Care of the NICU Graduate: Bronchopulmonary Dysplasia & Home Oxygen Therapy

Khanh Lai, MD

Pediatric Pulmonologist

Medical Director, Bronchopulmonary Dysplasia Clinic

February 12, 2020

Disclosure

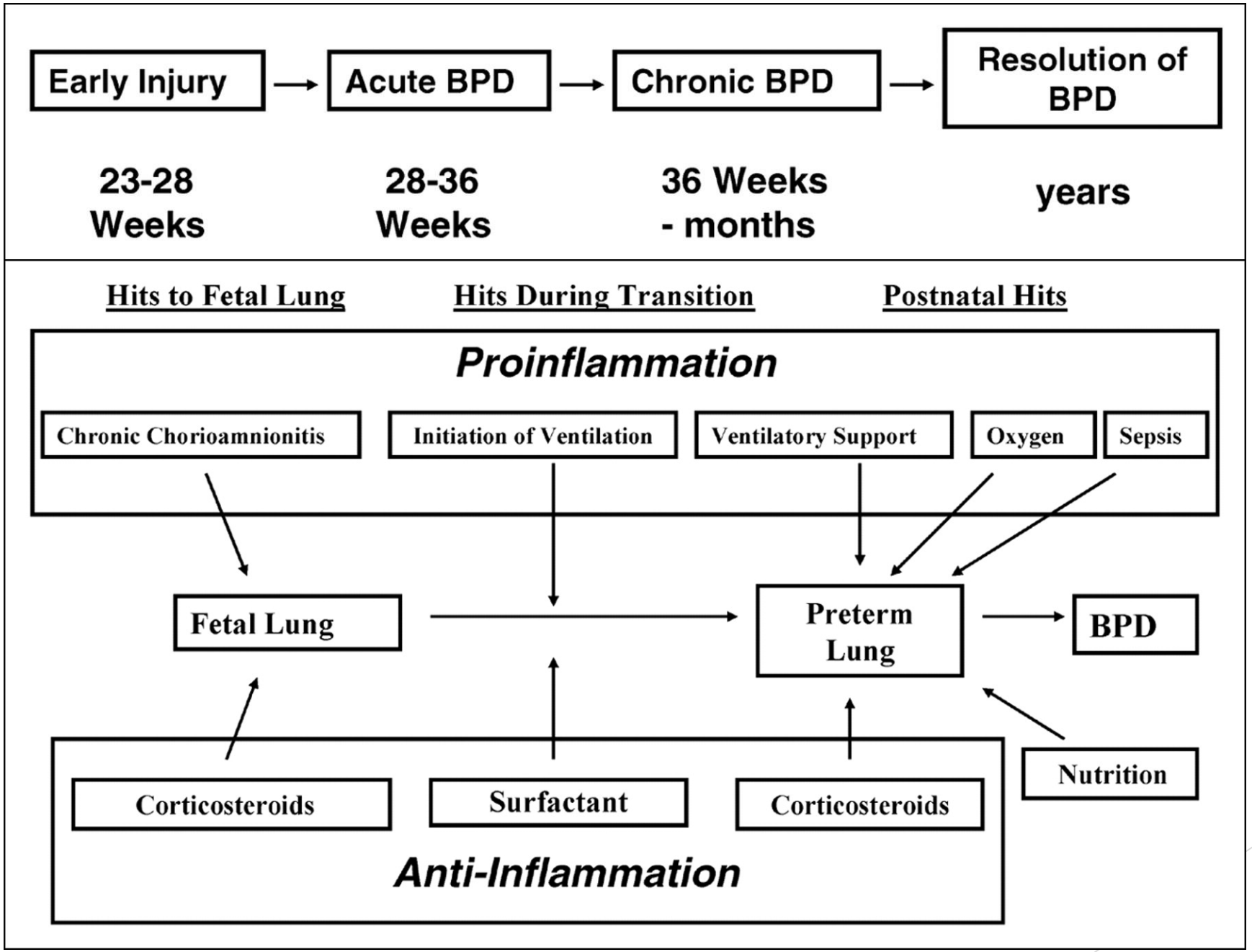
- I have no relationship to report.

Objectives

1. Understand the varied manifestations of bronchopulmonary dysplasia (BPD) (aka chronic lung disease of prematurity)
2. Become familiar with using home pulse oximetry to diagnose chronic hypoxemia in children
3. Understand the indications for home oxygen therapy (HOT), and when and how HOT should be weaned or discontinued
4. Know when to refer a child with BPD for further evaluation

What is bronchopulmonary dysplasia?

- Type of chronic lung disease that affects primarily children born prematurely
- Can also occur in children born at term who experience significant acute lung injury (eg, pneumothorax, pneumonia, meconium aspiration)
- Etiology is multifactorial
  - Antenatal injury: fetal growth restriction, maternal smoking, chorioamnionitis, maternal preeclampsia
  - Postnatal factors: mechanical ventilation, oxygen toxicity, infection, patent ductus arteriosus, surgical NEC



Jobe. The new bpd. Neoreviews (2006).

BPD Incidence

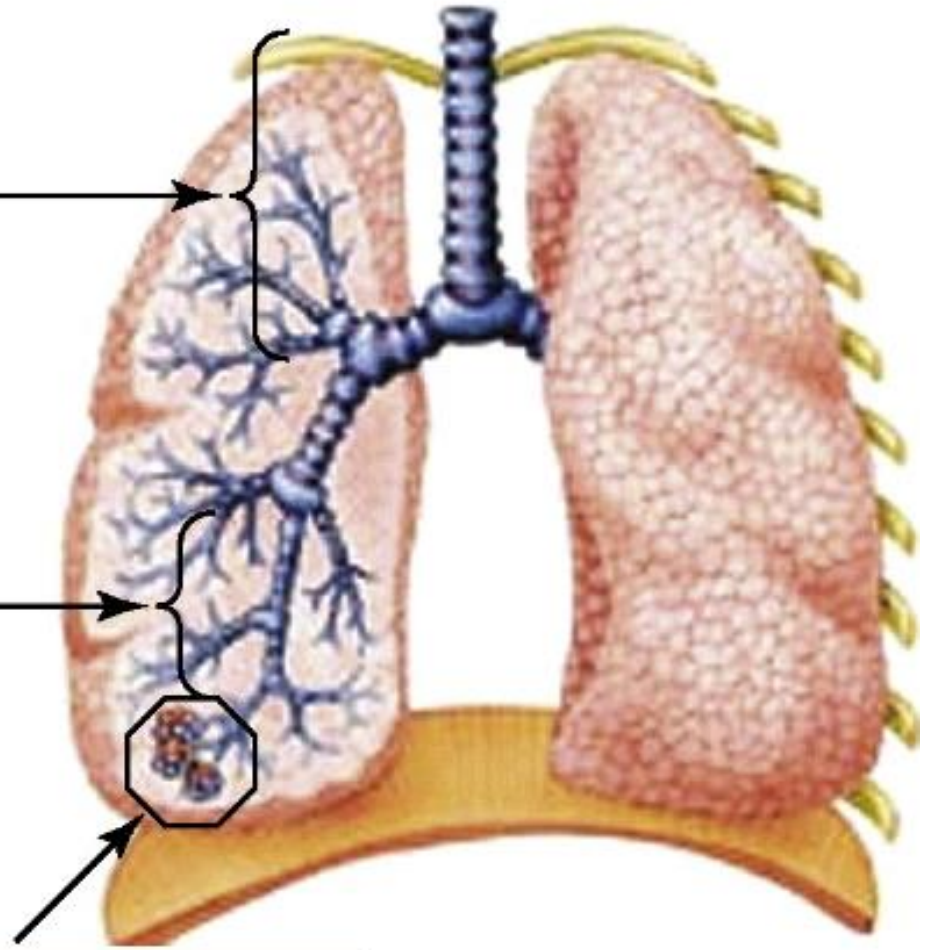
- BPD incidence increases with lower gestational age and birthweight
- Neonatal Research Network (N=9575 infants born 2003-2007, GA 22-28 wks)
  - 73% for GA 23 wks
  - 23% for GA 28 wks
- Approximately 1/3 of children with BW < 1000 gm develop BPD

Stoll et al, Pediatrics (2010).
Walsh et al, Pediatrics (2006).

LUNG PATHOPHYSIOLOGY OF BPD

Central airways:
- Tracheomalacia
- Subglottic stenosis, cyst
- Granulomas
- Bronchomalacia
- Bronchial stenosis

Small airways:
- Structural remodeling
  - Mucus gland hyperplasia
  - Epithelial injury, edema
  - Smooth muscle hyperplasia
- Bronchoconstriction
- Hyper-reactivity



Distal airspace and vasculature:
- Decreased alveolarization, vascular growth
- Abnormal vascular remodeling, tone and reactivity
- Impaired lymphatic function, structure

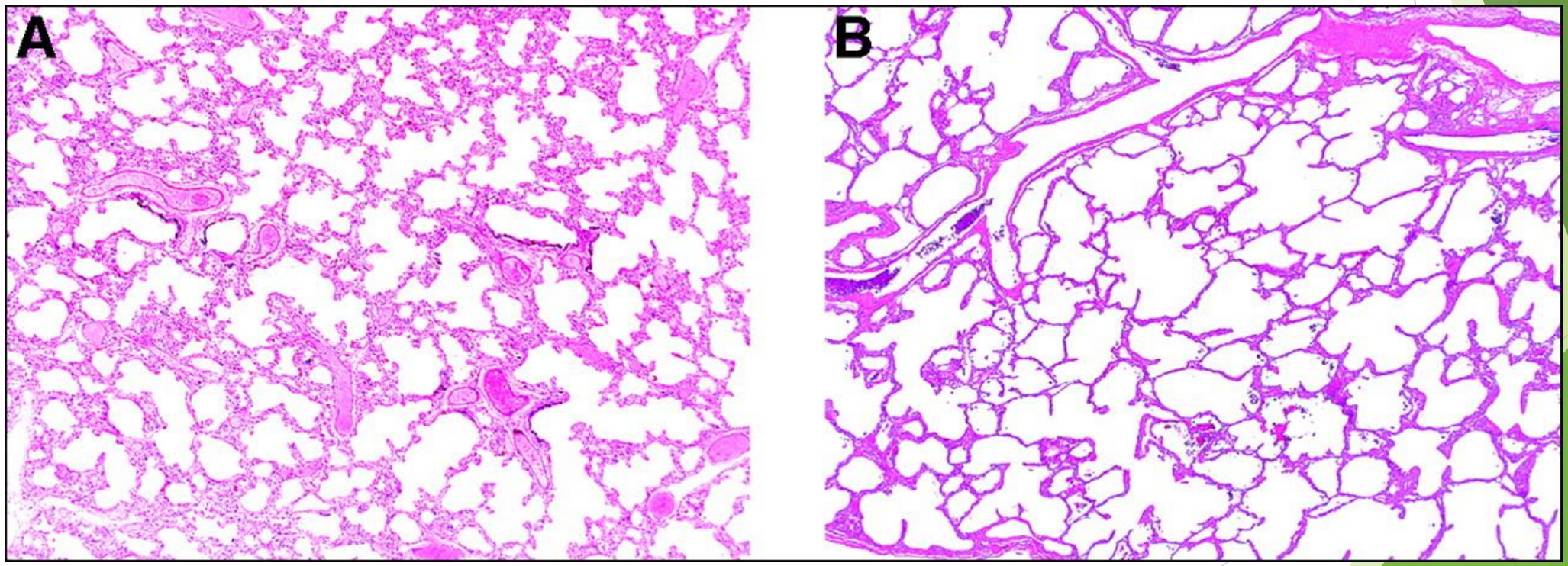
Sherlock L, Abman S. Bronchopulmonary Dysplasia. Kendig's Disorders of the Respiratory Tract in Children (9th Ed) (2019).

Normal vs. BPD

5 mo old term infant

8 mo old infant born at GA 28 wks

- Enlarged alveolar ducts
- Fewer alveoli



Jobe. The new bpd. Neoreviews (2006).

How is BPD diagnosed?

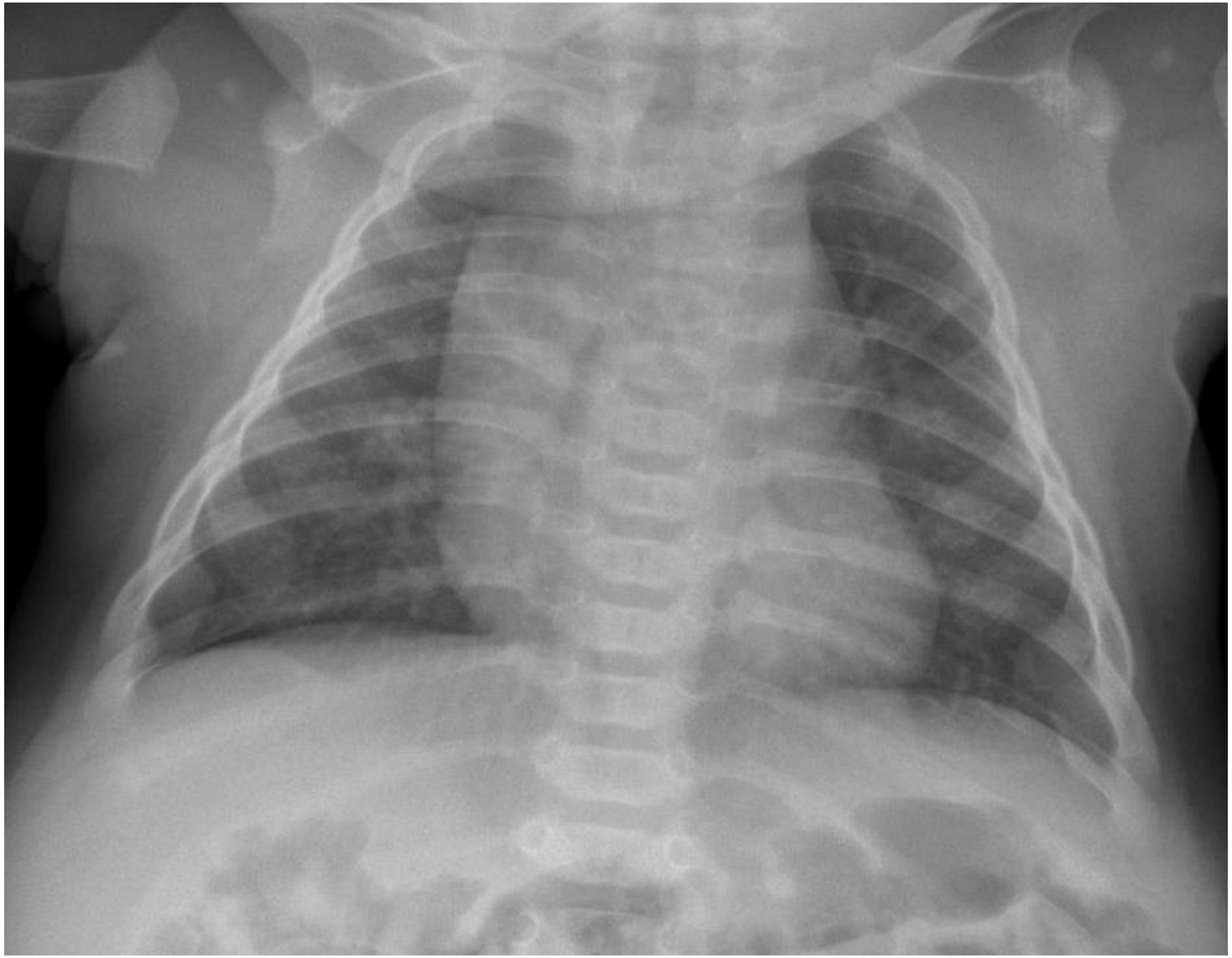
TABLE 23-2 NIH Consensus Conference: Diagnostic Criteria for Establishing BPD

Gestational Age		
	< 32 Weeks	**> 32 Weeks**
Time point of Assessment	36 weeks PMA or discharge to home, whichever comes first	> 28 d but < 56 d postnatal age or discharge to home, whichever comes first
	Treatment with oxygen > 21% for at least 28 d	
Mild BPD	Breathing room air at 36 wk discharge, whichever comes first	Breathing room air by 56 d postnatal or discharge, whichever comes first
Moderate BPD	Need for < 30% O_2 at 36 wks PMA or discharge, whichever comes first	Need for < 30% O_2 to 56 d postnatal or discharge, whichever comes first
Severe BPD	Need for > 30% O_2 +/– PPV or CPAP at 36 wks PMA or discharge, whichever comes first	Need for > 30% O_2 +/– PPV or CPAP at 56 d postnatal age or discharge, whichever comes first

PMA, Postmenstrual age; *PPV,* positive pressure ventilation; *NCPAP,* nasal continuous positive airway pressure.

- Most commonly used consensus definition: 2001 NICHD Consensus Workshop
- Requirement: 28 days continuous O2 therapy
- Mild, moderate and severe is based on level of support at 36 wks (for GA < 32 wks), or at discharge vs. 56 days (for GA > 32 wks).

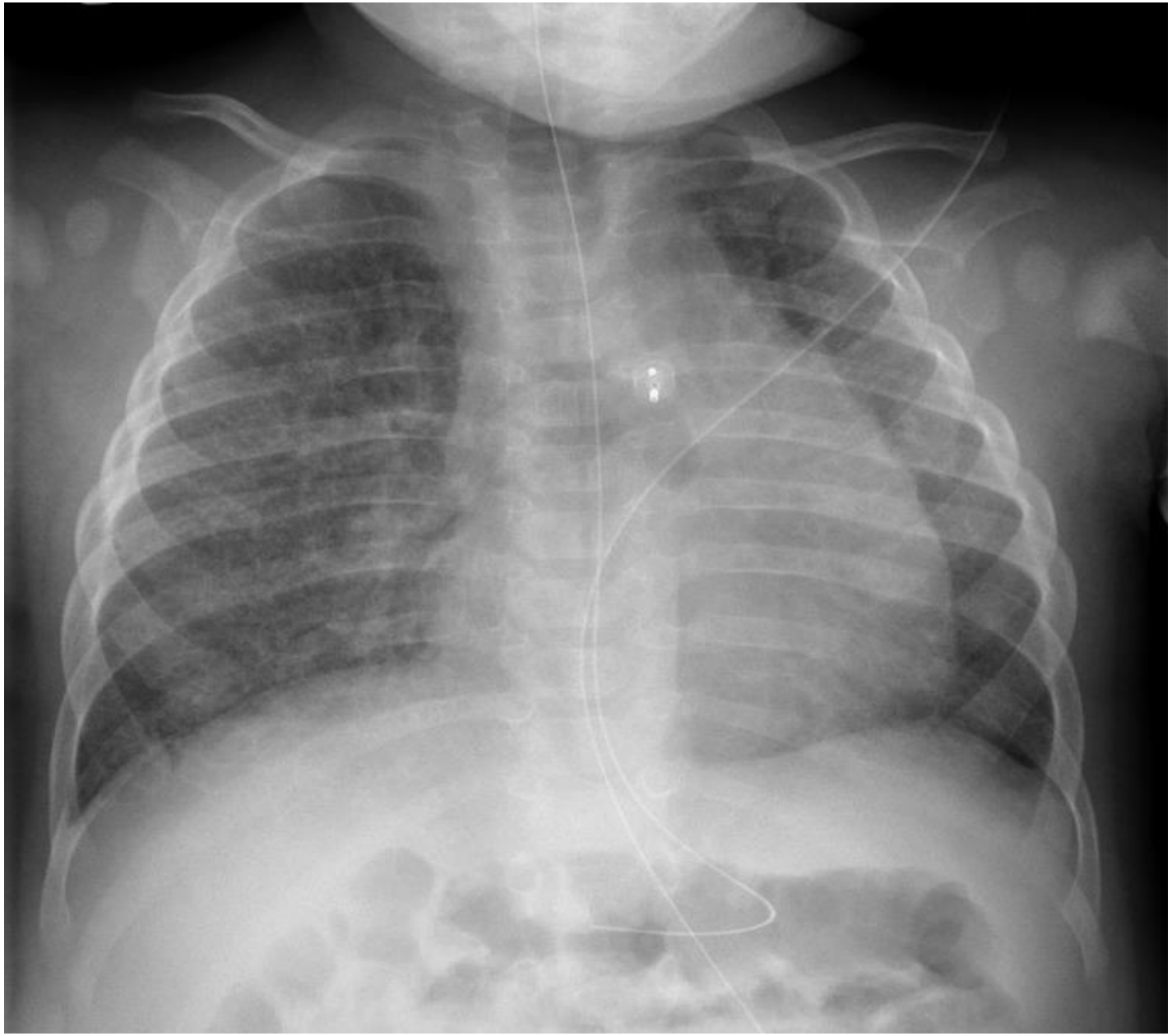
- Jobe, Bancalari. Am J Respir Crit Care Med (2001)



Clinical Pearl:

CXR in a well child with mild, moderate or severe BPD can look similar to CXRs of children with viral airways disease or reactive airways disease

Moderate BPD in a 5 mo old (CGA 1 mo) infant with 23 wk prematurity



Clinical Pearl:

- Severity grading for BPD is important
- Children with mild and moderate BPD have very different clinical trajectories and risk compared to children with severe BPD

Image: Abnormal airway and parenchymal architecture, hyperinflation, atelectasis, mediastinal shift secondary pulmonary hypoplasia, heterogeneous lung disease

Severe BPD in a 9 mo old (CGA 6 months) infant with history of 23 wk prematurity

Clinical Features

- Physical Exam:
  - Often normal
  - Sometimes lung findings: Tachypnea, retractions, rales, coarse crackles, intermittent wheezing
- CXR: Clear → Diffuse haziness → Coarse interstitial pattern (from atelectasis, inflammation, and/or pulm edema)
  - Normal or low lung volumes
- Increased risk of ER visits and hospitalizations in the first 2 years of life
  - Respiratory infections triggering inflammation will lead to more mucus production, airflow obstruction, atelectasis, and hypoxemia

Clinical Pearl:
Monophasic or biphasic wheezing localized at the anterior chest is suspicious for tracheomalacia

Natural Hx of Chronic Lung Disease - Prematurity and Respiratory Outcomes Program (PROP)[1]

- Multicenter observational prospective cohort study
  - Preterm infants < 29 wks GA up to 1 yr CGA
  - Questionnaires at 3, 6, 9, 12 mo CGA
- Prematurity respiratory disease (PRD)
- Severe disease = home supplemental O2 for > 3 months, multiple hospitalizations, systemic steroids or symptoms despite ICS
- Of 724 infants…
  - 68% had significant PRD at CGA 1 yr
  - 38% had severe PRD

[1]Pryhuber et al. BMC Pediatr (2015).

Cognitive Development & Quality of life

- Among 10-year-old children born extremely preterm, those who had BPD were at increased risk of:
  - Cognitive, language, and executive dysfunctions
  - Academic achievement limitations
  - Social skill deficits
  - Low scores on assessments of health-related quality of life.

Sriram et al. Pediatrics (2018)

Cognitive Development & QoL

- 2002-2004 Cohort: ELGAN (Extremely Low Gestational Age Newborns) study population
  - 863 children born preterm (<28 wks GA) +/- BPD (N=372, 43% O_2 dep at PMA 36 wks; N=78, 9% O_2 + vent dep)
  - Assessed at 10 yo age
- IQ z-scores ≤-2 occurred 2x as much in children with BPD vs no BPD
- "Severe" BPD (O_2 + vent) had lowest scores for all measures

Sriram et al. Pediatrics (2018)

Approximately one-half of children with “severe” or “moderate” BPD had scores in the normal range for academic achievement.

SUPPLEMENTAL TABLE 3 Distribution of IQ and Academic Achievement Test Scores Among Children Who Did and Did Not Have BPD

	Z Score	BPD (at 36 wk)			Row *N*
		Ventilation and Oxygen	Oxygen Only	Neither	
IQ					
DAS II verbal reasoning	≤−2	32	22	10	149
	>−2, ≤−1	19	19	19	161
	>−1	49	59	71	553
DAS II nonverbal reasoning	≤−2	30	19	8	129
	>−2, ≤−1	26	26	23	212
	>−1	44	55	68	522
Language					
OWLS listening comprehension	≤−2	34	24	11	158
	>−2, ≤−1	25	27	28	229
	>−1	41	49	61	455
OWLS oral expression	≤−2	36	25	13	163
	>−2, ≤−1	25	23	20	186
	>−1	39	54	66	492
Academic achievement					
WIAT III word reading	≤−2	29	14	7	104
	>−2, ≤−1	17	20	15	148
	>−1	55	65	78	602
WIAT III pseudoword decoding	≤−2	34	17	8	123
	>−2, ≤−1	17	19	15	145
	>−1	49	64	76	586
WIAT III spelling	≤−2	24	14	6	93
	>−2, ≤−1	22	17	13	136
	>−1	54	69	81	626
WIAT III numeric operations	≤−2	32	19	10	140
	>−2, ≤−1	26	27	19	198
	>−1	42	54	71	524
Maximum column *N*		78	372	413	863

These are column percents. *Z* score ≤−2: 2 or more SDs less than the normative or expected mean. *Z* score >−2, ≤−1: between 1 and 2 SDs less than the normative or expected mean. *Z* score >−1: 1 SD more than the normative or expected mean.

Sudhir Sriram et al. Pediatrics 2018;141:e20172719

Outcomes in adolescents

- Drummond 2019:
- Birth cohort 1996-1998 - Compared to 15 yo adolescents w/ h/o prematurity w/o BPD (N=249), h/o of BPD (N=55) was associated with:
  - Poorer academic performance:
    - Higher risk of attending a school for children with special needs ($p<0.05$)
    - Repeating a grade ($p=0.01$)
  - Higher healthcare utilization

Drummond et al. PLoS One (2019).

Long-term Respiratory Outcomes

- Abnormal lung function in childhood, adolescence and adulthood
- Higher rates of asthma or reactive airways disease
- Hypoxemia and hypercapnia with exercise or respiratory illness
- Possible increased risk of chronic obstructive pulmonary disease

Lung function

- Islam 2015:
- Preterm infants have reduced small airway flows compared to full-term matched control infants
- Infants with BPD has more severe airflow obstruction compared to those w/o BPD
- Trends persist into young adulthood

Islam. Am J respir Crit Care Med (2015)

Lung function changes over time

- Retrospective study of 24 patients with BPD & 355 PFTs:
  - 1st PFT: median 7.6 yrs; Last PFT: median 18.2 yrs

< 5th percentile:

- FEV1 - 75% (18/24)
- FEV1/FVC - 54% (13/24)

FEV1 and FEV1/FVC worsened over time:

- mean ppFEV1 - 71.3% (SD 18.3) → 66.7% (SD 21.7) ($p<0.05$)
- mean FEV1/FVC - 85.4% (SD 15.2) → 79.8% (SD 17.3) ($p=0.01$)

Lung function deterioration:

- FEV1 - 70% (17/24)
- FVC - 54% (13/24)
- FEV1/FVC - 70% (17/24)

Birth cohort:

- Born before 1990: None out of 11 pts improved in FEV1
- Born after 1990: 7 out of 13 pts born after 1990 showed improvement in FEV1 ($p=0.006$).

Lung function evolution towards adulthood was somewhat more favorable in children born after 1990 compared with those born earlier, probably reflecting improvements in neonatal care in subjects with new type BPD.

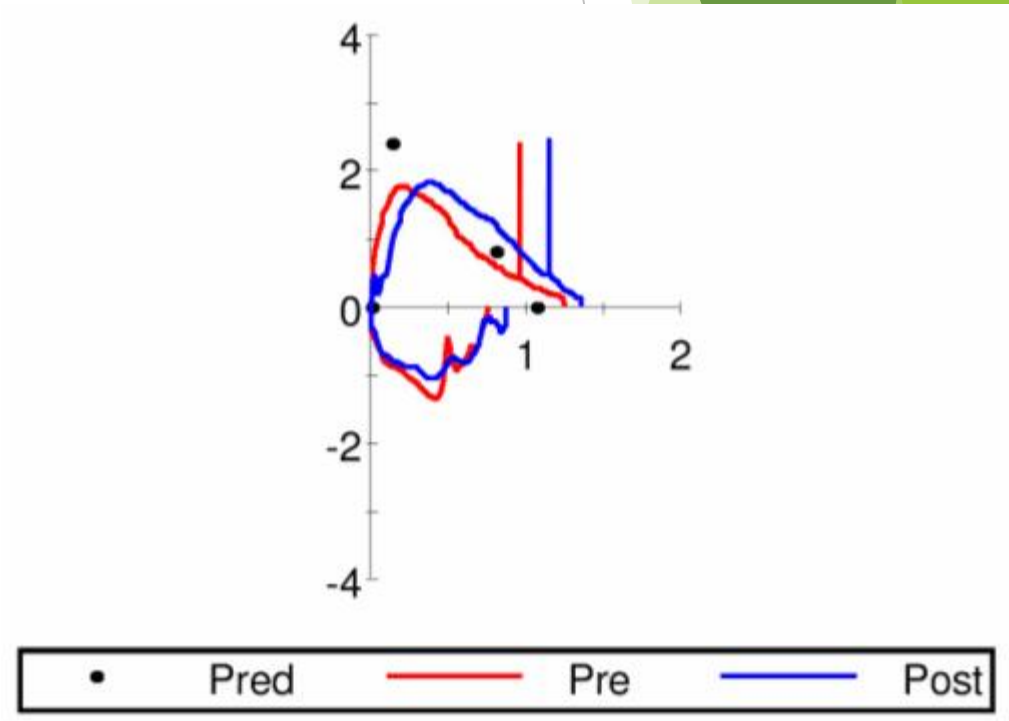
Cardoen, F., Vermeulen, F., Proesmans, M. et al. Eur J Pediatr (2019).

4 yo F with Hx of 32 wk prematurity

- Mild persistent asthma (previously RAD w/ viral triggers) – on low-medium dose fluticasone 110 mcg – 1 puff twice daily
- H/o RSV and Moraxella pneumonia and respiratory failure at age 2 months
- Maternal smoke exposure
- H/o choking, GERD, croup

Order Diagnosis: H/O BPD(Z87.09), HISTORY OF PREMATURITY (Z87.898), REACTIVE AIRWAY DISEASE (J45.909).

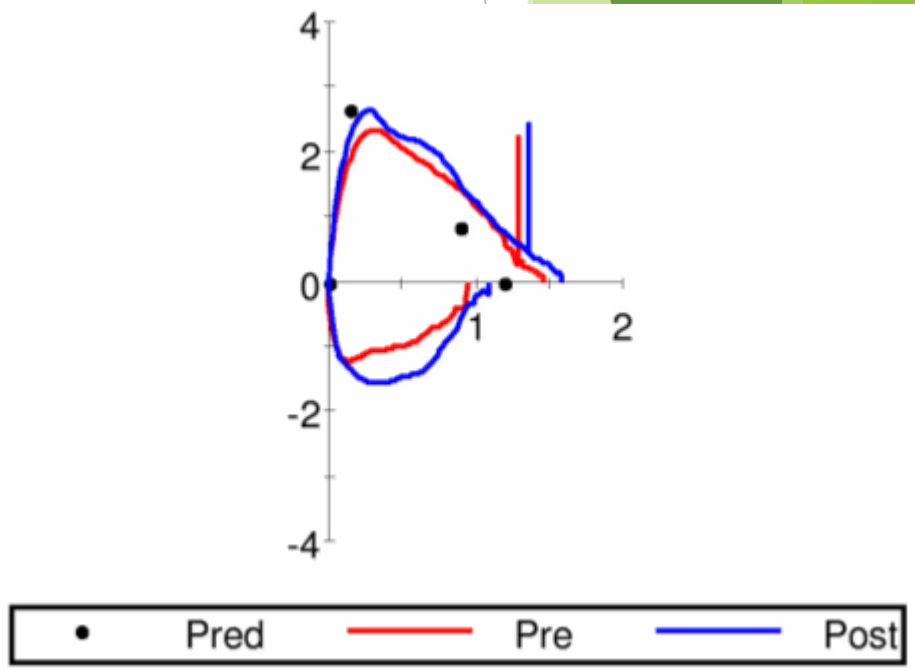
	Pre-Drug					Post-Drug				
	Actual	Pred	LLN	Z Score	%Pred	Actual	Z Score	%Pred	VolChng	Chng
---- SPIROMETRY ----										
FVC (L)	1.25	1.07	0.83	1.20	117	*1.36	1.92	*127	0.11	+8
FEV1 (L)	0.97	1.01	0.79	-0.28	96	1.16	1.17	115	0.19	+19
FEV1/FVC (%)	*78	94	86	-3		*85	-2			+9
FEF 25-75% (L/sec)	*0.82	1.51	0.92	-1.94	*54	1.24	-0.75	82		+52
FEF Max (L/sec)	1.98	2.41			82	2.11		87		+6
FEF50%/FIF50% (%)	72	90-100				135				+88
FIF Max (L/sec)	1.33					1.06				-20
Expiratory Time (sec)	4.23					3.48				-17



Asthma Interventions Matter

- After serial dose escalation from fluticasone 110 mcg – 1 puff twice daily to fluticasone/salmeterol 230/21 – 1 puff twice daily, lung function finally normalized.
- At 5 years of age: No obstructive pattern, no significant improvement with bronchodilator
- Categorized now as moderate persistent asthma, well controlled

	Pre-Drug					Post-Drug				
	Actual	Pred	LLN	Z Score	%Pred	Actual	Z Score	%Pred	VolChng	Chng
---- SPIROMETRY ----										
FVC (L)	*1.46	1.19	0.99	1.68	*123	*1.59	2.45	*134	0.13	+8
FEV1 (L)	*1.30	1.10	0.92	1.42	*118	*1.37	1.94	*124	0.07	+5
FEV1/FVC (%)	89	93	78	-1	95	86	-1	92		-3
FEF 25-75% (L/sec)	1.55	1.58	1.32	-0.06	98	1.49	-0.23	94		-4
FEF Max (L/sec)	2.41	2.66	2.22		90	2.64		99		+9
FEF50%/FIF50% (%)	169	90-100				126				-25
FIF Max (L/sec)	1.23					1.57				+27
Expiratory Time (sec)	4.11					3.23				-21



Defining Chronic Hypoxemia

- Low SpO2 for 2+ weeks
- Chronic respiratory condition
- Clinically stable

HAYES ET AL. HOME OXYGEN THERAPY IN CHILDREN: ATS SOCIETY CLINICAL PRACTICE GUIDELINE (2019)

Normative Values of SpO2

Table 2. Normative Values

	Wakefulness		Sleep		Desaturation Nadir	
	Mean (±SD)	Median (Range)	Mean (±SD)	Median (Range)	Mean (±SD)	Median (Range)
Children <1 yr old	97.8% (±1.4%)	98.7% (97.9–99.8%)	96.3% (±1.3%)	Not reported	86% (±1.5%)	85.5% (83–88%)
Children ⩾1 yr old	97.6% (±0.7%)	97.5% (97–98%)	97.8% (±0.7%)	Not reported	94.6% (±3.1%)	93% (91–94%)

Normative values come from 31 studies measuring oxygenation in healthy children, out of 1,711 articles on oxygenation in children.

Hayes et al. Home Oxygen Therapy in Children: ATS Society Clinical Practice Guideline (2019)
https://www.atsjournals.org/doi/full/10.1164/rccm.201812-2276ST#readcube-epdf

Healthy Children < 1 year old - Awake

- *Desaturation events were common in the first 48 hrs of life.*
- *Desaturations decrease with age.*
  - Desaturations to SpO2 ≤ 80%
    - 1 mo: median of 0.9/hr (range, 0-15.1/hr) for a median of 1.2 s (range, 0.3-2.2 s)
    - 6 wks: median 0.7/hr
    - 3 mo: median 0.4/hr
    - 6 mo: median 0.5/hr
  - Oxygen desaturation index (3% or more) :
    - Age 1.4 yrs (range, 1.1-1.9 yr): median 0.1/hr (range, 0-2.2/hr)

Hayes et al. Home Oxygen Therapy in Children: ATS Society Clinical Practice Guideline (2019)
https://www.atsjournals.org/doi/full/10.1164/rccm.201812-2276ST#readcube-epdf

Healthy Children < 1 year old - Sleep

- 5% of sleep time with median SpO2:
  - 2 wks: <92% (range, 73-99%)
  - 3 mo: <96% (range, 83-98%)
  - 6 mo: <95.5% (range, 69-99%)
- 10% of sleep time with median SpO2:
  - 2 wks: <96% (range, 77-99%)
  - 3 mo: <97% (range, 86-100%)
  - 6 mo: <97% (range, 75-99%)

Hayes et al. Home Oxygen Therapy in Children: ATS Society Clinical Practice Guideline (2019)

Healthy Children ≥ 1 year old

- Awake:
  - Mean 97.6% (SD, 0.7%)
  - Median 97.5% (range, 97-98%)
- Sleep:
  - Mean 97.8% (SD, 0.7%)
  - Desaturation nadir:
    - Mean 94.6% (SD, 3.1%)
    - Median 93% (range, 91-94%)
  - ODI (desaturations of 3 or 4% or more):
    - Mean 0.6/hr (SD, 1.0)
    - Median 0.4/hr (range, 0.1-0.8)
  - <1% of sleep with SpO2 <95%
  - <0.03% of sleep with SpO2 <90%

Hayes et al. Home Oxygen Therapy in Children: ATS Society Clinical Practice Guideline (2019)

Healthy Children ≥ 1 year old – High Altitude

- High Altitude:
  - Median SpO2:
    - 2,560 m – 92%
    - 3,200 mg – 87%

- SpO2 ranges:
  - 1,371 m – 95-96.7% (*SLC is 1,288 m)
  - 2,073 m – 93.9-95.4%
  - 2,393 m – 91.8-93.4%
  - 2,405 m – 93.4-96.1%
  - 2,484 m – 93.7-96.2%

Hayes et al. Home Oxygen Therapy in Children: ATS Society Clinical Practice Guideline (2019)

Healthy Children ≥ 1 year old – High Altitude

- High Altitude:
  - Desaturation events are more frequent but less common with age
  - Age 1-6 yrs:
    - 1,600 m – ODI (4%) – 4.0/hr (*SLC is 1,288 m)
  - Age 6+:
    - 4,000 m – ODI (4%) – 1.6/hr

Hayes et al. Home Oxygen Therapy in Children: ATS Society Clinical Practice Guideline (2019)

Chronic Hypoxemia Consensus Definition

- Age <1 yr:
  - 5% of recording time with SpO2 ≤ 90%
  - 3 intermittent, independent measurements of SpO2 ≤ 90%
- Age ≥1 yr:
  - 5% of recording time with SpO2 ≤ 93%
  - 3 intermittent, independent measurements of SpO2 ≤ 93%
- Normal intermittent measurements do not exclude chronic hypoxemia. Only continuous oximetry monitoring, which includes a period of sleep, can exclude chronic hypoxemia.

Hayes et al. Home Oxygen Therapy in Children: ATS Society Clinical Practice Guideline (2019)

American Academy of Sleep Medicine: Sleep Related Hypoxemia Disorder

Criteria A & B must be met.

A. PSG, OCST, or nocturnal oximetry shows the arterial oxygen saturation (SpO2) during sleep ≤ 88% in adults or ≤ 90% in children for ≥ 5 minutes.

B. Sleep related hypoventilation is not documented.

American Academy of Sleep Medicine. International Classification of Sleep Disorders, 3rd ed, American Academy of Sleep Medicine, Darien, IL 2014.

Untreated hypoxemia → Pulmonary Vascular Disease

- Hypoxic pulmonary vasoconstriction
- BPD & PH: Home O2 therapy helps to resolve RVH when SpO2 is maintained above 94-95%
- Effects of Alveolar hypoxia
  - Minimal effects in many children
  - In some susceptible children, there is heightened pulmonary vascular reactivity and remodeling
    - Infants with BPD
    - Young adults with h/o perinatal aphyxia
  - Mild chronic alveolar hypoxia → significant PH

Hayes et al. Home Oxygen Therapy in Children: ATS Society Clinical Practice Guideline (2019)

Hypoxemia & Neurodevelopment - Infants

- In RCT of infants born < 30 wks GA (N=358) who required supplemental O2 at 32 wks PMA:
  - No significant developmental benefit at age 1 yr between targeting SpO2 91-94% vs. 95-98%.
- Systematic review of 55 studies of CHD, SDB, asthma, chronic vent impairment and infants with resp instability:
  - Chronic intermittent hypoxemia negatively influences development, behavior, and academic achievement.

Hayes et al. Home Oxygen Therapy in Children: ATS Society Clinical Practice Guideline (2019)

Hypoxemia & Neurodevelopment – Children & adolescents

- 4-6th graders with overnight pulse oximetry – Hypoxemia was associated with impaired math performance.
- Children & adolescents - Short and long-term exposures to high altitude (3,500 m) impaired executive function, memory, and processing speed.

Hayes et al. Home Oxygen Therapy in Children: ATS Society Clinical Practice Guideline (2019)

Hypoxemia & Sleep – Apneas & BRUE's

- Hypoxemia during sleep predisposes infants to:
  - Increased periodic breathing, hypoventilation, central apneas, increased risk of BRUEs
- Severe BRUEs risk factors in premature infants:
  - Central apnea > 30 s
  - SpO2 < 80% for 10 s
  - HR < 50-60 bpm for 10 s
  - URIs
- Infants with BPD have lower SpO2 and more central apneas compared to preterm infants w/o BPD.
- Central apneas resolve with supplemental O2.

Hayes et al. Home Oxygen Therapy in Children: ATS Society Clinical Practice Guideline (2019)

Hypoxemia & Sleep

- Infants with BPD:
  - SpO2 90% was associated with sleep fragmentation, and less REM sleep
  - Supplemental O2 improved sleep fragmentation
  - No change in sleep architecture in infants with BPD with SpO2 > 93%

Hayes et al. Home Oxygen Therapy in Children: ATS Society Clinical Practice Guideline (2019)

Hypoxemia & Growth

- Infants with BPD:
  - Improved growth when SpO2 during sleep > 92% compared with SpO2 88-91%
  - Another study showed growth promotion when SpO2 > 93%.
  - Negative effect on growth when supplemental O2 was stopped.
- NEHI:
  - Some had improved growth velocity with starting supplemental O2 therapy

Hayes et al. Home Oxygen Therapy in Children: ATS Society Clinical Practice Guideline (2019)

Indications for Home Oxygen Therapy in BPD

- Chronic hypoxemia: 5% of recording time with SpO2 ≤ 93%; 3 separate measurements of SpO2 ≤ 93%
- Sleep disordered breathing (eg, OSA, CSA) complicated by severe nocturnal hypoxemia who cannot tolerate PAP or are awaiting surgical treatment
- Severe nocturnal hypoxemia: 5% of recording time with SpO2 < 90% during sleep

Hayes et al. Home Oxygen Therapy in Children: ATS Society Clinical Practice Guideline (2019)

Home Oxygen Therapy in Pulmonary Hypertension and Interstitial Lung Disease

- Pulmonary Hypertension w/o CHD:
  - Chronic hypoxemia: 5% with SpO2 ≤ 93% or 3 separate measurements of SpO2 ≤ 93%
- Pulmonary Hypertension w/ CHD before or after surgery: Do not prescribe HOT w/o consultation with Cardiology or Pulmonology with "expertise in management of PH"
  - Chronic hypoxemia: 5% with SpO2 ≤ 93% or 3 separate measurements of SpO2 ≤ 93%
- Interstitial Lung Disease:
  - Severe chronic hypoxemia (SpO2 <90% for 5% recorded time; 3 separate occasions)
  - Both mild chronic hypoxemia (SpO2 90-93%) & either dyspnea on exertion or desaturation during sleep or exertion (exercise for children, feeding for infants)

Hayes et al. Home Oxygen Therapy in Children: ATS Society Clinical Practice Guideline (2019)

Limitations of pulse oximetry accuracy

- Improper probe placement
- Movement artifact
- Nail color
- Ambient light
- Reduced distal extremity perfusion
- Hypothermia
- Skin pigmentation
- Dysfunctional hemoglobin

Hayes et al. Home Oxygen Therapy in Children: ATS Society Clinical Practice Guideline (2019)

Discontinuing Home Oxygen Therapy

- Assessing Readiness:
  - Stable health (no current or recent acute illness)
  - Age- and condition-appropriate growth, including positive trends in weight gain, linear growth, and head circumference
  - Meeting developmental milestones as expected for clinical condition
  - Acceptably low frequency and/or severity of illnesses requiring hospitalization
  - Reassuring physical exam
  - Oxygen saturation at steady state (not “spot check”) on room air; Pulse oximetry while awake does not correlate with nocturnal oxygenation in infants with BPD
  - Consider echocardiogram to assess for absence or improvement of pulmonary hypertension

Hayes et al. Home Oxygen Therapy in Children: ATS Society Clinical Practice Guideline (2019)

Successful Discontinuation of Home Oxygen Therapy

- Preterm infants with BPD 6 month post-discharge:
  - More successful weaning to room air if receiving ≤ 20 mL/kg/min of supplemental O2.
    - 3 kg: 0.06 L/min (1/16 LPM)
    - 4 kg: 0.08 L/min
    - 5 kg: 0.1 L/min
    - 6 kg: 0.12 L/min (1/8 LPM)
- Room air challenges if clinically stable:
  - Age < 1 yr: <0.1 L/min
  - Age 1-4 yrs: <0.1-0.25 L/min
  - School-age: 0.25-0.5 L/min

Hayes et al. Home Oxygen Therapy in Children: ATS Society Clinical Practice Guideline (2019)

Example 1: Almost normal pulse oximetry in a 3 year old F with sleep difficulties

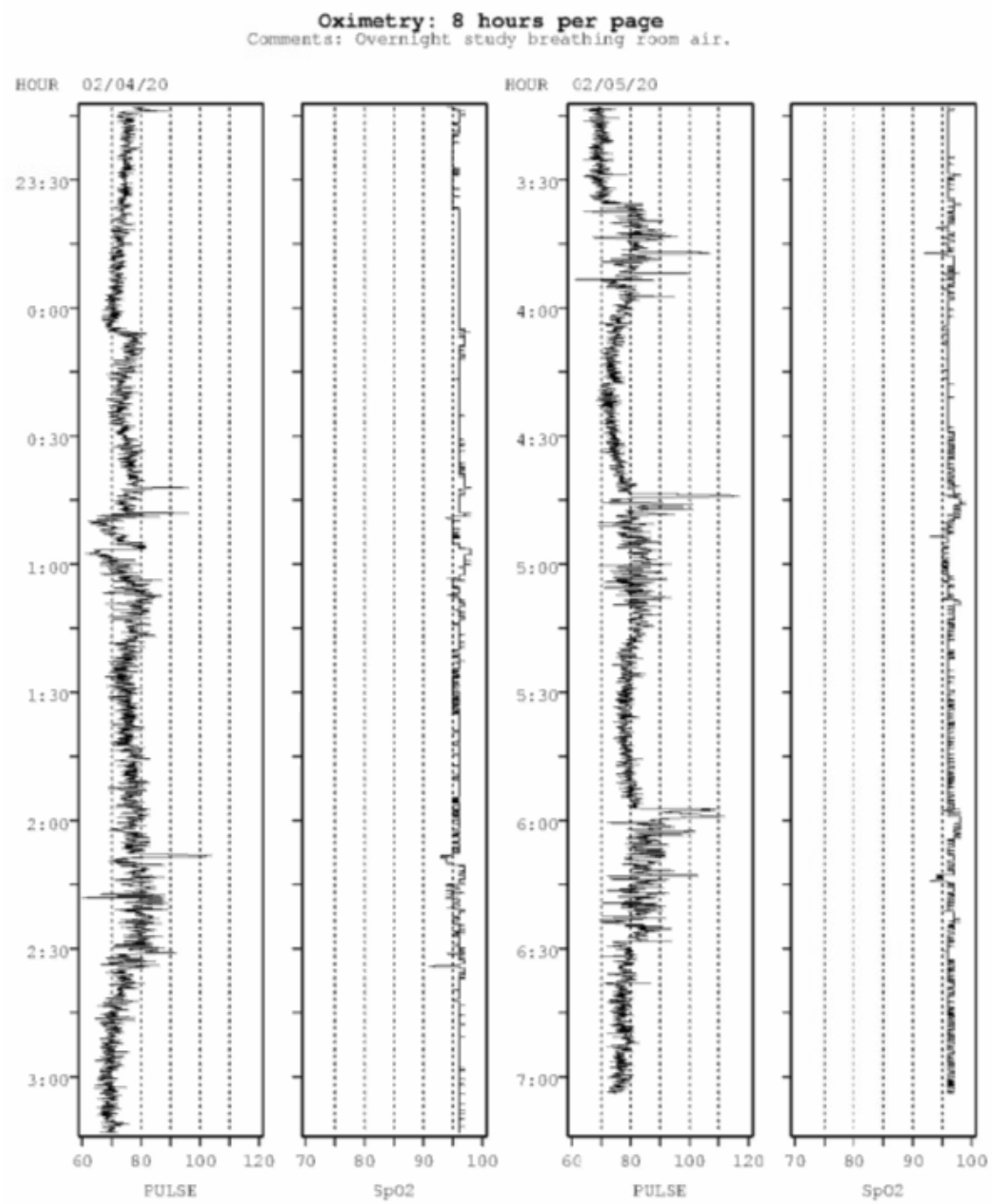
Oximetry: Summary Report

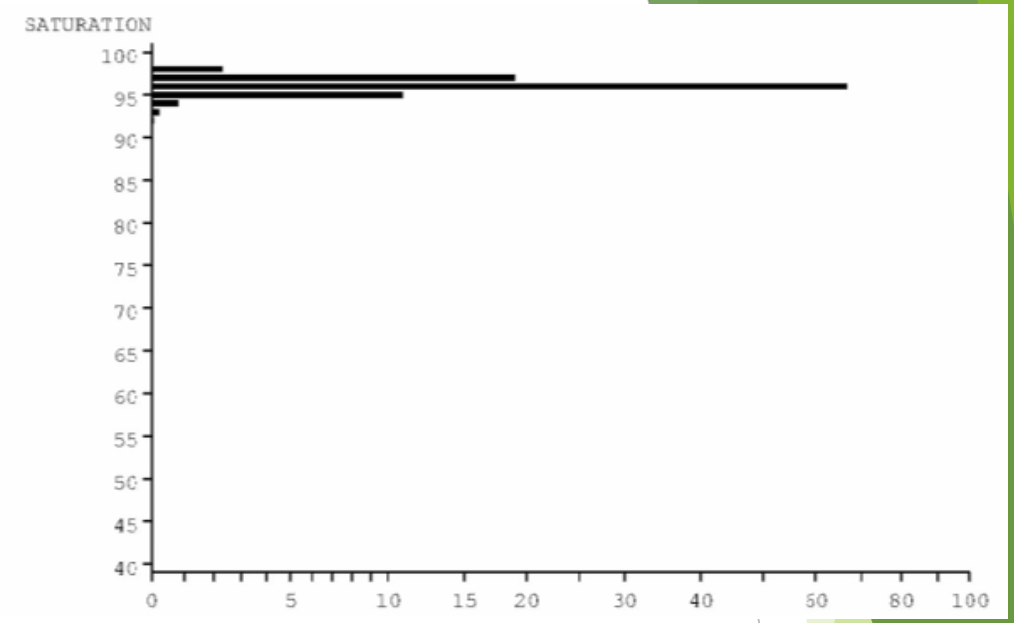
Comments: Overnight study breathing room air.

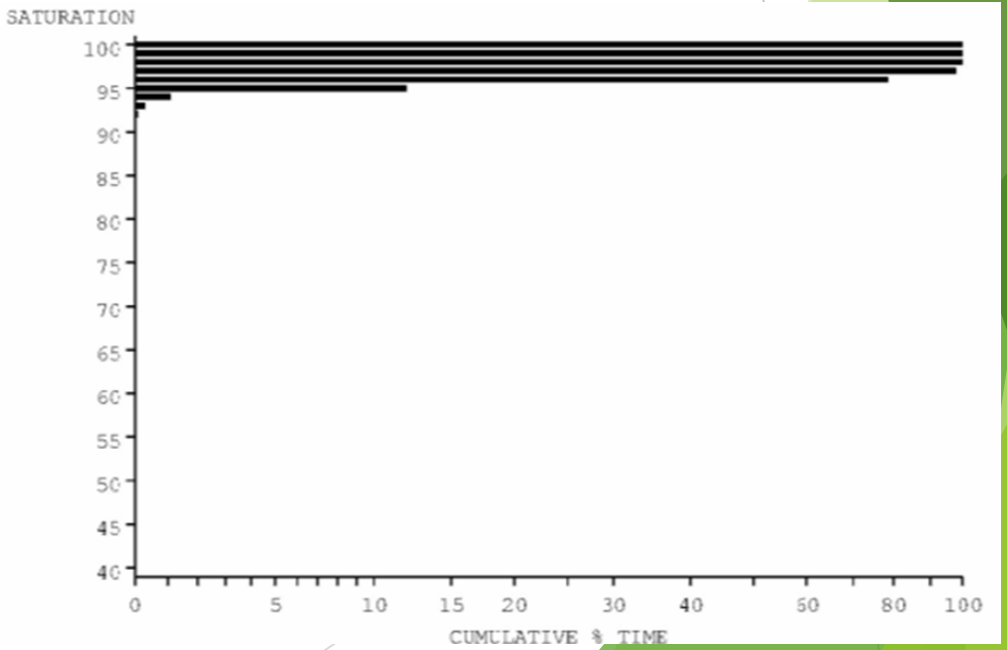
Recording time:	07:50:48	Highest pulse:	117	Highest SpO2:	99%
Excluded sampling:	00:00:00	Lowest pulse:	60	Lowest SpO2:	91%
Total valid sampling:	07:50:48	Mean pulse:	77	Mean SpO2:	96.1%
		1 S.D.:	5.8	1 S.D.:	.7

Time with SpO2<90:	0:00:00,	0.0%	Time with SpO2 =>90:	7:50:48,	100.0%
Time with SpO2<80:	0:00:00,	0.0%	Time with SpO2=>80 & <90:	0:00:00,	0.0%
Time with SpO2<70:	0:00:00,	0.0%	Time with SpO2=>70 & <80:	0:00:00,	0.0%
Time with SpO2<60:	0:00:00,	0.0%	Time with SpO2=>60 & <70:	0:00:00,	0.0%
Time with SpO2<88:	0:00:00,	0.0%			

The mean length of desaturation events that were >=10 sec & <=3 mins was:	54.8 sec.
Desaturation event index (events >=10 sec per sampled hour):	1.3
Desaturation event index (events >= 0 sec per sampled hour):	1.3


Oximetry: 8 hours per page
Comments: Overnight study breathing room air.
HOUR 02/04/20
HOUR 02/05/20
23:30
0:00
0:30
1:00
1:30
2:00
2:30
3:00
3:30
4:00
4:30
5:00
5:30
6:00
6:30
7:00
60 80 100 120
70 80 90 100
PULSE
SpO2


SATURATION
100
95
90
85
80
75
70
65
60
55
50
45
40
0 5 10 15 20 30 40 50 80 100


SATURATION
100
95
90
85
80
75
70
65
60
55
50
45
40
0 5 10 15 20 30 40 50 80 100
CUMULATIVE % TIME

Example 2: 6 mo old (CGA 4 mo) female w/ history of 31 wk prematurity, twin, h/o IUGR, feeding difficulties, on NG feeds, moderate BPD complicated by chronic hypoxemia

Oximetry: Summary Report

Comments: Overnight study breathing room air.

Recording time:	12:23:40	Highest pulse:	158	Highest SpO2:	99%
Excluded sampling:	00:01:04	Lowest pulse:	100	Lowest SpO2:	79%
Total valid sampling:	12:22:36	Mean pulse:	133	Mean SpO2:	95.4%
		1 S.D.:	7.0	1 S.D.:	1.3

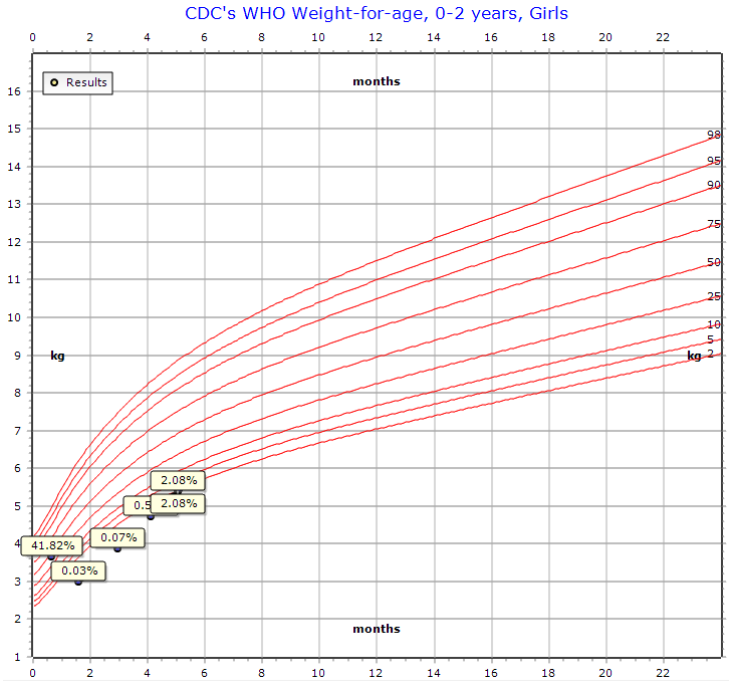
Time with SpO2<90:	0:03:16,	0.4%	Time with SpO2 =>90:	12:19:20,	99.6%
Time with SpO2<80:	0:00:08,	0.0%	Time with SpO2=>80 & <90:	0:03:08,	0.4%
Time with SpO2<70:	0:00:00,	0.0%	Time with SpO2=>70 & <80:	0:00:08,	0.0%
Time with SpO2<60:	0:00:00,	0.0%	Time with SpO2=>60 & <70:	0:00:00,	0.0%
Time with SpO2<88:	0:00:56,	0.1%			

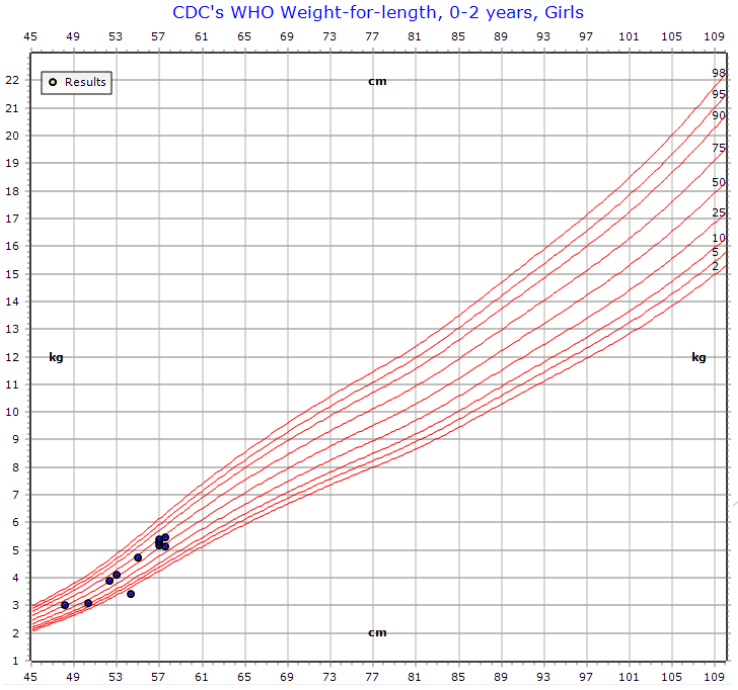
The longest continuous time with saturation <=88 was 00:00:12, which started at 01/17/20 06:18:01.

The mean length of desaturation events that were >=10 sec & <=3 mins was:	32.2 sec.
Desaturation event index (events >=10 sec per sampled hour):	8.6
Desaturation event index (events >= 0 sec per sampled hour):	15.4

Clinical features

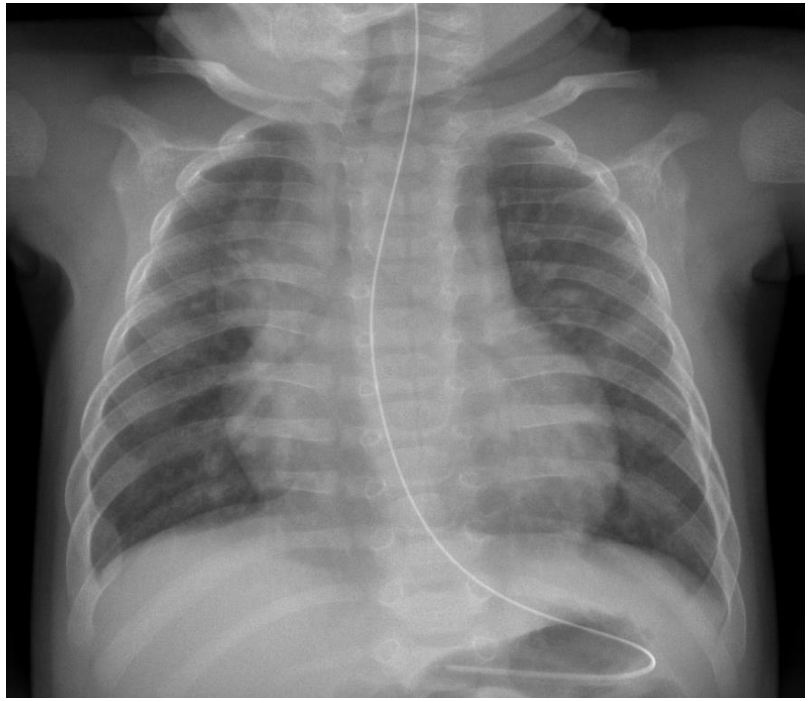
- Chronic tachypnea (RR 70's)
- Room air during awake, desaturations while sleeping (on 1/8 LPM while sleeping)
- Abnormal CXRs (patchy perihilar & bibasilar opacities)
- GER, chronic vomiting, on PPI
- h/o poor growth, improved with NG tube feeds, oral aversion
- h/o PDA closure (occlusion device)
- No h/o pulmonary hypertension



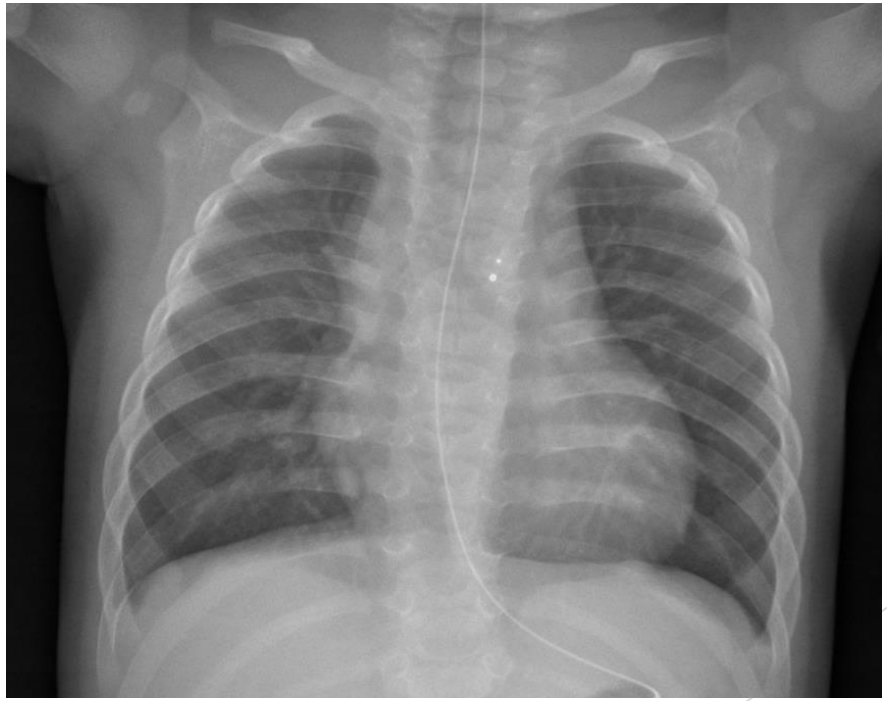


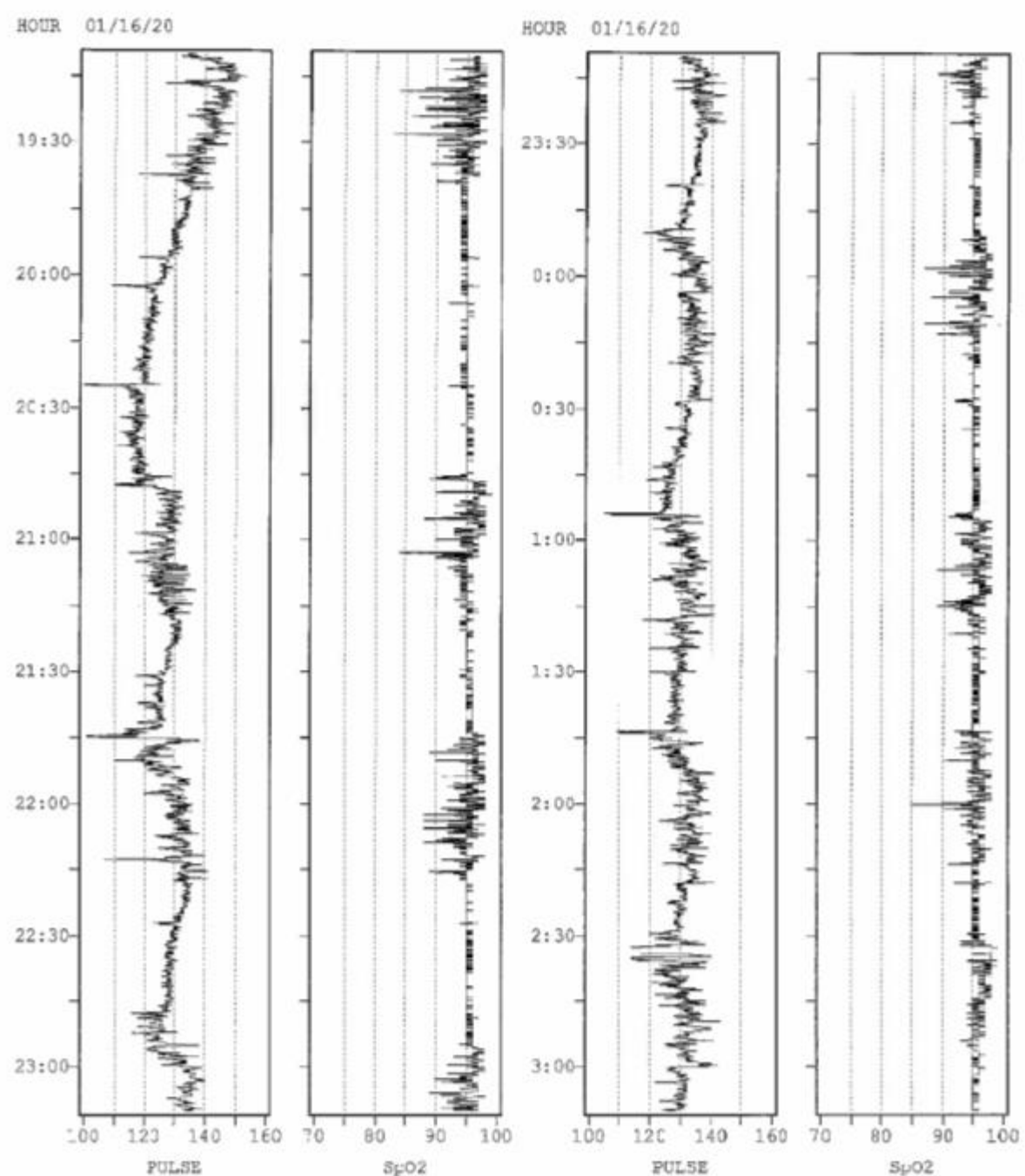
Serial chest imaging: PDA closure + time

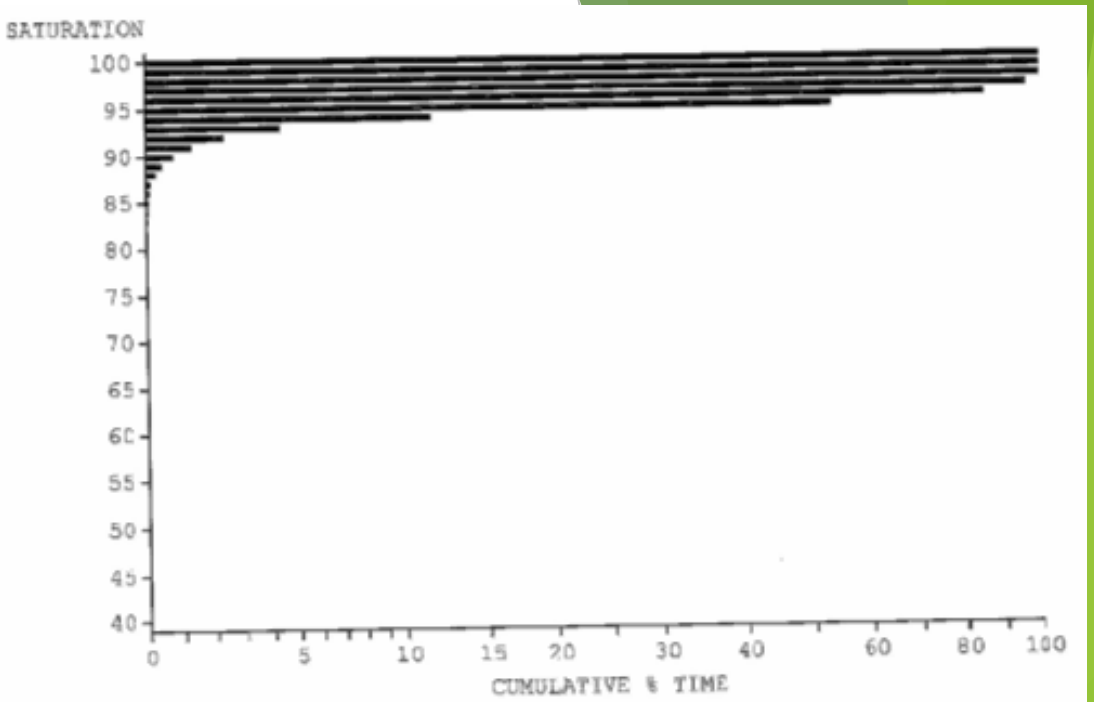
3 mo old (CGA 7 wks)



6 mo old (CGA 4 mo)







SpO2:100	0.0 % time		
SpO2: 99	0.1 % time	SpO2: 89	0.2 % time
SpO2: 98	3.8 % time	SpO2: 88	0.1 % time
SpO2: 97	11.4 % time	SpO2: 87	0.0 % time
SpO2: 96	31.7 % time	SpO2: 86	0.0 % time
SpO2: 95	41.6 % time	SpO2: 85	0.0 % time
SpO2: 94	7.1 % time	SpO2: 84	0.0 % time
SpO2: 93	2.0 % time	SpO2: 83	0.0 % time
SpO2: 92	1.0 % time	SpO2: 82	0.0 % time
SpO2: 91	0.6 % time	SpO2: 81	0.0 % time
SpO2: 90	0.3 % time	SpO2: 80	0.0 % time
Total 90's	99.6 % time	Total 80's	0.4 % time

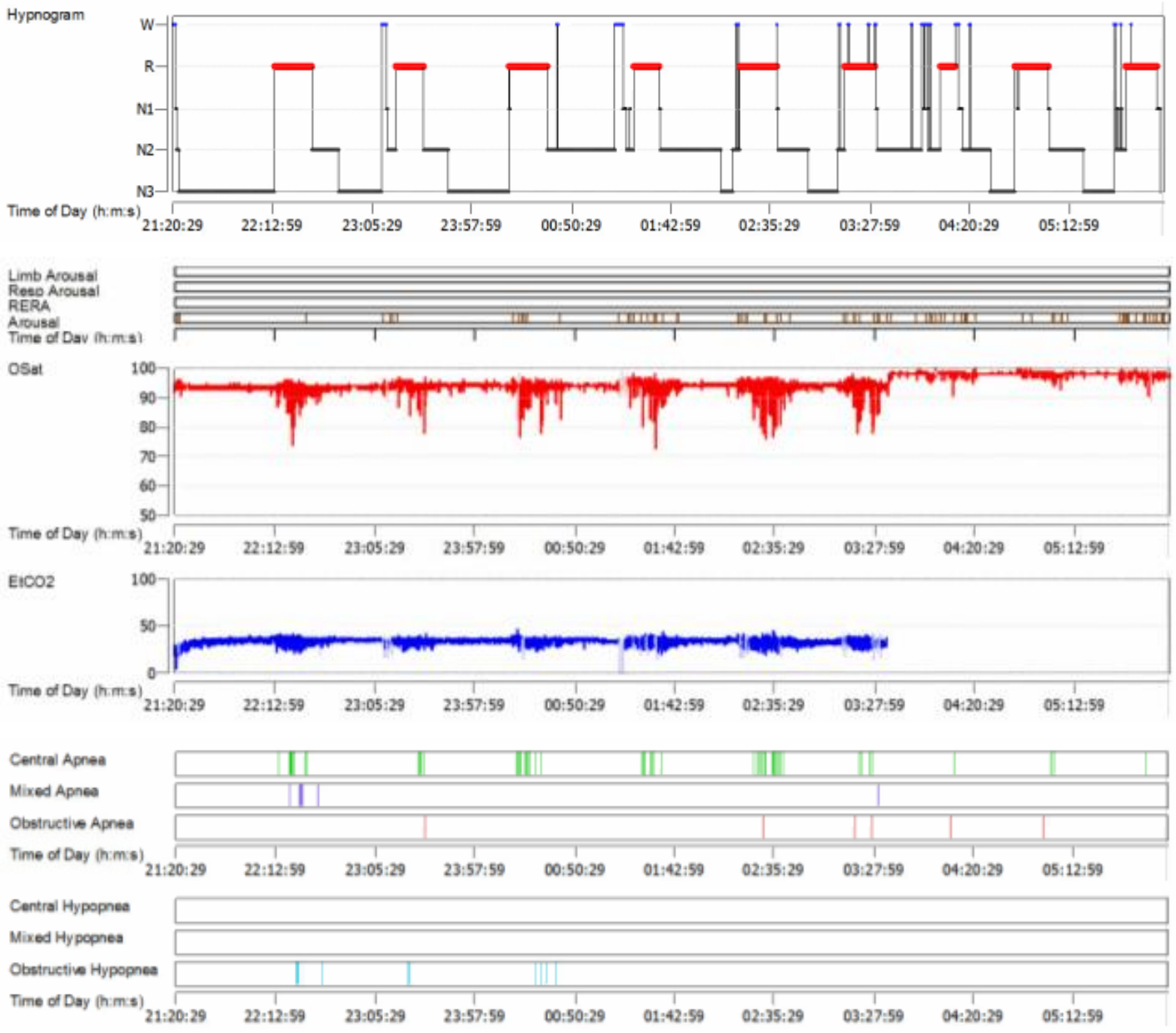
Polysomnography – 6 mo (CGA 4 mo)

- 1. Mild obstructive sleep apnea more pronounced during REM sleep (OAHI 3.3/hr, REM-OAHI 7/hr) was exhibited on room air. Frequency of obstructive events decreased with 1/8 LPM O2, likely due to masking effect of O2 therapy.
- 2. Central sleep apnea (CAI 9.4/hr) was exhibited while patient was on room air. Central apnea improved with 1/8 LPM O2.
- 3. Respiratory events were associated with mild to moderate desaturations.
- 4. CO2 measurements were normal while the patient was on room air and O2 therapy.
- Total sleep time with SpO2 < 90% was 7.9 minutes.

TABLE OF O2 SUMMARY:

PAP level	O2 LPM	TST (min)	REM (min)	SE (%)	OAHI	REM OAHI	CAI	Min O2 sat	Ave O2 Sat	ODI
Off	0	363.0	102.5	96.9%	3.3	7.0	9.4	73.0	93.9	33.9
Off	O2: 1/8	138.5	41.5	94.5%	0.9	2.9	1.7	91.0	98.0	3.9

PAP= Positive airway pressure, TST= Total sleep time, SE= Sleep efficiency, OAHI= Obstructive apnea hypopnea index (Events per hour), CAI= Central apnea index (Events per hour), ODI= Oxygen desaturation index (Events per hour).



Hypnogram
R = REM

Arousal

Oxygen Saturation

End tidal CO2

Central Apnea
Mixed Apnea
Obstructive Apnea

Obstructive Hypopnea

BPD Continuum of Care

Table 2. Potential early interventions for preterm lung disease

	Interventions	Rationale
Screening	Spirometry	Assessing lung function
	Overnight polysomnography	Screening for sleep-disordered breathing
	Chest CT with contrast enhancement	Assessing for parenchymal disease/cystic disease
	Echocardiograms (with or without cardiac catheterization)	Screening for pulmonary hypertension
	Airway endoscopy	Assessing for upper airway lesions and/or tracheobronchomalacia
	Exercise studies	Assessing pulmonary reserve
Preventive Care	Avoidance of active smoking, secondhand smoke, air pollution	Decreasing inhalational injury
	Prevention of aspiration	Preventing lung injury
	Palivizumab	Decreasing RSV disease severity
	Influenza vaccination	Preventing influenza infections
	Preoperative anesthesia consults for pulmonary hypertension	Reducing pulmonary hypertensive crises
	Interdisciplinary care team	Improving outcomes with coordination of care
	Promoting linear growth	Improving lung growth

Collaco & McGrath-Morrow. Annals of ATS (2018).

BPD Clinic – Severe BPD, Mild or Moderate BPD + risk factors, Chronic hypoxemia (2+ mo after NICU)

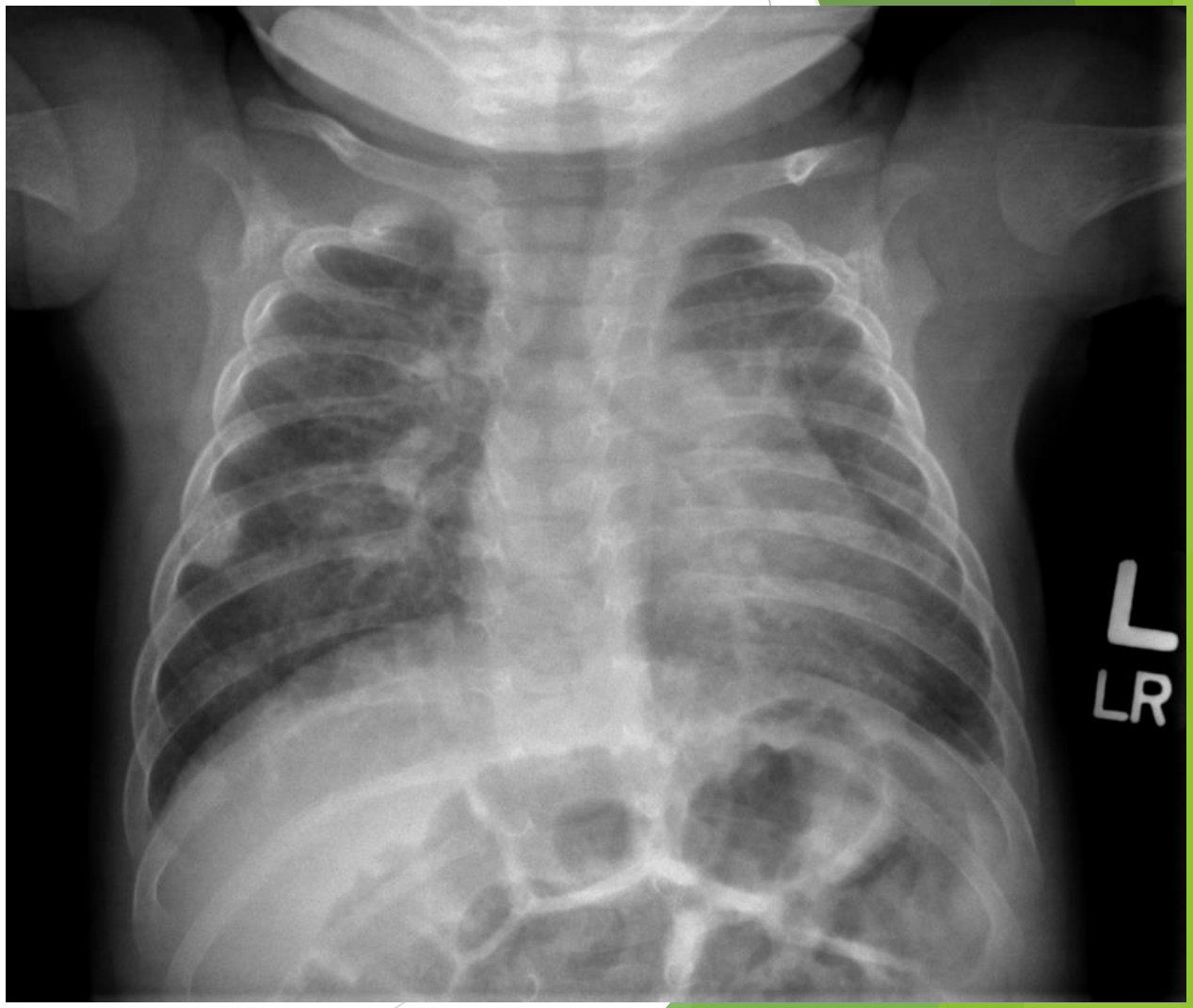
- 1st Visit:
  - CBG if on continuous supplemental O2
  - 2 view CXR
  - Review history & and post-NICU growth and events
  - Assess for appropriateness of further diagnostic work-up: home pulse oximetry, polysomnography, swallow study, echocardiograms, CT(A) chest, etc.
  - Assess parental understanding of BPD & gaps in knowledge
  - Review preventative care
  - Create a sick care plan
- Medications: Albuterol PRN, wean off diuretics (if possible), discuss potential benefits of inhaled steroids in future
- If imaging, history or physical exam are concerning (eg, atelectasis, poor growth, tachypnea) – consider manual CPT education for caregivers
  - Typically helpful in the short-term and PRN illnesses
- Create shared goals and plans (eg, weaning off supplemental O2, improved nutrition & growth)
- Provide resources where appropriate – Neonatal Follow-up Program, Early Intervention, Nutrition Clinic, HEFT Clinic, etc.

BPD Clinic – Lesson #1

Always get a baseline 2 view CXR

Preterm infants are high risk for NAT

- High medical complexity
- Small size
- Osteopenia of prematurity
- Iatrogenic calcium depletion (diuretics, steroids, antacids)



BPD Clinic Follow-up Visits

- Follow-up visits:
  - 1st year: every 1-3 months
  - 2nd year: every 3-6 months
  - 3+ year: every 3-12 months
- Goals:
  - Improve caregiver education/care
  - Wean off unnecessary medications
  - Provide support & resources
  - Optimize growth & development

Thank you!