Congenital Heart Disease Requiring Surgery

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Associated clinical guidelines/protocols:

Fundamental Knowledge:
List of topics relevant to PIC that will have been covered in membership examinations.
They will not be repeated here.

Information for Year 1 ITU Training (basic):

Year 1 ITU curriculum
ITU Management of the following clinical conditions:
- Congenital diaphragmatic hernia
- Tracheo-oesophageal fistula
- Gastrochisis
- Exomphalos
- Ano-rectal malformations

Curriculum Notes for Year 1:

Congenital Diaphragmatic Hernia
What is it? CDH is caused by the diaphragm not closing or forming at around 8 weeks gestation. Organs that would/should have been in the abdominal cavity then float freely into the chest cavity occupying space and contributing to the development of pulmonary hypoplasia. Pulmonary hypertension and pulmonary hypoplasia have been recognized as the 2 cornerstones of the pathophysiology of CDH. In recent years, evidence suggests that cardiac maldevelopment may further complicate the pathophysiology of CDH (1). CDH is characterized by a variable degree of pulmonary hypoplasia associated with a decrease in cross-sectional area of the pulmonary vasculature. The lungs have a small alveolar capillary membrane for gas exchange, which may be further decreased by surfactant dysfunction. In addition to parenchymal disease, increased muscleization of the intracardinal pulmonary arteries appears to occur. In very severe cases, left ventricular hypoplasia is observed. Pulmonary capillary blood flow is decreased because of the small cross-sectional area of the pulmonary vascular bed, and flow may be further decreased by abnormal pulmonary vasoconstriction.

Incidence: CDH occurs in 1 in 2,500 live births. There is no predilection for sex or race. Types: The 3 basic types of CDH include the posterolateral Bochdalek hernia, the anterior Morgagni hernia, and the hiatus hernia. The left-sided Bochdalek hernia occurs in approximately 85% of cases. Left-sided hernias allow herniation of both the small and large bowel and intra-abdominal solid organs into the thoracic cavity. In right-sided hernias (13% of cases), only the liver and a portion of the large bowel tend to herniate. Bilateral hernias are uncommon and usually fatal (1). The diaphragm initially develops as a septum between the heart and liver, progresses posterolaterally, and closes at the left Bochdalek foramen at approximately 8-10 weeks'
gestation. The herniation of viscera in CDH usually occurs during the pseudoglandular stage of lung development. Lung compression results in pulmonary hypoplasia that is most severe on the ipsilateral side, although both lungs may be abnormal. Pulmonary hypoplasia is associated with fewer bronchial generations, alveoli, and arterial generations (1).

**Causes:** Largely unknown. Familial CDH is rare (<2% of all cases), and both autosomal recessive and autosomal dominant patterns of inheritance have been reported. Studies also show that certain environmental factors might cause CDH, such as exposure to chemicals like Nitrofen or pesticides (2). Without a family history of CDH or genetic abnormality in the baby, the chances of CDH recurring in another sibling are given as 2%. About 10% of CDH cases occur in babies with chromosome abnormalities e.g., trisomy 13, trisomy 18, trisomy 21, and Turner syndrome; CDH is also a recognized finding in Cornelia de Lange syndrome. The genetics of CDH are a hot topic.

A genetic abnormality has been identified in mice, that causes diaphragm defects and underdevelopment of lungs. The gene causing these defects is called Fog2 (“Friend of GATA 2”). Ackerman et al (3) looked for human patients that might have changes in the same gene (which in humans is known as the FOG2 gene). Samples were taken from infants with CDH who had died and in one infant a mutation in the FOG2 gene was found which looked significant and was not found in the parents. Studies continue looking at more mouse models to learn more about the function of the Fog2 Gene. Perhaps this will allow better understanding as to how the lung and the diaphragm develop in normal children and in children with CDH.

**Diagnosis:** CDH is usually detected by ultrasound as early as 16 weeks gestation. Approximately 50% of infants are diagnosed early in pregnancy (16 to 24 weeks) (7). Prenatal evaluation of congenital diaphragmatic hernias consists of a Level II ultrasound, fetal MRIs are usually not available in the UK but would be performed in the US, fetal chromosome studies, and a fetal echocardiogram (4). The parents would then be offered an appointment with a paediatric surgeon and an obstetrician skilled in prenatal diagnosis to discuss prenatal management, delivery, and postnatal treatment options. Parents can also be offered a tour of NICU and familiarization with High frequency ventilation, nitric oxide and Extracorporeal Membrane Oxygenation (ECMO).

A prenatal diagnosis of CDH does not mandate a change in obstetric management or the necessity for Caesarean section.

**Antenatal MRI can be used to delineate the defect**
http://FetalSurgery.Chop.edu

**Prognosis:** Most population studies quote a survival rate of 50 – 65% for liveborn infants with CDH; some centres quote higher survival figures (Shands Hospital, Florida, USA: 85% (11), Toronto 80% (6,7)) but the compilation of figures in a tertiary centre has been problematic, often not including the outborn neonates who die shortly after birth. The largest study looking at outcome of congenital diaphragmatic hernia was done in Western Australia and published in Pediatrics in 2005 (5). The study group identified 116 cases of CDH. Of these, 71 (61%) infants were born alive and 37 survived beyond 1 year of age (52% of live-born infants, 32% of all cases of CDH). Pregnancies involving 38 (33%) fetuses were terminated electively, 4 (3%) fetuses were aborted spontaneously, and 3 (3%) fetuses were stillborn. Twenty-one (18%) cases had other anomalies that were likely to be fatal. Of live-born infants with
prenatally diagnosed CDH, 10 (33%) survived beyond 1 year of age. Postnatal diagnosis occurred in 55 (47%) cases; some were born in live infants after birth (74%) and some incidental findings at post mortem (terminations, stillbirths). Significant differences were found between prenatally and postnatally diagnosed live-born infants. Among live-born infants, prenatal diagnosis was associated with a significantly reduced survival rate (33%, compared with 66% for postnatally diagnosed infants). Prenatally diagnosed live-born infants were of lower birth weight and were born at an earlier gestational age.

Of 71 live-born infants, 37 (52%) survived to 1 year of age. The majority of deaths occurred within the first 7 days of life (44%). Preoperative air leaks occurred for 16 (22%) infants, of whom 14 (88%) died. Factors found to predict death of live-born infants included prenatal diagnosis, right-sided hernia, major air leak, earlier gestational age at birth, lower birth weight, and lower Apgar scores at 1 and 5 minutes (5,12).

**Management:** Many strategies have been employed to try and improve survival.

1. **Delayed operative repair**
2. **Inhaled Nitric Oxide**
3. **Gentle ventilation with permissive hypercapnoea**
4. **High Frequency Oscillation Ventilation**
5. **ECMO**

**Presentation:** Infants most commonly present with respiratory distress and cyanosis in the first minutes or hours of life, although a later presentation is possible. The respiratory distress can be severe, requiring aggressive resuscitative measures; however high airway pressures must be avoided. The aim is to achieve a preductal saturation of > 85%. The infant may have a scaphoid abdomen and barrel shaped chest (1).

**Intubation:** Endotracheal intubation and mechanical ventilation are required in all infants with severe CDH who present in the first hours of life. If the diagnosis is known at the time of delivery, avoid bag-and-mask ventilation in the delivery room because the stomach and intestines become distended with air and further compromise pulmonary function. A nasogastric tube should be placed as soon as possible to provide intestinal decompression.

**General Management:** Ventilation strategies are aimed at a “gentle ventilation” technique to avoid high pressures and VALI (6,7,11). This is the practice adopted at GOSH. Ventilated infants require continuous monitoring of oxygenation, blood pressure, and perfusion. A minimal stimulation approach that reduces handling and invasive procedures, such as suctioning, is suggested. Monitoring of oxygen saturations (pre and post ductal), ABGs, BP, glucose, U+E’s is required. Blood pressure is maintained at high normal with judicious use of fluid boluses (which also maintain RV filling pressures) and inotropes (dopamine, noradrenaline, adrenaline). Previous practice in infants with PPHN has been to alkalize because a higher ph produces rapid pulmonary vasodilation; this can be achieved by either hyperventilation or by sodium bicarbonate infusions. However, benefits of alkalosis have never been demonstrated in any prospective clinical trial, and these therapies are considered controversial. In addition, alkalosis may result in undesirable side effects. For instance, hypocarbia constricts the cerebral vasculature and reduces cerebral blood flow. Extreme alkalosis and hypocarbia are strongly associated with later neurodevelopmental deficits, including a high rate of sensorineural hearing loss. Previous studies by Walsh-Sukys and colleagues indicates that the use of alkali infusions may be associated with increased use of ECMO and an increased use of oxygen at age 28 days (8). Sedation is an important adjunctive therapy. The use of neuromuscular relaxants is decreasing, reserved only for the sickest infants in whom respiratory goals cannot otherwise be achieved.

The appropriate targets for pO2 and pCO2 are controversial. pO2 concentrations greater than 50 mm Hg (7 kPa) typically provide for adequate oxygen delivery at the tissue level. Aiming for higher PaO2 concentrations may lead to increased ventilator support and lung injury. Suggested parameters (7):

- PIP < 25 cm H2O
- Preductal saturation > 85% - ductal shunting can be tolerated as long as there is adequate right heart function (fluid, inotropes, progressing to NO if necessary)
- Normal lactate
- SvO2 > 70%
- pH > 7.20
- HFOV – keep MAP low 14 to 16 cm H2O
HFOV: No studies showing clear benefit as yet. Utilised because of lung protective strategy, lower peak pressures and independent pCO₂ control (infants with CDH often have hypercapnia because of pulmonary hypoplasia).

NO: Inhaled nitric oxide use in the infant with CDH is controversial. Nitric oxide has not been shown to reduce mortality or the need for ECMO in infants with CDH, although it may immediately stabilize infants with critical hypoxemia.

Surfactant: Infants with CDH may have immature lung development, and animal studies have indicated that surfactant deficiency may be present. However, recent reports from the CDH Study Group indicate that administration of exogenous surfactant does not improve survival, need for ECMO, or long-term outcome. Interestingly, this finding is true for both term and preterm infants with CDH (1).

ECMO: The overall survival rate for infants with CDH reported to the international Extracorporeal Life Support Organization registry is approximately 60%, which is the lowest rate in all the neonatal conditions treated with ECMO. It remains a commonly used therapy despite lack of conclusive evidence that outcome is improved. infants should generally be older than 34 weeks’ gestation, have a weight greater than 2 kg, have no major intracranial hemorrhage on cranial ultrasound, have been on mechanical ventilator support for fewer than 10-14 days, and have no evidence for lethal congenital anomalies or inoperable cardiac disease. The rate of referral for ECMO in this condition has been declining (7).

Surgery: Surgery for CDH has been performed on the fetus as well as postnatally.

- Fetal surgery: Theoretically, fetal surgery for CDH provides an elegant solution to the difficult problem of CDH. Unfortunately, this is far from reality. Harrison et al reported the first human fetal surgery for CDH in 1990. However, a randomized trial published in 1998 showed that in utero repair did not improve survival compared with standard therapy. Subsequent trials of fetal intervention focussed on occluding the fetal trachea. The fetal lung secretes fluid by active ion transport through gestation, and this lung fluid provides a template for lung growth. Occlusion of the fetal trachea traps this fluid and stimulates lung growth, either by retention of growth factors within the lung or stimulation of local growth factors by the gentle distension provided by the fluid. Unfortunately, a randomized trial in humans found that fetal tracheal occlusion did not improve outcome compared with standard treatment (10). Currently, fetal intervention is not indicated in CDH.

- Postnatal surgery: Previously it was believed that reduction of the herniated viscera and closure of the diaphragmatic defect should be emergently performed following birth. However, a delayed surgical approach that enables preoperative stabilization decreases morbidity and mortality. This change in protocol is due to the recent understanding that the medical problems of pulmonary hypoplasia and PPHN are largely responsible for the outcome of CDH and that the severity of these pathophysologies is largely predetermined in utero. Herniated viscera in the chest does not appear to exacerbate the pathophysiology as long as bowel decompression with a nasogastric tube is continuous. Several reports indicate that circulatory stability, respiratory mechanics, and gas exchange deteriorate after surgical repair. The ideal time to repair a CDH is unknown. Some suggest that repair 24 hours after stabilization is ideal, but delays of up to 7-10 days are typically well tolerated, and many surgeons now adopt this approach. Some surgeons prefer to operate on these neonates when normal pulmonary artery pressure is maintained for at least 24-48 hours based on echocardiography. Routine chest drainage is controversial. Some clinicians report improved survival when chest drainage is not used. Others think that balanced intrathoracic drainage, in which a closed gated pressure system is used to maintain intrathoracic pressure within the normal physiologic range, may minimize risk of pulmonary injury. At GOSH the practice is not for routine chest drain placement because of the risks of infection (particularly if there is a diaphragm patch in place).

Imaging Studies:

- CXRay: If CDH suspected in previously undiagnosed infant. Placement of an gastric tube prior to the study helps decompress the stomach and helps determine whether the tube is positioned above or below the diaphragm.

- Cardiac ultrasound: The incidence of associated cardiac anomalies is high (up to 25%), therefore an echocardiogram should be ordered shortly after birth. Cardiac
defects may be relatively minor (atrial septal defect) or life-threatening (transposition of great vessels, hypoplastic left heart). In addition, echocardiography is helpful in assessing myocardial function and determining whether the left ventricular mass is significantly decreased.

- **Renal ultrasound**: Genitourinary anomalies occur in 6-8% of infants.
- **Cranial ultrasound**: CNS defects (neural tube defects, hydrocephalus) may be associated with CDH, so ordered as part of routine evaluation. However if the infant is clinically deteriorating and ECMO is being considered then a cranial ultrasound should be obtained to rule out any intracranial haemorrhage.

**Long term difficulties:**

1. Severely affected infants have chronic lung disease. These infants may require prolonged therapy with supplemental oxygen and diuretics, an approach similar to that for bronchopulmonary dysplasia. The use of steroids, particularly high doses for prolonged periods, is controversial and may hinder appropriate lung and brain development.

2. Neurologic evaluation: Following recovery the infant should be referred to a neurologist or developmental paediatrician. A high proportion of CDH survivors can have neurological morbidity with significant developmental delay and will need ongoing support. The incidence of hearing loss appears to be particularly high in patients with CDH (approximately 40% of infants). An automated hearing test should be performed prior to discharge.

3. Gastroesophageal reflux: The incidence of significant gastroesophageal reflux is very high in patients who survive CDH, and recent studies document an incidence of 45-85%. The need for a diaphragmatic patch may be a significant predictor of gastroesophageal reflux. Severe reflux may result in chronic aspiration and is, therefore, aggressively treated. While most infants can be medically treated with H2-blockers or proton pump inhibitors in combination with a motility agent such as metoclopramide, surgical intervention is sometimes required.

4. Growth assessment: Failure to thrive is common, and, in some studies, more than 50% of patients are below the 25th percentile for height and weight during the first year of life. In one study, one third of infants required gastrostomy tube placement to improve caloric intake. The need for supplemental oxygen at the time of discharge is a significant predictor for subsequent growth failure. Possible causes include increased caloric requirements due to chronic lung disease, oral aversion after prolonged intubation, poor oral feeding due to neurologic delays, and gastroesophageal reflux.

**Tracheoesophageal Fistula and Oesophageal Atresia**

**Incidence**: 1 in 3,000 to 5,000 births. OA and TOF may exist separately but the majority of patients have both.

**What is it?**: TOF is a congenital fistulous connection between proximal and/or distal oesophagus and the airway. OA is complete interruption of the oesophagus.

**Causes**: There is abnormal growth of mesenchyme in the pharyngeal groove (this usually separates respiratory and GI tracts). This abnormal excess growth may lead to part of the oesophagus being incorporated into the posterior wall of the trachea, causing an epithelial lined connection between the 2 tubes. The abnormal growth is also thought to be responsible for the disruption of the oesophagus causing OA (13).
The presence of OA/TOF disrupts the myenteric plexus of the oesophagus causing disordered peristalsis and reduced lower sphincter function.

**Associations (14):** 25 to 50% of patients have other anomalies

**Cardiac 35%:** Cardiac anomalies include ventricular septal defect, patent ductus arteriosus, tetralogy of Fallot, atrial septal defect, and right-sided aortic arch.

**Genitourinary 24%:** Genitourinary anomalies include renal agenesis or dysphagia, horseshoe kidney, polycystic kidney, ureteral and urethral malformations, and hypospadias

**Skeletal 13%:** Musculoskeletal anomalies include hemivertebrae, radial dysphagia or amelia, polydactylly, syndactyly, rib malformation, scoliosis, and lower limb defect.

**Gastrointestinal 25%:** Anomalies include imperforate anus, duodenal atresia, malrotation, intestinal malformation, Meckel diverticulum, and annular pancreas. The VACTERL syndrome occurs when 3 or more of the associated anomalies are present. This syndrome occurs in approximately 25% of all patients with oesophageal atresia.

**Others:** Also associated with congenital abnormalities of the respiratory tree (tracheal bronchus, pulmonary or lobar agenesis, horseshoe lung), foregut malformations, Di George syndrome, Down’s syndrome, Pierre Robin syndrome. CHARGE association has also been linked to TOF/OA (coloboma, CHD, choanal atresia, retardation, genital and ear anomalies).

**Classification:** The Gross and Vogt classifications are commonly used. The Gross classification is shown below (A,B,C,D,E).
Diagnosis:

- **Prenatal:** The first sign of esophageal atresia in the fetus may be polyhydramnios in the mother (100% cases isolated OA but only 33% cases OA plus TOF). Polyhydramnios, however, has a broad differential diagnosis, including intestinal atresia, fetal hydrops, neural tube defects, diaphragmatic hernia and intrathoracic lesions. The inability to identify the fetal stomach bubble on a prenatal ultrasound in a mother with polyhydramnios makes the diagnosis of oesophageal atresia more likely.

- **Postnatal:** Neonates with oesophageal atresia usually develop copious, fine white frothy bubbles of mucus in the mouth and nose. Secretions recur despite suctioning. Infants may develop rattling respiration and episodes of coughing and choking in association with cyanosis. Symptoms worsen during feeding in the presence of a TOF. Clinically, the diagnosis of oesophageal atresia sometimes requires a high degree of suspicion. If a fistula between the esophagus and the trachea is present, abdominal distention develops as air builds up in the stomach.

- Plain CXRays may reveal tracheal compression and deviation. Absence of a gastric bubble indicates oesophageal atresia without a TOF or oesophageal atresia with a proximal TOF. Chest XRay leads to the diagnosis of TOF in most cases of congenital TOF, and other investigations are rarely required. Aspiration pneumonia in the posterior segments of the upper lobes may occur secondary to aspiration of the contents from the oesophageal pouch or stomach. Recurrent or massive aspiration may lead to acute lung injury in some patients. (Infiltrates occur diffusely in these patients.) Insertion of a nasogastric tube may show coiling in the mediastinum of patients who have concomitant esophageal atresia. This finding is diagnostic of TOFs associated with oesophageal atresia.

- If oesophageal atresia is suspected, a radiopaque 8 French (in preterm infants) or 10 French (in term infants) nasogastric or feeding tube should be passed through the nose to the stomach. In patients with atresia, the tube typically stops at 10 to 12 cm. The normal distance to an infant’s gastric cardia is approximately 17 cm. If a soft, flexible tube is used, it may curl in the upper pouch and give the physician a false sense that it has passed to the stomach. In cases of suspected oesophageal atresia, chest XRays (posteroanterior and lateral views) should be obtained to confirm the position of the tube. The CXR should include the entire abdomen (AXR also). In patients with oesophageal atresia, air in the stomach confirms the presence of a distal fistula, and the presence of bowel gas rules out duodenal atresia. The CXR also provides information about the cardiac silhouette, the location of the aortic arch and the presence of vertebral and rib anomalies, as well as the presence of pulmonary infiltrates. Contrast studies are seldom necessary to confirm the diagnosis.
Such studies increase the risk of aspiration pneumonitis and reactive pulmonary oedema, and usually add little to XRays.

Management (14,16):
Medical:
  a) Need to reduce risk of aspiration by clearing oral pharynx and placing a Repogle tube to allow continuous suctioning of the upper pouch. Keep head elevated and give intravenous fluids. Avoid BVM as it may cause acute gastric distention.
  b) Evaluate infant for other congenital anomalies: Cranial, renal US and echocardiography; skeletal XRays to look for skeletal abnormalities.
Surgical: Most repaired early by division of TOF and primary oesophageal anastomosis. Patients with long gap OA are most problematic and surgery may have to be delayed for weeks or months; the longer the anticipated delay the more likely that other surgical procedures may need to be performed such as gastostomy and cervical oesophagostomy (rare) – these infants do less well. Surgery will be delayed if infant very small or sepsis is suspected, a Repogle tube will be left in situ and care must be taken that secretions are adequately drained.

Complications (13):
1. Gastric Perforation: Occurs in infants with OA and distal TOF and is associated with extreme prematurity, RDS and requirement for assisted ventilation. Urgent surgical laparotomy required (15).
2. Anastomotic leak: 95% of these will resolve spontaneously or with pleural drainage. However many consequently get oesophageal strictures (50%). This can be followed by TOF recurrence.
3. Dysphagia: Common in childhood, reduced frequency as enter adulthood.
4. Oesophageal stricture: Commoner in long gap OA patients (>2.5 cm gap). This is thought to be because the lower oesophagus commonly has to be mobilised in these patients and the lower oesophagus has a more precarious blood supply which can more easily become compromised (segmental blood supply from aorta rather than rich blood supply from inferior thyroid artery which supplies upper and mid portions of the oesophagus). Oesophageal strictures are commoner in types A,C and D. They are also more common if there was an anastomotic leak or if there is GOR.
5. GOR: 35% to 60% of patients. Pathologic in two-thirds. There is an intrinsic motor dysfunction of the oesophagus. Infants present with aspiration, strictures, bronchial hyperreactivity, apnoea, cyanotic spells and FTT. 56% patients respond to medical treatment and approximately 25% require Nissen’s fundoplication.
6. Respiratory:
   a. Recurrent pneumonia/aspiration
   b. Choking / cyanosis with feeds
   c. Tracheomalacia – often present but clinically significant in 10 – 20%
   d. Recurrent TOF 9% (2 to 18 months later)
   e. Recurrent wheeze and chronic cough.
7. FTT
**Gastroschisis**

A congenital defect of the anterior abdominal wall resulting in extrusion of variable amounts of abdominal contents from the abdominal cavity. There is no peritoneal covering either the bowel or other contents. The defect is located to the right of the umbilicus and is completely separate from the umbilicus. The defect tends to be fairly uniform in size (< 5 cm) and is usually small, but the exposed contents can range from the stomach to the rectum (almost all of large and small bowel can become exposed). The stomach may be involved but not the liver.

- Gastroschisis has no sac covering the exposed contents.
- It occurs in the first born 74% of the time.
- The malformation is always obvious at birth and able to be seen as early as 12 weeks of pregnancy

**Problems:** The bowel is usually damaged with shortening, thickening and the development of a thick fibrous “peel”. Affected infants almost universally experience problems with absorptive function and prolonged hypomotility. The infant’s prognosis is determined by the condition of the exteriorised bowel and the possible development of short gut syndrome. Mothers tend to be younger than those of infants with exomphalos (another anterior abdominal wall defect).

**Incidence:** Gastroschisis is present in approximately 1 in 5,000 births. It does not appear to run in families, and there is no increased risk of recurrence in future pregnancies. The incidence of gastroschisis is increasing whereas the incidence of exomphalos is static.

**Embryology:** By the 6th week of gestation there is rapid growth of the midgut which causes a physiological hernia of the intestine through the umbilical ring. The intestine returns to the abdominal cavity during the 10th week and rotation and fixation of the midgut occur. This process does not occur in babies with gastroschisis or exomphalos. There is a failure of the mesoderm to replace the body stalk which persists in a region the somatopleure normally occupies causing abdominal wall defects. Embryonic dysplasia, decreased apoptotic cell death and inadequate mesodermal development causes insufficient growth at the umbilical ring and enlargement of its diameter. Rather than investing the yolk sac and body stalk centrally at the umbilicus, the amnion remains attached to the margins of the body wall defect, creating a persistent communication between the intraembryonic body cavity and the extraembryonic coelem.

**Diagnosis:** Detailed antenatal US may be ordered after finding raised maternal alpha feto protein levels (the causes of raised AFP are abdominal wall defects and spina bifida). The defect can be seen from 12th week and is easily differentiated from exomphalos by the absence of a sac, location of the defect and usually absence of associated anomalies (unlike exomphalos). Less than 5% of gastroschisis infants have chromosomal anomalies.

**Associations** (17): Though chromosomal abnormalities are not commonly associated gastroschisis is associated with:

- Intestinal atresia (10%); ? common vascular aetiology of 2 lesions or the result of intestinal ischaemia secondary to constriction at the abdominal wall.
- Malrotation and midgut volvulus
- GOR
- Hirschsprungs
- Prematurity and low birth weight

**Aetiology of bowel damage:** Controversial. Thought to be due to exposure of the bowel to amniotic fluid with urine in it. Experiments with chick embryos demonstrated fibrous peel when bowel was exposed to allantoic contents but not amniotic fluid alone (18). The bowel changes can be seen on US from about 30 weeks gestation and the bowel looks thickened and dilated (this can resolve postnatally). Interventions to deliver babies early based on US appearance of the gut failed to demonstrate any advantage for this strategy (19). The fibrous peel consists of type 1 collagen and fibrin, and it usually dissolves after surgical repair. Some authors suggest that the peel itself may cause the bowel motility disorder (22).

Another recent animal study has shown that bowel damage in gastroschisis at least partially depends on meconium exposure in utero. The authors of this study suggested that the increasing evidence of physiologic in utero defaecation supports the hypothesis that bowel damage in gastroschisis may be meconium dependent (Correia-Pinto, 2002).
Other theories regarding the bowel damage include ischaemic damage from mechanical constriction at the abdominal wall defect but ischaemic changes usually seen later in pregnancy; and ganglion cells in the bowel wall are normal.

**Delivery:** There is no advantage to Caesarean section delivery (20, 21).

**Management:** The infant may present with respiratory distress which may respond to gastric decompression or intubation may be required. The defect should be wrapped with a plastic film to provide a barrier against infection and to minimise heat and fluid loss at delivery. Operation is performed as soon as possible after delivery, which in practice means after rapid stabilisation and transport. Primary closure is the ideal and early surgical repair is often carried out but if the abdominal cavity is too small, a mesh sack is stitched (often Silastic sheets) around the borders of the defect and the edges of the defect are pulled up. Over time, the herniated intestine falls back into the abdominal cavity, and the defect can be closed. Other treatments for the baby include intravenous feeding and antibiotics to prevent infection. Too tight a closure of the abdominal wall is avoided as this limits excursion of the diaphragm which then necessitates high PIP, impedes venous return to the heart and causes high intra-abdominal pressures which may compromise renal and mesenteric blood flow resulting in NEC or renal failure.

Most infants with this abnormality return from the operating a theatre with a central line (Hickmann’s or Broviac catheter) inserted into the chest area, this enables the infant to be given a period of Total Parental Nutrition (Alimentation). T.P.N. solution is used for nutrition until the infant can absorb and tolerate Breast Milk or formula. The baby may require T.P.N. for a few weeks or months depending on how long it takes for the bowel oedema/hypomotility to settle.

**Prognosis:** Dependent on degree of prematurity, any associated atresias, the development of short gut and degree and persistence of hypomotility. Survival > 90%.

**Exomphalos**

**What is it?** Exomphalos is also an abdominal wall defect in which there is persistent herniation of the midgut with the abdominal viscera contained in a translucent sac. The sac contains intestinal loops, liver, spleen and bladder.

**Incidence:** Of gastroschisis and exomphalos is 1 in 2000 to 3000 births. The incidence of gastroschisis is increasing whereas the incidence of exomphalos is static. There is no geographical or race predilection. M:F is 1.5:1. There is a tendency for this defect to be inherited as there is a higher rate of occurrence in twins, consecutive children and different generations of the same family.

**Embryology:** (17) There is failure of central fusion at the umbilical ring due to defective mesodermal growth, this causes incomplete closure of the abdominal wall and persistent herniation of the midgut. The translucent sac covering the herniated abdominal contents is composed of amnion, Wharton’s jelly and peritoneum. The umbilical vessels radiate onto the wall of the sac. The umbilical cord arises from apex of sac. In 50% of cases the liver, spleen and ovaries or testes accompany the extruded midgut.

**Reference:**

[www.chop.edu](http://www.chop.edu)
Differs from gastroschisis in several respects: exomphalos has:

- Membranous sac covers herniated viscera which protrude through a relatively large defect. The defect can be 4 to 12 cm in size and may be central, epigastric or hypogastric.
- Intestine and liver remain morphologically and functionally normal.
- Older maternal age.
- Associated structural malformations are commoner 30 – 80%; Cardiac, Renal, Limb, Facial
- Associated syndromes are commoner; Beckwith-Weidemann, Pentalogy of Cantrell
- 10-40% cases are associated with chromosomal anomalies; Trisomies: 12, 13, 15, 18 & 21.

**Diagnosis:** Antenatally raised alpha feto-protein may prompt an earlier US scan and the defect may be seen from 12 to 14 weeks. Exomphalos is usually easily differentiated from gastroschisis as described previously (sac, location of defect and associated anomalies). Termination can be offered in certain cases.

**Prognosis:** Dependent on presence of associated anomalies, karyotype, and size of defect. Mortality is approximately 40%.

**Delivery:** For babies with small defects spontaneous vaginal delivery is advocated. For large defects, so called “giant exomphalos”, particularly if the liver is involved the baby may be delivered by Caesarean section. In 10 to 20% cases the exomphalos sac may rupture (in utero, during delivery, post delivery). If the sac ruptures the bowel is susceptible to oedema and inflammation.

**Management:** The baby is usually born with no respiratory distress unless it is a giant exomphalos with pulmonary hypoplasia. The baby should be checked for associated anomalies, the defect should be wrapped to prevent infection and surgical closure planned. The small defects are most likely to be associated with other anomalies (Beckwith Weidemann, congenital heart disease). No consensus exists on the optimal management of large unruptured exomphalos.

- Treatment depends on the size of the lesion
- Aims of treatment are to reduce contents into small abdominal cavity
- If bowel is covered there is no urgency to do this
- Treatment options are both surgical or conservative and included
  - Biological dressings
  - Polymer films
  - Direct surgical closure
  - Skin flap closure
- Small defects can usually be closed surgically
- Surgical closure of large defects may require staged procedures
- Overzealous reduction can result in caval compression
- After conservative treatment a ventral hernia repair may be required at about one year of age

**Giant exomphalos:** These are large defects with herniation of the liver. There is usually associated pulmonary hypoplasia with a small bell shaped thorax; respiratory management can be challenging with long term ventilation requirements. Even post successful surgical repair the liver remains in the epigastrium and is vulnerable to traumatic injury.

**Complications:** Ventral hernia are common and staged procedures can be protracted with risk of infection.

**Feeding:** Attention must be paid to giving adequate calories as these babies often have high metabolic demand and FTT. Most infants will have a normal gastrointestinal tract so enteral feeding with breast milk and/or normal formula milks is usual. Occasionally there may be an associated intestinal atresia or patent omphalomesenteric duct.

**Ano-rectal Malformations (23, 24, 25)**

Congenital anomalies of the anus and rectum are relatively common. Minor abnormalities occur in approximately 1 per 500 live births; major anomalies occur in 1 per 5000 live births. Among the various anomalies associated with rectal abnormalities are malformations of the urinary tract and oesophagus and, less often, the small bowel. The most useful clinical classification categorizes lesions by whether the rectum passes through the puborectalis
muscle sling. High lesions fail to pass through this muscle complex and are more likely to elicit long-term continence problems.

**Pathophysiology:** The anus and rectum develop from the dorsal portion of the cloacal cavity when lateral ingrowth of the mesenchyme forms the urorectal septum in the midline. This septum separates the rectum and anal canal dorsally from the bladder and urethra. The cloacal duct is a small communication between the 2 portions of the hindgut; downgrowth of the urorectal septum closes this duct by the seventh week of gestation. The anus develops by a fusion of the anal tubercles and an external invagination, known as the proctodeum, which deepens toward the rectum but is separated from it by the anal membrane. This separating membrane should disintegrate during the eighth week of gestation. Interference with anorectal structure development at varying stages leads to various anomalies, ranging from anal stenosis, incomplete rupture of the anal membrane (ie, covered anus), or anal agenesis (a low lesion) to complete failure of the upper portion of the cloaca to descend and failure of the proctodeum to invaginate (a high lesion). Continued communication between the urinary tract and rectal portions of the cloacal plate causes rectourethral fistulas or rectovaginal fistulas.

The external anal sphincter, derived from exterior mesoderm, usually is intact and is uninvolved with obstructive anal or rectal lesions. This sphincter marks the prospective anal opening when formation occurs normally. Careful identification of this sphincter is important in planning operative repair of these lesions.

High anomalies (ie, those above the puborectalis muscle) occur much more commonly in males.

![Imperforate Anus](https://www.emedicine.levittma.com/)

**Frequency:** Minor anomalies occur in 1 newborn per 500 live births. Major malformations occur in 1 newborn per 5000 live births. No racial differences in disease incidence or severity; although the disease appears more common in some areas. Some families have a genetic predisposition, and successive generations have anorectal malformations. A mother who has one child with these kind of conditions has a 1% chance of having another child who suffers from this ailment. Most studies report a male preponderance of 55-65%. High anomalies occur more often in males, while low lesions occur more often in females

**Mortality/Morbidity:** The lesions in the spectrum covered by the term imperforate anus are rarely fatal, although some associated anomalies can be life threatening. An inability to defaecate is the major disability associated with an imperforate anus, which manifests as faecal incontinence or, more commonly, constipation. Genitourinary problems (eg, vesicoureteral reflux, renal dysplasia) also are relatively common.

**Associations:** These occur in 50-60% of affected children, especially those with high anomalies.

1. Cardiovascular malformations occur in 12-22% of patients.
   - The most common lesions are tetralogy of Fallot and ventricular septal defects.
   - Transposition of the great arteries and hypoplastic left heart syndrome have been reported but are rare.
2. Many GI malformations have been described in association with imperforate anus.
   - Tracheoesophageal abnormalities exist in 10% of patients. Babies with high imperforate anus are at greater risk.
   - Duodenal obstruction from annular pancreas or duodenal atresia occurs in a small percentage of patients.
- Malrotation with Ladd bands causing obstruction.
- Hirschsprung disease has been well described in association with imperforate anus, although the incidence of this combined condition is unknown.
- Constipation is common.

3. The association of imperforate anus and vertebral anomalies has been recognized for many years. Patients with high lesions have an increased risk of this association.
   - Lumbosacral anomalies predominate and occur in approximately one third of patients with imperforate anus.
   - The frequency of spinal dysraphism (evaluated by ultrasonography or MRI) increases with the severity of the lesion (ie, 17% for patients with low lesions, as high as 46% for patients with cloacal anomalies). The most common type of dysraphism is tethered cord. Cord lipomas and syringohydromyelia also occur frequently.
   - Currarino described a triad of sacral defect, presacral mass, and imperforate anus. Screen all patients for these vertebral abnormalities in the newborn period.

4. Urologic abnormalities are common in patients with an imperforate anus. As they do for other associated problems, patients with high lesions have increased incidence of urinary anomalies.
   - Vesicoureteric reflux in 59% of patients (the most common finding), followed by renal agenesis and dysplasia.
   - Cryptorchidism reportedly occurs in 3-19% of males.
   - Vaginal and uterine abnormalities are common. Bicornate uterus and uterus didelphys occur in 35% of female patients with imperforate anus. A vaginal septum is the most common vaginal abnormality. Vaginal duplication and agenesis also have been reported.

Presentation:
- Imperforate anus may be detected on routine check post delivery. In either sex, a flat perineum with a short sacrum and little muscle contraction suggests a high anomaly (ie, above the levator muscles).
- In newborns, failure to pass meconium within the first 24 hours of life usually prompts an examination of the perineum. Occasionally, however, anal atresia is missed until the baby is fed and signs of intestinal obstruction appear. At the end of the first or second day, the abdomen swells and there is vomiting of faecal material.
- Newborns with high lesions have meconium in the urethra, or meconium is detected by urinalysis.
- Some types of malformations (eg, anterior ectopic anus, anal stenosis) are less readily detected. Patients may present with these lesions much later with a history of chronic constipation or pain on defaecation.
- Anorectal anomalies sometimes are detected during examination for cardiac or oesophageal anomalies.
- Plain film radiography is usually sufficient for the initial evaluation of imperforate anus.
• A distal colostogram accurately defines the type of lesion and the usual rectal fistula.
• In all patients, evaluate the sacrum and distal spinal cord with ultrasonography, although an MRI is more useful for this evaluation in older patients.

Management: These infants rarely require ICU. They will be given intravenous fluids until enteral continuity can be established. After defining the type of anomaly, maintain enteral decompression with a gastric tube. Antibiotics may be required if urinary tract abnormalities are suspected. Investigation to determine the presence or absence of associated anomalies during this period is mandatory because this may affect surgical planning. Surgical treatments may include a colonic diversion for patients with high lesions until later definitive repair can be achieved. Although a loop colostomy is easily performed, a completely diverting type of colostomy is preferred to prevent continued contamination of the urinary
system. Once an infant tolerates feedings, discharge can be planned with outpatient follow-up care and subsequent definitive surgical reconstruction. Later repair includes posterior sagittal anorectoplasty (moving the intestine into the anal sphincter and making a hole in the skin). Anal stenosis occurs in as many as 30% of patients and should be closely monitored in the postoperative period. Routine anal dilatation usually obviates this problem. The colostomy is closed several weeks later.

In low anal atresia, immediately after diagnosis, a hole is made in the skin to open the area where the anus should be. The anus and rectum are commonly dilated post op.

Websites:
1. www.emedicine.com
2. www.shands.org
3. http://fetalsurgery.chop.edu
4. www.surgical-tutor.org.uk
5. www.geeps.co.uk (parent support website)
6. www.gfmer.ch/genetic_diseases (Geneva Foundation for Medical Education and Research)

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1. www.emedicine.com – Article by Dr Rick Steinhorn, November 2006.
3. Ackerman K. “Fog2 Is Required for Normal Diaphragm and Lung Development in Mice and Humans”.
### Information for Year 2 ITU Training (advanced):

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### Curriculum Notes for Year 2:

**Bronchopulmonary Foregut Malformations (BPFM)**

These are malformations of the separation of the primitive foregut into the pulmonary system and the proximal gastrointestinal tract. The lung bud arises from the ventral surface of the foregut at 3 to 4 weeks gestation; over the next 2 weeks this is completely divided into a ventral trachea and dorsal oesophagus. If the septum fails to form properly OA and TOF may form. Abnormal budding of the ventral foregut causes a constellation of malformations:

- a) Bronchogenic cysts (foregut duplication cysts)
- b) Pulmonary sequestration
d) CBPM (communicating bronchopulmonary foregut malformation)
- e) CCAM (cystic adenomatoid malformation)
- f) Bronchial atresia/stenosis
g) Congenital lobar emphysema

Many theories to aetiology of BPFM but all common embryological origin arising in first few weeks of lung development; differences appear to reflect type or timing of insult. Many reports of mixed lesions have been described.

**Bronchogenic Cyst (Foregut Duplication Cyst)(1-3)**

This is the most common cystic lesion of the mediastinum, though very rare (the exact incidence is unknown as many are never detected). BCs develop following anomalous budding from the ventral or tracheal diverticulum with subsequent separation from normally developing bronchi. Timing of this separation determines site of BC; early separation results in a BC located in the mediastinum (85%), later separation and the BC can be located in the pulmonary parenchyma. Most BCs are single but rarely can be multiple.

**Presentation:** This is extremely variable and is determined largely by the size of the BC rather than the size; presentation can be in infancy or adulthood or may remain entirely asymptomatic for life (>50%).

- a) Adults: Chest pain, dysphagia, haemoptysis, infection
- b) Children: BCs can be life threatening if they compress vital structures (this is usually subcarinal cysts causing airway compromise). Symptoms include wheeze, stridor, respiratory distress, recurrent pulmonary infections, haemorrhage. Pneumonia, pneumothorax, pleural effusions, haemothorax can occur.

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Structure: These are thin walled cystic lesions filled with mucoid material and lined by respiratory epithelium +/- bronchial cartilage +/- gastric mucosa. They are usually unilocular and non-calcified. They can occur anywhere along the tracheoesophageal course and are usually < 10 cm in size; rarely they can present as neck lesions or subdiaphragmatic masses. They do not usually communicate with the airway but if they do infection is more likely. The blood supply is systemic or pulmonary. Once a BC has become infected it can be difficult to differentiate from acquired cysts.

Imaging: Usually seen on plain radiographs (CXR) as a round/oval water density in the mediastinal or perihilar region. If the BC becomes infected a fluid/air level may be seen. Further evaluation is with CT scan or MRI.
Management: This is by surgical resection. There have been some concerns about possible malignant change in these anomalies long term (adenocarcinoma, rhabdomyosarcoma), though the exact prognosis for these lesions is unknown, so surgery is recommended. The prognosis is excellent.

Congenital Cystic Adenomatoid Malformation (CCAM)

What is it?: A mixed solid and cystic mass thought to be caused by a failure of the pulmonary mesenchyme to develop fully. It consists of disorganised and dilated distal components of the respiratory tract with varying cell types and adenomatoid proliferation of cysts resembling bronchioles (2). The lesion usually communicates with the bronchial tree in surrounding normal lung and tends to rapidly inflate with air at birth; however within the lesion a well-defined intrapulmonary bronchial system is lacking, and normally formed bronchi supplying the mass are absent. CCAM differs from normal lung tissue because of a combination of increased cell proliferation and decreased apoptosis Embryologically formed after a failure of normal branching and budding of the ventral diverticulum of the foregut early in lung development (as all BPFMs). This common aetiology is reinforced by co-existence in some patients of CCAM with PS (ILS or ELS), or CCAM changes within a PS. CCAM represents approximately 25% of all congenital lung lesions and the estimated incidence of CCAM is 1 case per 25,000-35,000 pregnancies. There is no racial predilection.

Types: Stocker devised a classification system (4)

I. Type 1 – most common (50%); usually has a large central cyst > 2 cm surrounded by smaller cysts. Usually lined by mucin secreting epithelium and can contain cartilage plates.
II. Type 2 – 40% of CCAM; multiple small cysts < 1cm. Ciliated columnar epithelium, no cartilage and cells have the appearance of bronchioles.
III. Type 3 – 10% Microcystic; dilated bronchioles and alveolar ducts
IV. Type 4 – a large cyst lined with alveolar type cells
V. Type 0 – appears to arise from tracheo-bronchial structures

CCAM receives its blood supply from the pulmonary circulation and is not sequestered from the tracheobronchial tree. However, type II and III lesions can occasionally coexist with extralobar sequestration, and in such cases, they may receive systemic arterial supply. CAM may also occur in combination with a polyalveolar lobe. A polyalveolar lobe is a form of congenital emphysema with increased number of alveoli with normal bronchi and pulmonary vasculature.

Associations: CCAM can be associated with other anomalies (5). The most commonly associated anomalies occur in the type II form. The anomalies affect the renal (cystic disease, agenesis, dysgenesis), intestinal (atresias), cardiac, and osseous systems.

Diagnosis: Can be seen on antenatal ultrasound scan as a hyperechogenic mass in the thorax. However US is only 70-80% accurate in correctly identifying the histology even in the most experienced hands. The differential diagnosis includes other types of BPFM, neuroblastomas and teratomas.

Clinical course: This is extremely variable and ranges from causing fetal hydrops to being asymptomatic for life.

a) Fetus: A large CCAM (like other large BPFM defects) can cause SVC compression, mediastinal shift, cardiac compression and pleural effusions (fetal hydrops). Interventions such as thoracocentesis and thoracoamniotic shunts have been in employed in some fetal centres to help improve outcome in these patients with some success (6,7). Interestingly a proportion of CCAM lesions appear to regress during pregnancy, even those that have caused hydrops (which has resolved) – making prognosticating regarding outcome even more difficult in this group of patients.

b) Type 3 CCAMs are the most likely to cause fetal and neonatal symptoms as the lesions are usually large and associated with pulmonary hypoplasia; hence Type 3 is associated with a higher mortality.

c) At birth: Large or rapidly expanding lesions can compress heart, SVC and pulmonary vessels causing RS and CVS compromise requiring ICU. The prognosis may also be confounded in these patients by associated pulmonary hypoplasia (because of the SOL effect of lesion in utero).
Approximately 30% of CCAM lesions seen antenatally will produce symptoms at birth (compare 60% ELS and 57% CLE).

d) Infants requiring ventilation may benefit from PEEP to facilitate emptying of the cysts.
e) Infancy to childhood: can present with wheeze, cough, infection or bronchiectasis. Pneumatoceles that form subsequent to bacterial pneumonia (e.g., streptococcal, staphylococcal) can be mistaken for CCAM, particularly in the older child.

For large asymptomatic lesions surgery is usually planned – the timing is debatable but the aim is to operate before these lesions become infected.

Please see emedicine for CXR examples.

Treatment: As discussed above surgical treatment is definitive.

Prognosis: Type 3 is associated with the highest mortality as the lesion tends to be extensive; the mortality in Type 2 can be governed by the associated anomalies. The prognosis is also poor with bilateral lung involvement, hydrops and prematurity. Overall however the prognosis for this disorder is good.

**Pulmonary Sequestration (10)**

**What is it?:** Pulmonary sequestration (PS) is a mass of non-functioning ectopic pulmonary tissue with its own blood supply. Multiple feeding vessels may be present in 15-20% of cases. The pulmonary tissue has no identifiable communication with the normal bronchial tree. Congenital pulmonary abnormalities only comprise 2.2 – 6.6% of congenital abnormalities; PS is the second most common congenital lung anomaly. Occasionally, patients may have a systolic bruit or continuous murmur over the affected area. This is related to flow through the sequestration from the large systemic arterial supply.

**Types:** There are two types based on the pleural covering.

a) Extralobar PS (ELS): The pulmonary tissue has a distinct pleural covering maintaining complete anatomical separation of the tissue mass from adjacent normal lung.

b) Intralobar PS (ILS): The pulmonary tissue mass does not have its own separate pleural covering and is contiguous with the adjacent normal lung.

Aetiology: PS is the result of abnormal budding of the foregut which retains its embryonic systemic arterial connections. What causes this is unknown. The primitive bronchial tree begins as a ventral diverticulum of the foregut at 3 weeks; this then bifurcates into right and left lung buds by 26 days. Definitive right and left lobes develop between 5 and 8 weeks gestation. PS is therefore thought to develop between 4 and 8 weeks. There is a high incidence of CDH with ELS indicating development of the anomaly before 6 weeks.

ELS (25%):

- Separate from main lung mass
- Can be diagnosed antenatally at 16 weeks gestation; it is seen as an echogenic mass usually in the lower chest (Differential diagnosis: duplication cysts, CCAM, BC, neuroblastoma). More precise diagnosis can be made if the systemic feeding artery can be visualised.
- Most patients present by 6 months (60%), with a quarter presenting soon after birth with respiratory distress or feeding difficulties, 10% asymptomatic.
- Symptoms: Respiratory distress, feeding difficulties, high output cardiac failure, fetal hydrops, pleural effusions.
- Size: 0.5 to 15 cm.
- ELS composed of irregular bronchi, bronchioles and alveoli (2 to 5 times larger than normal)
- M:F 3.5:1
- ELS usually occur in the left thorax (65-90%) in the posterior costophrenic sulcus (sub pulmonary) but can occur anywhere in the thorax. 10-15% however occur below the diaphragm.
- Arterial supply: 80% directly from the thoracic or abdominal aorta. 15% arterial supply via another systemic artery. 5% from the pulmonary artery.
- Venous drainage: Mainly into systemic circulation, some to pulmonary veins
- 60% patients have co-existent congenital anomalies:
  - CDH most common 16%
  - 25% - lung hypoplasia, CCAM, congenital lobar emphysema, BC.
Others: pectus excavatum, pericardial defects, truncus arteriosus, TAPVD, dextrocardia, vertebral anomalies, accessory spleen.

- Prognosis is unclear; some lesions appear to regress during pregnancy; some lesions are found incidentally whilst investigating other anomalies. Treatment is surgical but careful planning is required to identify blood supply pre-op; some vessels are large enough to cause high output cardiac failure and could potentially cause life threatening haemorrhage peri-operatively.

**ILS (75%)**:
- More common than ELS
- Presents at any age, however unless it is diagnosed antenatally it rarely presents before 2 years of age. 20% present by 20 years old, 15% are asymptomatic.
- Usually presents with recurrent or chronic pneumonia. Also haemoptysis, high output cardiac failure (large feeding vessels), intrathoracic bleeding, pneumothorax.
- M:F 1:1
- Compared to ELS, ILS is less frequently associated with other anomalies (11%).
- Site: Medial/posterior basal segments of the lower lobes of the lung (left 60%).
- Arterial supply: descending thoracic aorta (70%), abdominal aorta (20%)
- Venous drainage: > 95% directly into pulmonary veins

**Investigations**: CXR – may be seen as triangular shaped lucency on plain films or may not be visualised

Doppler US – to identify feeding arteries or draining veins

CT scan

Angiography

Intralobar pulmonary sequestration. Chest radiograph in an 8-year-old patient who presented with signs of an acute chest infection showed a left lower lobe consolidation. After appropriate medical treatment, the child improved clinically, but opacity in the left lower lobe persisted. A sequestrated lung segment was suspected because of a history of several previous respiratory infections from age 3 years and up.
Aortogram shows contrast material injected within the upper abdominal aorta. An anomalous artery is arising from the infradiaphragmatic portion of the aorta and is supplying a supradiaphragmatic mass in the left lower lobe (arrow).

Prognosis: Recurrent infection is the usual complication but the exact incidence of infection and the natural evolution of sequestration are unknown. The management of antenatally diagnosed and/or asymptomatic PS is hence controversial. Mortality is 13-25% due to persistent pulmonary hypertension and co-existent anomalies in some cases. Long term morbidity includes pneumonia, asthma and gastroesophageal reflux. Management: Surgical resection is the definitive treatment after careful delineation of the blood supply (as described above) and treatment of any infection. ILS may require lobectomy whereas ELS only sequestrectomy.

Congenital Lobar Emphysema (CLE) (3, 11, 12, 14)
What is it?: Overinflation of the alveoli in a segment or lobe of lung due to obstruction of the supplying bronchus. The name of this disorder is a little misleading as there is no emphysematous destruction of alveoli. The cause of the bronchial obstruction is not always clear but some causes are:
- Intrinsic obstruction of the bronchus due to deficiency of the cartilaginous support or deficiency of elastin.
- Intrinsic endobronchial obstruction from mucosal folds or fibrosis of the interstitium.
- Extrinsic compression from cysts, lymph nodes, mucous plugs or aberrant vessels.

Imaging: CLE is initially fluid filled at birth producing the appearance of a distended fluid filled lobe with hazy soft tissue opacity on CXR. Once the fluid is absorbed the lobe becomes hyperinflated and hyperlucent with attenuation of the pulmonary vasculature; there may also be compression of the adjacent lung and mediastinal shift. If a V/Q scan is performed CLE is seen as a perfusion defect. CT scan may help delineate the lesion and reveal the cause of obstruction (as described previously one may not be found). CT will also give details of the vascularity of the lesion and the condition of the rest of the lung.

CXR of a neonate showing marked overdistention of the left upper lobe with mediastinal shift to the right.

Reference: emedicine Oct 2006 Wood B
Clinical:
- M>F
- The commonest lobe affected is the left upper lobe (41%) followed in descending order of frequency by the right middle lobe (34%) then the right upper lobe (21%).
- < 1% cases are in the lower lobes.
- Usually only one lobe is affected but 20% cases are bilateral with multiple lobar involvement.
- Associated anomalies (10% cases): CVS common, rib cage anomalies, aplasia/dysplasia of the kidneys
- Most present within the first month of life; a third within hours of birth. Occasionally milder cases present in infancy or childhood.
- Symptoms: Mild to moderate tachypnoea +/- cyanosis.

Treatment: Lobectomy is the definitive treatment but timing again is controversial as there have been reports of spontaneous resolution in some. For this reason a period of conservative management has been advocated in mild to moderate cases; low volume, low pressure ventilation techniques should be employed to prevent overdistention and the patients should be nursed with the affected lobe dependent.

CT scan of the patient shows marked hyperaeration of the left upper lobe and mediastinal shift to the right.

Reference: emedicine Oct 2006 Wood B

CXR showing RUL CLE with mediastinal shift

Cases of the week, Jan 2007. www.learningradiology.com
**Prognosis:** Mildly affected cases may resolve without surgery. Those who have uncomplicated lobectomies will do well – infections carry the risk of greater morbidity. Multiple lobar involvement confers an extremely poor prognosis. Care must be taken not to mistake CLE for a pneumothorax, as placement of a chest drain may result in lung puncture and formation of a bronchopleural fistula.

**Malrotation**

**Embryology:** During early gestational life the colon and small bowel grow rapidly and extrude from the abdominal cavity. During the seventh week of gestation the midgut starts being reduced back into the abdominal cavity and as it does so it rotates 270 degrees in a counterclockwise direction with the caecum coming to rest in the right lower quadrant of the abdomen and the duodenojejunal junction to the left upper quadrant. This process is completed by 12 weeks gestation.

In patients with malrotation this rotation fails to occur fully stopping after a 90 degree turn. The cause is unknown. This results in the duodenum and ascending colon being juxtaposed around the superior mesenteric vessels, with the entire midgut suspended from this narrow axis (13).

The malrotated bowel itself doesn’t cause a problem but triggered by peristaltic action. Once twisted bowel obstruction occurs and the arterial blood supply is also twisted causing ischaemia of the bowel. Unless the twist is quickly decompressed there can be extensive loss of small and large bowel and peritonitis.

Reference: e-medicine, Anjali Parish July 2006; Intestinal Malrotation
**Clinical:** Volvulus can occur at any time but many occur in the first week of life. Bile stained vomiting is the initial symptom and must always be assumed to be due to volvulus in an infant or child until proven otherwise; this is accompanied by abdominal distention. The child or infant presents with severe abdominal pain, bilious vomiting, abdominal distention, acidosis and in late presentations with circulatory collapse. Some patients experience partial duodenal obstruction because of extrinsic compression by mesenteric bands. Chronic diarrhoea and protein losing enteropathy may be seen among others without complete obstruction.

**Imaging:** Ultrasound can demonstrate malposition of the superior mesenteric vessels, this is diagnostic.

**Management:** Urgent surgery is required. Mortality approximately 10%, depending upon timing and clinical state of the patient. Prior to surgery:
- Urgent resuscitation may be required A,B,C.
- Place a gastric tube to achieve gastric decompression and reduce further vomiting and aspiration.
- Site intravenous access and resuscitate CVS as appropriate with normal saline or 4.5% albumin boluses.
- Send bloods for investigations and crossmatch, check clotting and electrolytes.
- Plain AXRay

At surgery a fibrous band, called Ladd’s band, is found to extend from the retroperitoneum to the malpositioned caecum. This band is divided in a Ladd’s procedure, to release duodenal obstruction. Then the bowel is untwisted and the mesentery dissected to widen its axis. Failure to promptly relieve the volvulus leads to ischaemic necrosis of all the gut supplied by the superior mesenteric artery (proximal jejunum to midtransverse colon). Short gut syndrome results from extensive resection of affected intestine. Early operative intervention has an excellent prognosis.

**Spina Bifida** (12, 17-21)

**What is it?** Failure of closure of the caudal neural tube and or its coverings during the 3rd week of gestation leads to spina bifida. This takes a number of forms;
• Spina bifida occulta: the least severe form in which the vertebral arches do not form in the lumbar area but the spinal cord is relatively normal. There may be a sacral dimple, usually patients are asymptomatic.

• Bony defect contains a protruding sac of tissue = spina bifida cystica. This is divided into closed and open defects.
  - Open defects are covered by a thin red membrane called the area medullovasculsa, the margin of which blends into the more normal surrounding skin.
  - If the sac contains meninges and CSF but no neural elements = meningocele (5% of open spina bifida cases). This is associated with a normal neurological examination. No associated hydrocephalus or Arnold Chiari malformation. Prognosis after surgical repair is good.
  - If the sac contains neural elements = myelomeningocele (95% cases open spin bifida). These patients usually have both hydrocephalus and Chiari 2 malformations.

Closed defects are associated with cutaneous abnormalities in 50% cases – hairy patch, dermal sinus tract, dimple or haemangioma (may be only external sign of abnormality). If these skin lesions are found the underlying spinal cord should be investigated; some may have neurological problems (weakness one or both legs, loss sensation, hyperreflexia, back pain, gait abnormalities, neurogenic bladder). 10% may be associated with imperforate anus. Imaging such as MRI may reveal a tethered cord, diastematomyelia, diplomyelia, dermal sinus tract; surgical repair of lesions is best done prophylactically to try and preserve neurologic function (though this is not always guaranteed).

**Myelomeningocele**
  - Myelomeningocele occurs in one to five babies per 1,000 live births. It develops in the third week of a mother’s pregnancy. There is probably a genetic factor.
  - If a woman has one child with this defect, she has a 3 to 5 percent chance of having another.
  - The neural placode protrudes through the bony and muscular defect to be visible at at its junction with the cutaneous ectoderm. The neural tube does not form at this point and the spinal cord ends in this lesion.
  - Most common in lumbar and lumbosacral region.
  - Associated abnormalities common: cardiac, intestinal, renal, urogenital and orthopaedic.
  - Neurological associations – agenesis corpus callosum, heterotopias, polymicrogyria.
  - A prenatal diagnosis of myelomeningocele mandates a Caesarean section because research has shown that infants born by vaginal delivery are twice as likely to be born with severe paralysis.
  - After delivery need: Cranial, cardiac and renal ultrasounds.

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A view of a myelomeningocele or spina bifida
Hydrocephalus and Arnold Chiari 2 malformations are common.
- Hydrocephalus seen in 80 – 95% patients particularly those with thoracic myelomeningocele.
- Hydrocephalus significant in 20% at birth
- Arnold Chiari 2 – hindbrain herniation.

Syringomyelia present in 20-40% patients and can cause rapid development of scoliosis. Formation of a syrinx can result from a tethered cord or Arnold Chiari 2 malformation.

Repair defect within a few days. This is to prevent infection and further trauma to the cord – it does not bring back neurological function. This involves:
- Reapproximating the neural tube
- Closing the dura
- Skin closure
- Placement VP shunt if significant hydrocephalus us the meninges are in a skin covered sac and the spinal cord is relatively normal.

The open neural tube confers risk of bacterial meningitis and CSF leak can occur.

Long term prognosis:
- 75% normal intelligence
- Children with meningo(myelo)cele average IQ of 97 whilst those without IQ 102.
- IQ drops by 24 points after a CNS infection.
- 80% require intermittent catheterisation
- Children with sacral lesions can often walk, those with thoracic lesions can’t. For lumbar lesions variable numbers can walk and this can worsen with age – most commonly due to tethered cord problems.
- Progressive neurologic deficits of delayed onset in patients with myelomeningocele are often related to uncontrolled hydrocephalus and the Chiari II malformation.
- Repeated, prolonged shunt dysfunction as well as CNS infections are associated with an increased risk of functional and cognitive deficits. Shunt dysfunction may result in an acute or chronic rise in intracranial pressure and occurs more commonly in the first 2 years of life. Diagnosis may be difficult, as early signs and symptoms are extremely variable and often nonspecific.
  - In general, infants present with symptoms of lethargy, poor feeding, irritability, stridor, ocular motor incoordination, and development delay.
  - Older children may present with cognitive or behavioral changes, decreased strength, increased spasticity, changes in bowel or bladder function, lower cranial nerve dysfunction, back pain, and worsening spinal or lower extremity orthopedic deformities.
  - Some patients may present with only papilledema.
  - In any patient with myelomeningocele who presents with deterioration in neurologic, orthopedic, or urologic function, uncontrolled hydrocephalus should be excluded as a cause before any other treatment is pursued.
- The Chiari type II malformation may cause acute or subacute signs and symptoms of lower brainstem and/or upper cervical spinal cord compression, including laryngeal and pharyngeal paralysis, apnea, swallowing difficulty, respiratory stridor, nystagmus, and upper extremity weakness. Treatment initially involves control of hydrocephalus. Surgical decompression of the Chiari malformation is indicated for those patients with severe or progressive symptoms.
- Other causes of delayed neurologic deterioration in myelomeningocele are due to spinal cord pathology such as tethered cord syndrome and syringomyelia. Tethered cord syndrome occurs more frequently during periods of rapid growth.

**Diagnosis:** Elevation of maternal serum α-fetoprotein concentrations obtained in the first trimester of pregnancy identified 75% to 80% of pregnancies with myelomeningocele before
16 weeks of gestation. Amniocentesis is performed in at-risk cases identified by maternal serum α-fetoprotein concentration screening and amniotic fluid. α-Fetoprotein and acetylcholinesterase elevations suggest the presence of a neural tube defect. The structural defect can be readily identified by ultrasound by 18 to 22 weeks' gestation. The presence of a myelomeningocele may also be suggested by the presence of a "lemon" sign, which is a scalloping of the frontal bones. A full anatomic survey should be performed to detect associated anomalies such as:

- Ventriculomegaly
- Chiari malformation with hindbrain herniation
- Clubfoot

The presence or absence and quality of leg and foot movements should be assessed, but it may be difficult to distinguish spontaneous from reflex fetal movement.

**Causes:** Largely unknown but some include lack of folate, hypervitaminosis A and obesity have been implicated. Dietary folate supplementation has been shown to prevent myelomeningocele in some cases, but to be effective folate must be supplemented soon after conception. 50% of women of childbearing age do not take supplemental folate, and most pregnancies are unplanned.

In addition, it is estimated that 30% of neural tube defects are refractory to folate supplementation. For these reasons, despite folate supplementation, Myelomeningocele is an anomaly that likely will continue to affect children. Cases tend to occur sporadically but the chance of recurrence in a second pregnancy is 1 in 50.

**Management:** If the lesion is ruptured at delivery it should be covered with a sterile non-adhesive dressing soaked with saline and covered with a transparent dressing. The infant should be nursed prone or on his/her side and the defect protected. Intravenous access should be obtained and antibiotics started (Benzylpenicillin and Amikacin). The head circumference should be measured and additional abnormalities looked for.

Attempts at fetal repair of defects have occurred but remain experimental. There is currently a National-Institutes-of-Health-sponsored prospective randomized clinical trial of 200 patients comparing fetal surgery to postnatal treatment of myelomeningocele in the MOMS trial (Management of Myelomeningocele Study).

The selection criteria for the MOMS trial include:

- Myelomeningocele at T1 through S1 with hindbrain herniation, maternal age greater than or equal to 18 years
- Gestational age at randomization of 19 0/7 weeks to 25 6/7 weeks
- A normal karyotype

The primary outcome variable of the MOMS trial is whether or not fetal repair of Myelomeningocele at 19 to 25 weeks' gestation improves outcome measured by death or the need for ventriculoperitoneal shunting at 1 year of age.

Secondary outcomes include the effect on the Chiari II malformation by neuroimaging, neuromotor status at 12 and 30 months of age. Neonatal morbidity and need for postnatal surgical interventions will also be evaluated.
This trial has been open and acquiring patients for 1.5 years. The results of fetal myelomeningocele repair are difficult to evaluate, especially given the limited duration of follow-up. Although hindbrain herniation definitely is reversed, ventriculoperitoneal shunting may still be needed. It is hoped that the results of the MOMS trial will determine if fetal intervention can improve outcomes for children with spina bifida.

Genitourinary Abnormalities (22-25)
These cover a wide spectrum of disorders. Bladder extrophy and cloacal extrophy will be discussed. Extrophic anomalies are a group of disorders resulting from the maldevelopment of the caudal fold of the anterior abdominal wall. In bladder extrophy the anterior wall of the bladder is absent and the posterior wall is exposed. Cloacal extrophy is a more severe spectrum of anomalies involving both the urinary and intestinal tracts caused by a defect in the formation of the urorectal septum.

Extrophy = eversion of a hollow organ at birth

Bladder extrophy
What is it?: This is the result of failed closure of the anterior abdominal wall at the ventral end of the cloacal membrane. The bladder is flattened and exposed to the outside of the body through a midline lower abdominal wall defect. The size of the bladder is variable. The
bladder neck, which is made largely of muscle, fails to form. The urethra and genitalia are also affected and fail to form completely. This results in epispadias (dorsal cleft in penis exposing urethral mucosa) in the male and an anteriorly placed vagina and bifid clitoris in the female; the anus is also often displaced anteriorly and divergent elevator ani and puborectal muscles may result in rectal incontinence and anal prolapse. The pelvic bones are widely separated (diastasis) and the perineum is short and broad.

**Cause:** Most cases are sporadic. Familial cases have been reported and the risk of recurrence for a second pregnancy is 1 in 100. If a parent has bladder extrophy the risk of an offspring being affected is 1 in 70. The defect occurs between 4 and 10 weeks gestation. Incidence is 1 per 30,000 to 50,000 live births. This defect can run in families. (1 in 70 if the parent has also been affected). There is a male preponderance, M:F is 2:1.

**Associated problems:** Generally bladder extrophy is an isolated abnormality, but 13% may have an associated spinal cord abnormality.

**Diagnosis:** Often found on antenatal ultrasound as operator fails to find a bladder and may spot associated genitourinary abnormalities. Instead of a bladder the ultrasonographer may find an external, well-defined, solid or complex mass immediately superior to the fetal genitalia. Prolonged and repeated scans fail to reveal the fetal bladder. The renal collecting system and ureters need not be dilated, and unilateral or horseshoe kidneys may be found. Uterine and adnexal anomalies are relatively frequent. The pubis is abnormally wide, and the umbilical cord insertion may be abnormal.

Once diagnosis has been made the parents should be referred to a multidisciplinary team for careful counselling.

**Management:** Staged surgical reconstruction of the defect is performed.

1. **1st Stage:** Close the bladder and the abdomen
2. **2nd Stage:** Epispadias repair
3. **3rd Stage:** Achieve urinary continence. Observe/preserve renal function.

This is a simplified agenda as often these children need other procedures such as ureter reimplantation, bladder augmentation (as all extrophied bladder are small) etc.

**Prognosis:** There can be long term difficulties with recurrent urinary tract infections, urinary continence (75% will achieve 3 to 4 hour continence after surgery) and sexual dysfunction. Patients can have psychological and functional difficulties with the cosmetic consequences of the genital lesions (particularly males). Sometimes gender reassignment is advocated when the defects are extremely severe and when an adequate functional penis cannot be created. Genetic defects in females are less complex, though vaginal dilatation and perineoplasty may be required. Fertility in reduced in both sexes but pregnancy is possible although there is an increased risk of uterine prolapse post partum because of hypoplasia of the cardinal ligaments.

**Cloacal Extrophy**

**What is it?** This is a more severe defect and results in a spectrum of abnormalities of which bladder extrophy is one.

Early in gestation the cloaca is a blind pouch that receives the midgut and the allantoic duct. The anterior wall of the cloaca is formed by the cloacal membrane, which extends from the 2 lateral mesodermal ridges to the body stalk. By the 6th week the cloaca is divided by a mesodermal ridge called the urorectal septum into a urogenital sinus and hindgut. The 2 mesodermal ridges normally fuse in the midline to form the genital tubercle and the cloacal membrane retracts downwards towards the perineum. If the cloacal membrane does not retract the mesodermal ridges fuse inferiorly and when the cloacal membrane disappears (as expected) the posterior wall of the bladder is exposed (10 weeks); this gives rise to bladder extrophy. If however the membranes disappear before the urorectal septum divides the primitive cloaca both the bladder and rectum will be exposed giving cloacal extrophy. Hence this is a defect of mesodermal migration.

**Defect:** In cloacal extrophy there is:

- Bladder extrophy
- 2 hemibladders each with an ureteral orifice separated by an area of intestine
- Diphallus – separation of the 2 corpora.
- Bicornuate uterus
- Duplicated vagina, which often enters the bladder
- No anus or anal canal
- Exomphalos (67%)
- Pubic diastasis

**Associated anomalies:** Rare with bladder extrophy but common in cloacal extrophy (60%).
- Spina bifida 50%
- Vertebral anomalies 46%
- Upper urinary tract anomalies 40 - 60% (renal agenesis, multicystic kidney, hydrourerter)
- Malrotation 30%
- Lower limb anomalies 30%
- Double appendix 30%
- Short gut 20%
- Small bowel atresia 5%
- Cardiovascular anomalies 16%
- Double vena cava

**Cause:** Thought to be sporadic. Affected patients have never reproduced. Incidence is 1 in 250,000. Male to female incidence is equal.

**Diagnosis:** On ultrasound there may be initial recognition of a spinal cord defect prompting further evaluation of the fetus; or bladder extrophy may be recognised with exomphalos or splaying of the pubic rami. If diagnosed antenatally, termination can be offered after careful counselling of the parents; other than this obstetric care is as usual. There is no benefit from early or Caesarean delivery.

**Prognosis:** Poor 50% mortality. Infants can die from short gut, renal or central nervous system defects. After surgery about 40% may achieve urinary continence for 3 to 4 hours.

**Management:** Surgery involves a series of operations to repair all the defects and to reconstruct the deficits. Males are often converted to females because of the poor results at trying to create a functionally acceptable penis.

**Other sources of information:** Other interesting papers are included in last year’s folder for this module; particularly the readings on short gut syndrome.

**Websites:**
1. www.emedicine.com
2. www.learningradiology.com – Lessons of the week, an excellent way to test yourself on XRays.
3. www.gfmer.ch/genetic_diseases - (Geneva Foundation for Medical Education and Research)
4. www.fetalcarecenter.org/medicine/therapies/spina-bifida - website of Fetal Care Center of Cincinnati, US.
8. www.pedsurology.com - pediatric urology website

**References:**
20. www.fetalcarecenter.org/medicine/therapies/spina-bifida - website of Fetal Care Center of Cincinnati, US.