Is It Just a Lot of Hot Air?

High Flow Nasal Cannula: Theory, Indications, Complications and Evidence

Alexandre T. Rotta, MD, FCCM, FAAP

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Chief, Pediatric Critical Care

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School of Medicine

Case Western Reserve University

Disclosure

- Consultant and Advisory Board member, Vapotherm Inc (Exceter, NH).

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Objectives

- HFNC Theory
- Indications
- Complications
- Evidence

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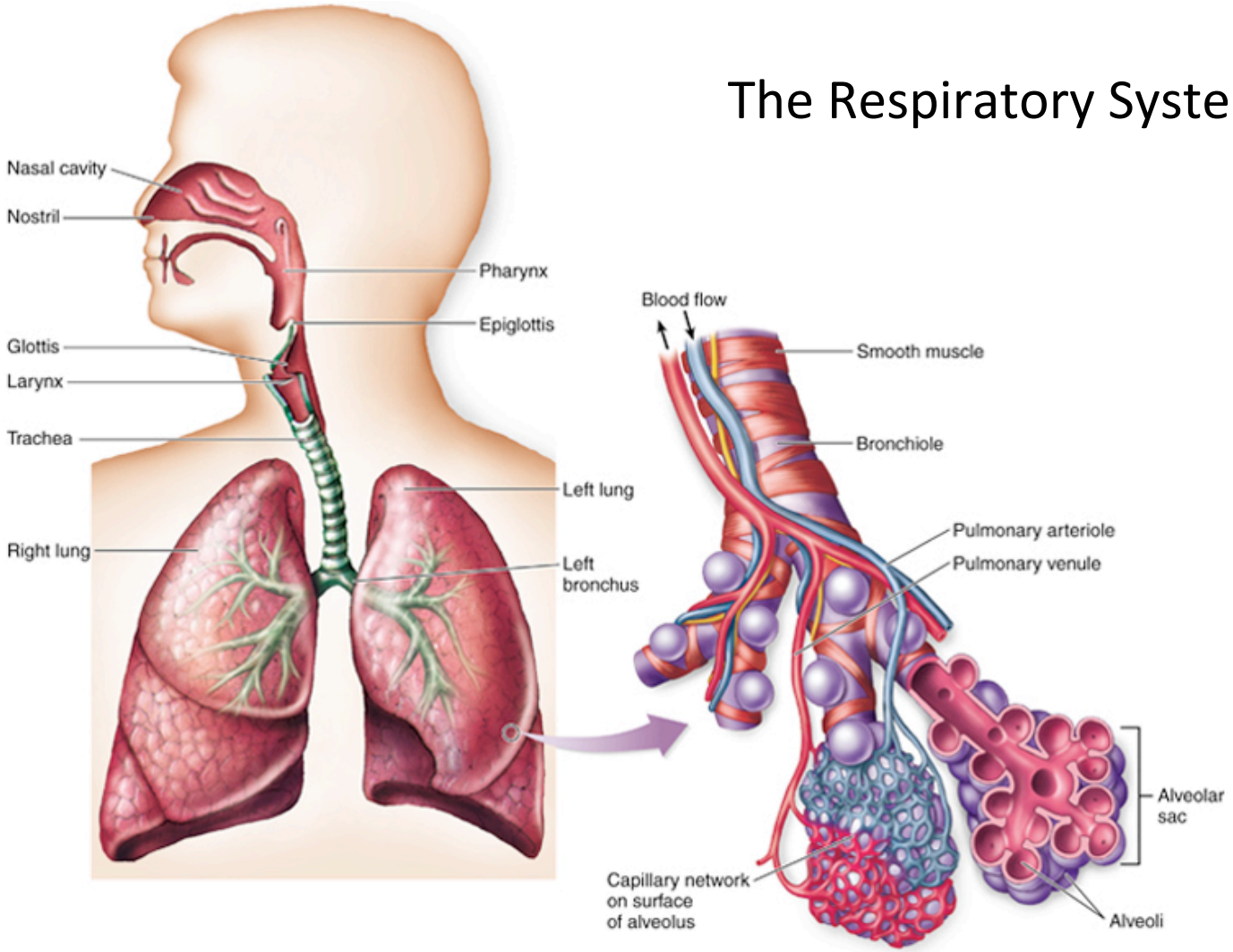
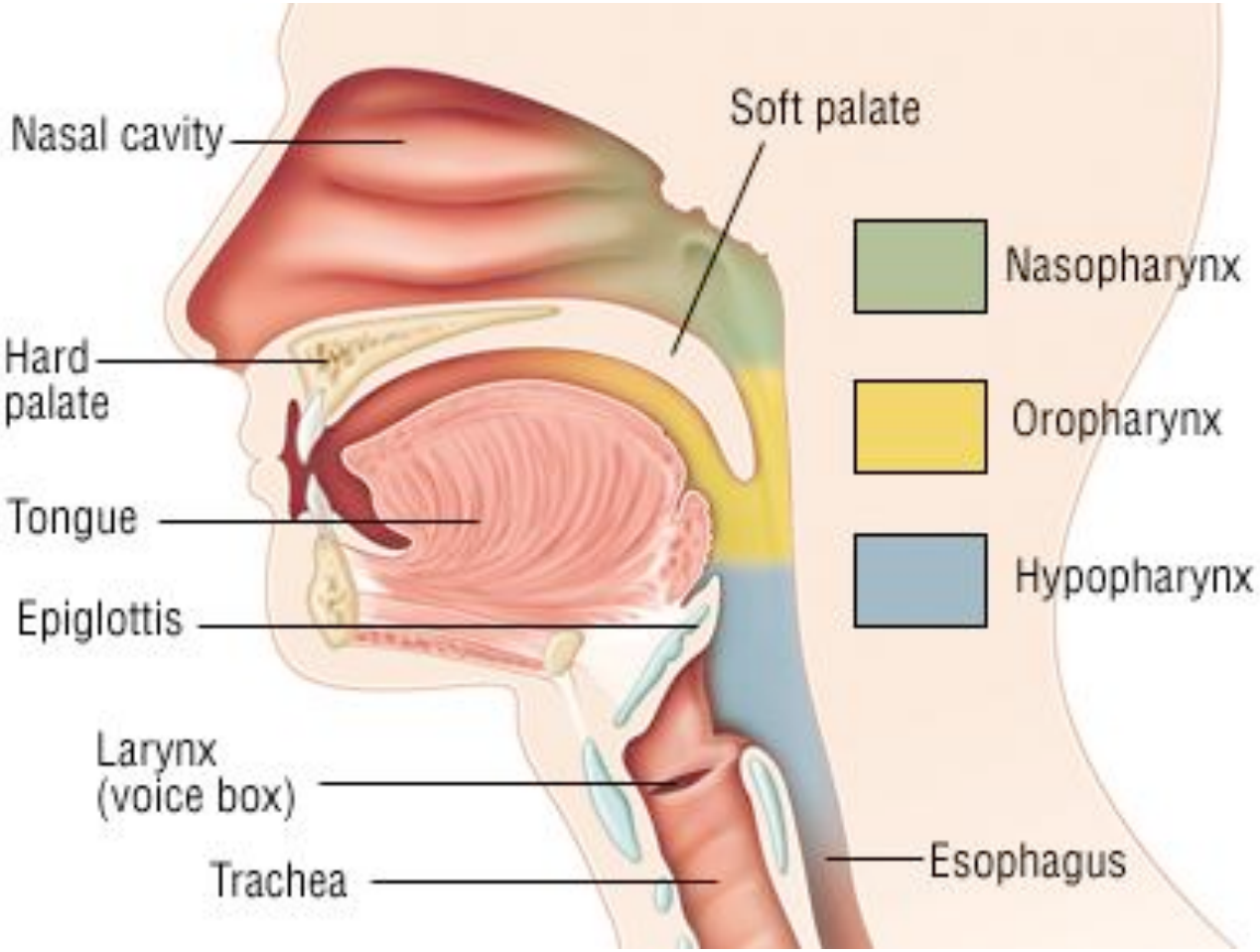
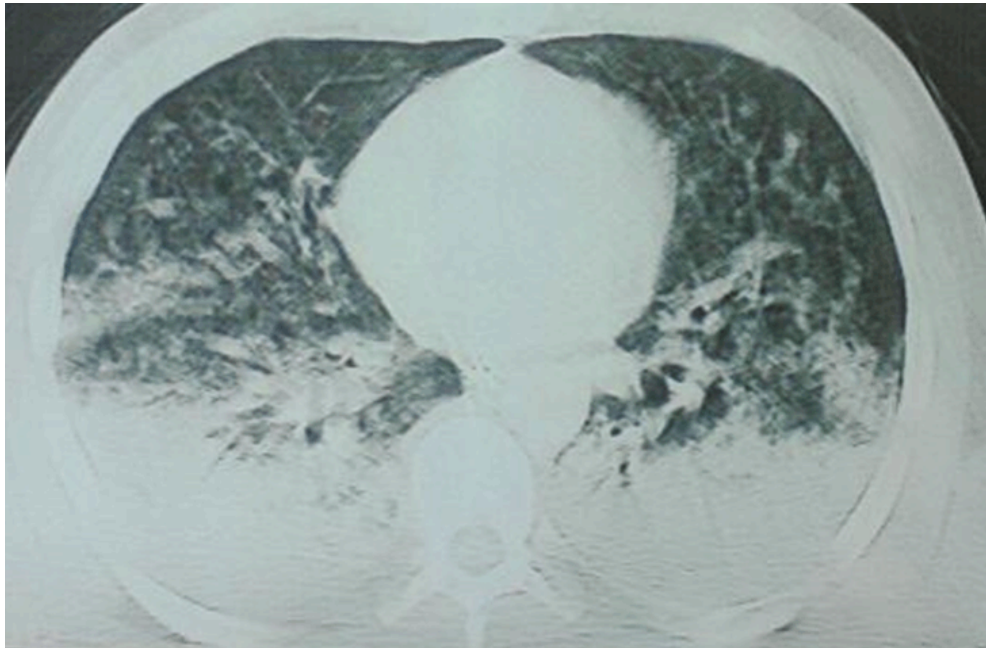
The Respiratory System



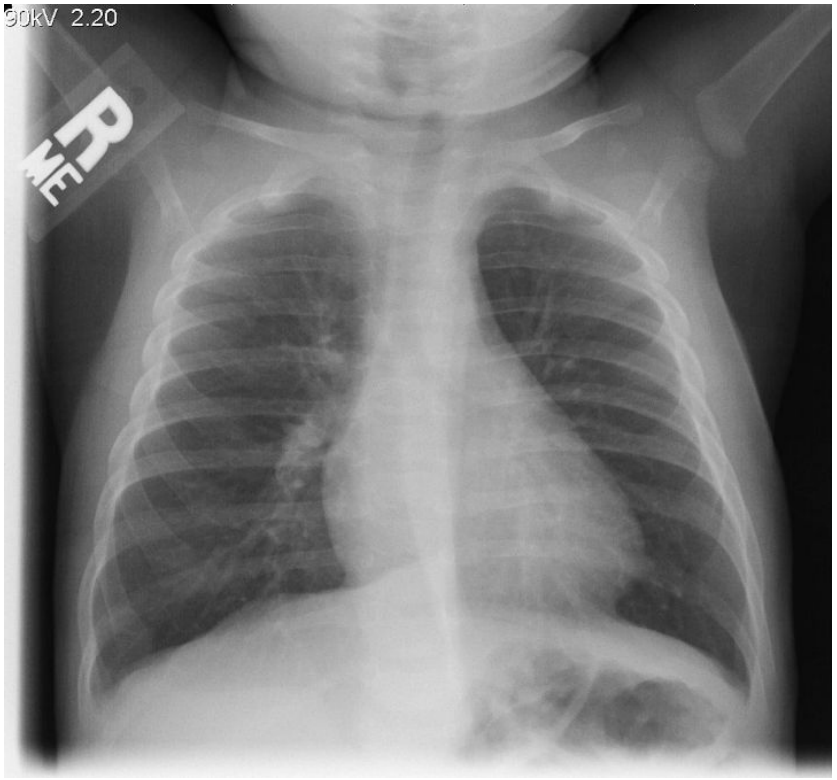

Nasal cavity
Soft palate
Nasopharynx
Hard palate
Oropharynx
Tongue
Hypopharynx
Epiglottis
Larynx (voice box)
Esophagus
Trachea

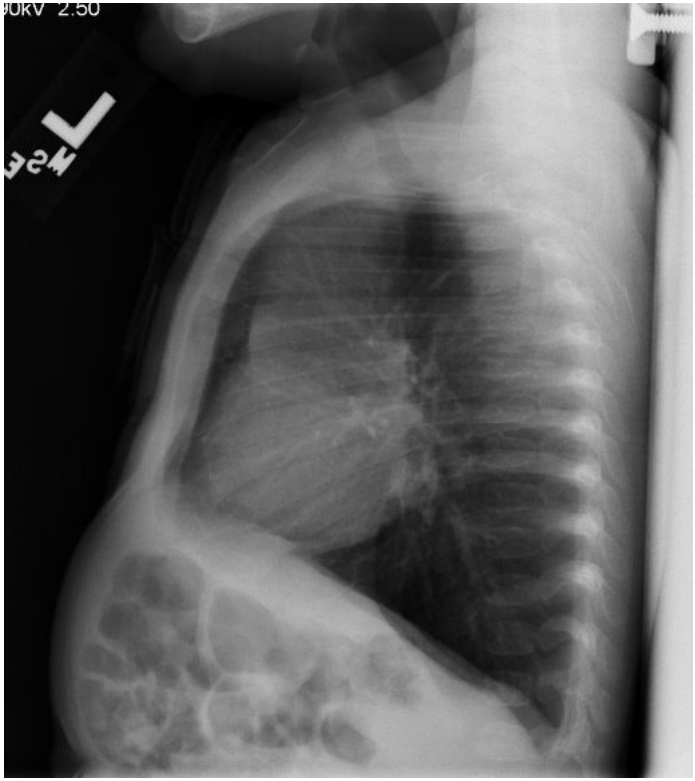
RSV Bronchiolitis
Chest Radiograph

ARDS
Chest CT

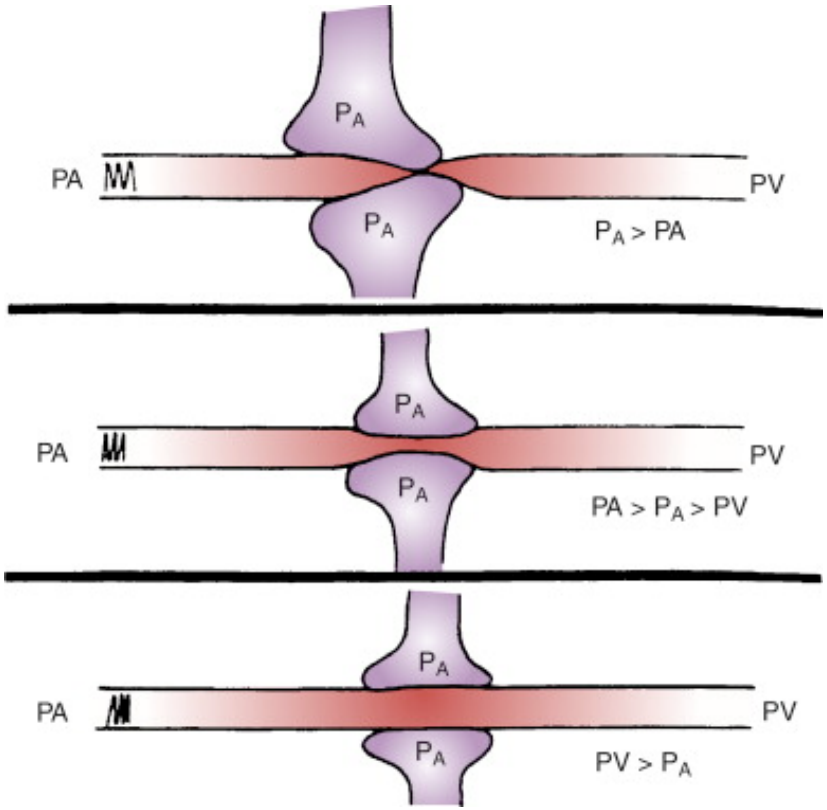


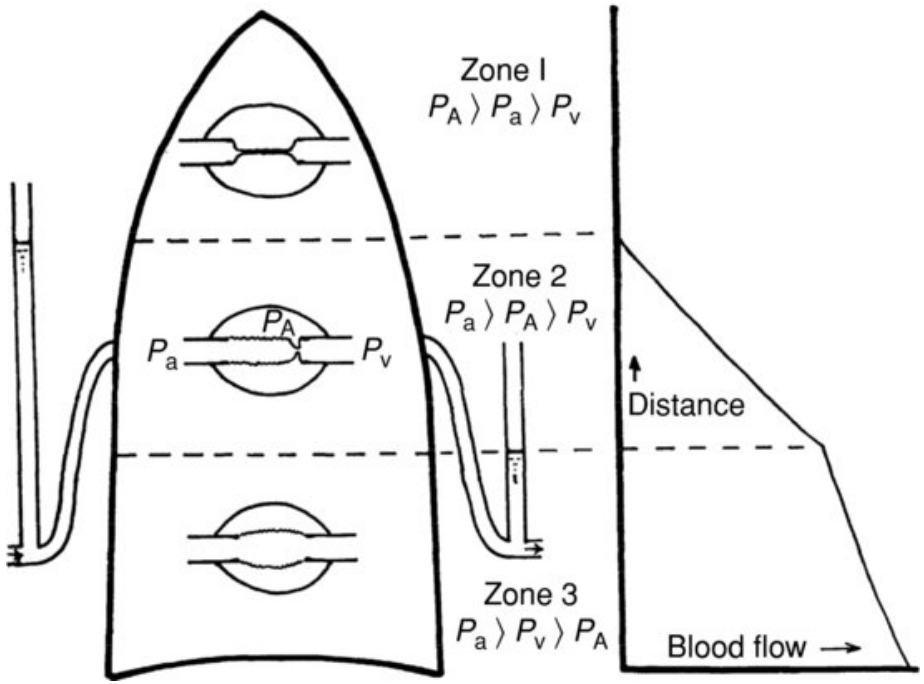
RSV Bronchiolitis- Chest Radiograph





West Zones of the Lung





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Oxygen Delivery via Simple Nasal Cannula

Oxygen Flow Rate (L/min)	FiO2
0	.21
1	.24
2	.28
3	.32
4	.36
5	.40
6	.44

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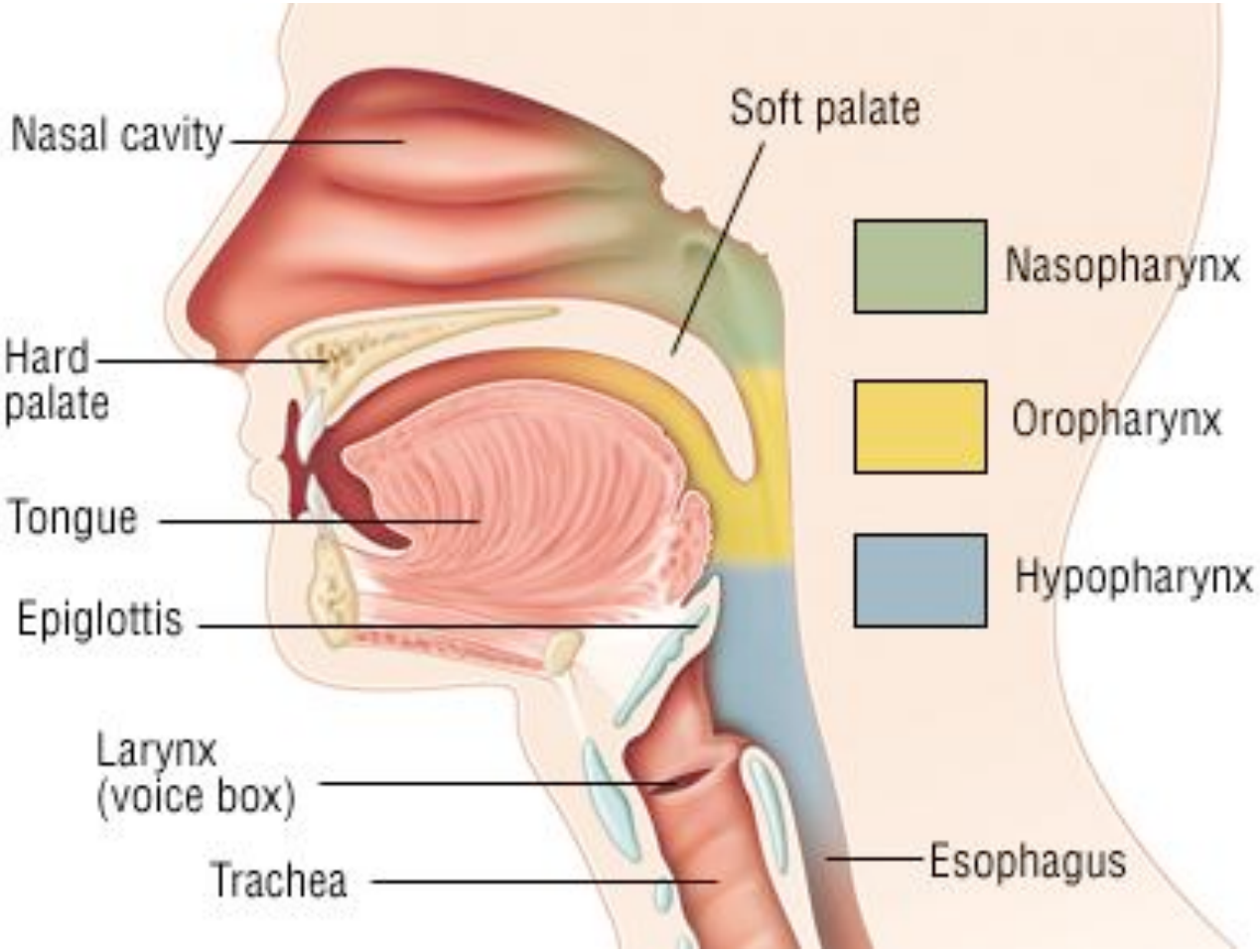
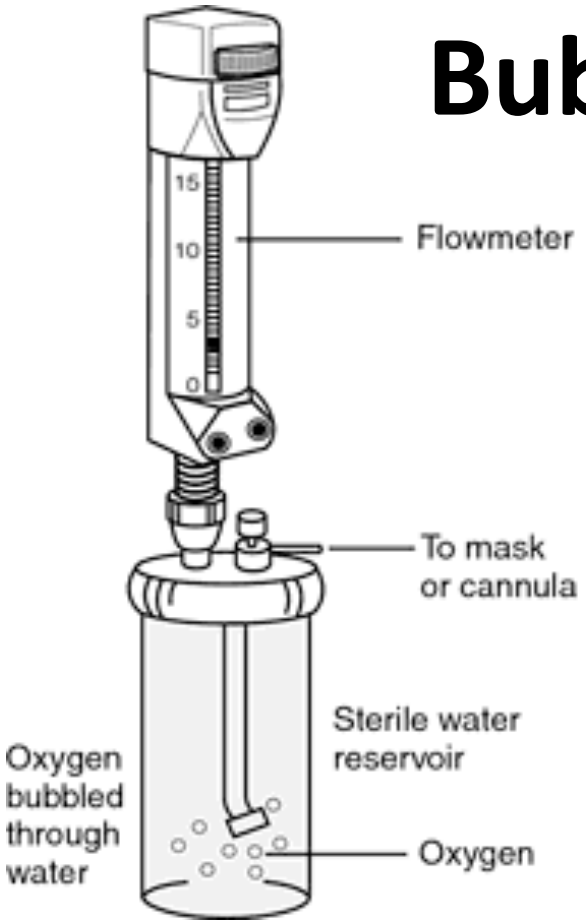

Nasal cavity
Soft palate
Nasopharynx
Hard palate
Oropharynx
Tongue
Hypopharynx
Epiglottis
Larynx (voice box)
Esophagus
Trachea

Bubble Humidifier



- Humidifies dry medical gases
- Simple
- Cheap
- Inadequate for flows >5 LPM

High Flow System

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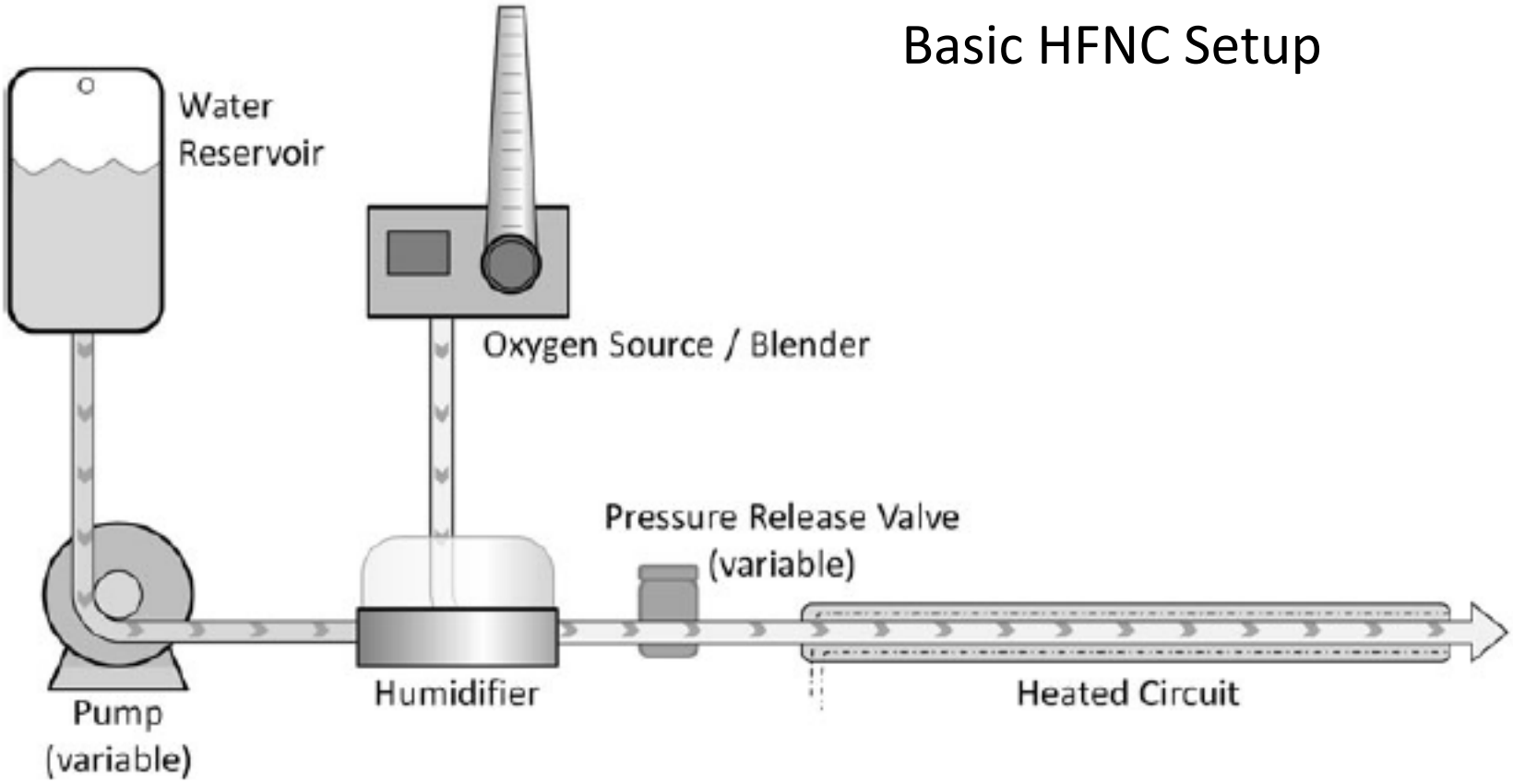
Basic HFNC Setup



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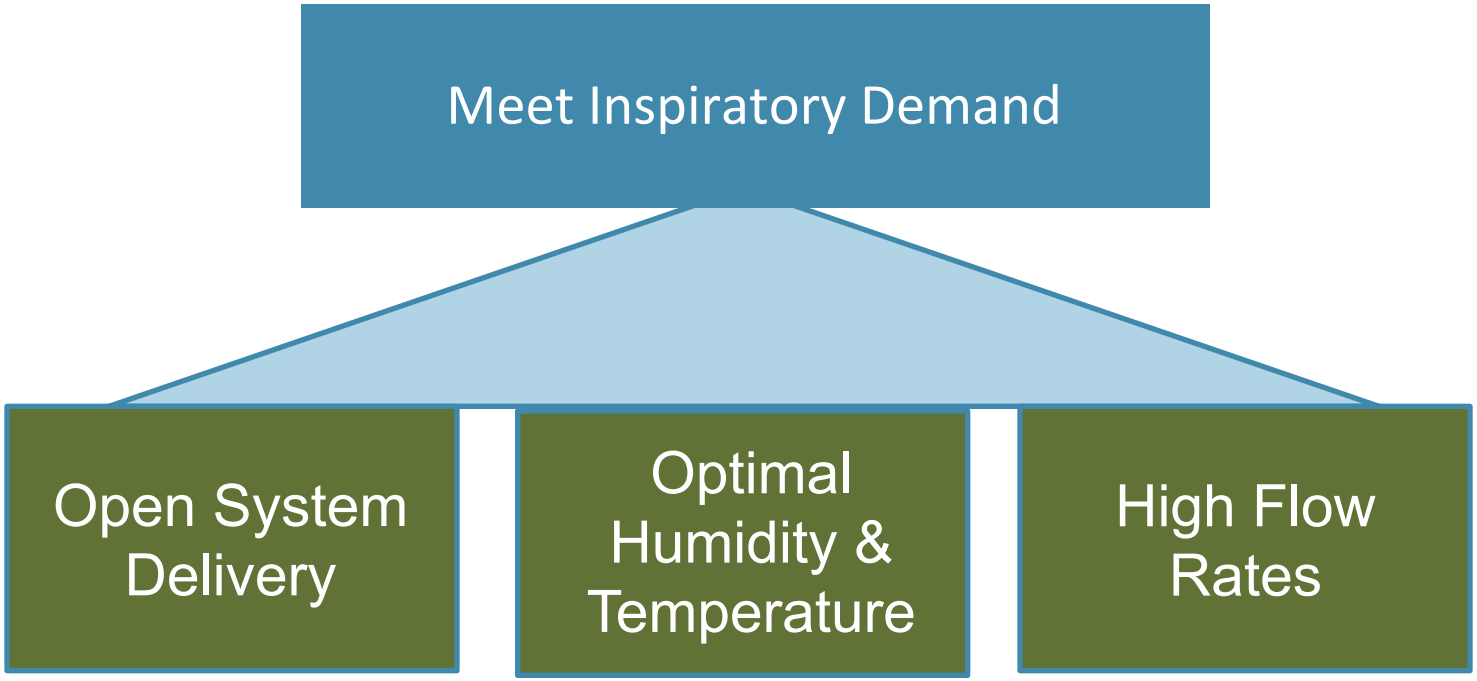
Critical Features of a High Flow System



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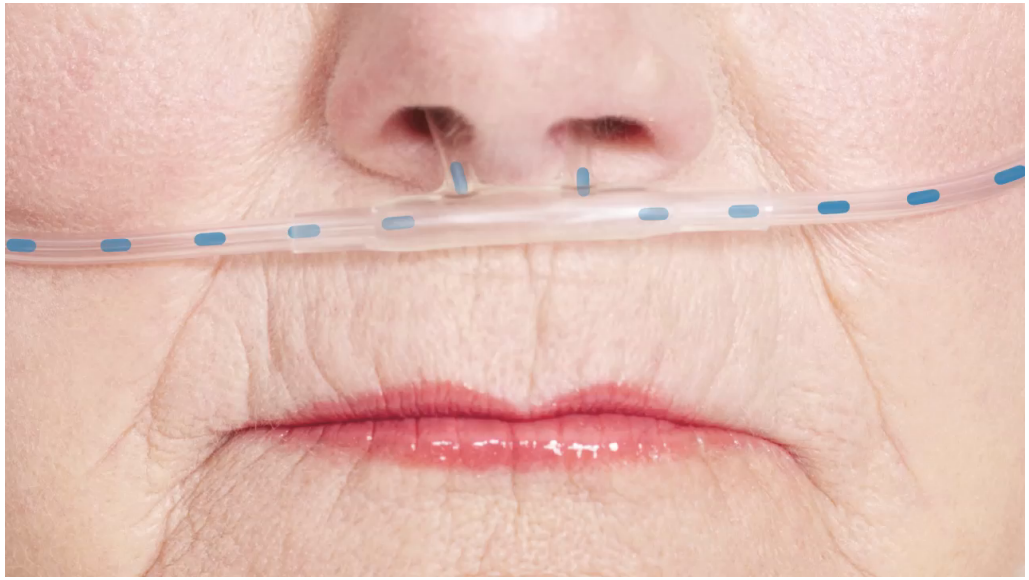
Open System Delivery

Occludes less than 50% of the nares



Optimal Humidity & Temperature

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Optimal Humidity & Temperature

Optimal Humidity & Temperature

Creating Medical-Grade-Vapor™

- Medical-Grade-Vapor
  - No water droplets
  - Less condensation
- Allows high flow rates to be comfortable

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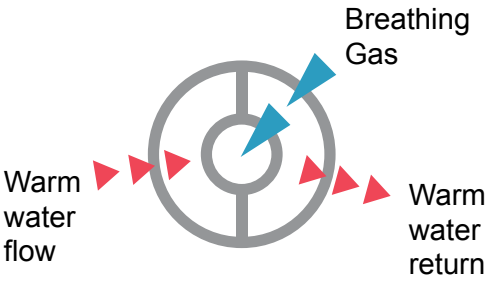
Delivering Highly Conditioned Gas

Warm Water Jacket Insulation

- No rain out in delivery tube
- Maintain temperature & humidity all the way to the patient



Cross-section of tubing

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Delivering High Flow Therapy

- Operational Flow Range
  - 1 to 8 L/min (Low Flow Cartridge)
  - 5 to 40 L/min (High Flow Cartridge)
- Fraction of Inspired Oxygen (FiO_2)
  - 0.21 to 1.0
- Temperature
  - 33 to 43°C

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Delivering High Flow Therapy

- Operational Flow Range
  - 2 to 50 L/min
- Fraction of Inspired Oxygen (FiO_2)
  - 0.21 to 1.0

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Delivering High Flow Therapy

Age	Weight	Cannula	Clinical Flow Range (L/min)	Typical Starting Flow (L/min)
0 to 30 days	<4 kg	Neonate	2-8	4-5
1 mo to 1 yr	4-10 kg	Infant	2-14	5-8
1 to 6 yrs	10-20 kg	Pediatric Small	2-16	5-10
6 to 12 yrs	20-40 kg	Pediatric	4-20	10-14
> 12 yrs	> 40 kg	Pediatric Large /Adult	4-30	12-16

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THE NEW ENGLAND JOURNAL OF MEDICINE

July 15, 1993

AUTO PEEP

To the Editor: A 51-year-old woman was admitted to our hospital in severe respiratory distress due to the acute onset of pulmonary edema and bronchospasm. She was comatose and required emergency intubation. Arterial-blood gas measurement before intubation showed the following: pH, 6.89; partial pressure of carbon dioxide, 88.8 mm Hg; partial pressure of oxygen, 60.2 mm Hg; and oxygen saturation, 69.5 percent.

The patient responded well to conventional treatment. Eventually, she recounted her harrowing trip to the hospital. Her husband had been driving the car. She said that she would have lost consciousness en route had she not held her head out the window to breathe. Her husband confirmed that her mental status and breathing had improved substantially with this maneuver. He stated that he was driving the vehicle at 80 mph (130 kph). He also noted that for his wife, the effect of holding her head out the window quickly abated when he was forced to slow his vehicle near the hospital.

According to Bernoulli's equation, the additional inspiratory pressure provided at this velocity is approximately 6 mm Hg, or 8 cm of water at sea level.* Bernoulli's equation

(valid for steady, incompressible, nonviscous, and irrotational flow) for the case of constant height is as follows:

$$\text{change in pressure (i.e., gauge pressure)} = \tfrac{1}{2}\ \text{density} \times \text{velocity}^2.$$

The velocity of the vehicle was 80 mph, or 36 m per second, and the density of air is 1.21 kg per cubic meter. Thus, the change in pressure is approximately 784 Pa, which is 5.9 mm Hg, or 7.8 cm of water.

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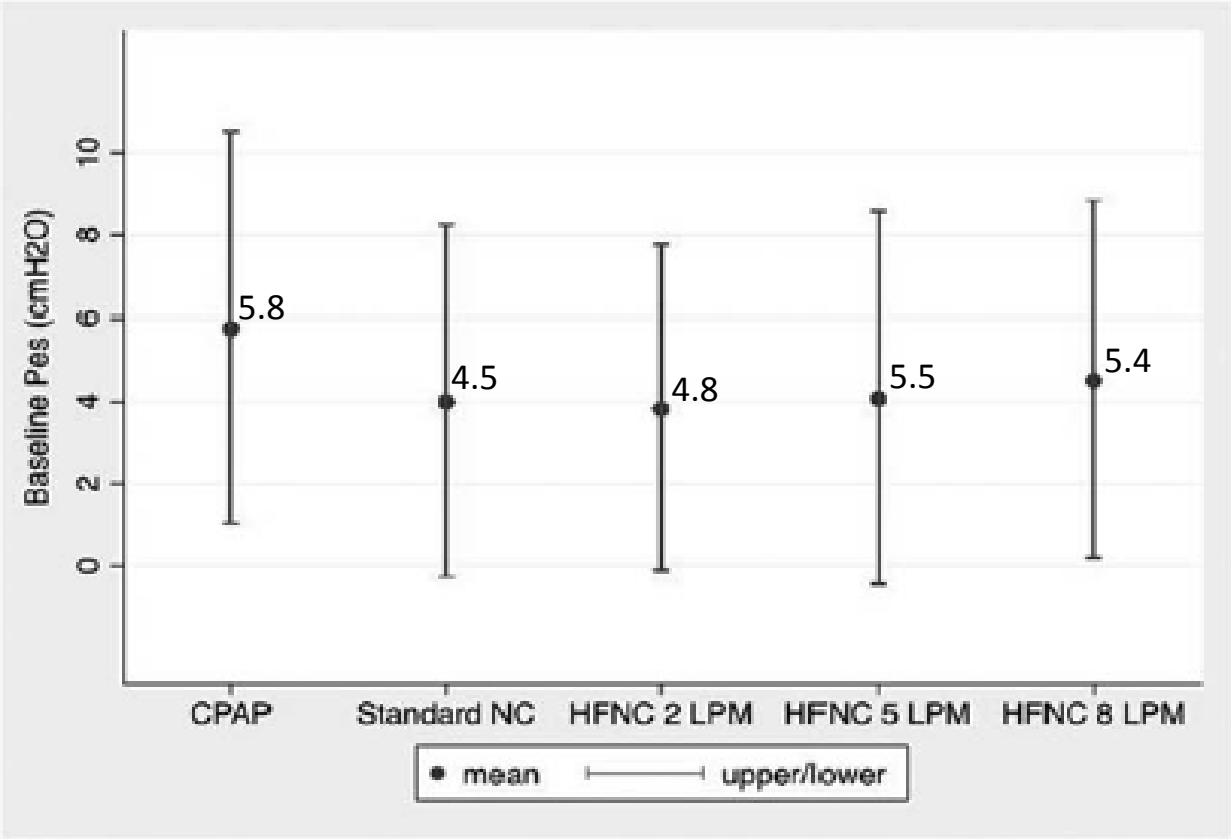
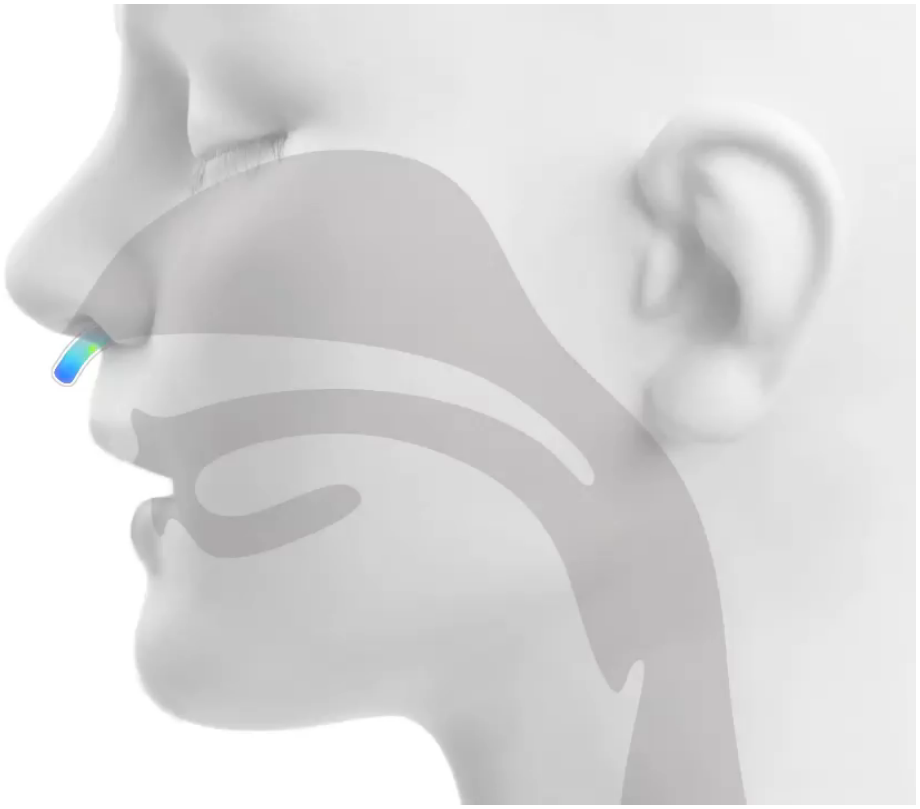


Rubin S, Ghuman A, Deakers T, Khemani R, Ross P, Newth CJ. Pediatr Crit Care Med. 2014 Jan;15(1):1-6

Gas Dynamics Modeling during HFNT



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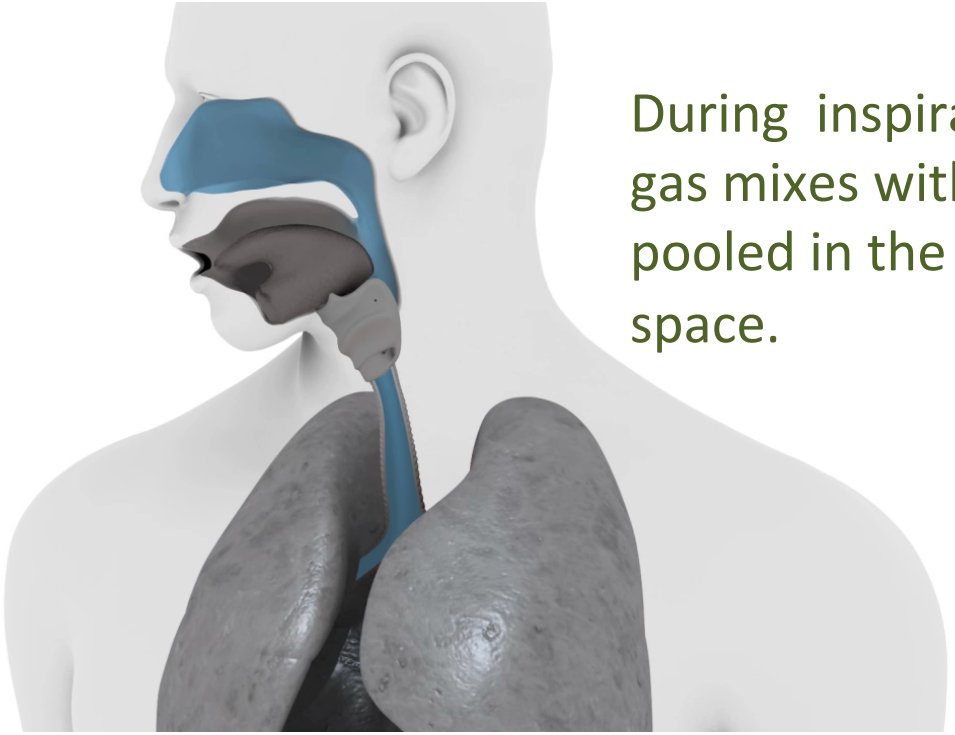
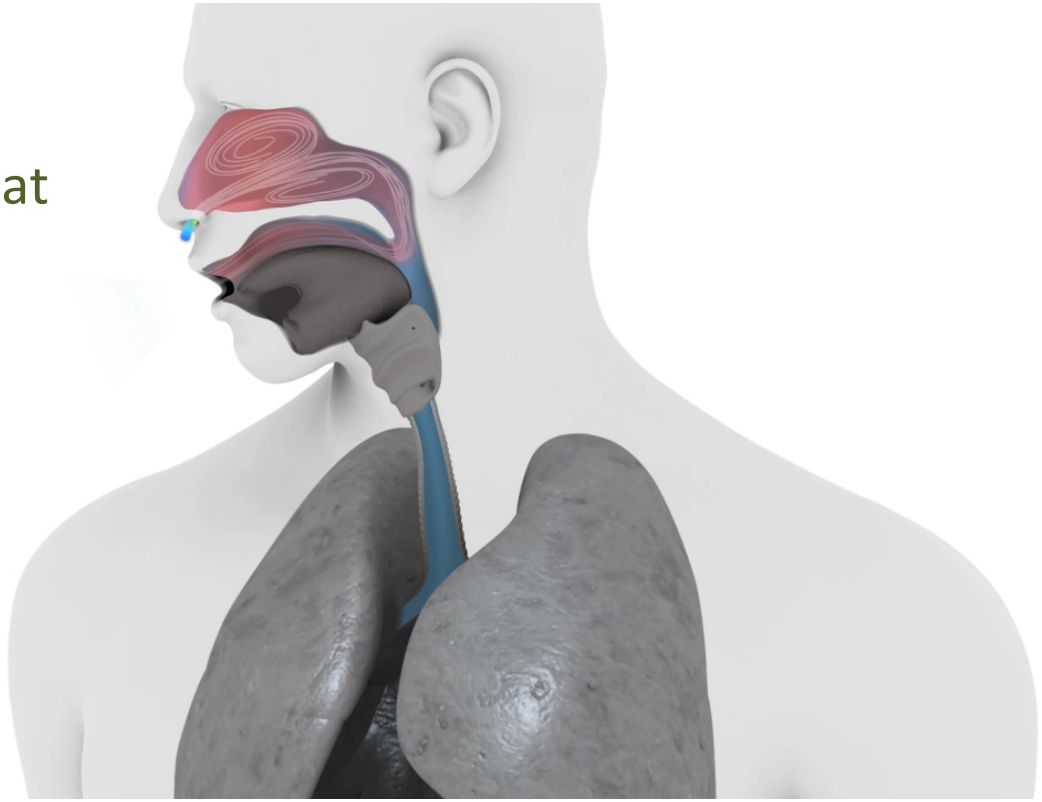
Spontaneous Breathing



During inspiration, fresh inspired gas mixes with CO_2-rich expired gas pooled in the anatomical dead space.

High Flow Therapy Mechanisms

HFNT purges the anatomical dead space of pooled exhaled CO_2 so that the subsequent breath contains more fresh gas and less end-expiratory gas



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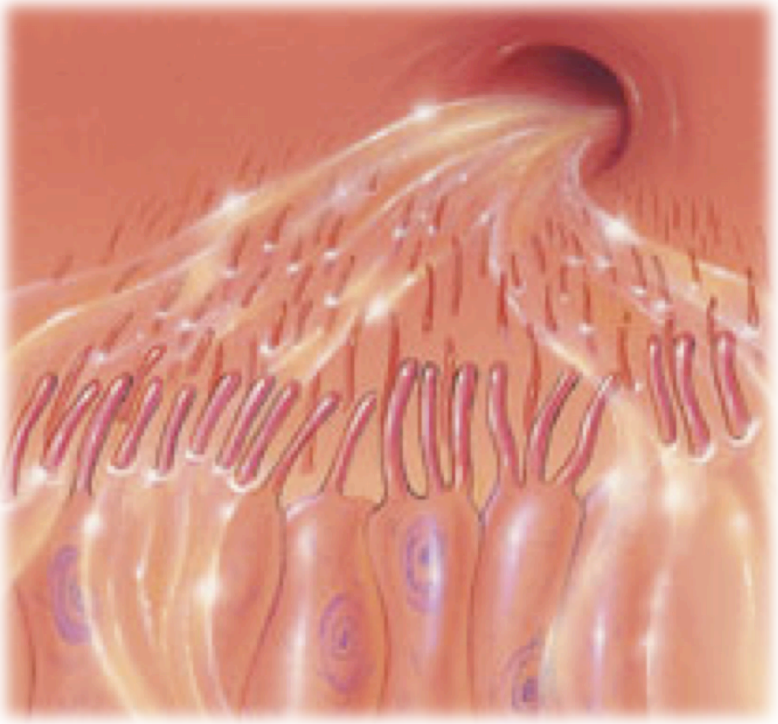
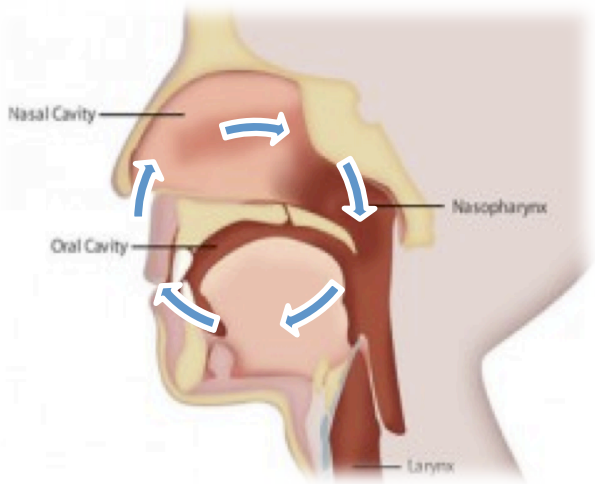
The Importance of Optimal Humidification



Optimally heated and humidified gas helps restore cilia to its natural state, allowing for secretion clearance

Effects of High Flow Nasal Cannula Therapy

- Flow rates to exceed the patient's inspiratory demand
- Decreased inspiratory resistance
- Flushes out CO_2 from dead space
- Internal reservoir of desired FiO_2
- Allows patient to breathe through own airway instead of from external source (e.g., mask)
- Decreases work of breathing
- Decreases energy expenditure



Potential Clinical Impact

By instituting High Flow Therapy:

- Reduce work of breathing with dead space flush
- Precise FiO_2 delivery
- Manage secretions to permit lower intensity of care
- Allow for better feeding tolerance

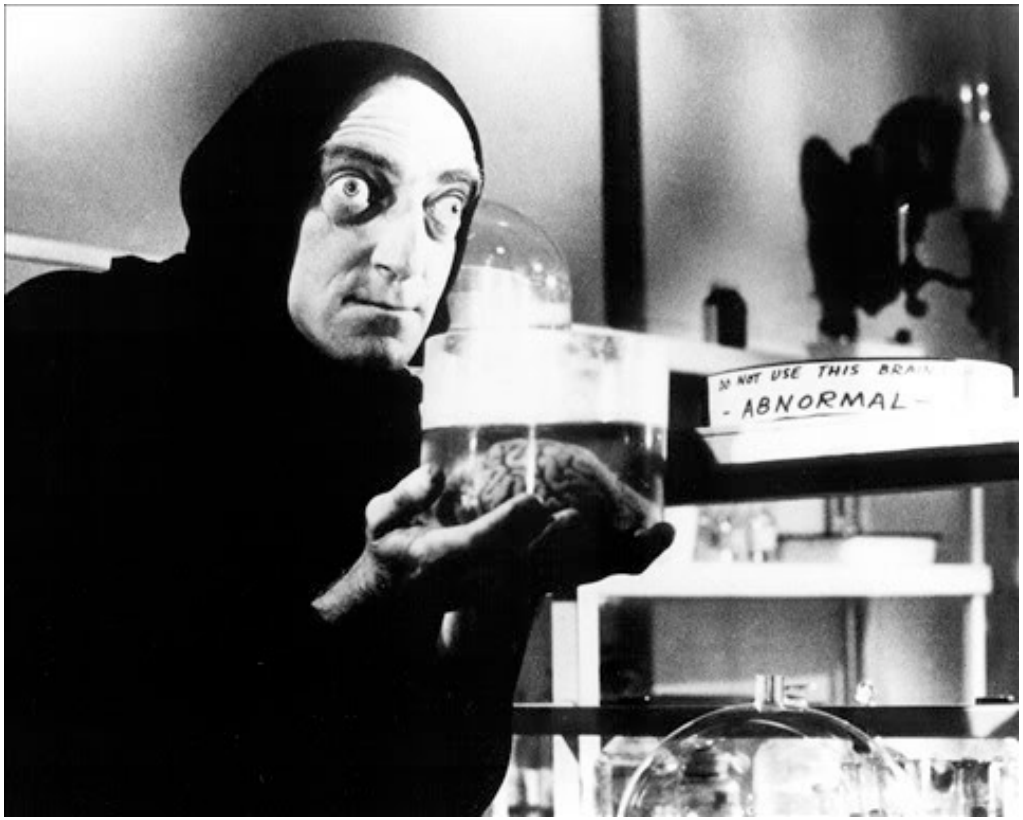
Indications

- Diseases of compliance
  - Bronchiolitis
  - Pneumonia
  - ARDS
- Diseases of resistance
  - Bronchiolitis
  - Asthma
- Post-extubation
- Post-cardiac surgery
- Extrathoracic airway obstruction
- To decrease anatomical deadspace
- Mucociliary elevator

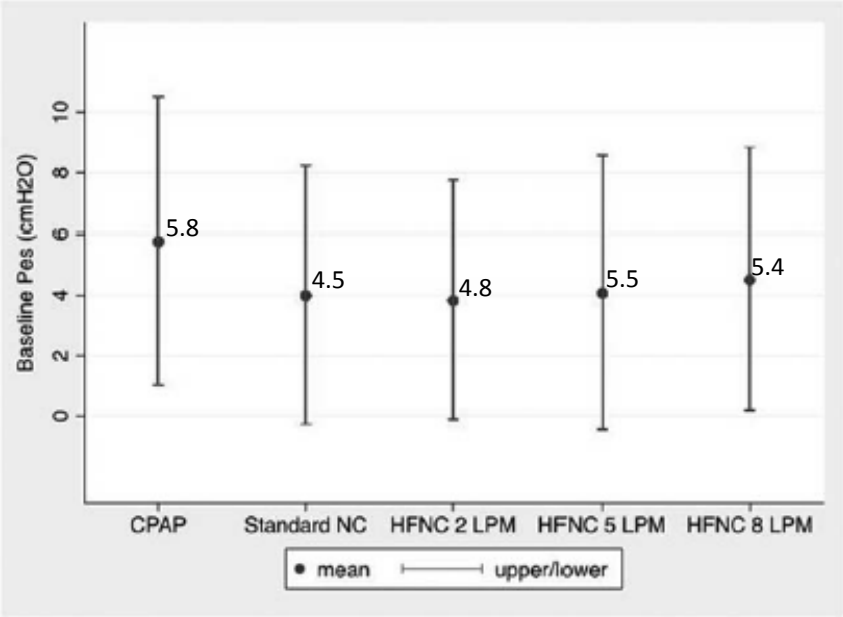
Potential Complications

- Nasal trauma
- Facial trauma
- Epistaxis
- Pneumothorax
- Aerophagia / gastric distension
- Delay in endontracheal intubation

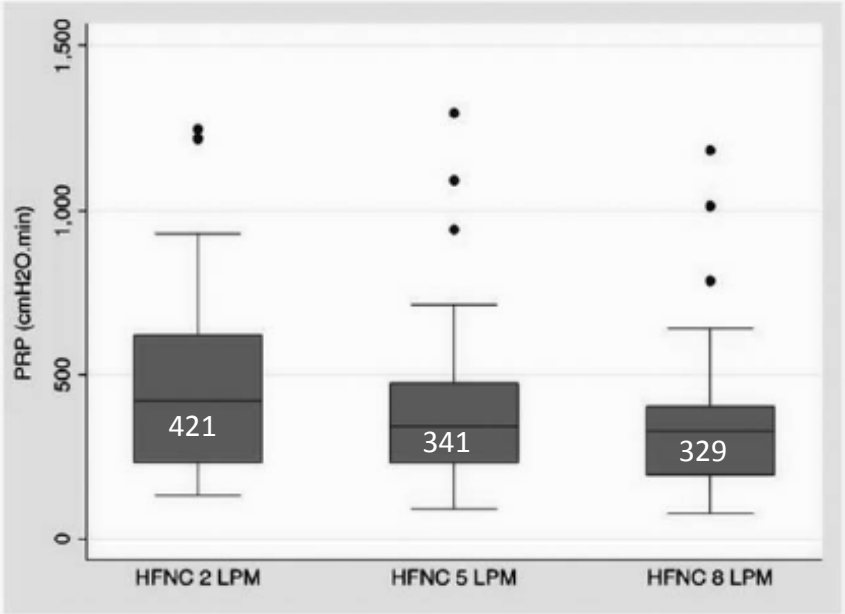
Clinical Studies



- Pediatric Studies
  - Post-extubation
  - Bronchiolitis
- Neonatal Studies
  - Prematurity
  - HFNC vs CPAP
- Device vs Device



Pleural Pressure at end-exhalation



Pressure-Rate Product

Rubin S, Ghuman A, Deakers T, Khemani R, Ross P, Newth CJ. Pediatr Crit Care Med. 2014 Jan;15(1):1-6

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ORIGINAL ARTICLES

www.jpeds.com • The Journal of Pediatrics

High Flow Nasal Cannulae Therapy in Infants with Bronchiolitis

Christine McKiernan, MD, Lee Chadrick Chua, MD, Paul F. Visintainer, PhD, and Holley Allen, MD

Objectives To determine whether the introduction of heated humidified high-flow nasal cannulae (HFNC) therapy was associated with decreased rates of intubation for infants <24 months old with bronchiolitis admitted to a pediatric intensive care unit (PICU).

Study design A retrospective chart review of infants with bronchiolitis admitted before and in the season after introduction of HFNC.

J Pediatr 2010;156:634-8

Table I. Patient characteristics, vital signs and initial respiratory support in PICU in the 2005–2006 group, before the introduction of HFNC and in the 2006–2007 group after introduction of the HFNC

Characteristic	2005–2006 (HFNC-NA) (n = 57)	2006–2007 (HFNC-A) (n = 58)	*P* value
Age (mos) (median)	3.0 (0.5-19.0)	2.0 (0.25-24.0)	.09
Weight (kg) (median)	5.8 (2.5-12.3)	5.2 (2.6-14.6)	.25
Gestational age (wks) (median)	40 (24-40)	40 (23-40)	
Admission RR (breaths/min) (median)	47 (21-85)	61 (24-120)	<.001
Admission O_2 saturation (median)	97 (68-100)	95 (56-100)	.18
Pediatric Index of Mortality 2 (median)	0.40 (0.2-1.8)	0.40 (0.2-1.2)	.39
Sex (% male) (median)	32 (56.1%)	37 (63.7%)	.45
RSV positive (median)	29 (50.9%)	40 (69.0%)	.06
Respiratory support			<.001
Room air	9 (15.8%)	1 (1.7%)	
Blow-by oxygen	9 (15.8%)	1 (1.7%)	
Nasal cannula	33 (57.9%)	5 (8.6%)	
Simple face mask	1 (1.8%)	0	
Non- rebreather mask	2 (3.5%)	0	
Nasal CPAP	3 (5.3%)	0	
HFNC	0	51 (87.9%)	

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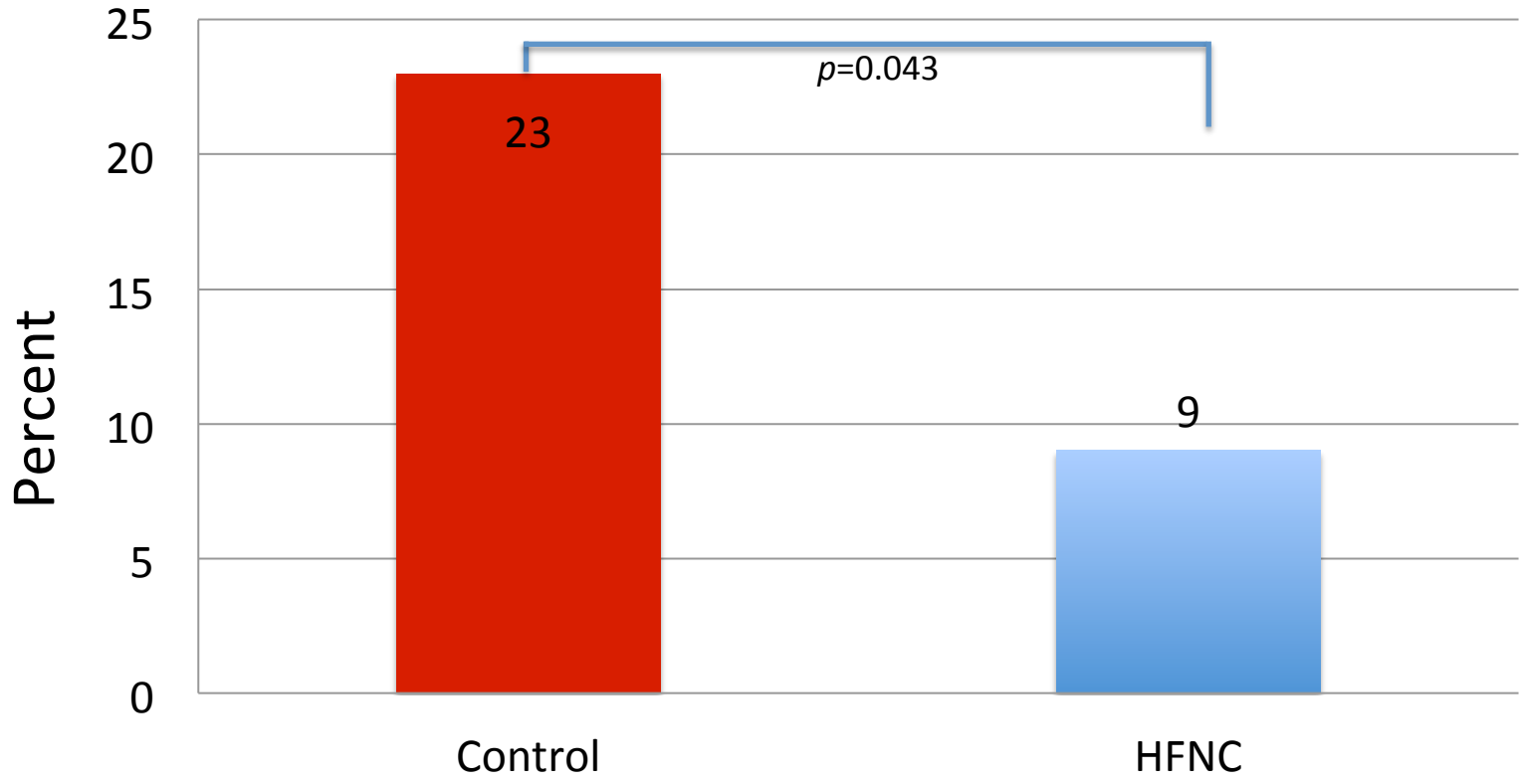
McKiernan C, et al. J Pediatr 2010

Patients with Bronchiolitis Requiring Intubation



McKiernan C, et al. J Pediatr 2010

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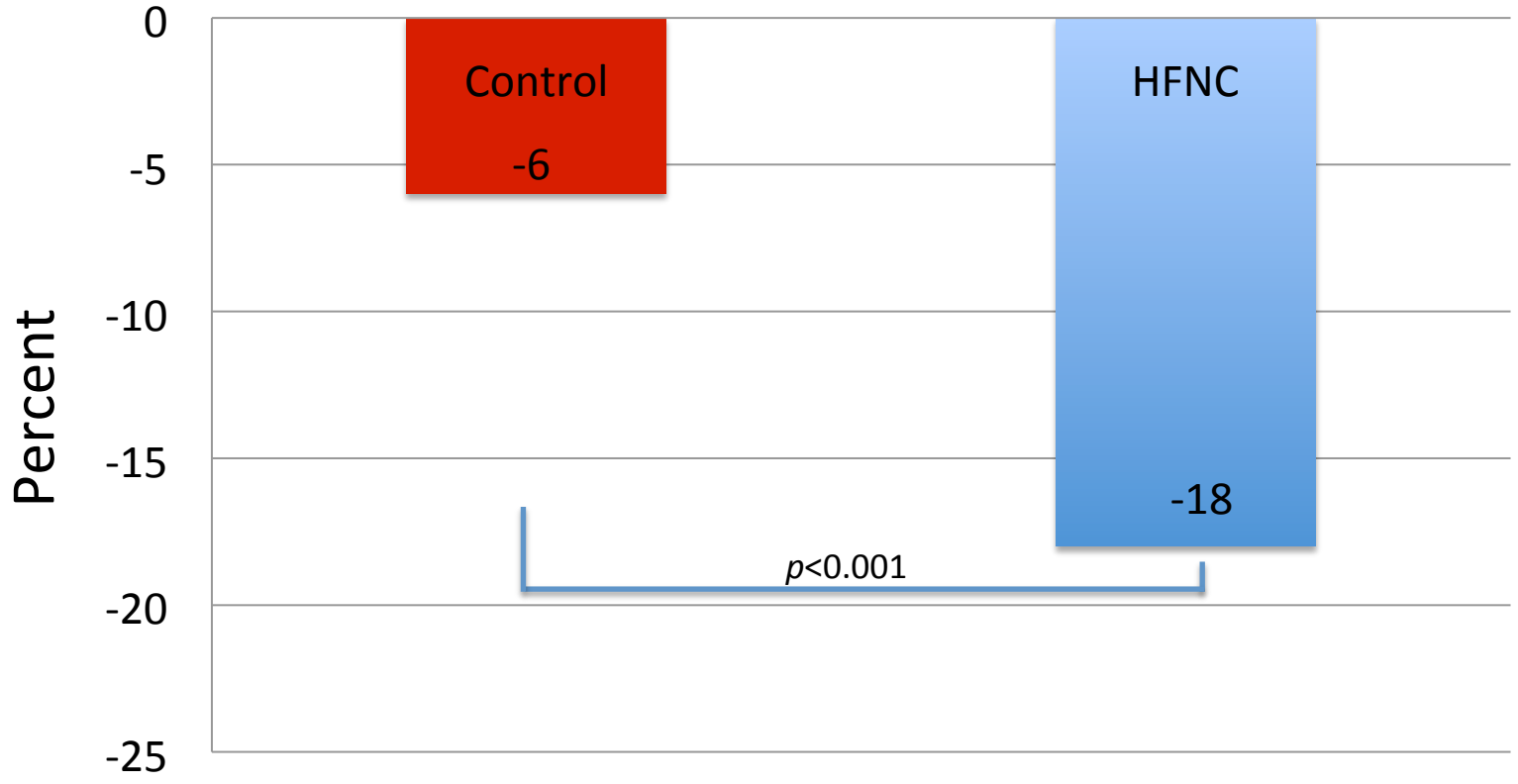
Change in RR 1h after Initiation of Therapy



McKiernan C, et al. J Pediatr 2010

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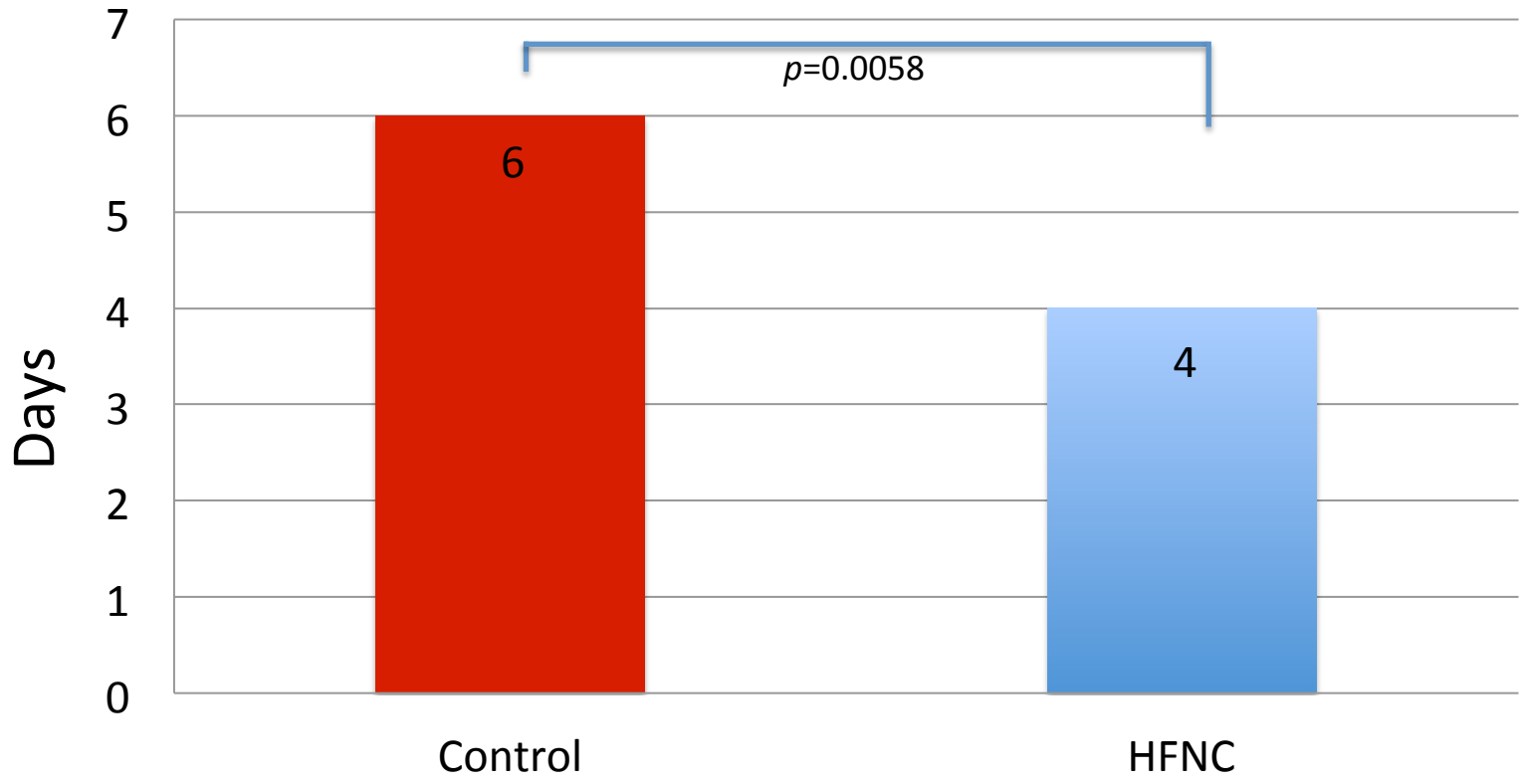
Median PICU Length of Stay



McKiernan C, et al. J Pediatr 2010

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Intensive Care Med (2011) 37:847–852
DOI 10.1007/s00134-011-2177-5

PEDIATRIC ORIGINAL

A. Schibler
T. M. T. Pham
K. R. Dunster
K. Foster
A. Barlow
K. Gibbons
J. L. Hough

Reduced intubation rates for infants after introduction of high-flow nasal prong oxygen delivery

Received: 26 July 2010
Accepted: 17 January 2011
Published online: 3 March 2011

- Retrospective study of 298 children < 24mo of age admitted to PICU
- 167 patients with bronchiolitis
- Describe the change in PICU ventilator practice after adoption of HFT
- Identify the patient subgroups requiring escalation of therapy.

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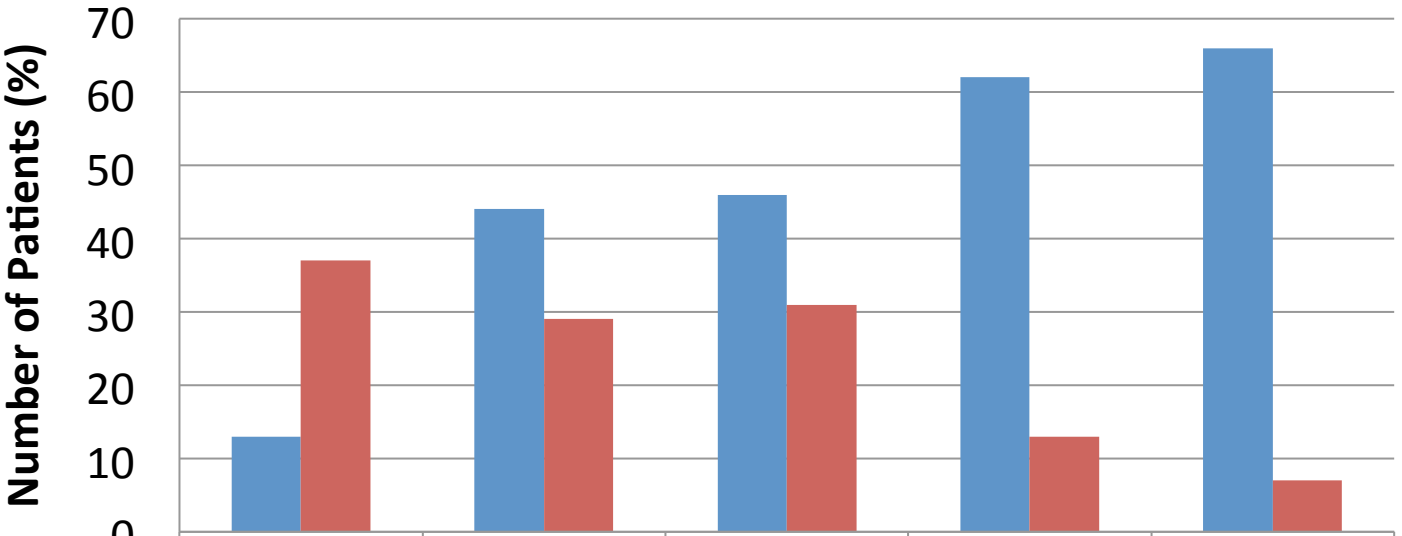
Support Trends Over Time



	2005	2006	2007	2008	2009
HFNC	13	44	46	62	66
MV	37	29	31	13	7

Schibler A, et al. Intensive Care Med 2011

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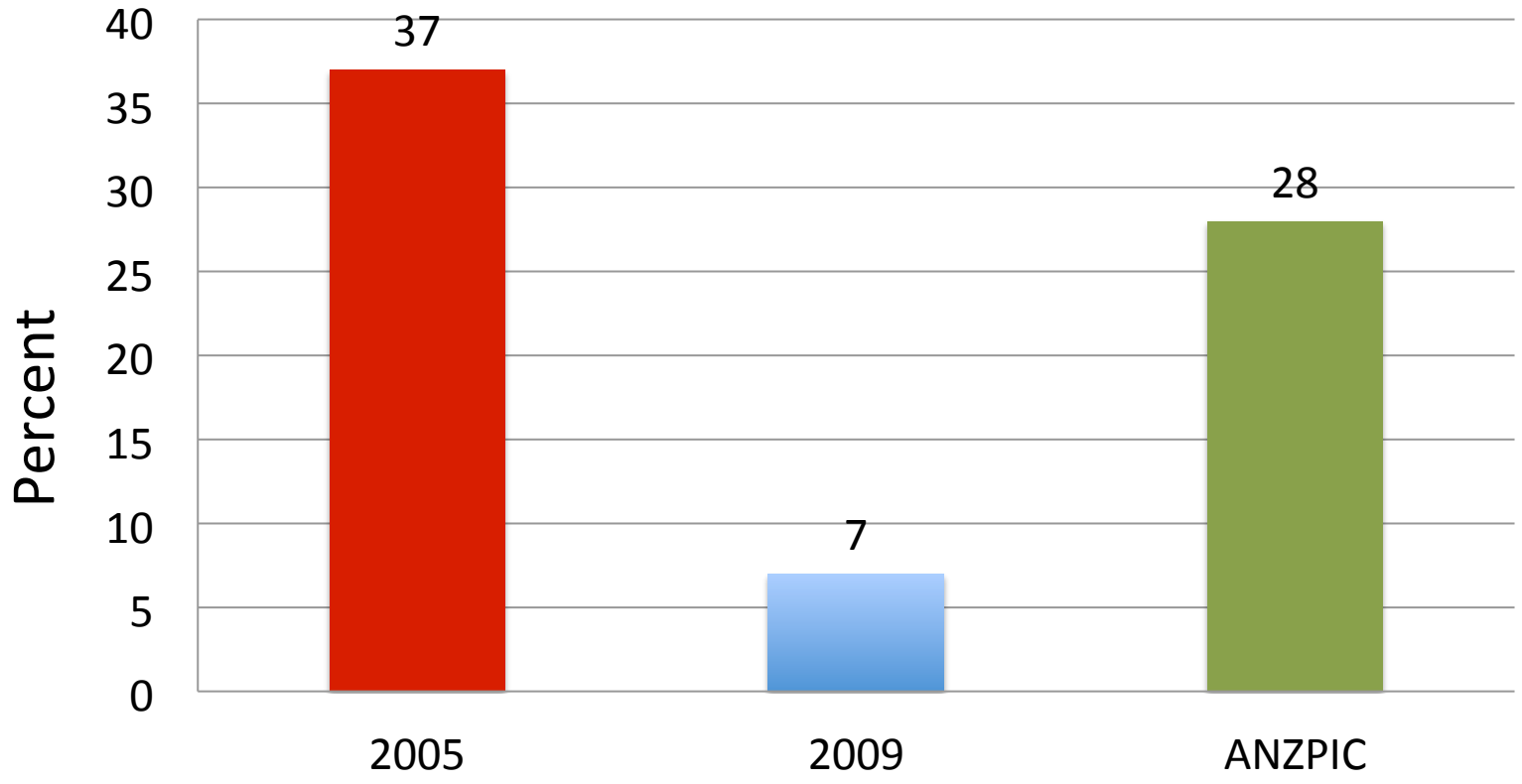
Intubation Rate for Patients with Bronchiolitis



Schibler A, et al. Intensive Care Med 2011

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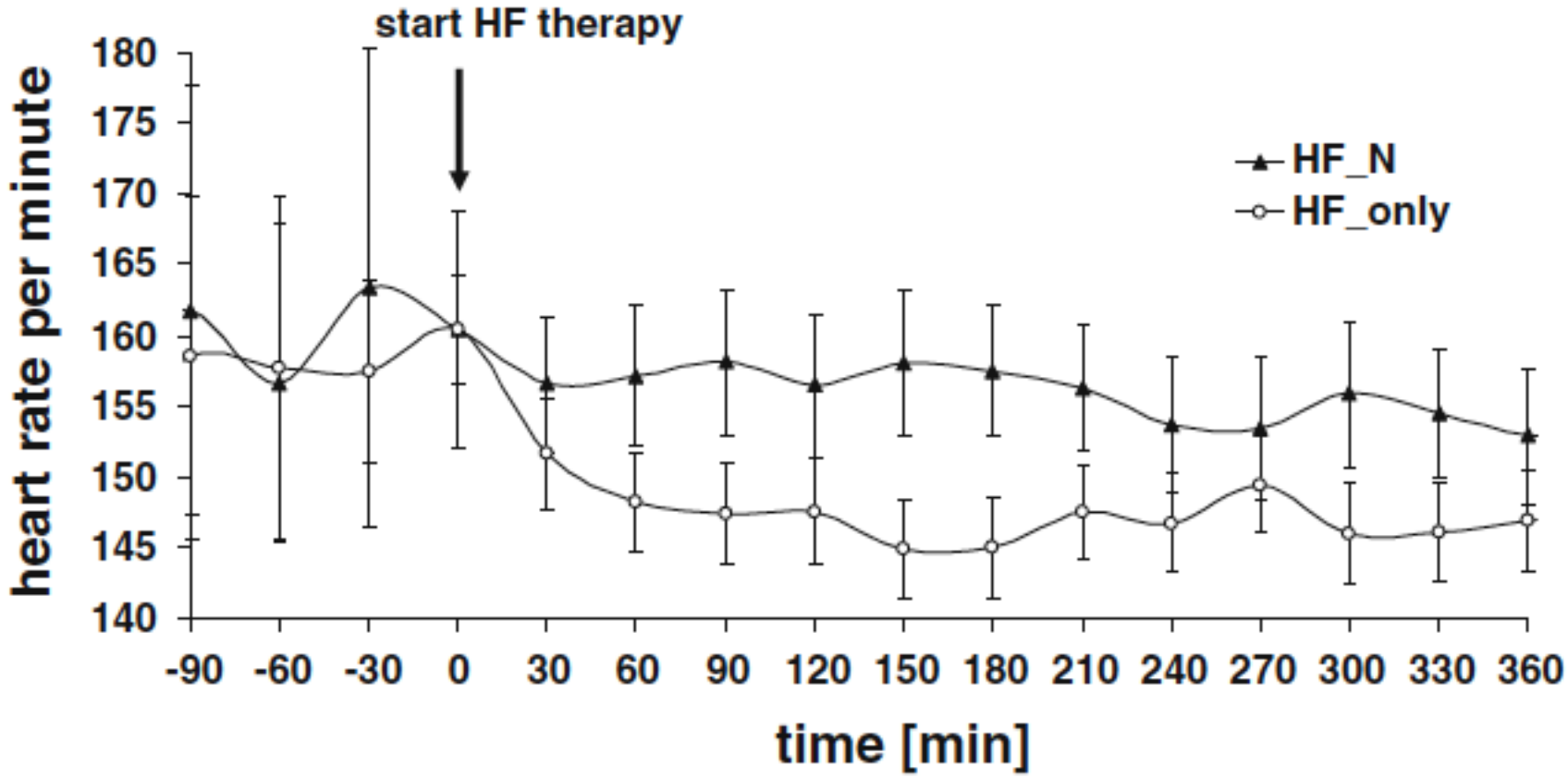
Infants with Viral Bronchiolitis: Heart Rate



Schibler A, et al. Intensive Care Med 2011

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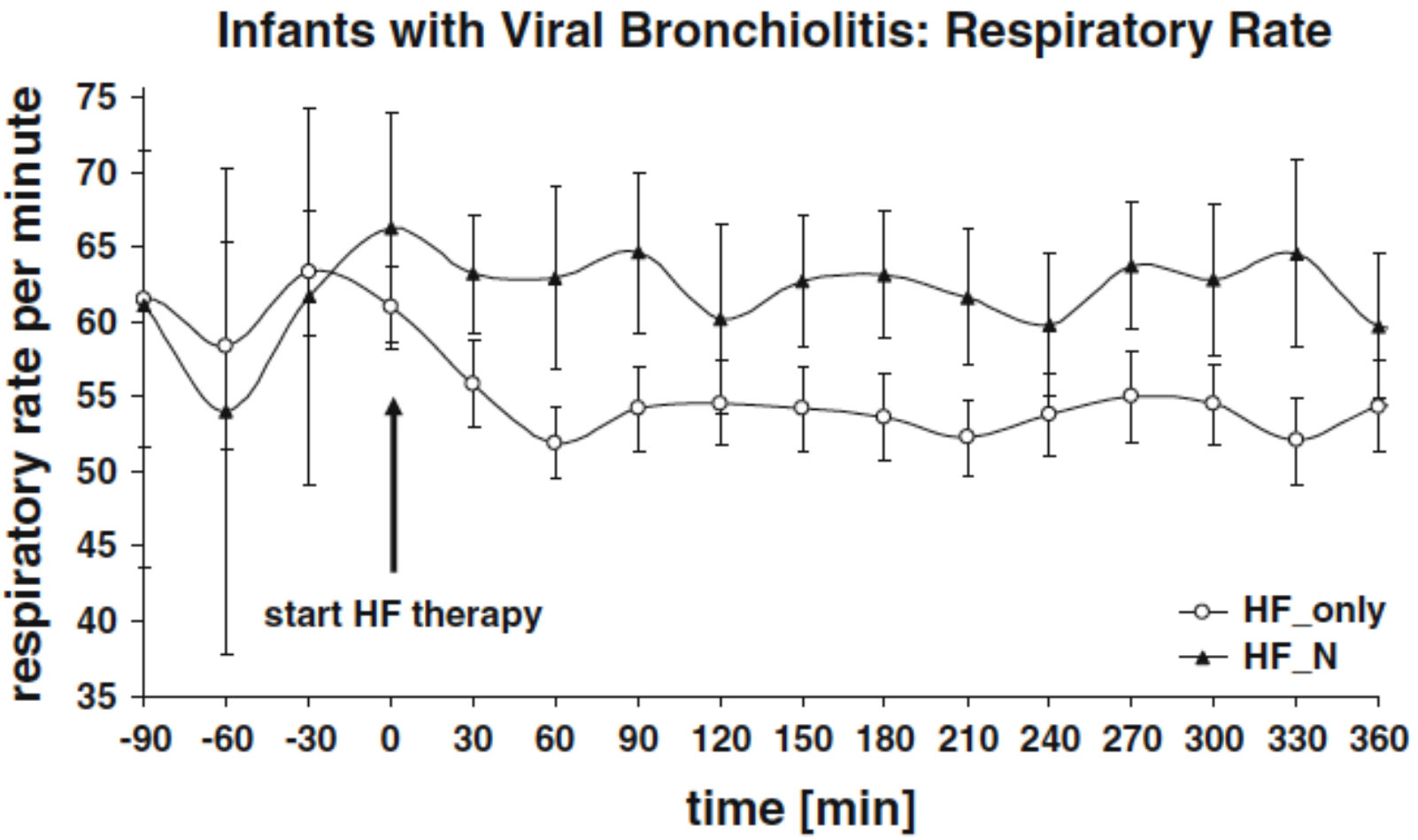

Schibler A, et al. Intensive Care Med 2011

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The NEW ENGLAND JOURNAL of MEDICINE

ORIGINAL ARTICLE

High-Flow Nasal Cannulae in Very Preterm Infants after Extubation

Brett J. Manley, M.B., B.S., Louise S. Owen, M.D., Lex W. Doyle, M.D., Chad C. Andersen, M.B., B.S., David W. Cartwright, M.B., B.S., Margo A. Pritchard, Ph.D., Susan M. Donath, M.A., and Peter G. Davis, M.D.

N ENGL J MED 369;15 NEJM.ORG OCTOBER 10, 2013

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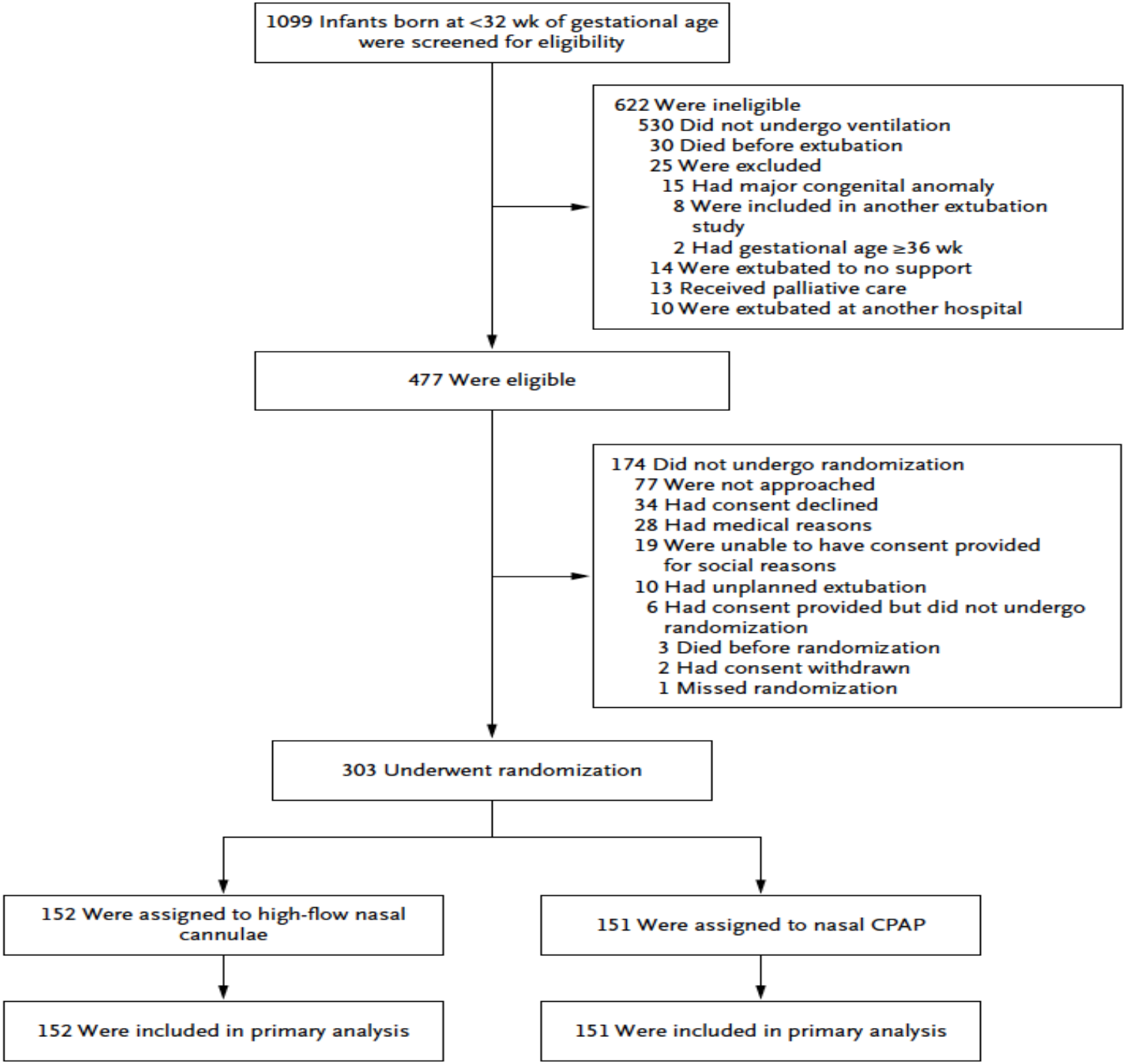
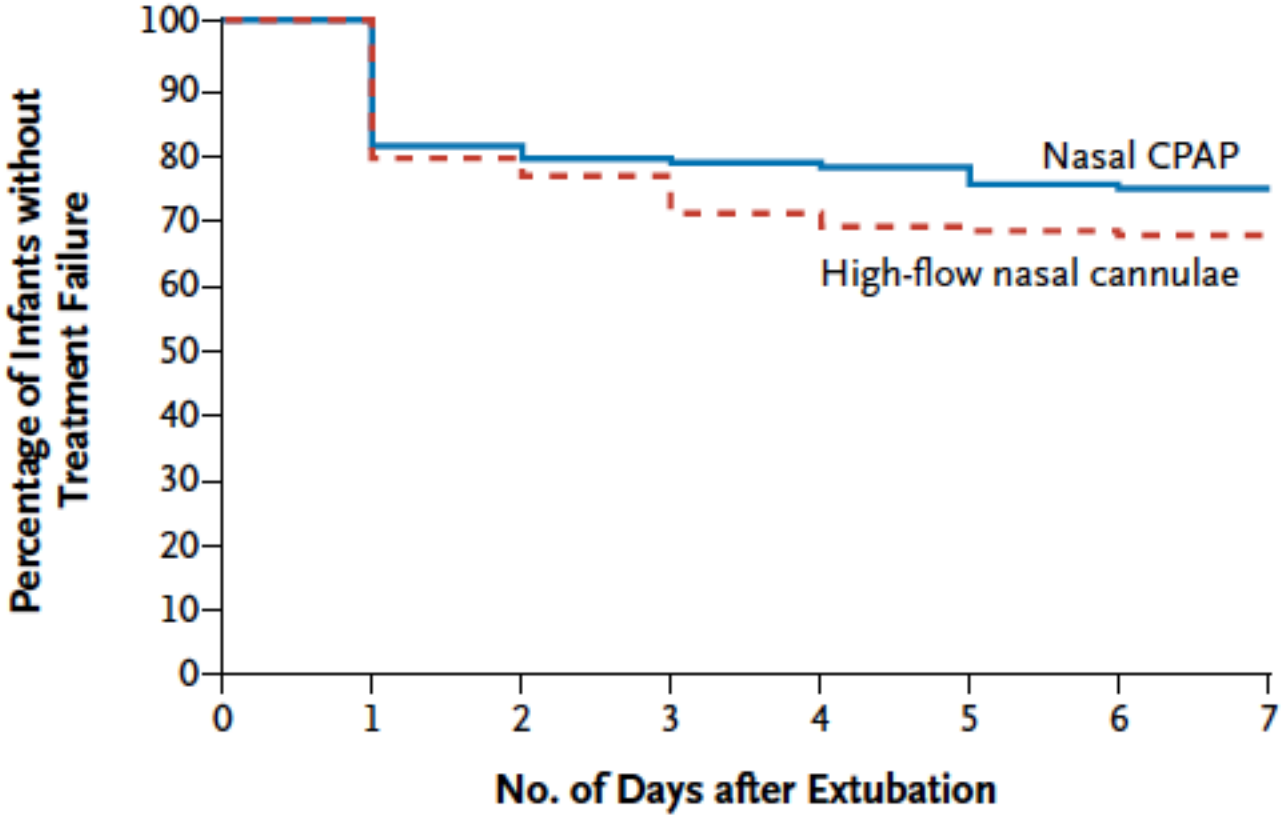

1099 Infants born at <32 wk of gestational age were screened for eligibility
622 Were ineligible
530 Did not undergo ventilation
30 Died before extubation
25 Were excluded
15 Had major congenital anomaly
8 Were included in another extubation study
2 Had gestational age ≥36 wk
14 Were extubated to no support
13 Received palliative care
10 Were extubated at another hospital
477 Were eligible
174 Did not undergo randomization
77 Were not approached
34 Had consent declined
28 Had medical reasons
19 Were unable to have consent provided for social reasons
10 Had unplanned extubation
6 Had consent provided but did not undergo randomization
3 Died before randomization
2 Had consent withdrawn
1 Missed randomization
303 Underwent randomization
152 Were assigned to high-flow nasal cannulae
151 Were assigned to nasal CPAP
152 Were included in primary analysis
151 Were included in primary analysis



No. at Risk								
High-flow nasal cannulae	152	120	116	107	104	103	102	100
Nasal CPAP	151	122	119	118	117	113	112	112

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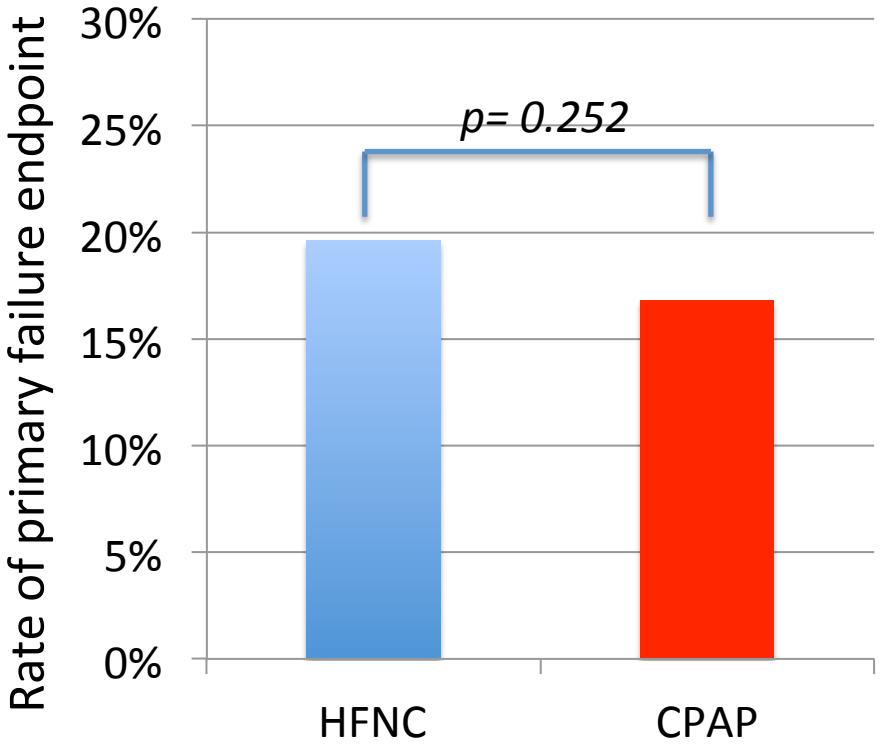
- Manley BJ, et al. NEJM 2013
  - HFNC vs Nasal CPAP
- Collins CL, et al. Jpeds 2013
  - HFNC vs Nasal CPAP
- Yoder BA, et al. Pediatrics 2013
  - HFNC vs Nasal CPAP
- Lavirazzi A, et al. PAS 2013
  - HFNC vs Nasal CPAP
- Miller SM, et al. J Perinatol 2010
  - HFNC (F&P) vs HFNC (Vapotherm)

- Pooled analysis
- 4 RCTs
- 998 patients
- HFNC: 510 patients
- CPAP: 488 patients
- Primary outcome: treatment failure



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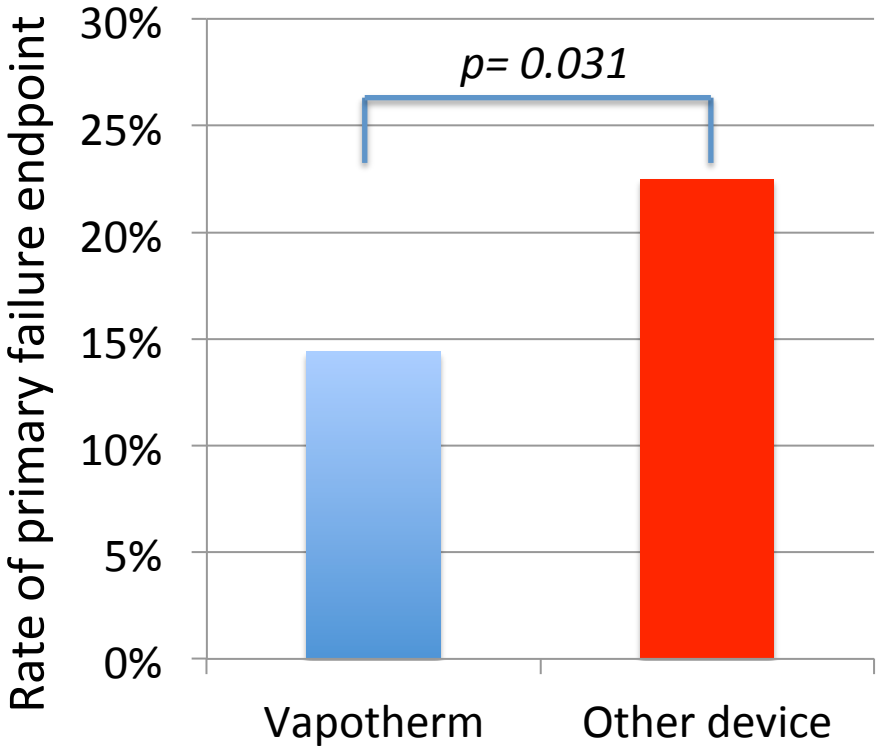
- Pooled analysis
- 5 RCTs
- 510 patients on HFNC
- Vapotherm: 181 pts
- F&P: 312 pts
- Hudson RCI: 17 pts
- Primary outcome: treatment failure



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Patient Tolerance and Comfort during HFNC Therapy

High flow cannula provides:

- Simple interface
- Improved comfort / tolerance
- Less skin trauma
- Ability to resume enteral feeds
- Decreased care demands

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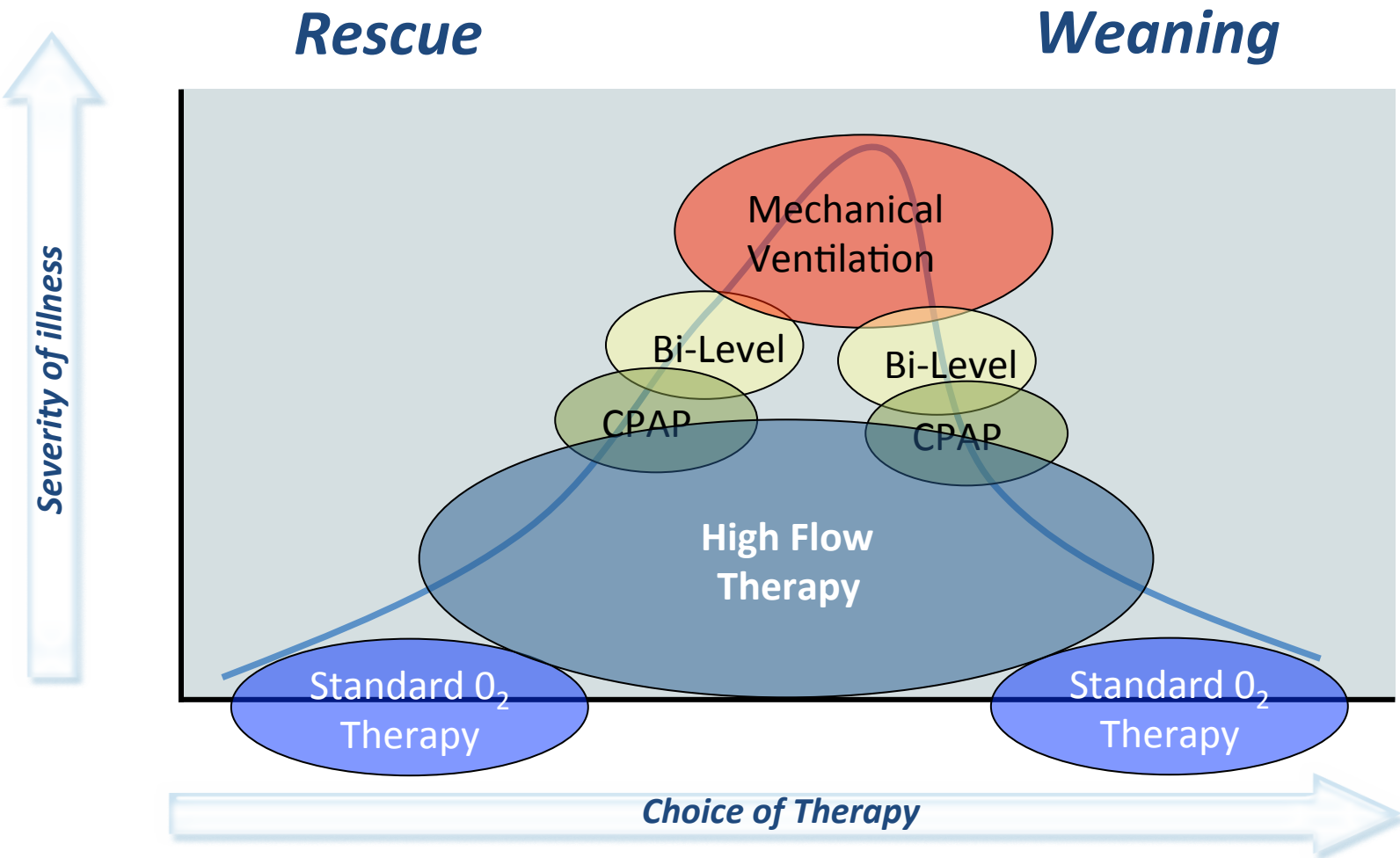
Continuum of Care



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Questions?

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