blood flow to the systemic circulation). Clinical features of pulmonary overcirculation include increased requirements for respiratory support including prolonged ventilator dependence, and pulmonary haemorrhage[5]. Markers of systemic hypoperfusion include feed intolerance, necrotising enterocolitis, acute kidney injury and periventricular leukomalacia[5], which is a pattern of brain injury observed in preterm neonates. Presence of an hsPDA is also associated with an increased risk of periventricular/ intraventricular (brain) haemorrhage[6,7], bronchopulmonary dysplasia[8] and mortality[8].

Haemodynamic significance of a PDA can be assessed based upon both clinical and echocardiographic criteria; incorporation of both is recommended in clinical decision-making[9]. There are varying views on whether the hsPDA should be allowed to close spontaneously over time, though this may risk prolonged exposure of the infant to consequences of the left-to-right shunt, or whether closure should be sought through medical or surgical intervention[5]. Timing of intervention is also controversial[5]. Treatment of PDA (whether medically or surgically) has not been shown to improve long-term outcomes for preterm infants, however clinical trials have been complicated by variable assessment and definition of haemodynamic significance of the PDA[10] and other limitations. There continues

to be significant institutional variation in approaches to management of PDA in preterm neonates, including regarding indications for and timing and nature of treatment.

Medical Management for PDA closure

First-line treatment for hsPDA is generally medical, with non-steroidal anti-inflammatory (NSAID) medication; namely indomethacin or ibuprofen. Success rates for closure with indomethacin are around 60-80%[5], and results using ibuprofen are similar[11]. Paracetamol is also increasingly being used for PDA closure[12-14], having the advantageof a more favourable side-effect profile[12] and similar efficacy to ibuprofen or indomethacin[13]. However, paracetamol is not currently recommended routinely as first-line treatment for hsPDA due to the paucity of long-term follow-up data[13], limited number of infants studied to-date[15], and insufficient controlled trial data for use in the most extremely preterm neonates (<26 weeks)[5]. There is limited evidence to support the use of paracetamol as a 'rescue' treatment after failed NSAID therapy[16], and use may also be considered where NSAIDS are contraindicated.

Surgical or Transcatheter Management for PDA closure

Closure of a PDA, either by surgical ligation or device closure in the catheterisation laboratory, is largely utilised as a 'rescue' therapy for neonates who have failed medical management or where NSAIDS are contraindicated. There has also been a move away from early surgical closure following unsuccessful medical management due to associations between surgical PDA ligation and adverse outcomes in large studies of preterm infants[17-20], including an increased risk of neurodevelopmental impairment[17,18,20]. However, Weisz *et al*[21] have highlighted a number of limitations of these trials, including:

- Inclusion of all infants who received medical therapy for PDA, irrespective of whether the ductus was still patent
- Lack of adjustment for postnatal morbidities prior to surgery, noting that it is often the sickest infants (e.g. dependent on mechanical ventilation), who are referred for ligation
- The potential for survival bias – where ligation is used as a 'rescue' treatment, only infants who survive to this point would be eligible for surgery

A retrospective cohort study of 754 extremely preterm infants that accounted for neonatal morbidities prior to ligation did not show an increased risk in the combined outcome of death or neurodevelopmental impairment with surgical ligation[22]. As has been observed previously, ligation was associated with a lower risk of mortality[22].

In GCNIC, the decision for closure of PDA (by ligation or transcatheter device closure) is taken after assessment of the infant's individual case. This incorporates clinical and echocardiographic information, including Cardiologist assessment, and is strongly influenced by input from clinicians caring for the baby at the referring NICU.

Surgical Ligation versus Transcatheter Device Closure (TCDC)

Surgical ligation has been the traditional means of PDA closure in preterm infants. TCDC is increasingly preferred due to avoidance of complications associated with thoracotomy[23-25]. TCDC has been shown to be a safe and effective procedure for closure for hsPDA in preterm infants, including those ≤1000 grams, with minimal complications[24-26]. However, not all PDAs

are suitable for device closure and there are technical considerations regarding suitability of TCDC, including regarding the PDA itself and the size of the patient. Assessment for suitability for TCDC is on a case by case basis by the Interventional Cardiologist, with input from the broader Cardiology and Cardiac Surgery teams.

The incidence of cardiorespiratory instability, including post-ligation cardiac syndrome (PLCS – see "Post-Ligation Cardiac Syndrome" on page 13), may be lower following TCDC when compared with surgical ligation[25,27]. TCDC has also been associated with a shorter time to return to pre-procedure respiratory status and extubation in a retrospective study[26]. Long-term outcomes after TCDC and the role of TCDC in earlier closure of PDA (<4 weeks of age) are focuses of ongoing research.

Admission criteria

In GCNIC, preterm infants referred for closure of PDA (ligation or TCDC) should typically have received at least 1 course of NSAID treatment, unless there is a clear contraindication. There should be both clinical and echocardiographic evidence of an hsPDA, including review of a recent echocardiogram by a Paediatric Cardiologist.

Assessment for suitability of surgical closure should take into account: patient age, gestation at birth, comorbidities, treatments received, likely degree of contribution of the PDA to the requirement for ongoing respiratory support and/or gastrointestinal issues, and the likelihood of spontaneous closure of the PDA in the short-term.

The decision as to *whether* a PDA should be closed surgically is made jointly by the Neonatology and Cardiology teams, taking into account the above factors. The Neonatologist on-call may choose to involve one of the GCNIC neonatologists with an interest and training in assessment of PDA haemodynamic significance, including interpretation of echocardiographic information. This approach may be beneficial for standardising patient selection for intervention in the setting of PDA[28]. Decisions regarding *how* the PDA should be closed – by surgical ligation or TCPC – are made by the Cardiology and Cardiac Surgery teams, often led by an Interventional Cardiologist.

Nursing Considerations

1.1 Admission of a neonate for surgical PDA closure

The admission of a neonate for PDA closure (by catheter device or ligation) will be determined by the Neonatologist on-call and the Nursing Unit Manager (NUM), with involvement of the Cardiology team.

For guidance on the admissions process for a neonate to GCNIC, please see the **Admission of a Neonate to the Grace Centre for Newborn Intensive Care Guideline:**

1.2 Preoperative Nursing Care

Consent

Consent for transcatheter device closure and/or surgical ligation of PDA will be attended by the Interventional Cardiologist or Cardiothoracic Surgeon, or their representative. In some instances, for example in infants <1000 grams, consent for both procedures may be obtained

in the event that a planned catheter closure is converted to surgical ligation. This is at the discretion of the Cardiology team.

Thermoregulation

Infants admitted for surgical PDA closure are largely a preterm population. These infants are at risk of hypothermia, particularly during procedures performed outside GCNIC. For specific guidance on maintaining normothermia, and management of neutral thermal zones, please refer to the following guidelines:

Thermoregulation in Neonatal Care
http://webapps.schn.health.nsw.gov.au/epolicy/policy/5493

Small Baby Protocol

http://webapps.schn.health.nsw.gov.au/epolicy/policy/5074

Newborn Bloodspot Screening Test

Preoperatively a Newborn Bloodspot Screening Test (NBST) should be obtained unless already collected, in the event the patient receives transfusion of a blood product. Further guidance around NBST collection can be found here:
http://webapps.schn.health.nsw.gov.au/epolicy/policy/3347

Bloods

- Routine bloods should be collected prior to the theatre time.
- A crossmatch should be obtained and signed by the collecting officer and a witness.
- Full Blood Count (FBC), Electrolytes, Urea & Creatinine (EUC) and Coagulation studies should be obtained at a minimum.
- Calcium, Magnesium and Phosphate (CMP) should also be collected in most instances unless recent results are available from the referring hospital.
- Liver function tests (LFT) may be specifically requested where indicated.
- A blood gas analysis should also be obtained preoperatively, both as a baseline and to optimise ventilation support.

Some centres perform routine adrenocorticotropic hormone (ACTH) stimulation (Short Synacthen) testing prior to PDA closure. This is not done routinely in GCNIC, however should be considered where there is a history of prolonged steroid treatment for lung disease (7 days or more, particularly if in the preceding 14 days). If relevant, this should be discussed with the Neonatologist on-call.

ECG

A formal ECG is to be obtained in the preoperative period. This should be ordered by the Medical Officer or Nurse Practitioner. The Heart Centre for Children (HCFC) should be notified and requested to attend this as soon as practicable.

Fluids and fasting

For fasting instructions, please see the CHW fasting guideline.

A Total Fluid Requirement (TFR) of 120 mL/kg/day of clear IV fluids is ideal for hydration and glucose management in the fasting patient, but this may be liberalised to a higher TFR as required to meet the metabolic demands of the baby at the discretion of the Neonatologist.

Imaging

A chest x-ray and formal echocardiogram by the Cardiology team should be attended. A formal echocardiogram should be attended at The Children's Hospital at Westmead prior to surgical PDA closure, even if recent imaging has been performed at another hospital. A cardiac and/or cranial clinician performed ultrasound may be performed pre-procedure to obtain additional baseline haemodynamic information and/or assess for pre-existing periventricular/intraventricular haemorrhage, respectively.

Medications

- Stress-dose hydrocortisone should be considered for infants already receiving steroids for lung disease or hypotension prior to surgery[29] and for those with an unsatisfactory ACTH stimulation test result.
- Refer to the Australasian Neonatal Medicines Formulary (ANMF) for dosing.
- A random cortisol level should be collected prior to administration of hydrocortisone, however it is not necessary to wait for the result prior to giving the medication.
- A loading dose of caffeine may be given prior to induction of anaesthesia if it is anticipated that the patient is likely to be extubated post operatively.
- Regular caffeine maintenance dosing should continue as usual if the patient is to remain intubated and ventilated.

The Neonatologist or Neonatal Fellow will advise regarding whether the patient's usual oral medications should be withheld preoperatively or converted to intravenous dosing, including any diuretics.

Vascular access

As a minimum, one peripheral venous cannula is required for intravenous fluids during preoperative fasting. A peripheral arterial line is recommended where possible for postoperative monitoring – this may be inserted by a Neonatal Medical Officer or Nurse Practitioner preoperatively, or by the Anaesthetic team perioperatively.

1.3 General Postoperative/Post-procedural Care

Ventilation

- A chest x-ray should be performed within 1 hour of return from theatre/catheter laboratory to exclude air leak or hyperinflation. This is most important after surgical ligation, however changes in lung compliance can occur as a result of resolution of pulmonary overcirculation irrespective of the means of ductal closure.
- A blood gas should also be performed on return to GCNIC.
- Systemic oxygen saturation (SpO_2) is continuously monitored using pulse oximetry.

- The oxygen saturation target for preterm neonates is 90-95% and this should be used unless directed otherwise by the Neonatologist or Neonatal Fellow.
- Normal neonatal ventilation strategies are used. A pCO_2 of 40-55 mmHg is acceptable provided the pH is >7.25.
- Use of volume guarantee (VG) ventilation is recommended wherever possible, due to the clear benefits in terms of reducing morbidity in preterm neonates[30]. Preterm neonates with established chronic lung disease (CLD) often exhibit gas trapping and may require higher tidal volumes (5-6 mL/kg) due to dead space within the lungs.
- Positive end expiratory pressure (PEEP) may need to be decreased due to a reduction in pulmonary overcirculation, however some infants develop pulmonary oedema due to left ventricular dysfunction and require a higher PEEP[31]. PEEP should be titrated according to x-ray findings, including chest expansion, and oxygenation.
- If there are difficulties with oxygenation and/or ventilation (CO_2 clearance) on conventional ventilation, high frequency oscillatory ventilation (HFOV) may occasionally be required. Please refer to the Respiratory Support in Neonates policy.
- Infants will generally remain mechanically ventilated until the day following PDA closure. Timing of extubation will depend on the infant's background lung disease and clinical stability, as well as considerations regarding timing of transfer back to the referring hospital.

Cardiovascular

- Heart rate and rhythm are monitored continuously and assessed.
- Continuous intra-arterial monitoring of blood pressure is generally continued until after extubation or transfer back to the referring hospital. The arterial line should remain in-situ until removal is requested by the Neonatologist or Neonatal Fellow.
- Systolic, diastolic and mean blood pressure should be monitored, as this provides additional haemodynamic information compared with monitoring of mean blood pressure alone. In the absence of an arterial line, non-invasive blood pressure should be measured at least hourly for the first 6 hours post-procedure. Ongoing frequency of monitoring will depend on the infant's condition and should be confirmed with the Neonatologist or Neonatal Fellow.
- Signs of poor systemic perfusion include oliguria, prolonged capillary refill time (can be unreliable in preterm newborns unless very prolonged), tachycardia, hypotension, metabolic acidosis and elevated lactate. Lactate measures should be performed at least every 6 hours in the first 24 hours post-procedure; more frequently in the event of clinical concern. **Any lactate level of 3.0 mmol/L or greater should be reported to the Consultant Neonatologist.**
- Where the expertise is available, a cardiac clinician performed ultrasound (CPU) may be performed within approximately 2 hours post-procedure, including assessment of left ventricular output (LVO). Early CPU may enhance prediction of the infant's likely postoperative course[32] - an LVO of < 200 mL/kg/minute appears to be a sensitive predictor of later cardiorespiratory instability and requirement for inotropic support[32].

Some centres opt to treat with prophylactic milrinone where the LVO is <200 mL/kg/min on early postoperative assessment[32,33], however this approach has not yet been investigated in randomised controlled trials.

- In GCNIC, decisions regarding initiation of inotropic support are made on clinical criteria in conjunction with additional information from CPU and/or formal echocardiogram and should be in consultation with the Neonatologist and Cardiologist.
- Due to the sudden increase in left ventricular afterload following PDA closure, inotropes/vasopressors that increase afterload (e.g. dopamine, noradrenaline) may not be desirable. Decisions regarding inotropic support, if required, will be made by the Neonatologist together with the Cardiologist.
- Near-infrared spectroscopy (NIRS) may be used pre- and post-procedure in infants undergoing PDA closure by surgical ligation and/or TCDC to aid in assessment of haemodynamics.
- A cranial clinician performed ultrasound may be performed post-procedure to assess for periventricular/intraventricular haemorrhage, and should be strongly considered where the expertise is available and there is significant haemodynamic instability, particularly in infants less than 1000 grams. A formal head ultrasound by Radiology may be performed where indicated, either instead of, or in addition to CPU.
- An early Cardiology assessment, including formal echocardiogram, should be considered for any infant who is unstable post-procedure, including any neonate with significant hypotension or hypoxaemia – **any infant who is unstable post-procedure should be discussed with both the Neonatologist and either the Interventional Cardiologist (in-hours, following TCDC) or Cardiology Fellow/Cardiologist on-call.**
- *Irrespective of whether a CPU is performed, a formal echocardiogram by the Cardiology team is required within 24 hours post-procedure and must be performed prior to transfer back to the referring hospital.*

Fluids and Electrolytes

- Maintaining euvolaemia is recommended
- Strict fluid balance assessment is essential. This includes weighing all nappies for an accurate record of urine output.
- Generally,120 mL/kg/day total fluid intake is sufficient in the initial post-procedure period, and clear intravenous fluids are generally not prescribed above this rate.
- Many preterm infants have disturbances of serum sodium and/or potassium levels, which may be exacerbated by recent diuretic therapy. Attention should be paid to maintaining normal electrolyte levels post-procedure, including assessment of blood gas electrolyte values and formal electrolyte testing as appropriate.

Pain Management

Please refer to the GCNIC Pain Management in Newborns Practice Guideline for guidance regarding analgesia and sedation (No. 1/C/06:0028)

http://webapps.schn.health.nsw.gov.au/epolicy/policy/5455

Post-operative pain relief requirements may differ depending upon the type of procedure attended and should be taken into consideration.

Enteral Feeds

Clinicians should remain vigilant for clinical signs of necrotising enterocolitis (NEC) because of the risk of NEC in association with prolonged exposure to a moderate or large left-to-right shunt across a PDA, particularly in preterm infants.

- Feeds are generally recommenced post-procedure in liaison between the Neonatology, Cardiology and Cardiac Surgery teams.
- Once commenced, feeds are graded up as tolerated by the infant as per local guidelines. http://webapps.schn.health.nsw.gov.au/epolicy/policy/5121
- Neonates who are stable post-procedure may return to their usual enteral feeding regimen, including any caloric supplementation, once enteral feeds have been re-established.
- In the instance where insufficient breast milk is available from the mother, consideration should be made for the provision of Pasteurised Donor Human Milk (PDHM) aligning with local guidelines. http://webapps.schn.health.nsw.gov.au/epolicy/policy/4724
- Immune Supportive Oral Therapy with mother's breast milk should continue to be offered in the post-operative period. http://webapps.schn.health.nsw.gov.au/epolicy/policy/3637

1.4 Transcatheter Device Closure: Post-Procedure Care

In the event of transcatheter PDA device closure via the cardiac catheterisation laboratory, please refer to the practice guideline on cardiac catheterisation:

http://webapps.schn.health.nsw.gov.au/epolicy/policy/4559/download

Upon return from the catherisation laboratory, the Interventional Cardiologist will provide handover as to the vessel(s) accessed – generally the catheter is inserted via the femoral venous route. This information should be clearly documented in the patient's electronic record in the medical and nursing entries following return to GCNIC and should form part of subsequent patient handover.

Key points for post-operative nursing management include:

- Limb observations should be performed every half hour for the first 2 hours, hourly for the next 2 hours, 2nd hourly for the following 2 hours and then 4th hourly until discharge unless otherwise specified.
- The baby should remain flat in their bed for 4-6 hours post procedure. Ideally the limb should be kept straight, however this is not always able to be achieved in the neonate as flexion is a natural position for the alert, non-sedated neonate.
- If bleeding occurs at the puncture site, apply continuous pressure above the site.
- Obtain a blood gas to rationalise ventilation
- Neurovascular observations are to be attended to assess for development of thrombus or device occlusion of vessels.

- If decreased perfusion is noted, such as mottling, pale limb, decreased palpable pulses, limb cool to touch or difference in temperature noted between limbs, the team leader and Neonatologist/Neonatal Fellow must be informed immediately. Doppler may be required to ascertain if there is blood flow through a vessel.
- Most preterm infants will return with steri strips applied to the site, with gauze as a pressure dressing. This needs to remain exposed to check for bleeding at the site.

Safeguard® Pressure Assist Device dressings (In larger, non-preterm infants).

- 7mL balloon: remove 1ml/hour until all air is removed
- If bleeding occurs, reinflate with last amount of air removed and contact the on-call Cardiology fellow via switch
- These dressings should be left intact overnight.
- Remove Safeguard® dressing before discharge. Clean the sites with 0.1% Chlorhexidine gluconate prior to redressing and redress site with new Steri-Strips®.

1.5 Surgical Ligation: Postoperative Care

The surgery is performed via a left posterolateral thoracotomy. The ductus is either ligated, clipped, or if very large may be divided and oversewn.

In addition to a blood gas, infants undergoing surgical ligation should have bloods collected for an FBC and UEC on arrival back to GCNIC.

If a chest drain is in-situ, care is in accordance with the SCHN chest drain management policy.

Dressings/Wound sites

- The dressings/wound sites are monitored and assessed each shift.
- Dressing site, ooze and integrity of the wound sites and dressings is documented in the assessment chart in the electronic medical record.
- Usually the dressing will remain intact until day five post-operatively or until discharge, whichever occurs first.
- If the patient has a chest drain insitu it should have an occlusive dressing applied and management should be as per the post-operative instructions from the surgeon. See SCHN chest drain management for details on CHW dressing application.
- If there are concerns with the wound or drain sites please contact the cardiothoracic fellow on-call for review.
- For preterm infants if non-absorbable sutures are utilised, ensure the date for removal is documented in the electronic medical record (usually 10-14 days).

Complications following PDA closure

The procedure is generally well tolerated, even in very small and preterm infants. The most common problems seen relate to prematurity and underlying lung disease.

Potential complications include[24,33-35]:

Surgical PDA ligation

- Chest infection – particularly in preterm neonates and those with pre-existing congestive cardiac failure
- Chylothorax due to injury to the thoracic duct (uncommon)
- Haemorrhage – either from ligation and division or rupture of the ductus if the ductal tissue is friable
- Ligation of the incorrect vessel, e.g. aorta, left pulmonary artery. This is a rare complication[36].
- Phrenic nerve injury, resulting in dysfunction of the diaphragm (uncommon)
- Pneumothorax
- Unilateral (left-sided) vocal cord paresis due to injury to the left recurrent laryngeal nerve. Symptoms include hoarse cry/dysphonia, stridor, respiratory distress, aspiration due to impaired airway protection and difficulty with oral feeding. The risk is higher with decreasing weight, particularly <1000 grams[37,38]. The incidence of a symptomatic left vocal cord palsy following PDA ligation in infants <29 weeks at GCNIC is 31%[39].
- Worsening of respiratory status due to collapse of the left lung required as part of left thoracotomy to access the PDA
- Wound infection

Transcatheter Device Closure

- Aortic obstruction by the device
- Device embolisation
- Haemorrhage due to bleeding from the catheter entry site. The risk can be minimised by adherence to the Post-Procedure Care instructions in the preceding section.
- Left pulmonary artery (LPA) stenosis[34] – this most commonly occurs due to impingement of the device used for catheter closure on the LPA, which is anatomically adjacent to the PDA, in very small infants and generally improves with time as the infant grows. There is often an associated cardiac murmur, though the majority of infants are otherwise asymptomatic. The Cardiology team will advise regarding timing of follow-up echocardiography should LPA stenosis occur.
- Vascular complications (vessel injury, thrombosis), including those related to the catheter entry site[40]

General Complications

- Adrenal dysfunction – early hypotension (0-4 hours post-procedure) may be related to adrenal dysfunction, thought to be due to a combination of immaturity of the hypothalamic-pituitary-adrenal axis and adrenal hypoperfusion due to chronic 'steal' from a haemodynamically significant PDA[41]. Low postoperative cortisol levels have also been observed in infants who respond poorly to catecholamines for hypotension[42].

- Hydrocortisone should be considered for treatment of early postoperative hypotension and hypotension unresponsive to inotropes/vasopressors. A random cortisol level should be sent prior to administering hydrocortisone, but treatment should be commenced if indicated without waiting for the result.

- Possible increased risk of neurosensory impairment – see "Surgical Management for PDA Closure" (page 5)
- Hypothermia
- Post-ligation cardiac syndrome (see below)
- Pulmonary hypertension – particularly in infants with a long-standing high-volume left-to-right PDA shunt
- Pulmonary oedema
- Recurrent patency of the ductus arteriosus

Post-ligation cardiac syndrome

Post-ligation cardiac syndrome (PLCS), defined as systolic arterial blood pressure less than the third percentile requiring inotropic/vasopressor support with associated oxygenation and ventilation failure[29], has been reported in 29-45% preterm infants undergoing surgical PDA ligation[43-45]. This complication has been associated with an increased mortality risk[44]. The risk of PLCS may be higher in infants who are younger at the time of surgery (<4 weeks after birth) and of lower weight (<1000 grams)[46]. The syndrome is thought to be a result of sudden physiologic changes at the time of ductal closure, particularly an increase in left ventricular afterload[29]. Effects may include a combination of reduced systolic function, causing hypotension and shock, and diastolic dysfunction (impaired myocardial relaxation), which can result in pulmonary oedema, with resultant hypoxia and impaired ventilation[29,46].

PLCS typically presents between 6 and 12 hours post-operatively[29], and patients may be asymptomatic prior during a period of compensation for the changes in cardiac loading conditions that occur at the time of PDA closure. Although milrinone has been advocated for use in PLCS prophylaxis[29,32], dobutamine or adrenaline are suggested for treatment of established PLCS where there is hypotension[29]. Hydrocortisone should be considered for early-onset hypotension (<4 hours) and for hypotension refractory to inotropic support[29]. A complete clinical assessment, including examination, blood gas, chest x-ray and imaging with CPU and/or formal echocardiography is recommended prior to initiation of treatment. Any decision to treat with inotropic agent(s) following PDA closure (by ligation or TCPC) should be discussed with the Neonatologist and Cardiologist.

Discharge Criteria and Follow-Up Care

Discharge Criteria

Infants are transferred back to their referring NICU once approval has been given by the Cardiology and Neonatology teams, as well as the Cardiac Surgery team for infants undergoing surgical ligation. Requirements for transfer include:

- The infant is at least 12 hours post-procedure
- Satisfactory post-procedure echocardiogram by the Cardiology team

- Chest drain removed (if applicable) with satisfactory chest x-ray post-removal
- Post-procedure clinical review by the Grace Neonatologist or Neonatal Fellow confirming the infant's suitability for transfer. Consideration should be given to the infant's stability with handling, particularly in terms of oxygenation.
- Patient accepted by on-call Neonatologist or Neonatal fellow in the receiving NICU and medical handover provided.
- Bed confirmed in receiving NICU following discussion between GCNIC NUM and receiving NICU NUM. If the infant is ready for transfer and no bed is available, this should be discussed with the Neonatologist on-call.
- Follow-up plans in place (see below).

Infants who were receiving mechanical ventilation support prior to transfer to GCNIC will generally be transferred back to the referring NICU mechanically ventilated, provided this occurs within 24-48 hours post-procedure. Infants who were intubated at the time of transfer to GCNIC (i.e. for the purposes of transfer) or at the time of PDA closure may be transferred either mechanically ventilated or on non-invasive respiratory support following extubation, depending on their clinical condition and the timing of transfer.

Extubation the same day as transfer back to the receiving centre should generally be avoided in order to maximise stability in retrieval. *However, where the infant is clinically ready, extubation should not be delayed where transfer does not occur as planned.*

A Newborn and Paediatric Emergency Transport Service (NETS) Elective Retrieval Form should be completed and faxed to NETS to facilitate transfer back to the referring centre.

Follow-up Care

In general, infants are recommended to have a follow-up echocardiogram at their referring NICU by one of the visiting paediatric cardiologists prior to discharge home. The follow-up plan should be confirmed with the Cardiology team prior to transfer back to the referring NICU and must be communicated clearly both in the discharge summary and at medical handover.

Endocarditis prophylaxis is recommended for 6 months following transcatheter device PDA closure. This information should be included in the discharge summary from GCNIC.

Post-procedure clinical examination findings should be documented in the discharge summary and conveyed to receiving medical and nursing representatives at the time of handover. This includes presence of any residual murmur, which can sometimes occur related to the PDA device used in catheter closure, particularly in very small infants.

Long-term neurodevelopmental follow-up for infants undergoing PDA closure will generally occur through the referring perinatal NICU as part of routine follow-up for extremely preterm and extremely low birthweight infants in NSW and the ACT. In the unlikely event that an infant undergoing PDA closure does not meet criteria for follow-up through their perinatal NICU, the possibility of long-term follow-up through the Grace Development Clinic should be discussed with the Neonatologist on-call prior to transfer. This might include for example, infants born at >29-30 weeks of gestation, who do not meet universal follow-up criteria.

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