Congenital Bronchopulmonary Malformations:

Ccam/cpam
Sequestration
Lobar emphysema
Bronchogenic cyst

Forgut malformations-tef/ea, esoph bronchus, esoph duplication, cartilage ring, Diaph hernias
Controversies:
(I wish I knew the answer)

- lobar emphysema- cong vs acquired
  - surgical technique-
  open/scope/lobectomy/wedge excision
  - termination counseling?
  - timing of CTA/elective surgery
    - timing/place of birth
    - maternal/fetal mri
      - steroids
    - prenatal intervention
  - asymptomatic, normal cxr, hx of lesion
    prenatally
  - obs vs surgery for sequestration
    - obs vs resect for ccam/cpam
  - incidence of complications-
    infection/bleeding/ptx

- cancer
The lung buds form during the 4\textsuperscript{th} week

- Initially appear as the respiratory diverticulum, which is a ventral outgrowth of foregut endoderm.
- **MESODERM dependent process**: Retinoic acid produced by adjacent mesoderm induces expression of TBX4 in foregut endoderm. TBX4 induces growth and differentiation of the trachea and lungs.
Splitting of foregut into esophagus and trachea

Tracheo-esophageal ridges: longitudinal ridges that eventually fuse to separate trachea from esophagus.
STAGES OF LUNG GROWTH

Embryonic
4-7wks

Pseudoglandular
Development of lung tissue involved in air exchange

Canalicular Period: (16th-26th week)

Terminal Sac Period: (24th weeks to birth) Type I squamous cells

Alveolar Period: (late fetal thru childhood, Type II, surfactant-producing cells)
Postnatal human lung growth

WILLIAM M THURLBECK

From the University of British Columbia Department of Pathology, Vancouver, Canada

\[ N_v = \frac{N^{3/2}}{B \cdot V_{valv}^{1/2}} D, \]
Bronchopulmonary Sequestration

An abnormal, non functioning portion of lung tissue that does not communicate with the tracheobronchial tree

Extra lobar = If mass has its own pleural investment

Respiratory distress and Feeding Intolerance

All Should be Resected

Intralobar = Contained within the normal pleural

Recurrent Infection
### Indications for Resection of Extralobar Bronchopulmonary Sequestration

<table>
<thead>
<tr>
<th>Indication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large systemic vascular supply</td>
</tr>
<tr>
<td>Large lesions with significant compression of surrounding lung parenchyma or mediastinal shift</td>
</tr>
<tr>
<td>Lesions with cystic abnormality on prenatal US or postnatal CT scan as this likely represents CPAM elements within BPS.</td>
</tr>
<tr>
<td>Growth of an ELS on serial imaging</td>
</tr>
<tr>
<td>Lesions in or under the diaphragm near the esophageal hiatus causing obstructive symptoms</td>
</tr>
</tbody>
</table>
Congenital Lobar Emphysema

Defined as the abnormal inflation of a histologically normal lobe of the lung

Most common cause is an intrinsic defect in bronchial cartilage, leading to airway collapse on expiration and progressive air trapping

ECHO required to rule out cardiac anomalies

Appears on CXR as lobar hyperinflation, flattening of ipsilateral diaphragm and mediastinal shift

All lung lobes affected by CLE should be surgically resected, over expansion of the lung needs to be avoided especially after endotracheal intubation.

Progressive air trapping may require emergent thoracotomy
Bronchogenic Cyst - Fluid filled cysts derived from abnormal budding of the foregut

During development obstruction of the lobar bronchus will manifest as lobar hyperplasia beyond the obstruction.

May be asymptomatic, but because of potential for respiratory distress, pneumonia and dysphagia should always be excised, not drained.
ccam/cpam

1:10,000 live births (~)
Growth 20-26 weeks
Plateau 26-28 weeks
Relative regression after 28 weeks
?disappearing ccam/cpam
~9% ped lung tumors have/had ccam/cpam
Stocker Classification
<table>
<thead>
<tr>
<th>Stocker classification</th>
<th>Type 0</th>
<th>Type 1</th>
<th>Type 2</th>
<th>Type 3</th>
<th>Type 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Large cysts, 3–10 cm</td>
<td>Medium cysts, 0.5–2.0 cm</td>
<td>Very small cysts, &lt; 0.2 cm</td>
<td>Peripheral cyst type</td>
</tr>
</tbody>
</table>
Case Presentation

5m female presented with severe respiratory distress.

Born at term, developed normally until the age of 4 months.

At admission, had cough, fever, and dyspnea

Physical examination revealed tachypnea w/ subcostal and intercostal retractions.

Breath sounds absent in the right hemithorax
CASE PRESENTATION - CYSTIC MASS IN FETAL THORAX

30y female presents at 24wks for her first prenatal ultrasound

A large 7cm cystic structure is present in the thoracic cavity

There is mild polyhydraminos noted

Non-immune hydrops is present
Thoracoamniotic shunting was performed and fetal hydrops improved.

What is the most likely diagnosis?
Stocker Type 1

Bronchial/bronchiolar

Age = Birth to adolescence (1st m)

Symptoms = neonatal RD

Imaging = Multiple large cysts

Frequency = 60%

Adapted Stocker et al 2008
Cystic Adenomatomoid Malformation Volume Ratio Predicts Outcome in Prenatally Diagnosed Cystic Adenomatomoid Malformation of the Lung

By Timothy M. Crombleholme, Beverly Coleman, Holly Hedrick, Kenneth Liechty, Lori Howell, Alan W. Flake, Mark Johnson, and N. Scott Adzick

Philadelphia, Pennsylvania

CVR = Length x Height x Width x 0.52 / Head Circumference
In fetuses with CVR < 1.6 at presentation, 86% did not progress to hydrops. Enhanced to 97% if fetuses with dominant cyst are eliminated.

Survival without the development of hydrops is 100%.

CAM with CVR > 1.6 have a 53% survival rate and are uniformly fatal without intervention.

Fetuses with CVR < 1.6 are in a low risk group but still require close surveillance, especially with a dominant cyst.
Prenatal findings:

- solid vs cystic
- mediastinal shift/mass
effect/size/diaph
- cystic prominence
- polyhydramnious
- CVR/MTR/LMVR
- hydrops
Detailed Sonography
Ultrafast MRI
Fetal Echocardiogram
(Amniocentesis)

Isolated CPAM without fetal hydrops

Follow up with Serial US

Low risk

Extreme MS
Mild MS
No MS

Delivery at Fetal Center
Neonatal Resection

Planned Delivery at Term

Counsel

Associated Anomalies

Isolated CPAM with fetal hydrops

High risk
CVR >1.6

Microcystic
Macrocystic

Steroid

Hydrops

<32 weeks
>32 weeks

Open Fetal Surgery
(Fetal lobectomy
Thoracoamniotic Shunt)

No hydrops

EXIT-to-CPAM resection

Macrocystic

Delivery at Fetal
Center
Neonatal Resection

Steroid

Hydrops

No hydrops

EXIT-to-CPAM resection

Planned Delivery at Term

Low risk

Isolated CPAM with fetal hydrops

Follow up with Serial US

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Extreme MS
Mild MS
No MS

Delivery at Fetal Center
Neonatal Resection

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Open Fetal Surgery
(Fetal lobectomy
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Detailed Sonography
Ultrafast MRI
Fetal Echocardiogram
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Isolated CPAM
with fetal hydrops

High risk
CVR >1.6

Follow up
with Serial US

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without fetal hydrops

Associated
Anomalies

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Isolated CPAM
with fetal hydrops

Macrocytic

No hydrops

Delivery at Fetal
Center
Neonatal Resection

Mild MS

No MS

Steroid

Hydrops

<32 weeks

>32 weeks

EXIT-to-CPAM resection

Planned Delivery
at Term

Microcytic

Open Fetal Surgery
(Fetal lobectomy
Thoracoamniotic Shunt

Macrocystic

No

Planned Delivery
at Term

Counsel

Macrocystic
Candidates for BMZ include fetuses <28wks with a CVR >1.6 or the presence of hydrops

82% (23/28) and 68% (19/28) experience negative CVR and LVGR following single course

Mediastinal shift resolved in 51% and hydrous in 71% (7/8 single course and 5/9 multiple)

93% of fetuses receiving a single BMZ course survived, 86% survival with multiple
It is the current role for maternal BMZ in prenatally diagnosed CP

- Candidates for BMZ include fetuses <28wks with a CVR >1.4 or the presence of hydrops

- 12mg betamethasone deliver IM for 2 doses 24h apart = 1 course

- Weekly ultrasound, if no response to first course may consider additional courses

- Failure to respond to the initial course of steroids is indicative of a non responder to steroids and may require fetal or perinatal surgical intervention
Detailed Sonography
Ultrafast MRI
Fetal Echocardiogram (Amniocentesis)

Isolated CPAM with fetal hydrops
High risk CVR >1.6

Isolated CPAM without fetal hydrops

Follow up with Serial US

Low risk

Microcystic
Steroid
Hydrops

Macrocystic
No hydrops

Counsel

Open Fetal Surgery (Fetal lobectomy)
Thoracoamniotic Shunt

<32 weeks
>32 weeks

Delivery at Fetal Center
Neonatal Resection

EXIT-to-CPAM resection
Planned Delivery at Term

Associated Anomalies

Planned Delivery at Term

Macrocystic

Delivery at Fetal Center
Neonatal Resection

Low risk

No MS

Mild MS

Extreme MS

Expanded Steroid Hydrops

32 weeks
<32 weeks

No MS"
Should we get a fetal MRI?
Fetal MRI lung volumes are predictive of perinatal outcomes in fetuses with congenital lung masses

Irving J. Zamora a,b, Fariha Sheikh a,b, Christopher I. Cassady a,c, Oluyinka O. Olutoye a,b,e, Amy R. Mehollin-Ray a,c, Rodrigo Ruano a,d, Timothy C. Lee a,b, Stephen E. Welty a,d, Michael A. Belfort a,e, Cecilia G. Ethun a,b, Michael E. Kim a,b, Darrell L. Cass a,b,e

- 98% of fetuses w/ LMVR < 2 did not develop hydrous or heart failure
- If LMVR > 2 80% survival
- Fetuses w/ LMVR > 1.3 had greater need for postnatal care (respiratory distress, longer NICU stay)
- 80% of fetuses w/ LMVR > 1.3 required urgent operation while only 10% of fetuses with < 1.3 required resection

Multivariable logistic regression for development of fetal hydrops.

<table>
<thead>
<tr>
<th>Covariate</th>
<th>OR</th>
<th>95% CI</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>LMVR</td>
<td>6.97</td>
<td>1.58-30.84</td>
<td>0.01</td>
</tr>
<tr>
<td>O/E-NFLV</td>
<td>5.11</td>
<td>0.14-192.02</td>
<td>0.38</td>
</tr>
<tr>
<td>Right-sided lesion</td>
<td>0.27</td>
<td>0.01-9.69</td>
<td>0.47</td>
</tr>
<tr>
<td>Gender (male)</td>
<td>0.24</td>
<td>0.01-4.65</td>
<td>0.34</td>
</tr>
<tr>
<td>GA at 1st MRI</td>
<td>0.81</td>
<td>0.48-2.59</td>
<td>0.81</td>
</tr>
</tbody>
</table>
Postnatal Management

<25%

Symptomatic: Respiratory Distress
- Ventilatory support
  - Preoperative stabilization
    - CT scan & ECHO
  - Delayed open surgery once stable + Manage PPHN

Minimal respiratory compromise
- Urgent CT scan & ECHO
  - Thoracoscopic/open resection

Asymptomatic
- Chest X-ray before discharge
  - Investigate in Outpatient
    - CT scan
    - ECHO
    - Upper GI Contrast Study
    - US Abdomen
  - Thoracoscopic resection 6 to 12 months

Approach?
When?
Thoracoscopy Versus Thoracotomy Improves Midterm Musculoskeletal Status and Cosmesis in Infants and Children

Taiwo A. Lawal, MBBS, Jan-H. Gosemann, Joachim F. Kuebler, MD, Sylvia Glüer, MD, PhD, and Benno M. Ure, MD, PhD

Department of Pediatric Surgery, Hannover Medical School, Hannover, Germany

Thoracotomy associated with increased chest asymmetry, narrower intercostal spaces, increased desired for scar revision
Table 3
Learning curve in the thoracoscopic group: breakdown of the 100 cases by consecutive thirds.

<table>
<thead>
<tr>
<th>Subgroup</th>
<th>Thoracoscopic group—learning curve</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>First 1/3 (n = 33)</td>
<td>Second 1/3 (n = 33)</td>
<td>Third 1/3 (n = 34)</td>
<td></td>
</tr>
<tr>
<td>Number of ports used</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>13</td>
<td>33</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>Mean operative time</td>
<td>208 minutes</td>
<td>176 minutes</td>
<td>173 minutes</td>
<td></td>
</tr>
<tr>
<td>Conversions to open</td>
<td>10 cases</td>
<td>2 cases</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Postoperative Complications</td>
<td>5 cases</td>
<td>2 cases</td>
<td>2 cases</td>
<td></td>
</tr>
<tr>
<td>Mean hospital stay</td>
<td>3.6 days</td>
<td>2.5 days</td>
<td>2.8 days</td>
<td></td>
</tr>
<tr>
<td>Readmissions</td>
<td>2 cases</td>
<td>1 case</td>
<td>1 case</td>
<td></td>
</tr>
</tbody>
</table>

$p$ value
- $<0.001$
- 0.094
- 0.325
- 0.248
- 0.984
- 0.746
- 0.388
- 0.535
- 0.094
No difference in the mean operative time or the conversions in children operated on before the age of 7 weeks or less than 4.8kg.

Thoracoscopic lobectomy easier in smaller babies: less hilar lymphadenopathy, bronchi and vessels are smaller, easier to dissect and more amendable to sealing devices or clips.

Table 4
Technical aspects of the thoracoscopic lobectomies: breakdown by weight (A), breakdown by age (B), and comparison between the converted and nonconverted cases (C).

<table>
<thead>
<tr>
<th>A</th>
<th>Thoracoscopic group—median weight: 4.8 kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>&lt;4.8 kg</td>
</tr>
<tr>
<td>Number of cases</td>
<td>49</td>
</tr>
<tr>
<td>Mean operative time</td>
<td>180 minutes</td>
</tr>
<tr>
<td>Conversions</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B</th>
<th>Thoracoscopic Group—median age: 7 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>&lt;7 weeks</td>
</tr>
<tr>
<td>Number of cases</td>
<td>48</td>
</tr>
<tr>
<td>Mean operative time</td>
<td>173</td>
</tr>
<tr>
<td>Conversions</td>
<td>7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C</th>
<th>Thoracoscopic group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subgroup</td>
<td>Converted cases</td>
</tr>
<tr>
<td>Number of cases</td>
<td>12</td>
</tr>
<tr>
<td>Mean weight</td>
<td>4.7 kg</td>
</tr>
<tr>
<td>Mean age</td>
<td>6.2 weeks</td>
</tr>
<tr>
<td>Converted cases by location</td>
<td>RU</td>
</tr>
<tr>
<td>2 (22%)</td>
<td>2 (20%)</td>
</tr>
<tr>
<td>Bilobectomies</td>
<td>0/4</td>
</tr>
<tr>
<td>Hospital stay</td>
<td>3.6 days</td>
</tr>
</tbody>
</table>
Comparing 30-day outcomes between thoracoscopic and open approaches for resection of pediatric congenital lung malformations: Evidence from NSQIP

Afif N. Kulaylat, Brett W. Engbrecht, Christopher S. Hollenbeak, Shawn D. Safford, Robert E. Cilley, Peter W. Dillon

*Department of Surgery, College of Medicine, The Pennsylvania State University, Hershey, PA, United States
Department of Public Health Sciences, College of Medicine, The Pennsylvania State University, Hershey, PA, United States

Table 3
Surgical outcomes for patients with CLM following resection.

<table>
<thead>
<tr>
<th>Variable</th>
<th>All patients (n = 258)</th>
<th>Thoracoscopic (n = 112)</th>
<th>Open (n = 146)</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operative time, minutes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (St Dev)</td>
<td>175.1 (92.2)</td>
<td>181.6 (95.6)</td>
<td>170.1 (89.5)</td>
<td>0.32</td>
</tr>
<tr>
<td>Median (IQR)</td>
<td>159.5 (110-226)</td>
<td>172 (111-246.5)</td>
<td>153.5 (110-214)</td>
<td>0.60</td>
</tr>
<tr>
<td>Length of stay</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Days, median (IQR)</td>
<td>3 (2.5-5)</td>
<td>3 (2.4)</td>
<td>4 (3-6)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Days, mean (St Dev)</td>
<td>5.3 (7.3)</td>
<td>4.2 (5.4)</td>
<td>6.3 (8.4)</td>
<td></td>
</tr>
<tr>
<td>Post-operative complication (any)a</td>
<td>48 (18.6%)</td>
<td>11 (9.8%)</td>
<td>37 (25.3%)</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Table 4
Propensity score matched primary outcomes by operative technique.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Thoracoscopic</th>
<th>Open</th>
<th>ATT</th>
<th>95% Confidence</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operative time, minutes, mean</td>
<td>191.11</td>
<td>169.06</td>
<td>22.05</td>
<td>-7.96 to 52.06</td>
<td>0.15</td>
</tr>
<tr>
<td>Length of stay, days, mean</td>
<td>4.37</td>
<td>4.12</td>
<td>0.45</td>
<td>-1.12 to 2.01</td>
<td>0.59</td>
</tr>
<tr>
<td>Postoperative complication (any)</td>
<td>12.3%</td>
<td>13.6%</td>
<td>-1.2%</td>
<td>-0.11 to 0.08</td>
<td>0.79</td>
</tr>
<tr>
<td>Failure to wean off vent in 48 hours</td>
<td>3.7%</td>
<td>6.1%</td>
<td>-2.4%</td>
<td>-0.09 to 0.04</td>
<td>0.47</td>
</tr>
<tr>
<td>Transfusion</td>
<td>1.2%</td>
<td>7.4%</td>
<td>-6.2%</td>
<td>-1.32 to 0.01</td>
<td>0.09</td>
</tr>
<tr>
<td>Readmission</td>
<td>4.9%</td>
<td>4.9%</td>
<td>0.0%</td>
<td>-0.07 to 0.07</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Thoracoscopic resection of CLL is a safe alternative to open surgery
Does earlier lobectomy lead to better outcomes and better long term lung function in children with congenital lung lesions?

Yes

Avoid recurrent infection, pneumothoraces, lung malignancy, compensatory lung growth more complete

No

Risks of lobectomy, bleeding, infection, chest wall deformity, general anesthesia
Does earlier lobectomy result in better long-term pulmonary function in children with congenital lung anomalies? A prospective study

Yoko Naito^a, Alana Beres^b, Eveline Lapidus-Krol^b, Felix Ratjen^a, Jacob C. Langer^b,^*

No difference in exercise tolerance, TLC, FVC, FEV1, Power, and Vo2 max in children receiving lobectomy prior to 24m versus after

Trend toward lower Vo2 max in children operated on at an older age
Segmentectomy vs. Lobectomy for Congenital Lung Lesions

What is the preferred approach?
Must we operate?

Uh, oh... I think he just Googled "neuter"
CPAM and the Associated Conditions

CPAM 1 - Bronchoalveolar Carcinoma / Adenocarcinoma
CPAM 2 - Rhabdomyosarcoma/ Renal Dysgenesis
CPAM 3 - Pulmonary Hypoplasia
CPAM 4 - Pleuroplulmonary Blastoma
Factors for Intervention

- Prevention of disease
  - Infection (5-10%)
  - Air leak (1-5%)
  - Malignancy (1-3%)
- Surgery has less complications if elective
- Improved restoration of lung volume (with early surgery)
- Psychological benefit to “do something”

Factors against Intervention

- Over treatment of “non-disease”
- Over estimation of risk of complications.
- Lack of evidence of malignancy association.
- Risk of surgery & anaesthesia

Factors for Debate

- Timing of Intervention
  - Early vs. late
- Scale of intervention
  - VAT vs. Open
- Degree of resection
  - Lobectomy vs. Segmentectomy

Factors for Debate

- Use of serial CT scan
  - Frequency
  - Risks of radiation.
- ?Need for any follow-up if no investigation proposed?
Elective vs. Emergency Surgery for Congenital Lung Lesions

Risk of Complications
Management algorithm (for dummies):

Massive size/shift/hydrops—
steroids/intervention/exit/ecmo/birth at
surgical/neo center/counseling

Mod-large/shift---- serial US, birth at center

Small/no shift/nothing else----serial US, birth
anywhere
Management algorithm postpartum: (for dummies)

Symptomatic/large mass/shift--- urgent cta/surgery

Asymptomatic/small mass/no shift—serial cxr’s, elective cta 4-6 mo and elective scopic surgery
Controversies:
(I wish I knew the answer)

-lobar emphysema- cong vs acquired
  -surgical technique-
  open/scope/lobectomy/wedge excision
  -termination counseling?
  -timing of CTA/elective surgery
  -timing/place of birth
  -maternal/fetal mri
    -steroids
  -prenatal intervention
  -asymptomatic, normal cxr, hx of lesion prenatally
  -obs vs surgery for sequestration
  -obs vs resect for ccam/cpam
  -incidence of complications-
    infection/bleeding/ptx
  -cancer