Nuts and Bolts of Bubble Nasal C P A P

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C P A P

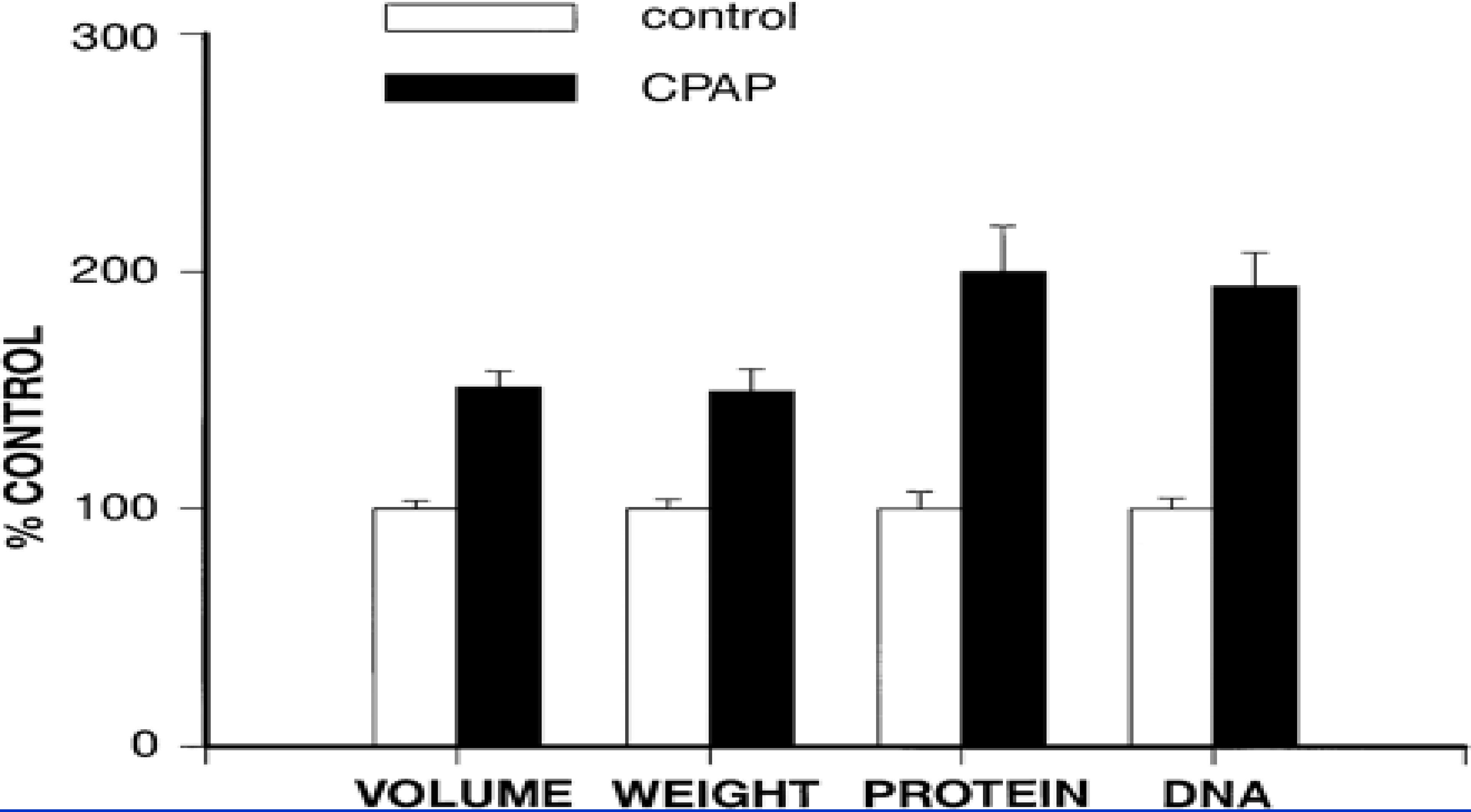
Continuous Positive Airway Pressure

- To a spontaneous breathing patient, a positive pressure is applied to the airways throughout the respiratory cycle
- Nasal CPAP has been used at Columbia University NICU since 1973 for >20,000 infants

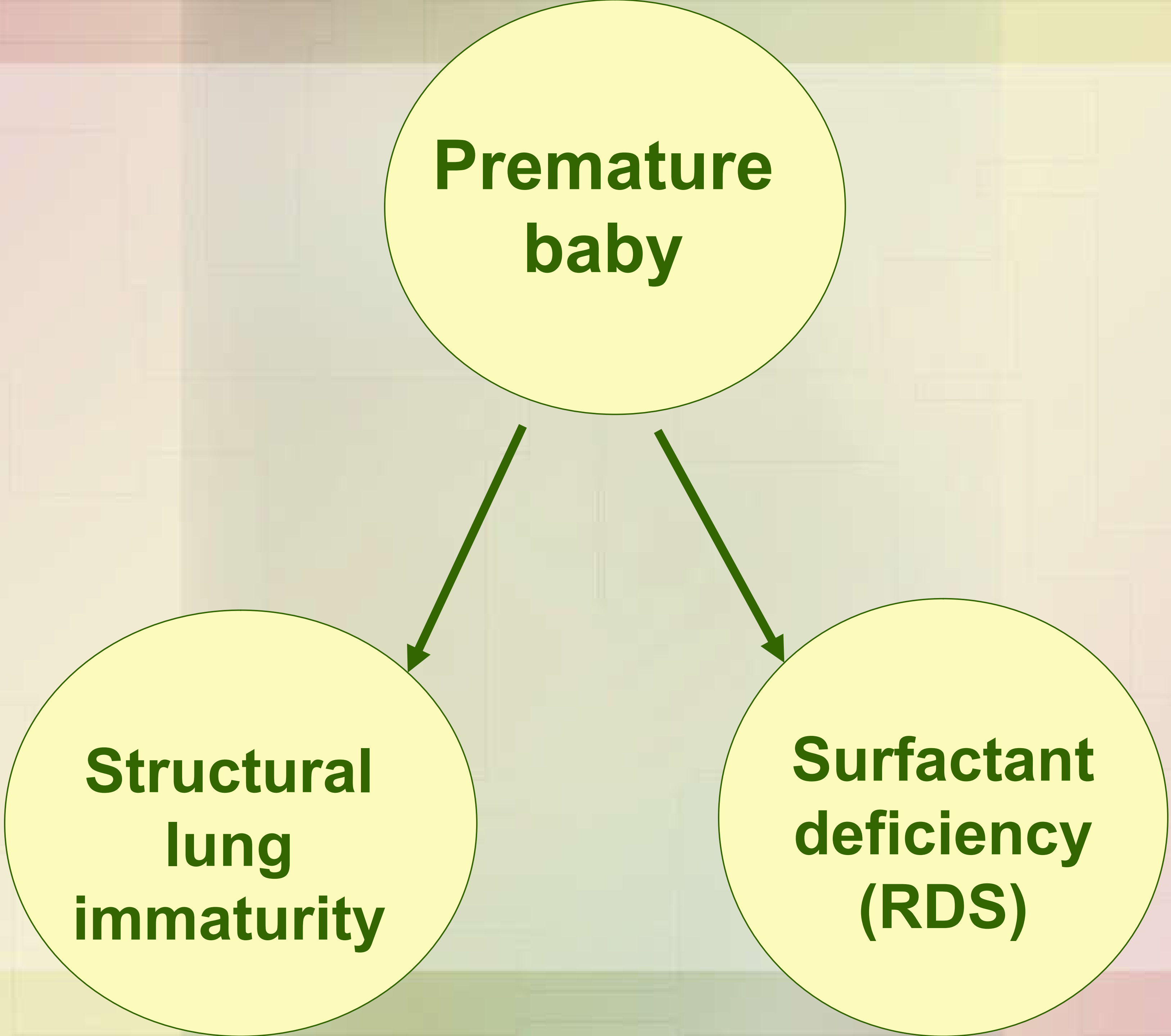
CPAP

Effects

1. Increases transpulmonary pressure and functional residual capacity (FRC)
2. Prevents alveolar collapse, decreases intrapulmonary shunt and improves lung compliance
3. Conserves surfactant
4. Prevents pharyngeal wall collapse
5. Stabilizes the chest wall
6. Increases airway diameter and splints the airways
7. Splints the diaphragm
8. Stimulates lung growth
9. Bubble CPAP has HFV effect/stochastic resonance

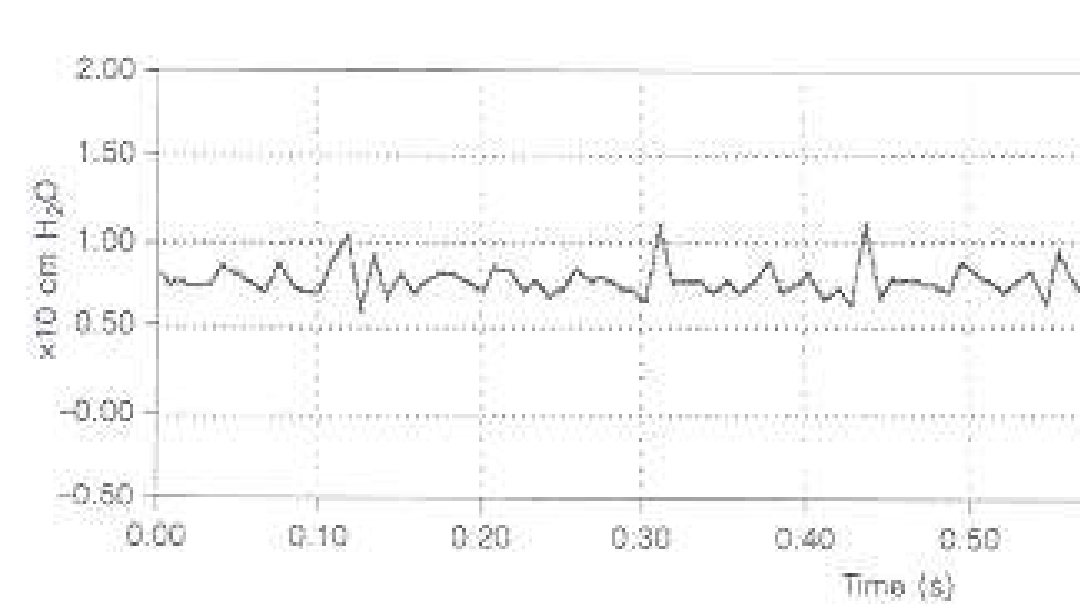


Lung volume, lung weight, and protein and DNA contents at end of study were higher in CPAP-exposed than in control animals (all *P* < 0.01). Strain-induced growth of the immature lung. Zhang S. et al. J. Appl Physiol 1996;81:1471-6


Premature baby
Structural lung immaturity
Surfactant deficiency (RDS)

CPAP

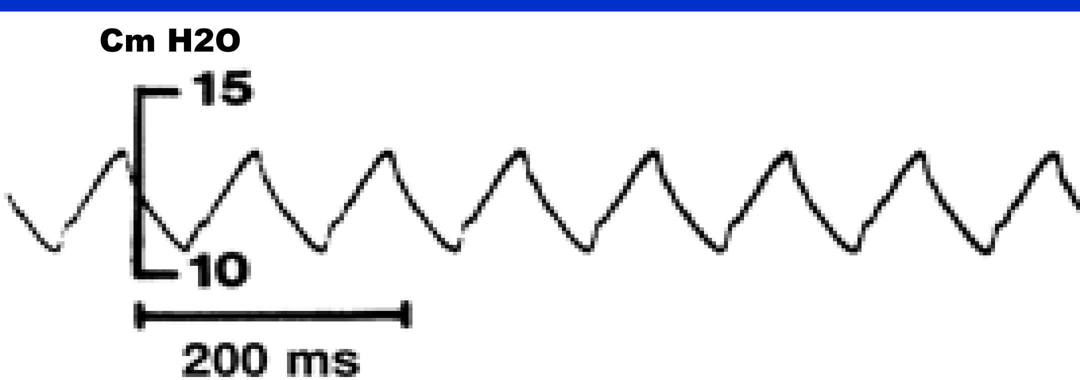
- CPAP is not just for RDS
- CPAP stimulates the growth of premature lung
- We keep the premature infants on CPAP, even on room air CPAP, as long as they are symptomatic (e.g., tachypnea, retraction or apnea & bradycardia.)



Waveform produced at airway with underwater **Bubble CPAP**

Amplitude 2-4 cm H2O, Frequency 15-30 Hz

Lee K-S et al: Biol Neonate 73: 69-75, 1998



Waveform produced at airway with **HFOV (Sensormedics)**

Set I-time 0.3
Set Frequency 10 Hz

Thome U: J Appl Physiol: 84(5):1520-7, 1998

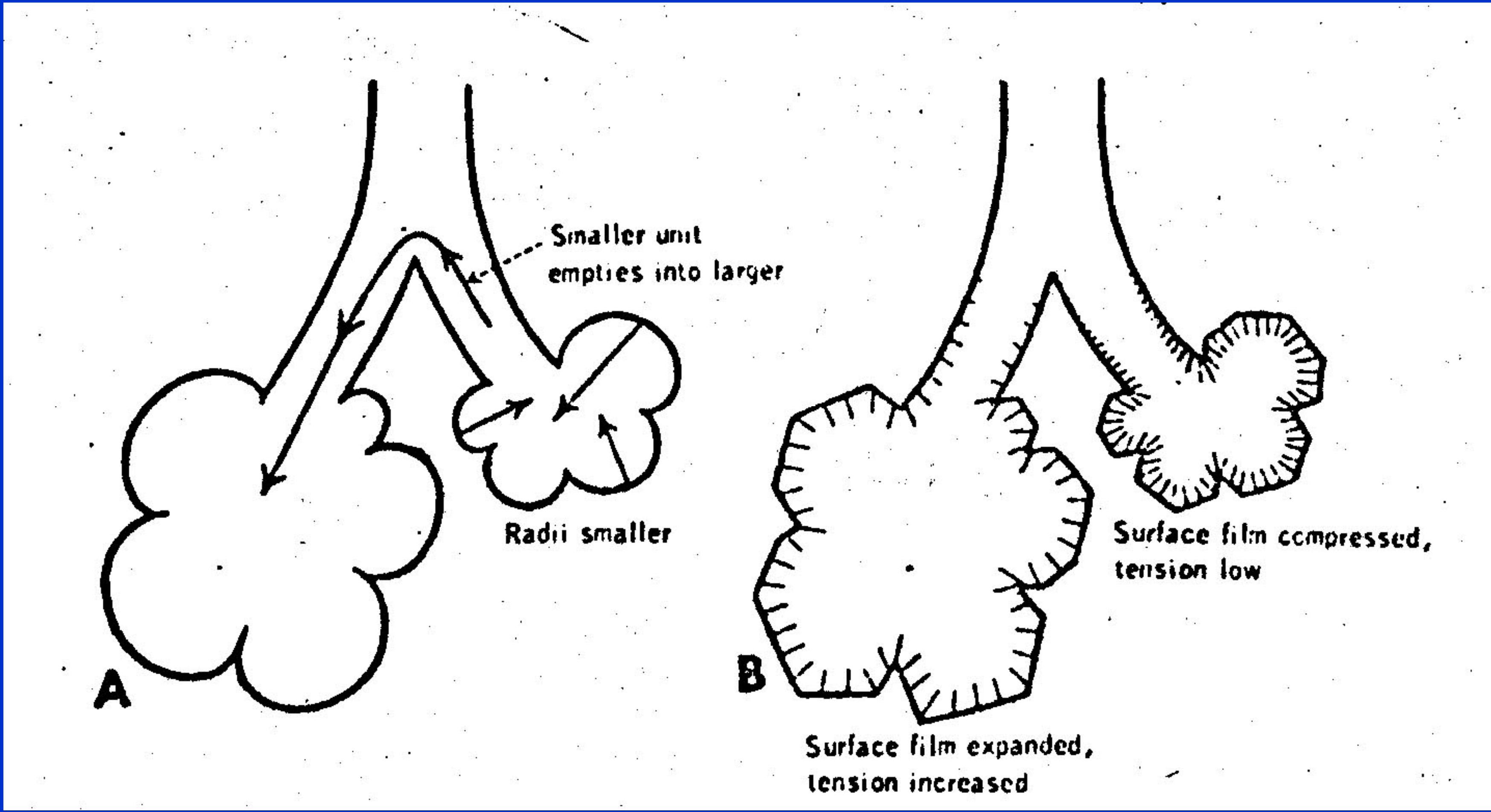
C P A P

Indication

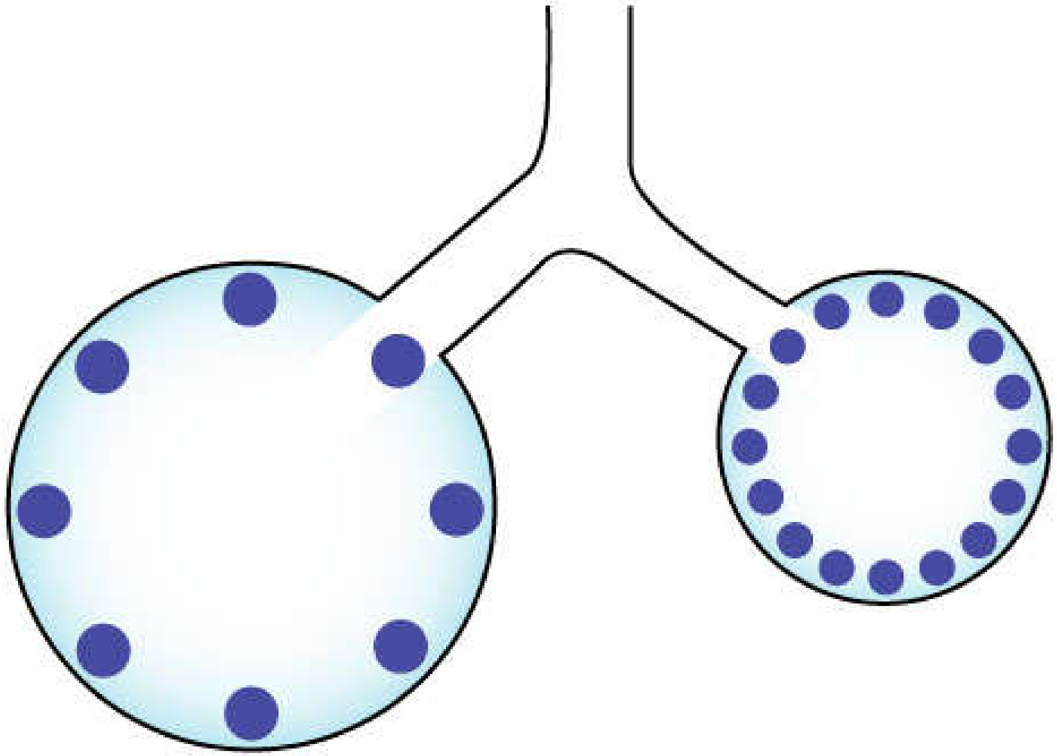
1. Diseases with low FRC, e.g. RDS, TTN, CPIP, PDA, pulmonary edema, etc.
2. Apnea and bradycardia of prematurity
3. Meconium aspiration syndrome (MAS)
4. Airway closure disease, e.g. bronchiolitis, BPD
5. Tracheomalacia
6. Partial paralysis of diaphragm
7. Respiratory support after extubation

Effect of alveolar radius and surface tension on alveolar stability w/ and w/o surfactant

Law of LaPlace P = 2 T/r



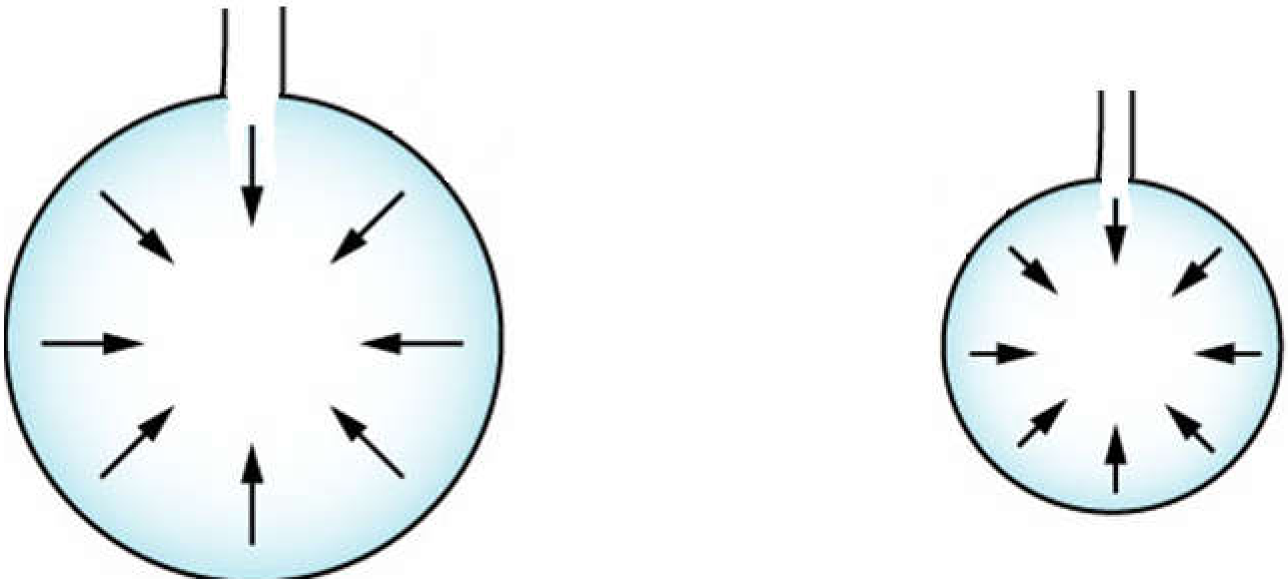
Surfactant reduces surface tension (T). Pressure is equalized in the large and small alveoli



r = 2	r = 1
T = 2	T = 1
P = (2 x 2)/2	P = (2 x 1)/1
P = 2	P = 2

Law of LaPlace : P = 2T/r

P : pressure   T : surface tension   r : radius



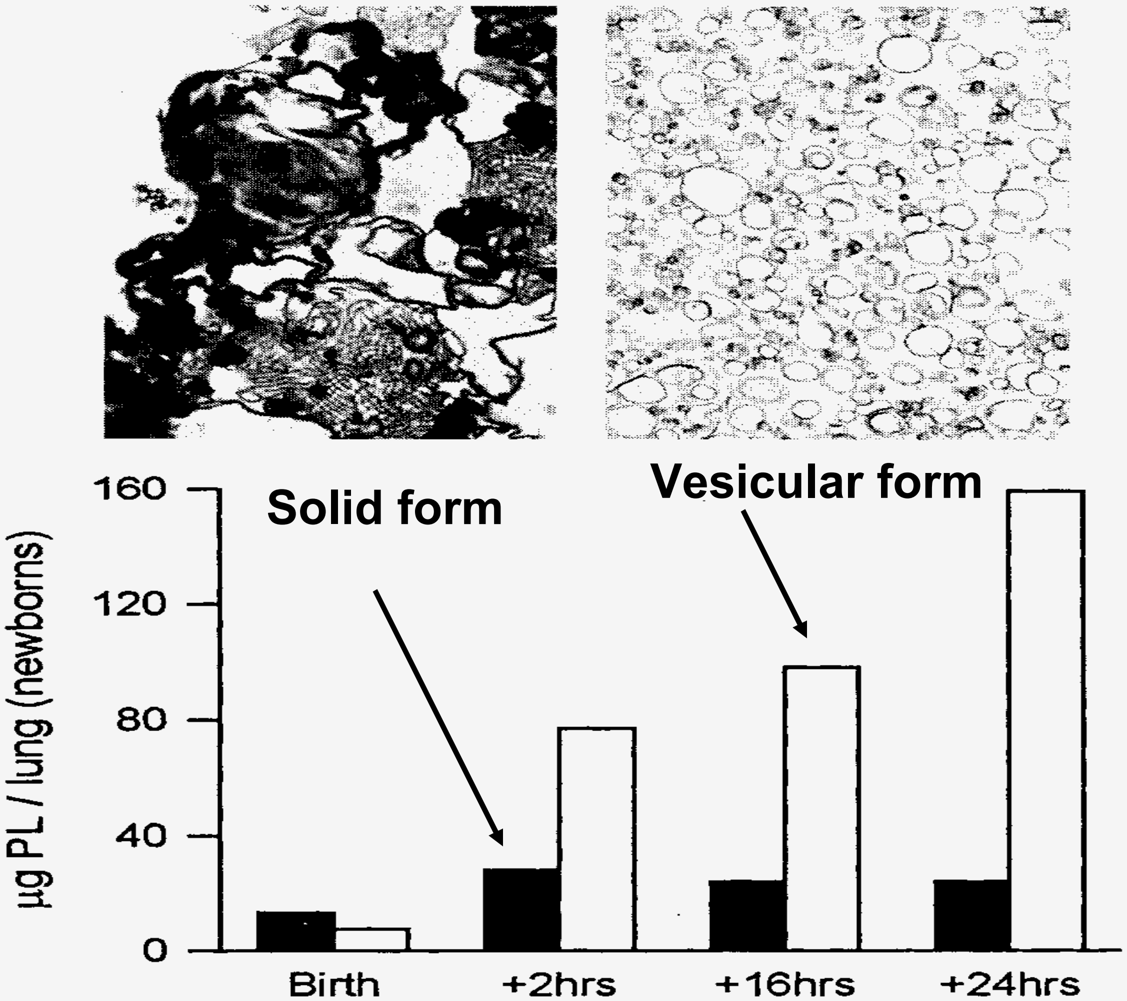
Larger alveolus
r = 2
T = 3
P = (2 x 3) / 2
P = 3

CPAP ←

Smaller alveolus
r = 1
T = 3
P = (2 x 3) / 1
P = 6

Natural response of surfactant producing cells to birth

Spain CL et.al. Ped. Research, 1987



At onset of breathing, amount of surfactant pool increases significantly

C P A P

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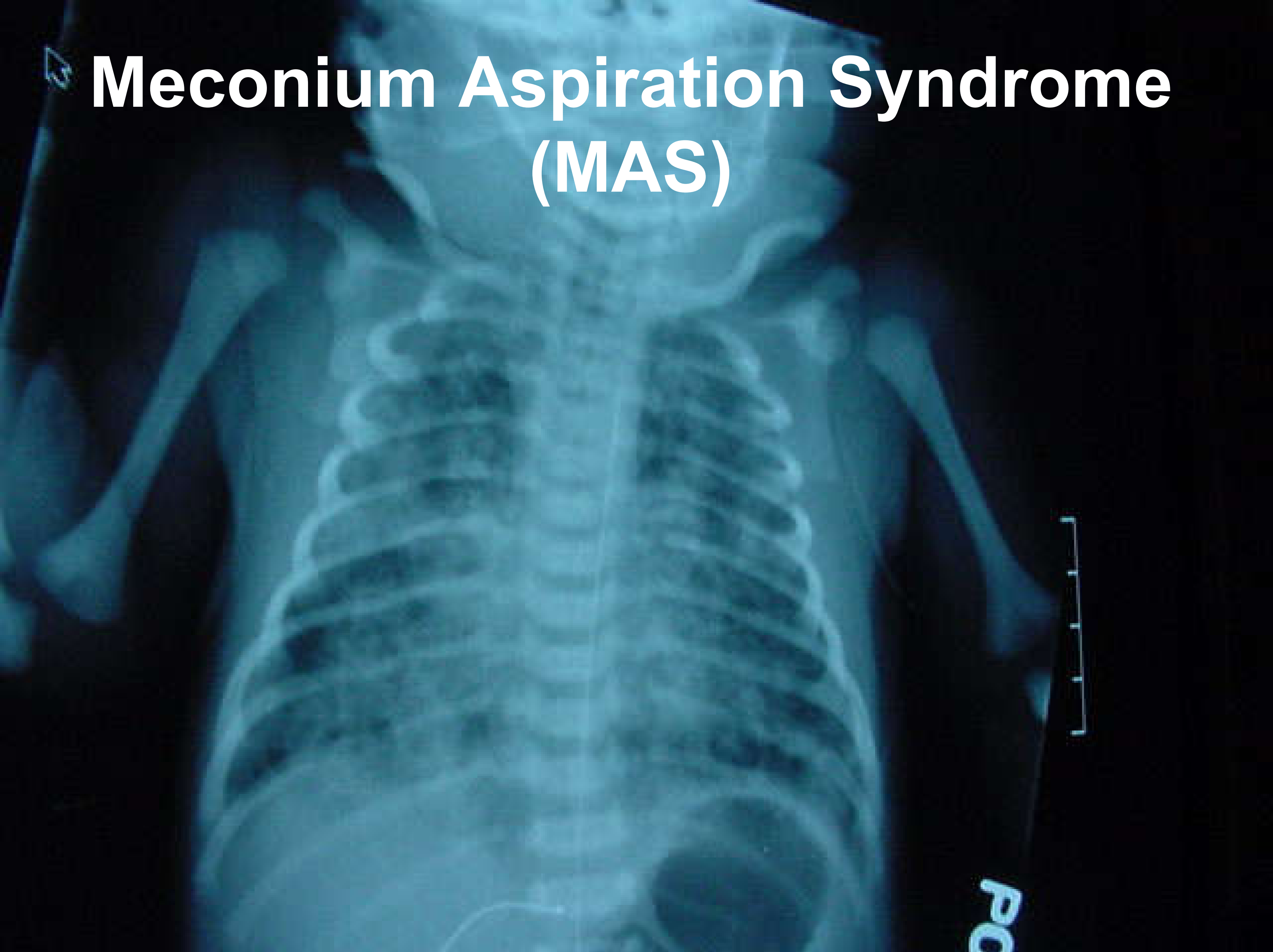
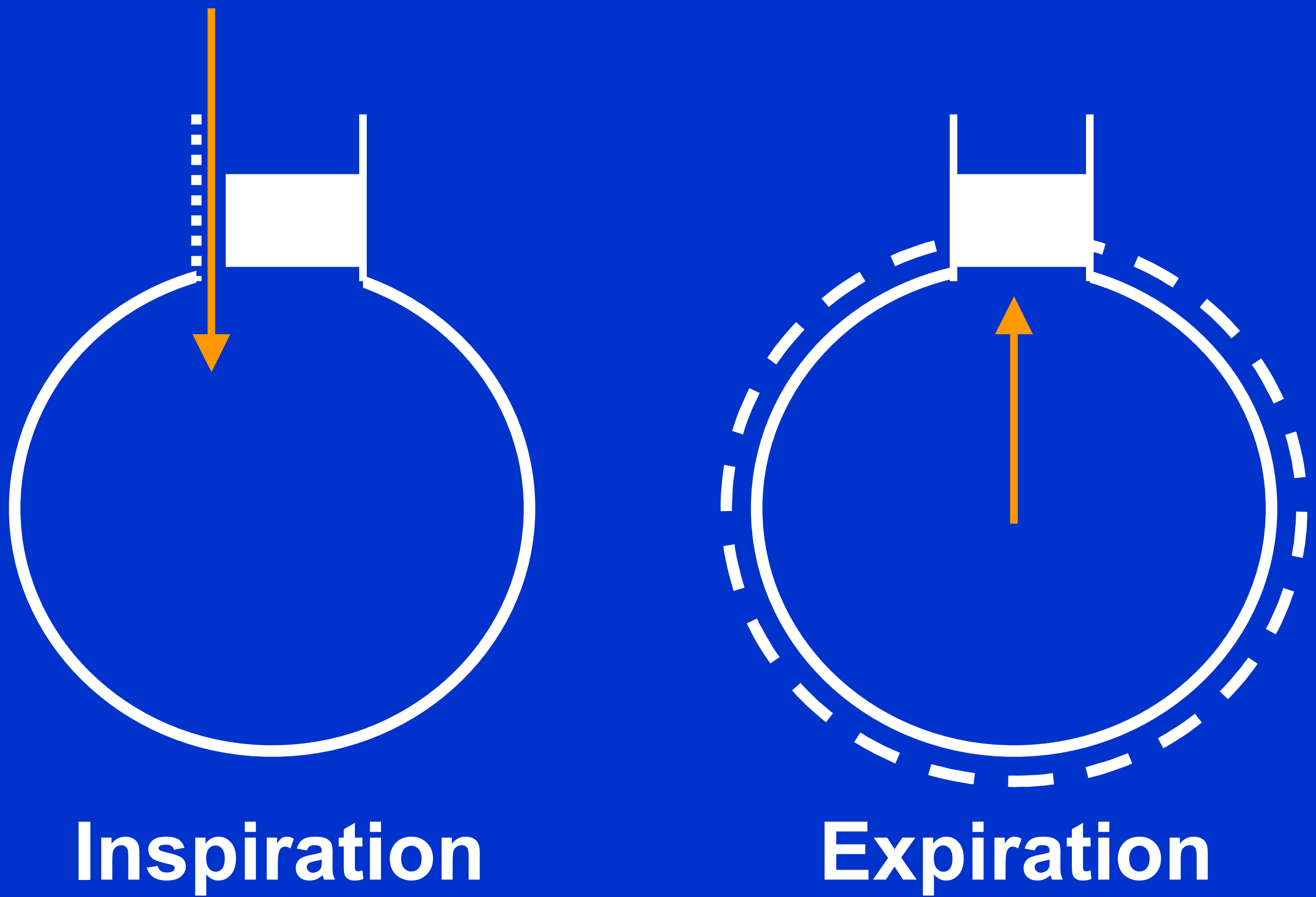
Meconium Aspiration Syndrome (MAS)



Meconium Aspiration Syndrome (MAS)



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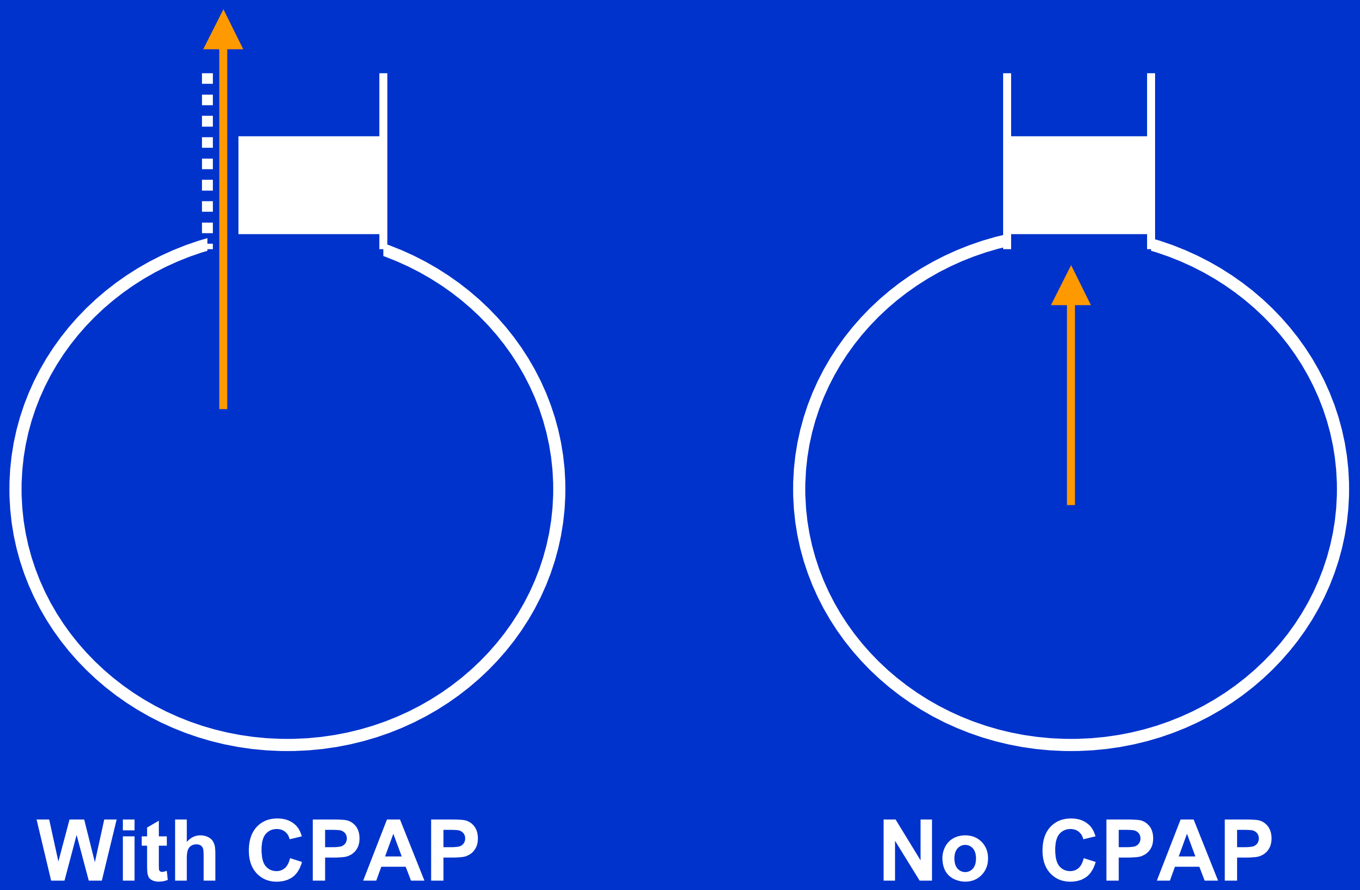
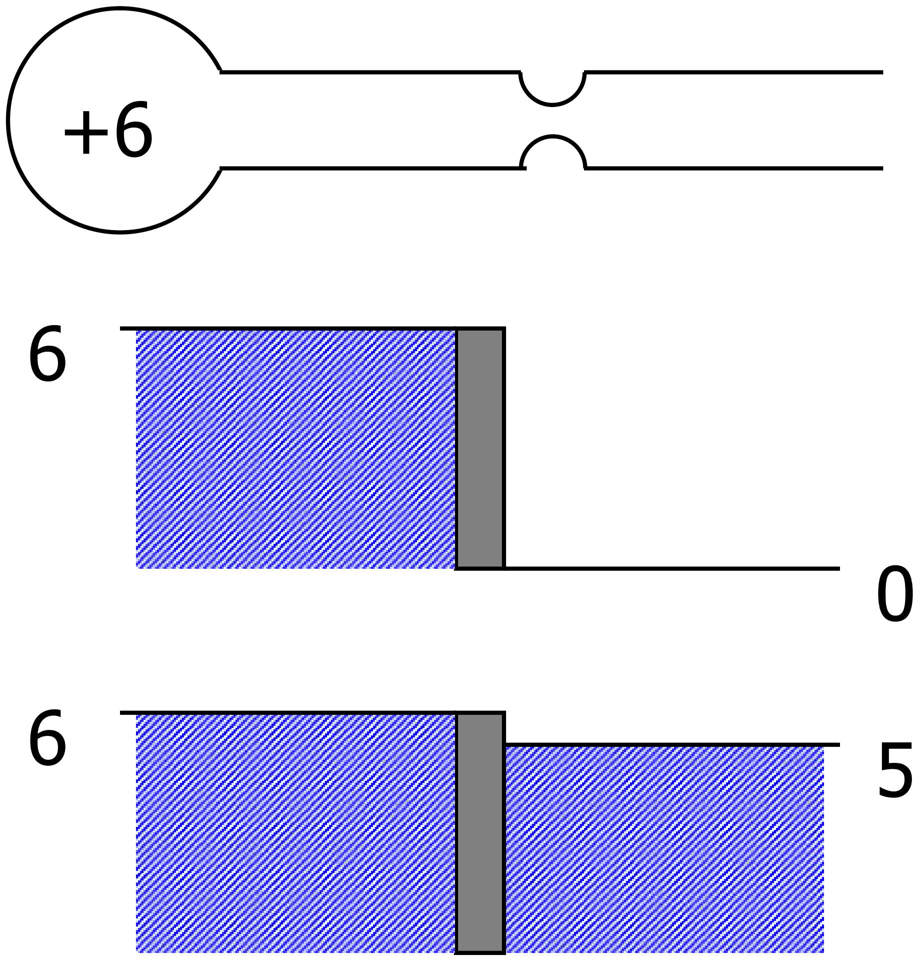


Waterfall Effect



C P A P

Indication

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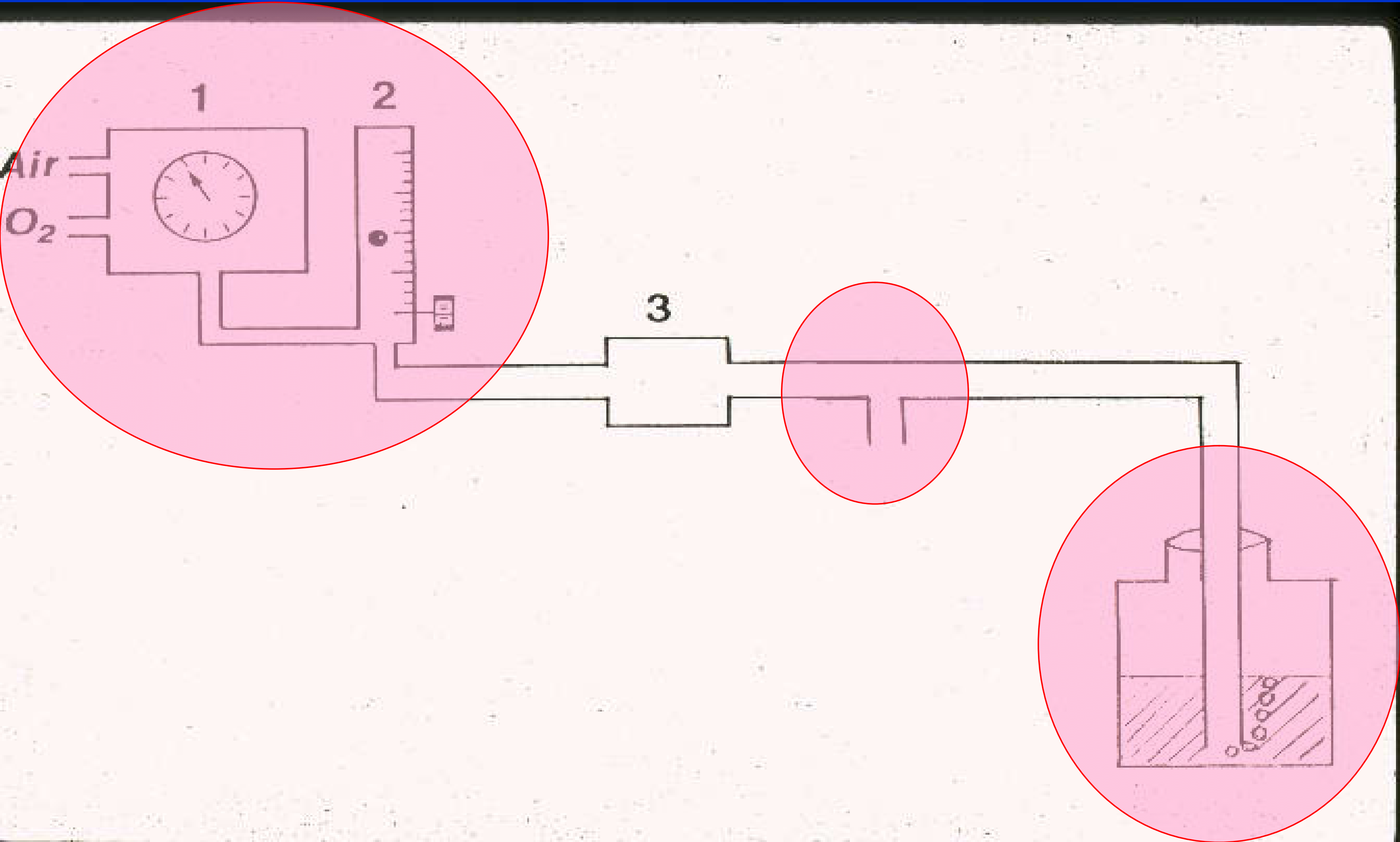
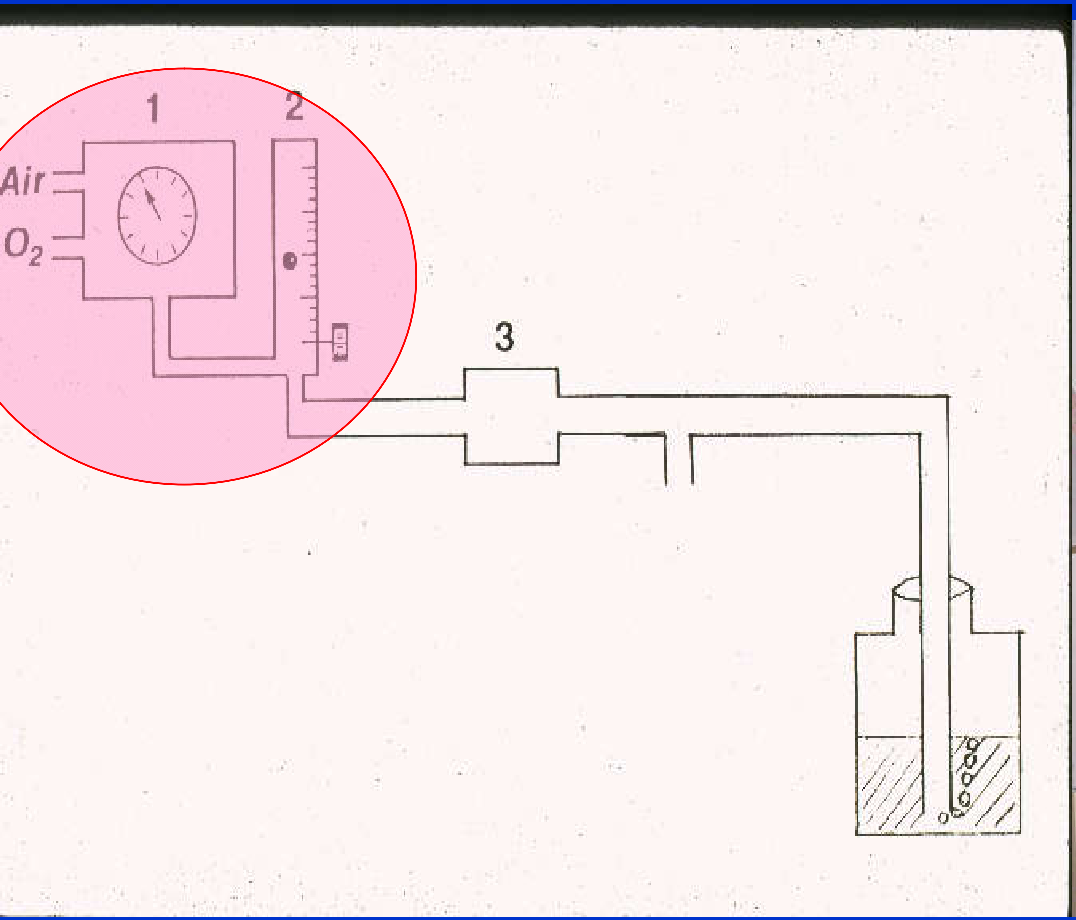
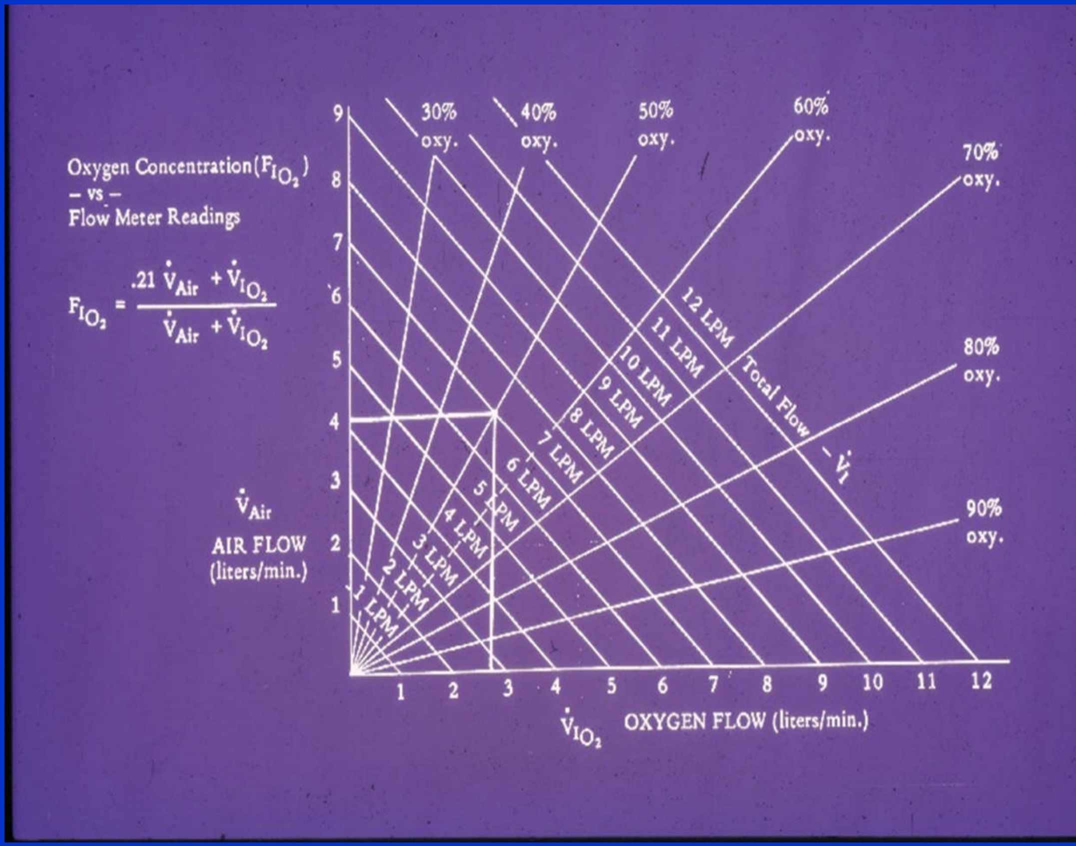
CPAP Device

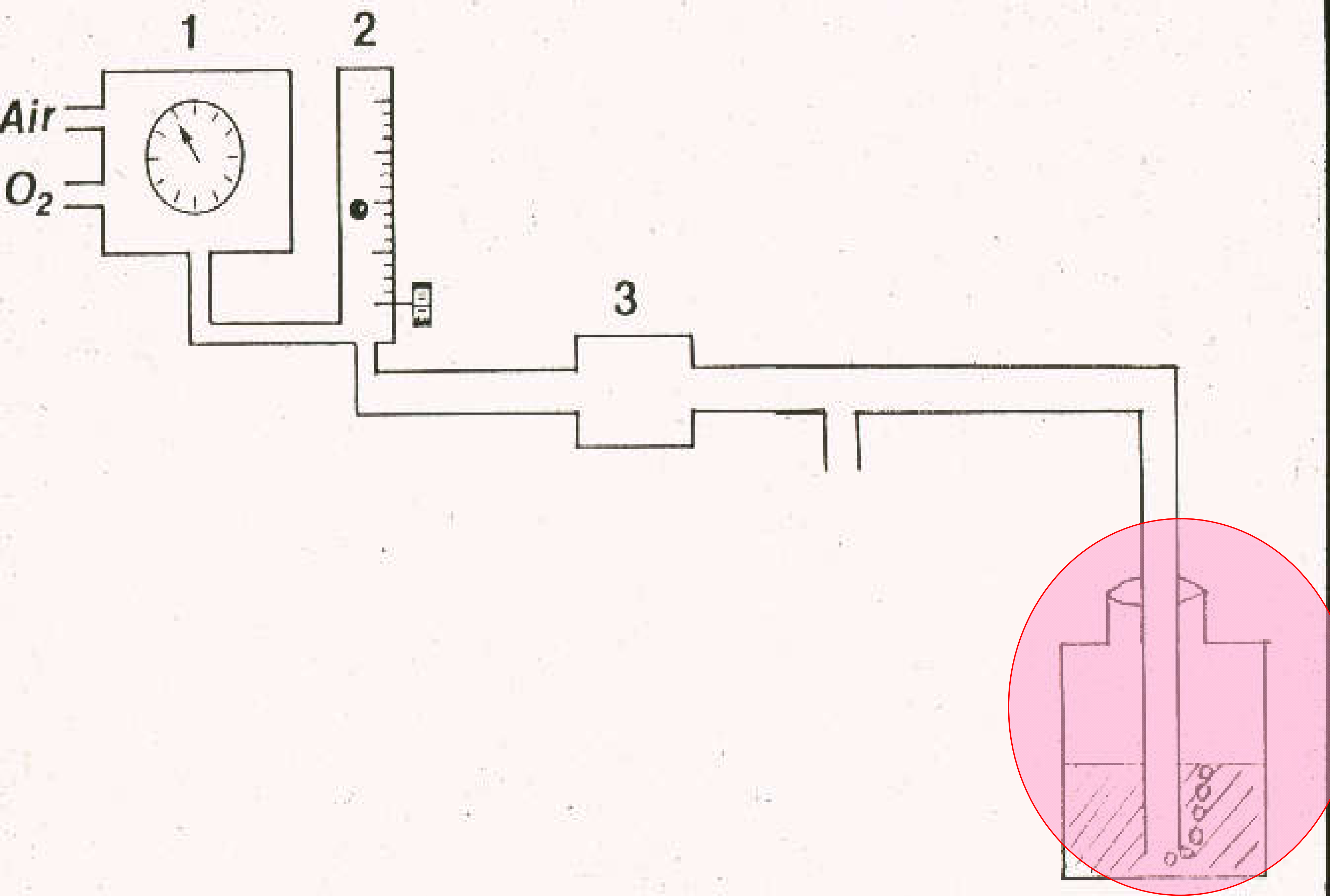



1
2
Air
O_2
3


Low Flow
Air/O_2 Blender


MEDICAL AIR
OXYGEN
PRECISION
PURITAN
BEACON MEDICAL PRODUCTS
USE NO OIL


Oxygen Concentration (F_{IO_2})
– vs –
Flow Meter Readings
$F_{IO_2} = \frac{.21\ \dot{V}_{Air} + \dot{V}_{IO_2}}{\dot{V}_{Air} + \dot{V}_{IO_2}}$
30% oxy.
40% oxy.
50% oxy.
60% oxy.
70% oxy.
80% oxy.
90% oxy.
1 LPM
2 LPM
3 LPM
4 LPM
5 LPM
6 LPM
7 LPM
8 LPM
9 LPM
10 LPM
11 LPM
12 LPM
Total Flow – $\dot{V}_I$
$\dot{V}_{Air}$
AIR FLOW
(liters/min.)
$\dot{V}_{IO_2}$
OXYGEN FLOW (liters/min.)


1
2
3
Air
O_2

Expiratory Valves

- **Threshold resistors** – the level is determined by the force applied to the surface area of the valve. The pressure generated is independent of flow. (Water bubble CPAP)

- **Variable pressure-flow resistors** – the level of PEEP/CPAP is directly proportional to the product of the gas flow through the orifice of the expiratory pressure valve and the resistance of the valve. (Ventilator)

Bubble-CPAP vs Ventilator-CPAP

All infants with bubble CPAP had:

- a lower minute volume with a **mean reduction in MV of 39%** (p<0.001)
- **7 % reduction in respiratory rate** (p=0.004)
- With no change in transcutaneous CO_2 and oxygen saturation values

Lee K-S et al: Biol Neonate 73: 69-75, 1998

Physiological Advantage of Bubble versus Ventilator-derived CPAP

- Lower $PaCO_2$
- Higher PaO_2, PH, FRC
- Less V/Q mismatch
- Lower alveolar protein

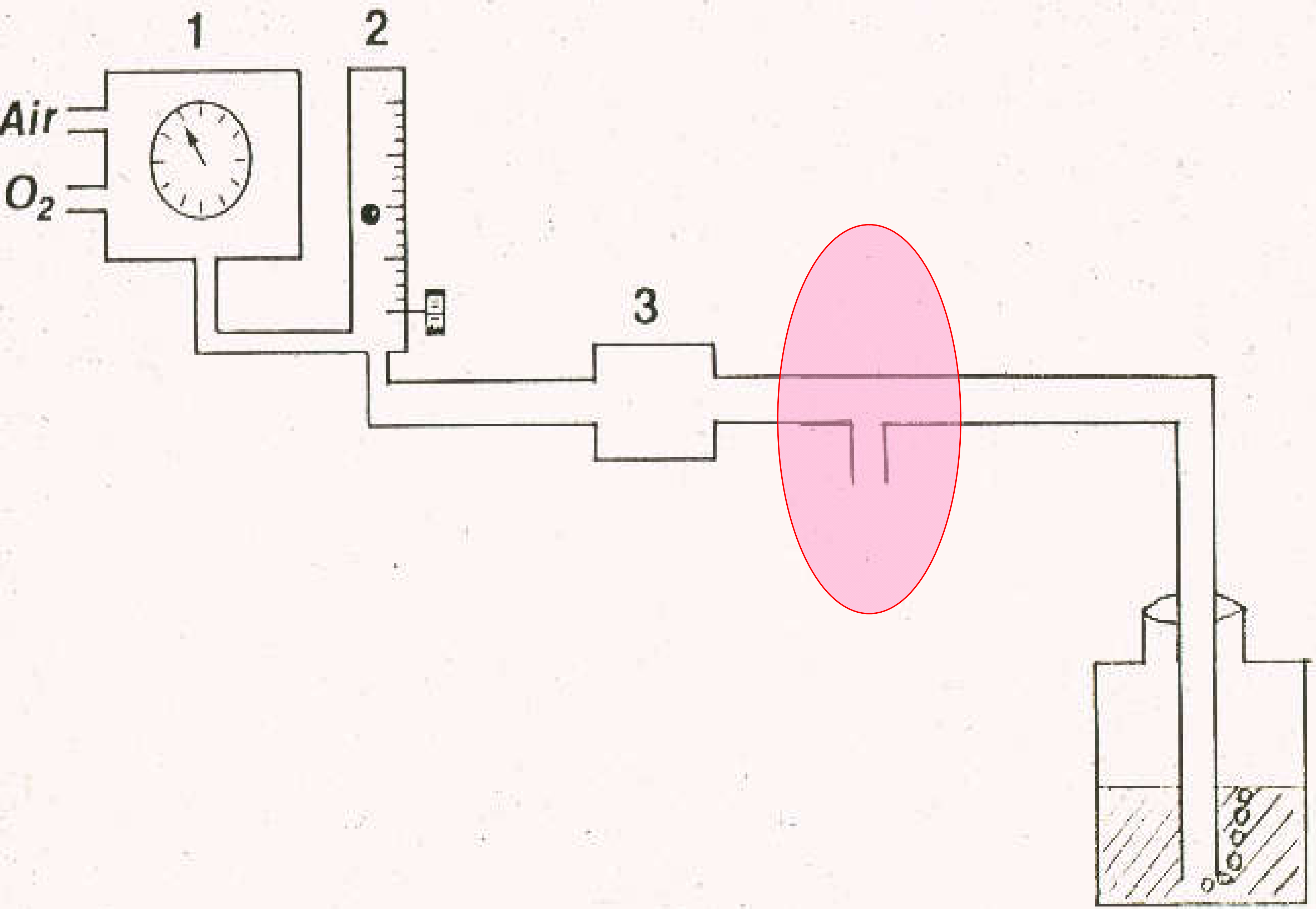
Bubble Continuous Positive Airway Pressure Enhances Lung Volume and Gas Exchange in Preterm Lambs

Jane Pillow et al. Am J Respir Crit Care Med. 2007 ; 176(1): 63–69.

B-NCPAP vs V-NCPAP

- Randomized crossover study in 18 premature infants (<1500 g) with mild respiratory distress
- Work of breathing, breathing asynchrony, respiratory rate, heart rate, tidal volume, minute ventilation, lung compliance or $TcPCO_2$ was not significantly different
- $TcPO_2$ was higher with B-NCPAP ($P=0.01$)

Courtney, SE et al.:Journal of Perinatology (2011) 31, 44–50;


1
2
Air
O2
3

CPAP Devices (Interface)

- Head hood
- Face shield
- Face mask
- Nasal mask
- Nasal prongs – Hudson, Babi-plus nCPAP
  INCA, Draeger, Fisher&Pakel, SiPAP, Arabella Infant Flow, NeoPAP
- Nasal cannula – *Vapotherm, Ram Cannula*
- Nasal pharyngeal tube
- Endotracheal tube

Not all CPAP devices are created equal

There is a learning curve for CPAP therapy

C P A P

was first described for use in newborn infants by

Professor August Ritter von Reuss

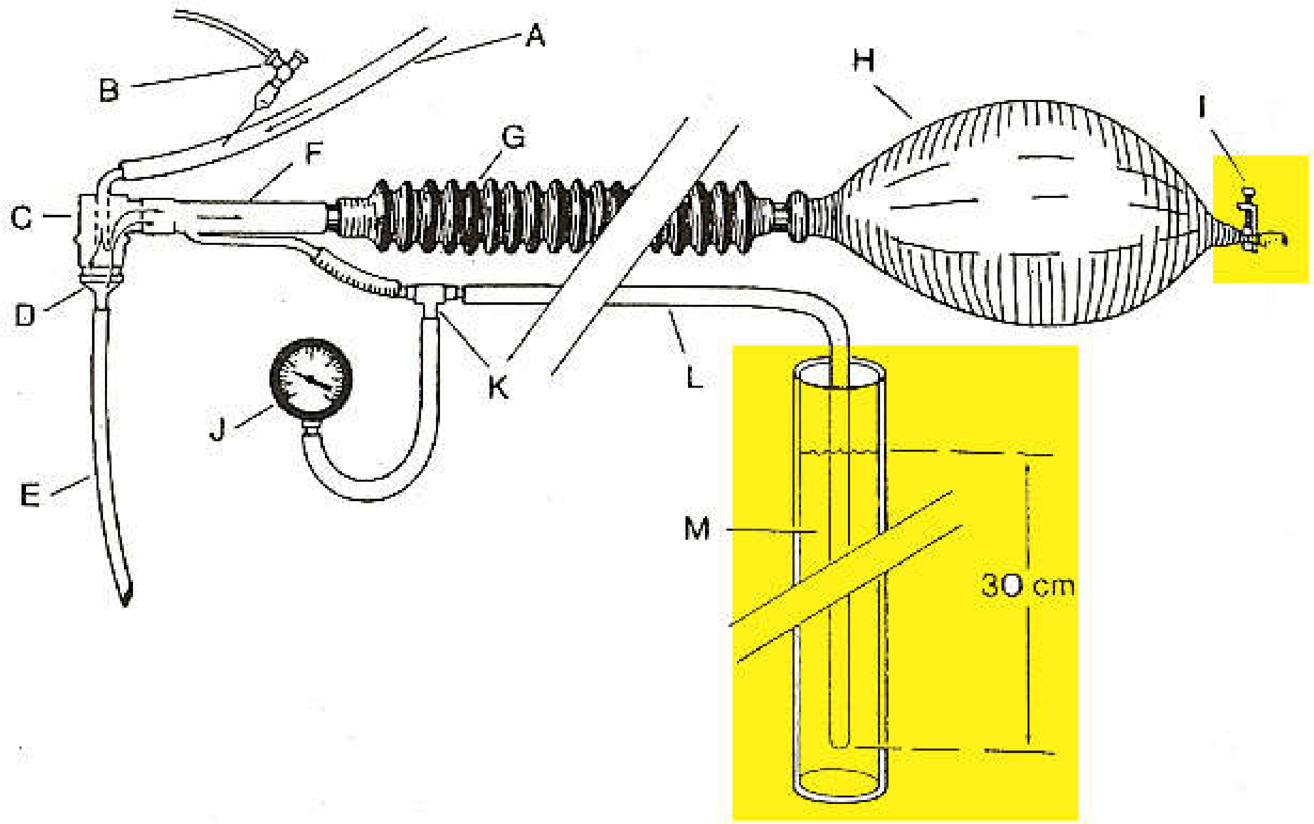
in his 1914 textbook on diseases of the newborn infant.

Treatment of idiopathic respiratory distress syndrome with continuous positive airway pressure

Weight	N	PaO_2 (pre)	PaO_2 (post)
930-1500	10	37.1	116.4
1501-2000	5	38.1	114.8
2001-3830	5	48.6	96.0

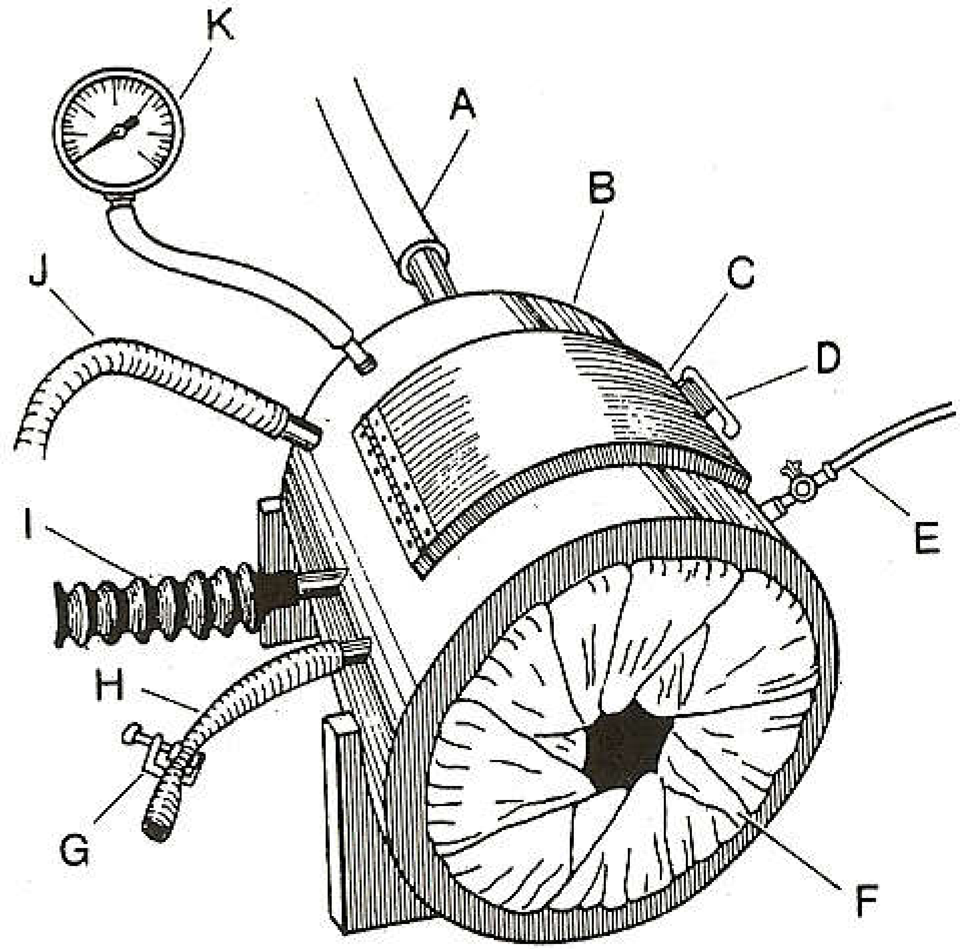
Gregory et al. N Engl J Med 284: 1333, 1971

Treatment of idiopathic respiratory distress syndrome with continuous positive airway pressure

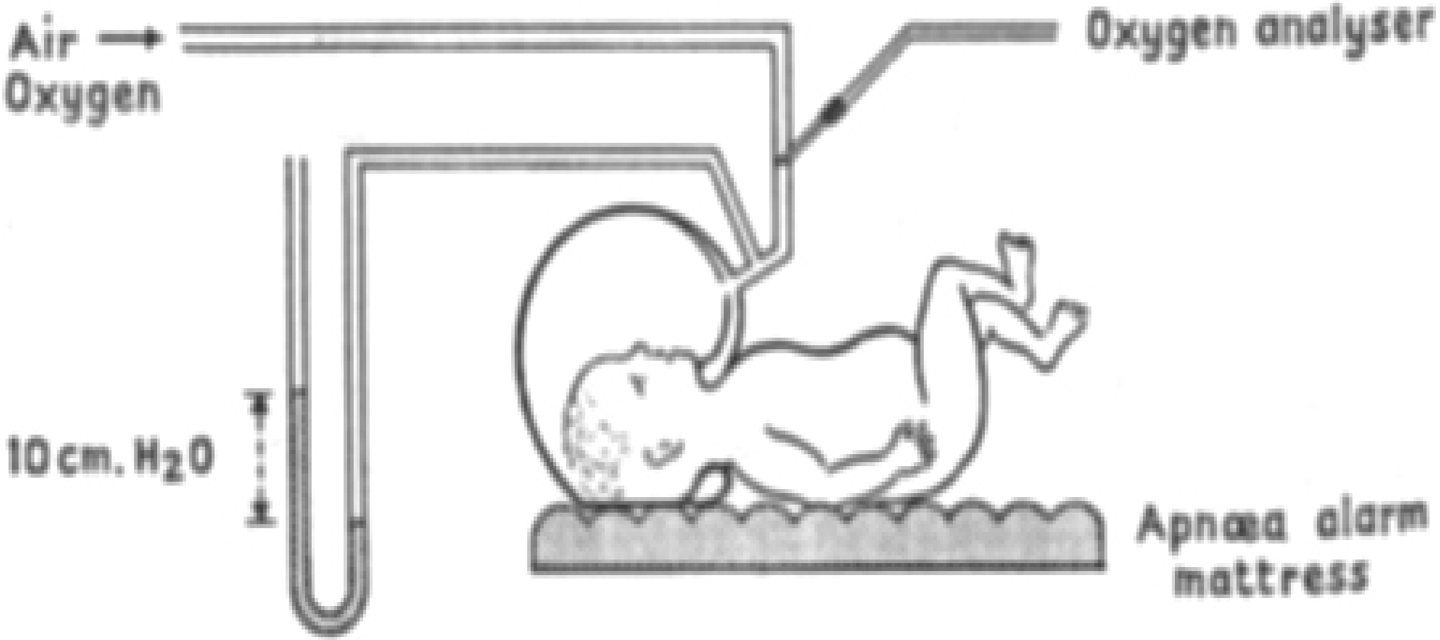


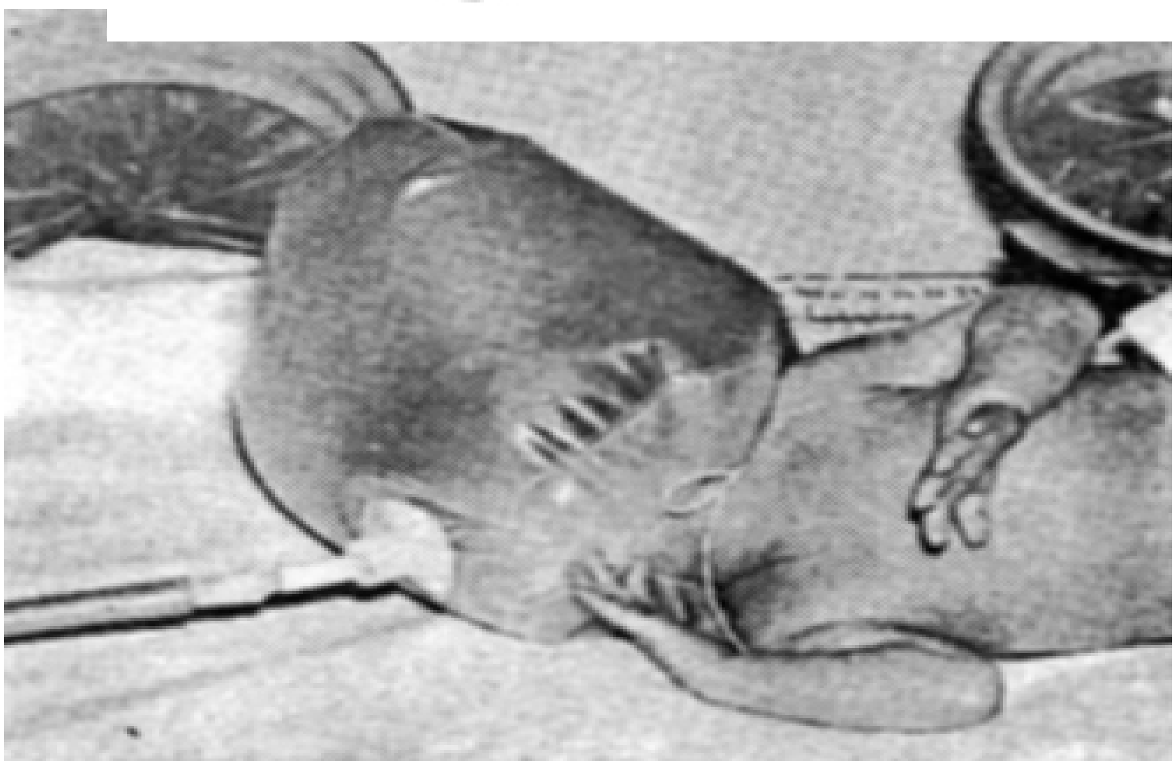
Gregory et al. N Engl J Med 284: 1333, 1971

Head Box for CPAP without Endotracheal Tube

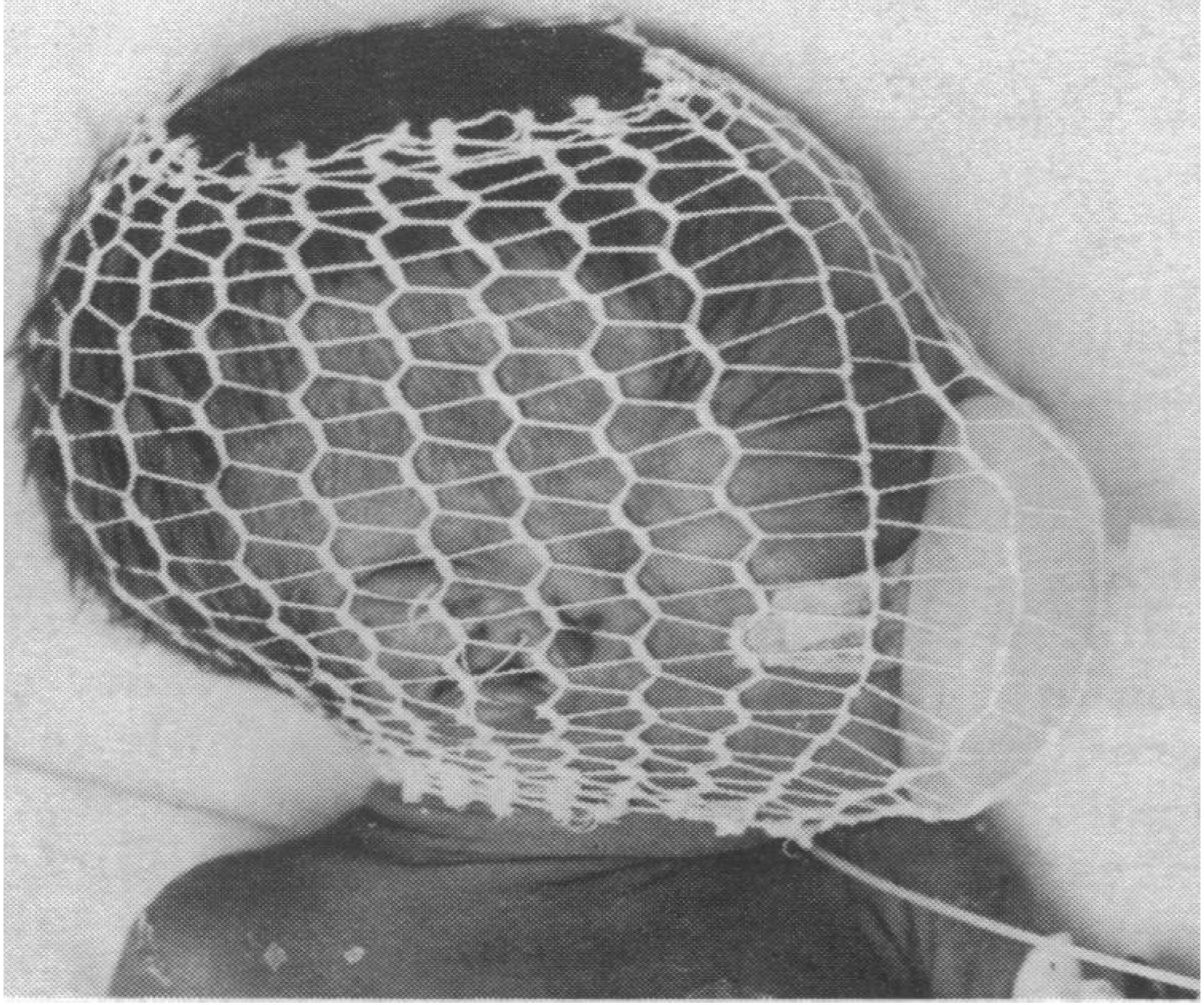


Gregory, et al., NEJM, 1971

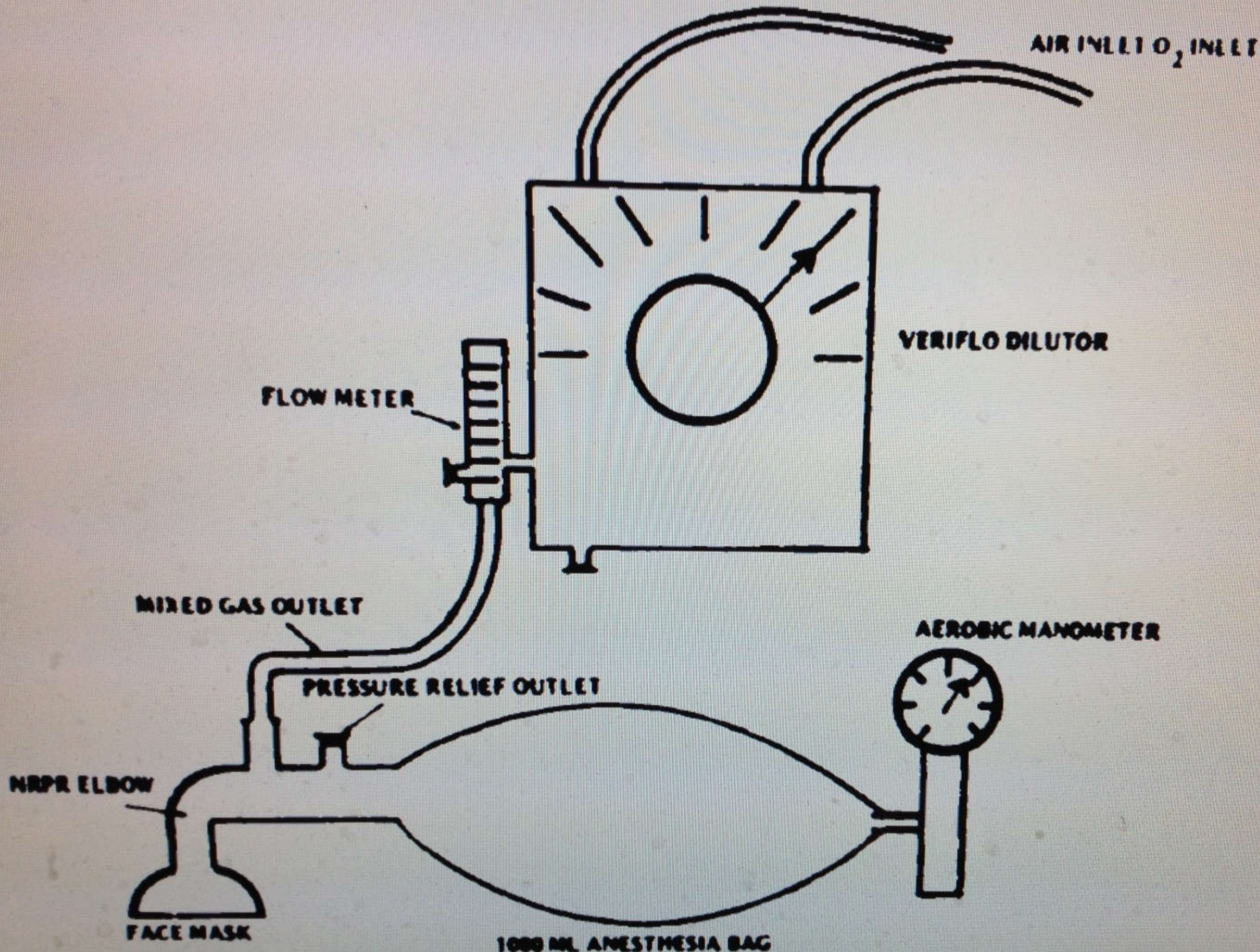




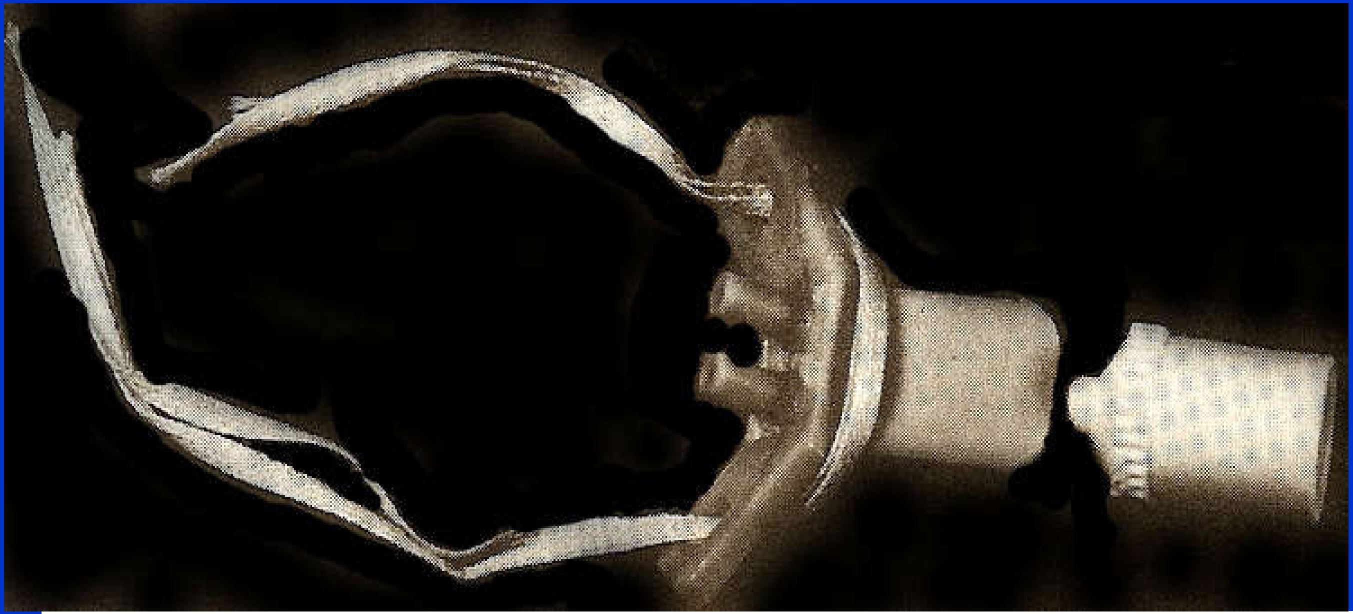
H. Barrie, Lancet, i (1972), p. 776

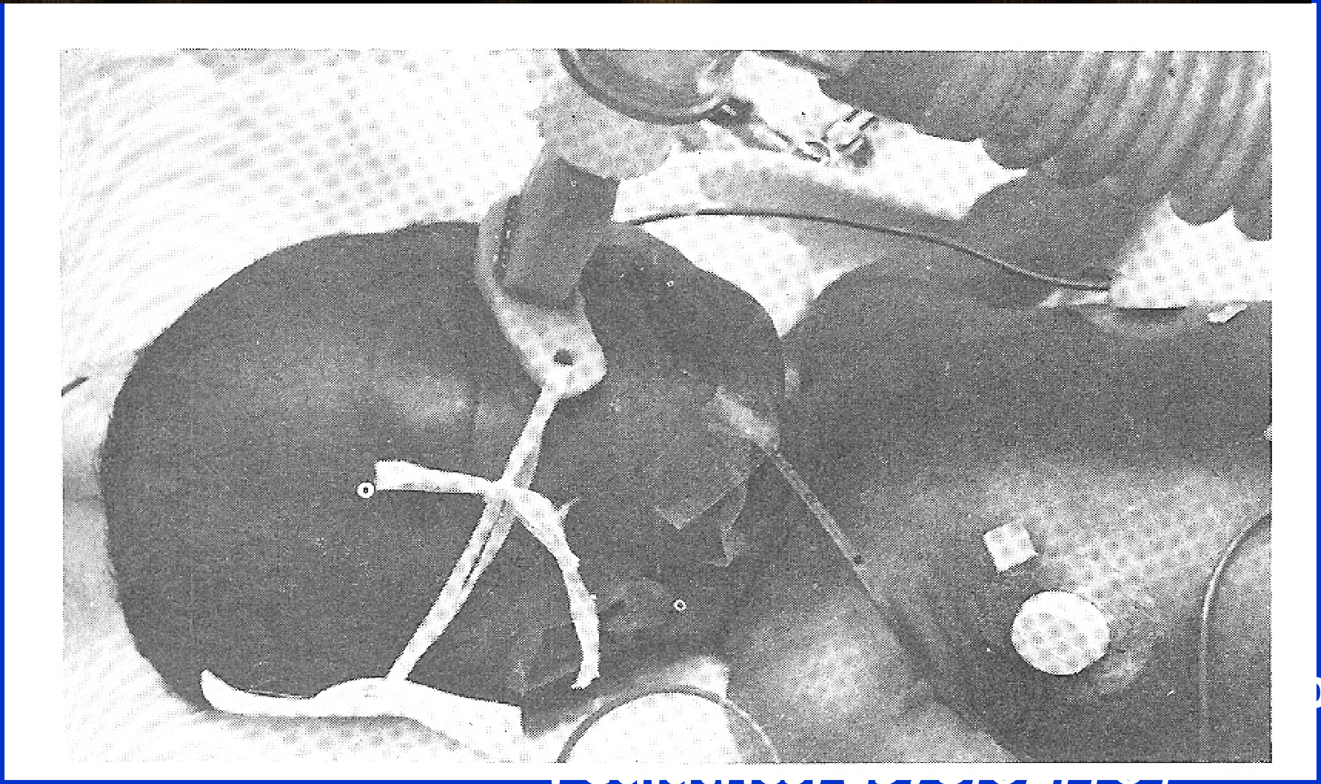


L. P. ALLEN et al
British Medical Journal, 1975, 4, 137-139

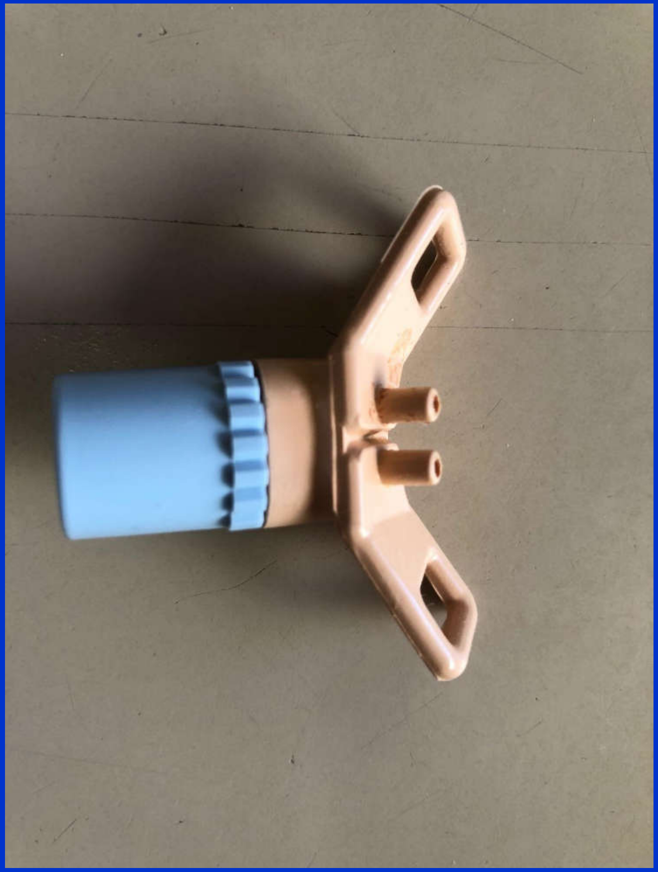


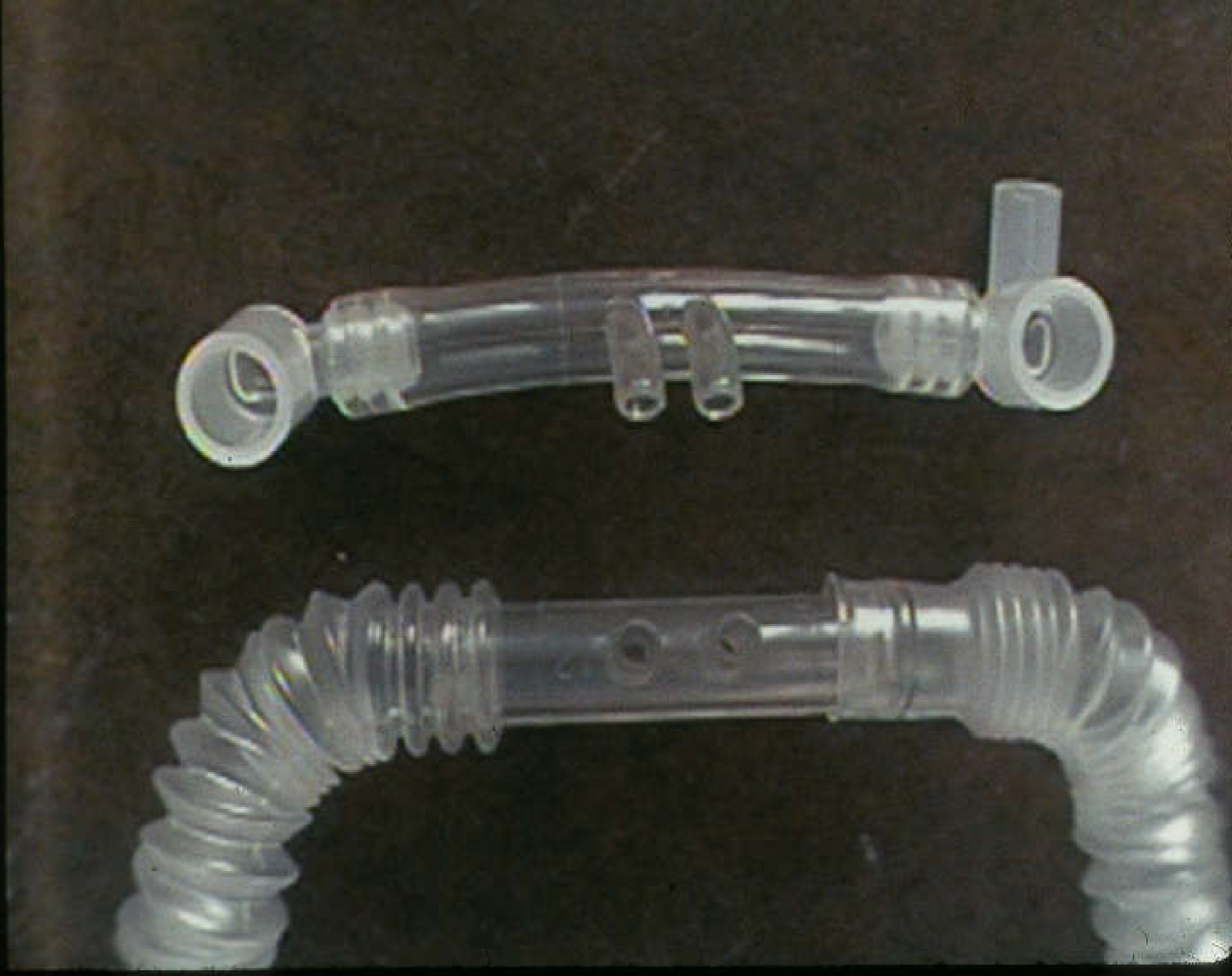
AIR INLET O2 INLET
VERIFLO DILUTOR
FLOW METER
MIXED GAS OUTLET
AEROBIC MANOMETER
PRESSURE RELIEF OUTLET
NRPR ELBOW
FACE MASK
1000 ML ANESTHESIA BAG



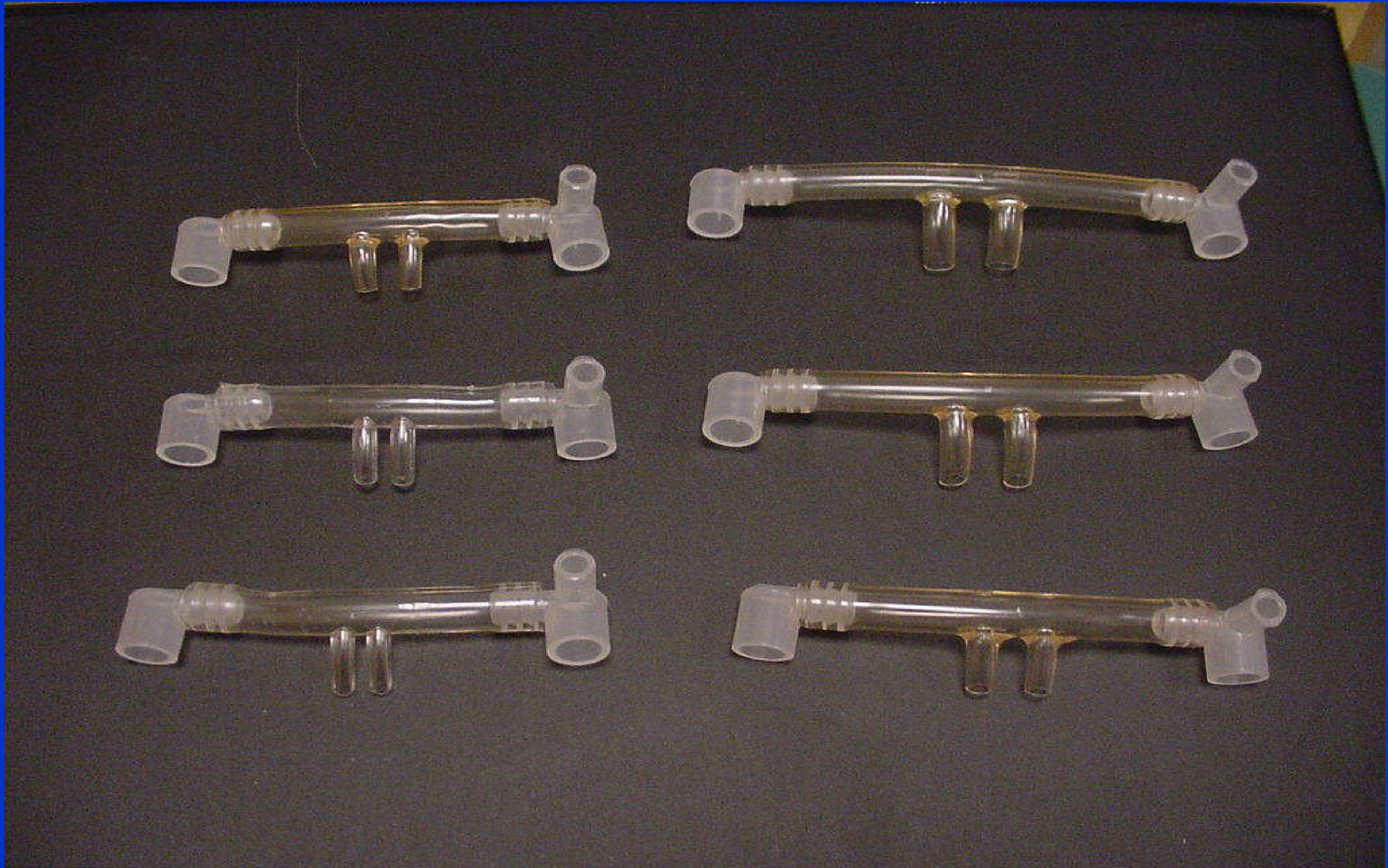


off,





CPAP Cannulae (Hudson)



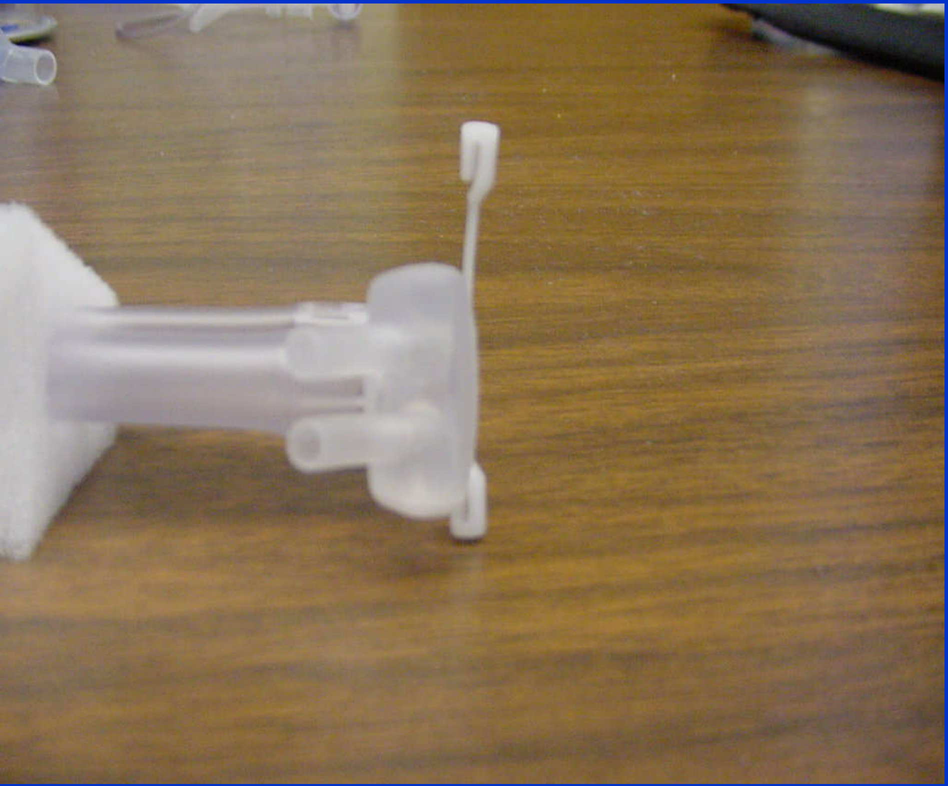
Babi-plus nCPAP

Size 7 – size 0

Made of silicone, not PVC.
latex-free

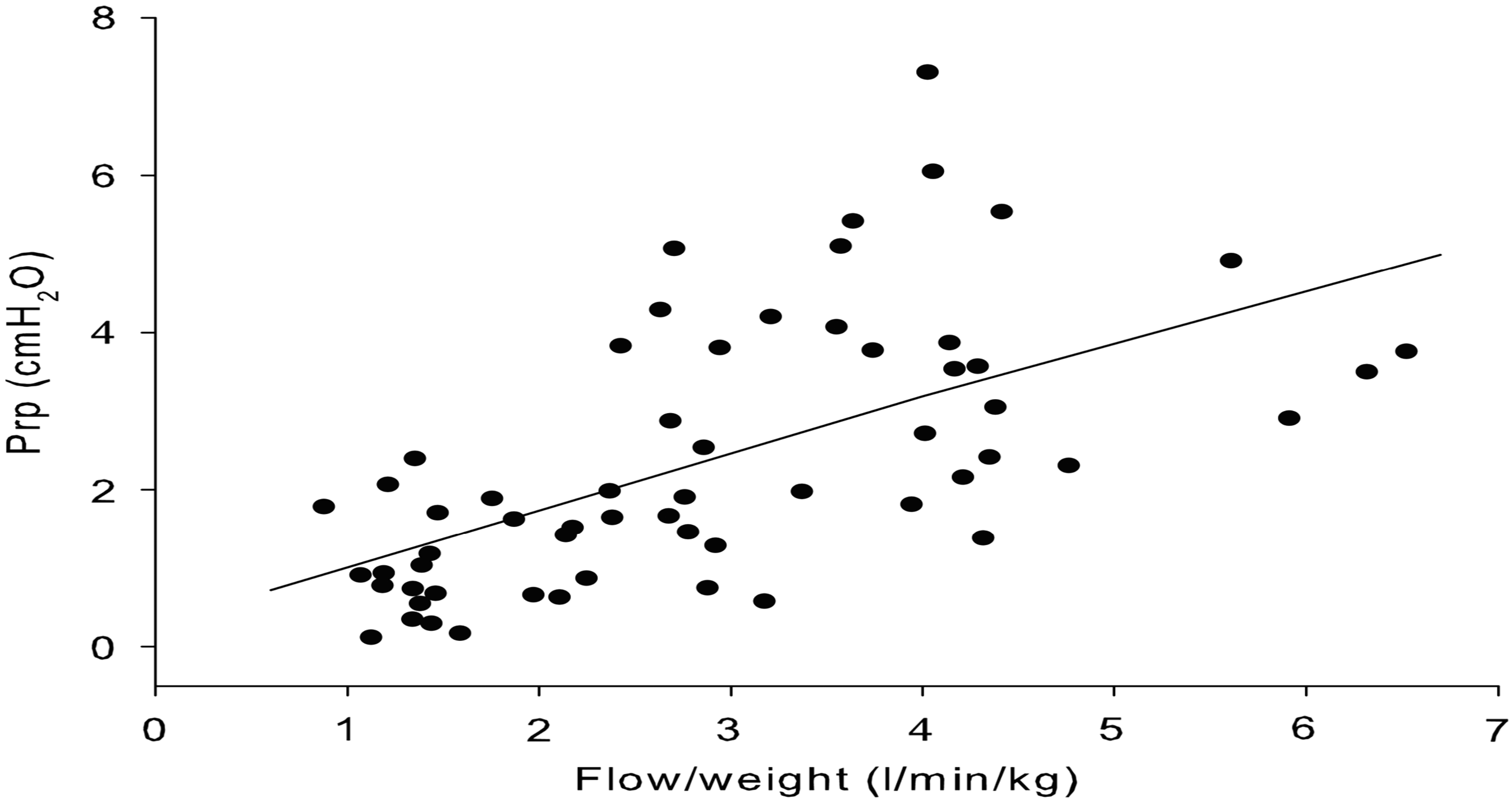
INFANT FLOW™ nCPAP System

Fisher & Pakel



Nasal Cannula

Nasal CPAP



Linear regression between flow rate divided by infants'weight and end-expiratory Prp in heated, humidified, high-flow, nasal cannula (HHHFNC) (Prp=0.3+0.7*V'; r2=0.37)

Respiratory Mechanics during NCPAP and HHHFNC at equal distending pressure, Anna Lavizzari et al. Arch Dis Child Fetal Neonatal Published online 30 April 2014

			HHHFNC	nCPAP
Collins, 2013	Extubation Failure	Total	15/67	22/65
(J Pediatr)		28-32 wk	7/37	8/36
		<28 wk	2/30	1/29
	BPD		24/67 (36%)	28/65(43%)
Manley, 2013	Extubation Failure	Total	52/152	39/151
(NEJM)		26-32 wk	26/120	20/120
		<26 wk	26/32	19/31
	BPD		47/152 (31%)	52/151 (34%)

Incidence of BPD

CHONY (6/99 –7/02)

Proposed New Definition

BW(g)	GA(wks)	O_2 (36 wks)	Mild	Mod.	Severe
< 750	25.4±2.0	1 8.3%	31.6%	15.0%	3.3%
750-1000	26.9±1.8	1.4%	16.9%	1.4%	0
1001-1250	29.0±1.8	1.1%	0	1.1%	0
Total	27.4±2.4	5.9%	14.1%	5.0%	0.9%

Sahni et al. J Perinatol 25(1):41-6, 2005.

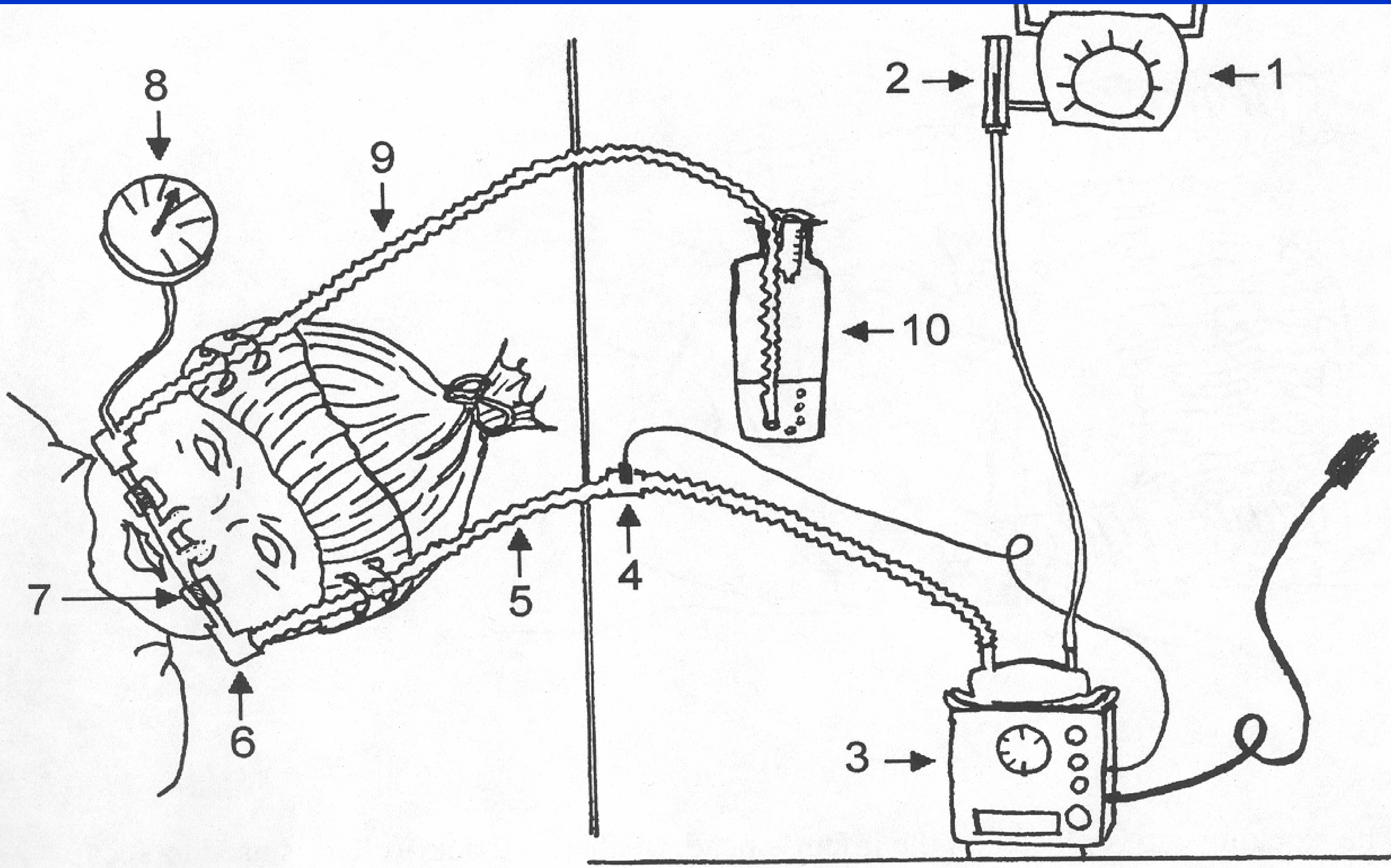
HFNC vs CPAP

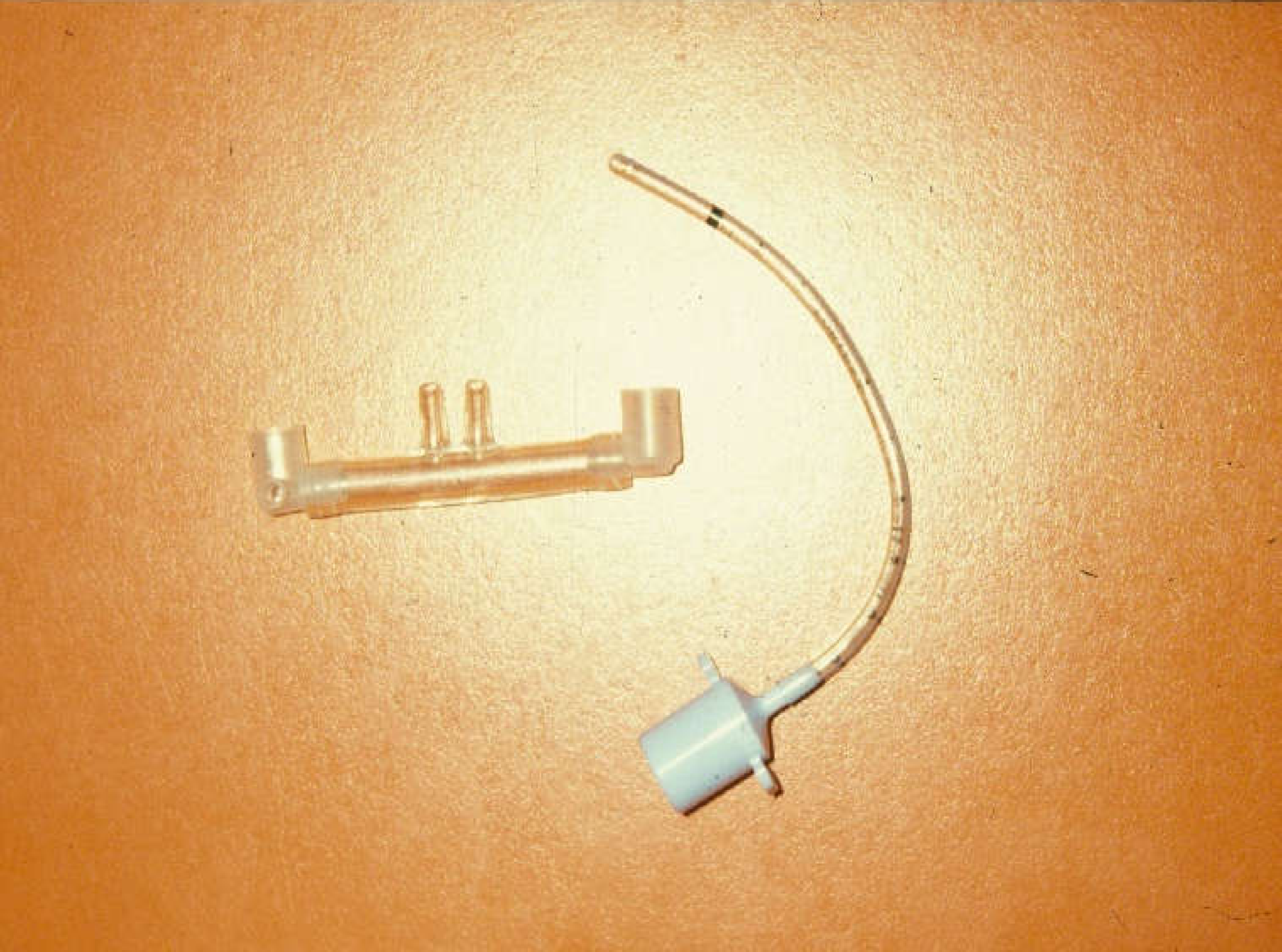
Use of HFNC in ELBW infants is associated with:

- A higher risk of death or BPD
- Increased respiratory morbidities
- Delayed oral feeding, and
- Prolonged hospitalization.

Dalal K. Taha et.al. J Pediatr 2016;173:50-5)

CPAP Delivery System (Columbia)



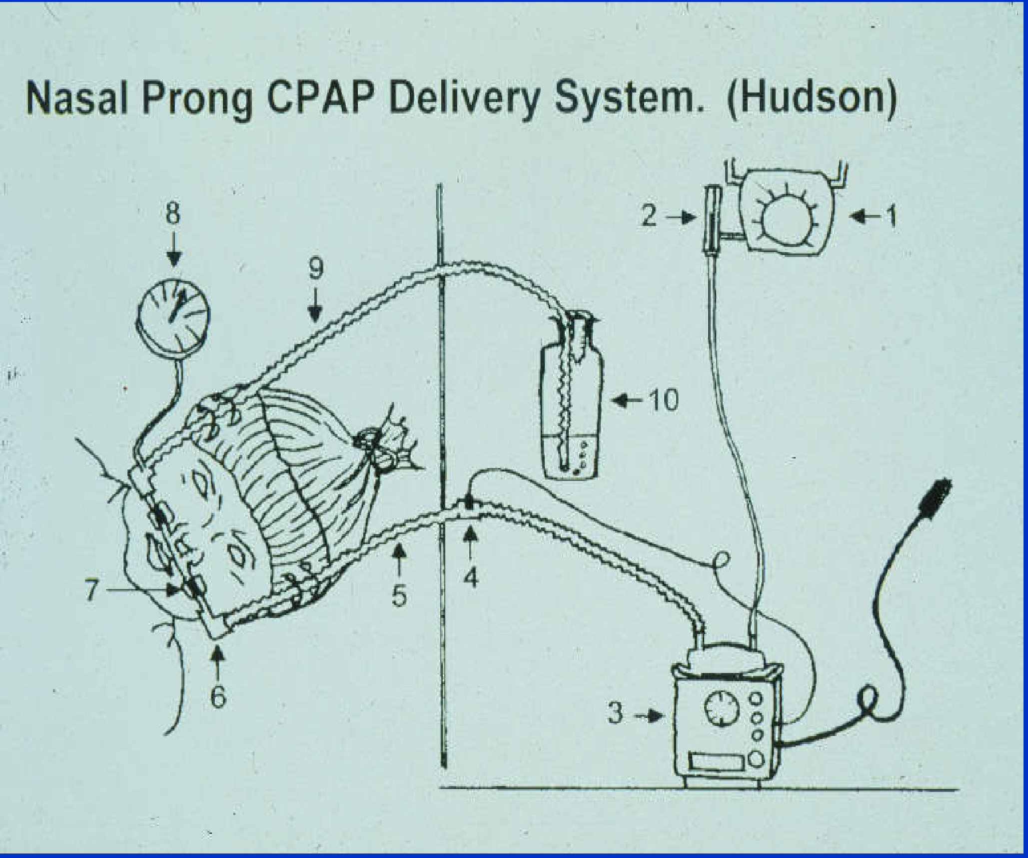


$$\text{Resistance} = \frac{\text{Viscosity} \times \text{Length}}{\text{Radius}^4} \times \frac{8}{\pi}$$

ET tube ID:	**Resistance (cmH2O/5lpm)**
2.5 mm (length 10 cm)	14.2
3.0 mm (length 12 cm)	6.5
3.5 mm (length 12 cm)	4.3
Hudson CPAP prong size:	
0	2.5
1	1.0
2	1.0
3	0.5
4	0.5
5	0.5

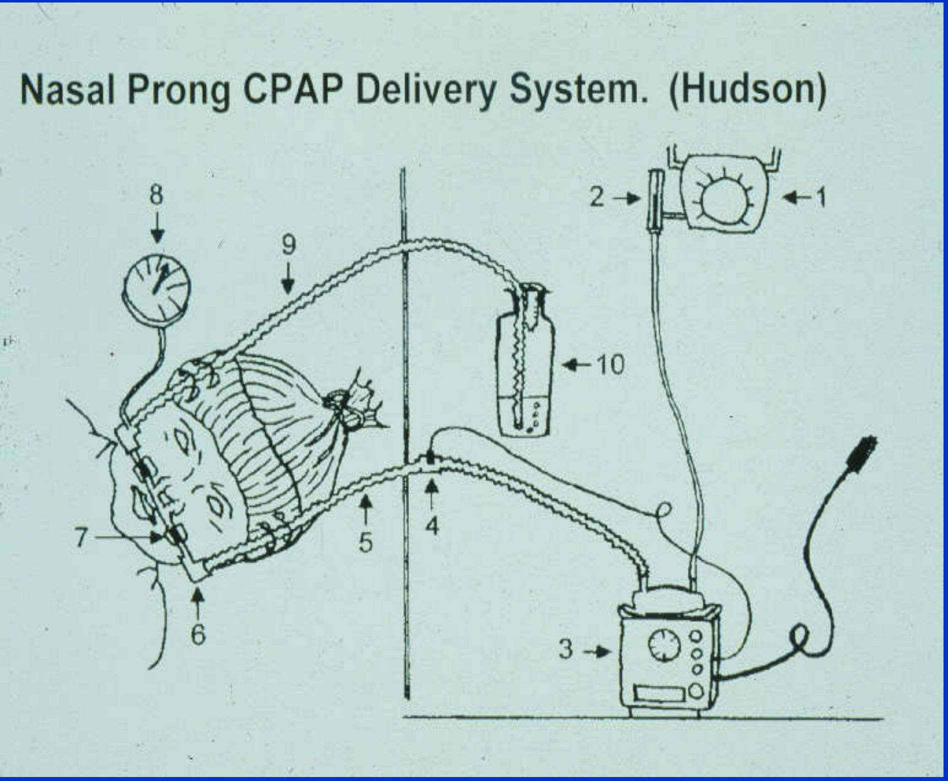
Nasal CPAP

Set up（1）



1. Oxygen blender
2. Flowmeter
   (5-10 LPM)
3. Heated humidifier
4. Thermometer
5. Inspiratory tubing
6. Nasal cannulae
7. Velcro

Nasal CPAP
Set up (2)



8. Manometer (optional)
9. Expiratory tubing
10. A bottle containing a solution of 0.25% acetic acid filled up to a depth of 7 cm. Distal tubing immersed to a depth of 5 cm to create +5 cmH_2O

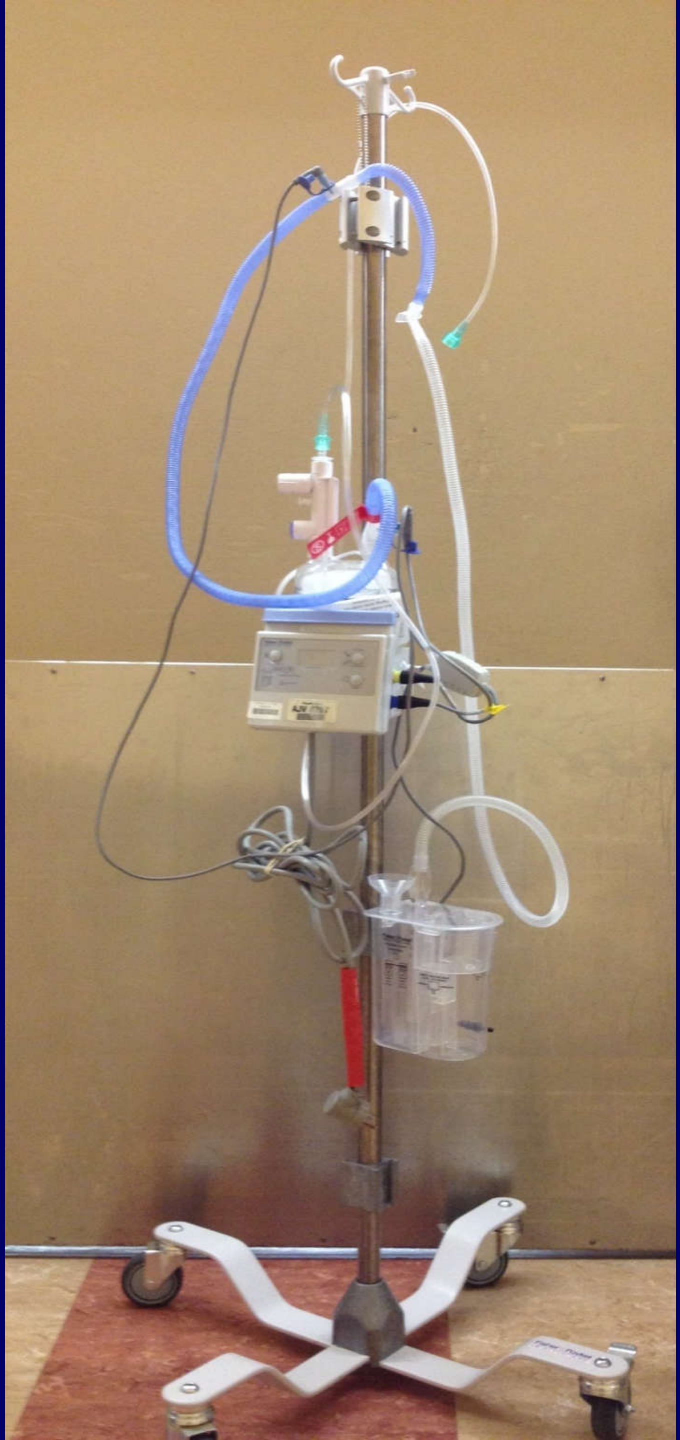
Nasal CPAP
Application (5)

7. Insert the lightweight corrugated tubing (preferrably with heating wire inside) in a bottle of 0.25% acetic acid solution or sterile water filled up to a height of 7 cm. The tube is immersed to a depth of 5 cm to create 5 cmH_2O CPAP as long as air bubbling out of solution

Babi-plus Bubble PAP valve

Fisher & Pakel

Bubble CPAP (Portable)



Nasal CPAP
Application (1)

1. Position the baby in supine position with the head elevated about 30 degrees
2. Place a small roll under the baby's neck
3. Put a pre-made hat or stockinet on the baby's head to hold the CPAP tubings

Nasal CPAP
Application (2)

4. Choose FiO_2 to keep PaO_2 at 50's or O_2 saturation at 85 – 95%

Nasal CPAP
Application (3)

5. Adjust a flow rate 5-10 lpm to:

a) provide adequate flow to prevent rebreathings CO_2

b) compensate leakage from tubing connectors and around CPAP prongs

c) generate desired CPAP pressure (usually 5 cmH_2O)

6. Keep inspired gas temperature at 37^{O} C

Nasal CPAP
Application (6)

8. Choose the proper size of nasal Cannulae

CPAP Cannulae

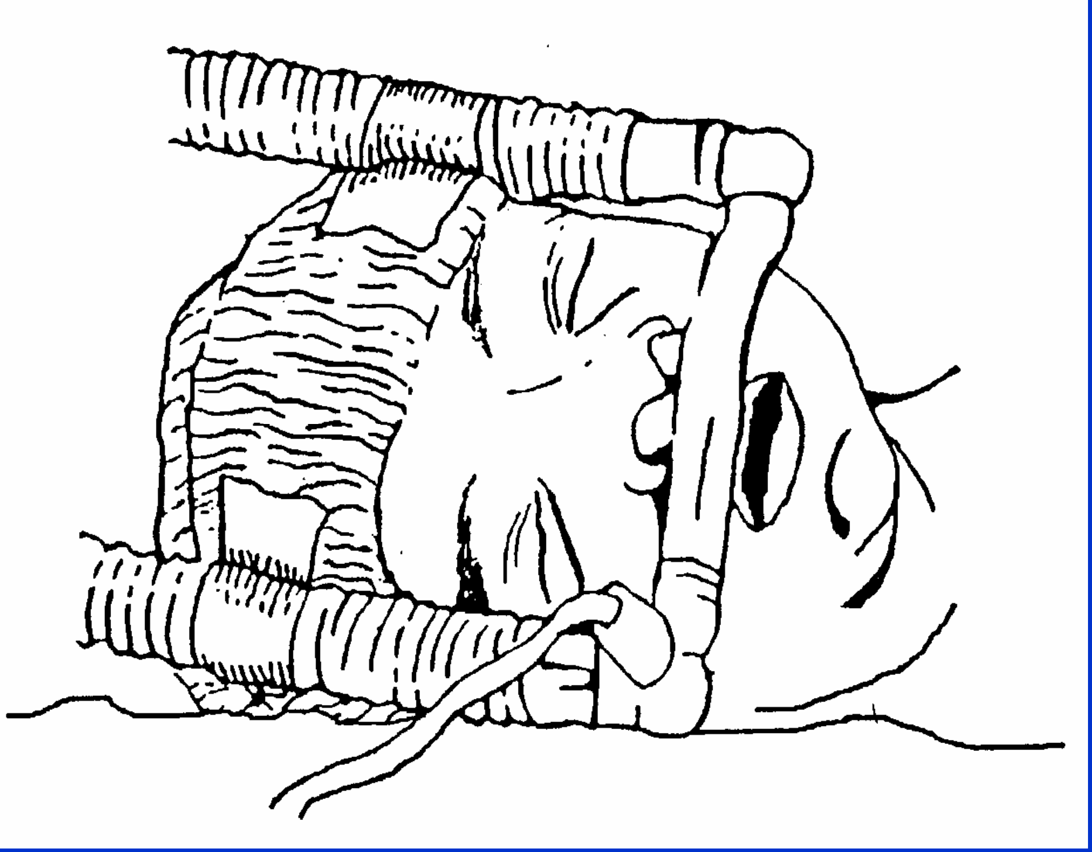
Size	B.W.
0	< 700g
1	~1000g
2	~ 2000g
3	~ 3000g
4	~ 4000g
5	infant

Nasal CPAP

Application

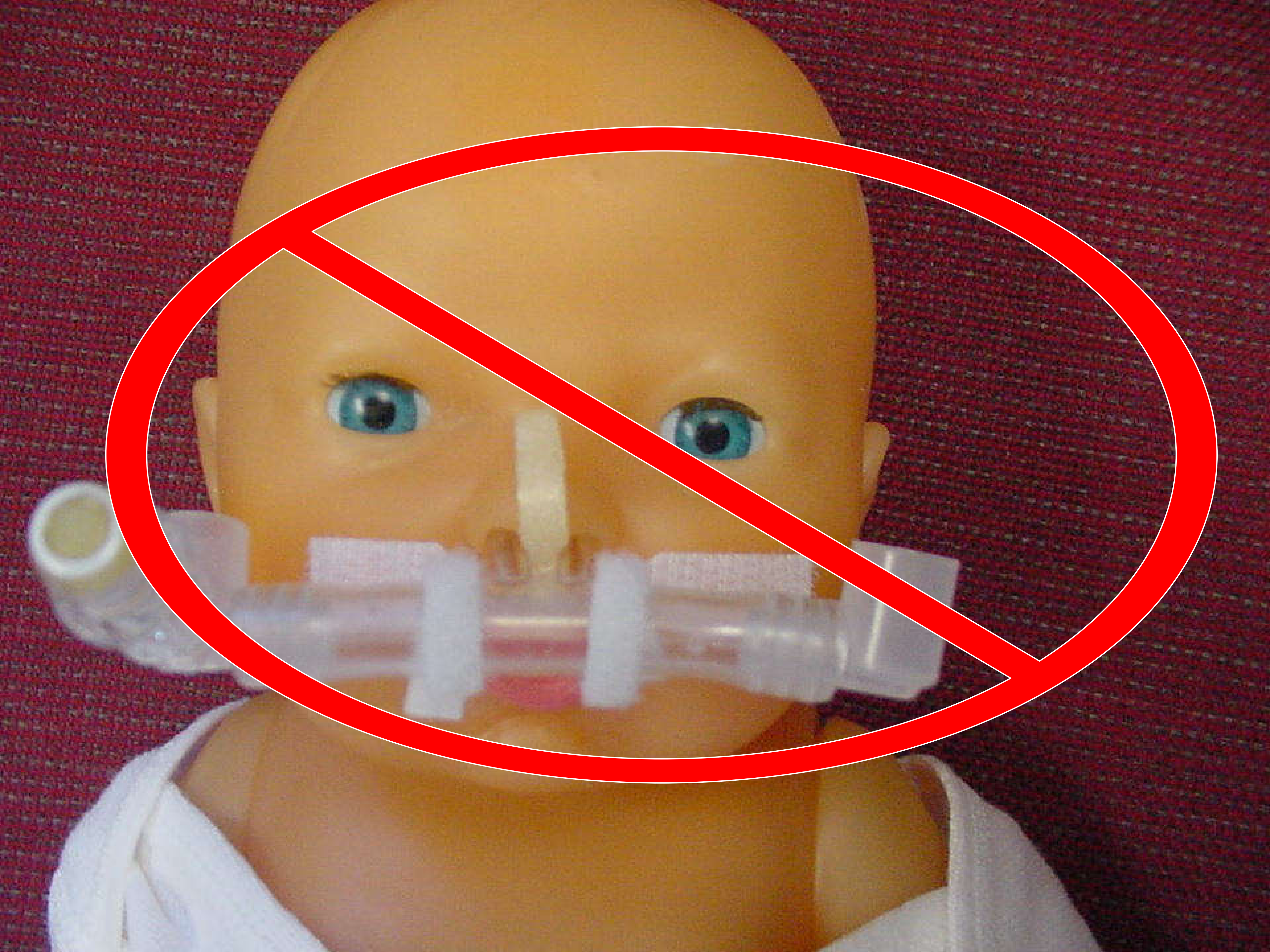
Secure tubings on both sides of the hat with either **safety pins and rubber band** or velcro

Nasal CPAP
Application (9)



11. Secure tubings on both sides of the hat with either safety pins and rubber band or **<u>velcro</u>**


Comfeel



Pressure = Force / Surface Area

Nasal CPAP

Maintenance (1)

1. Observe baby's vital signs, oxygenation and activity
2. Systematically check CPAP systems, inspired gas temperature, air bubbling out of acetic acid solution. Empty condensed water in the circuit
3. Check CPAP prongs position and keep CPAP cannulae off the septum at all times. A snug cap is used to securely hold the tubings in place and using self-adhesive Velcro to keep cannulae away from the septum if necessary

Nasal CPAP

Maintenance (2)

4. Suction nasal cavities, mouth, pharynx and stomach q4h and prn
5. If baby swallows lot of air, suction shoud be more often and insert gastric tube.
6. Change the baby's position
7. Change CPAP circuit once a week

Nasal CPAP

Weaning

- CPAP is kept at 5 cmH_2O
- FiO_2 is adjusted to keep PaO_2 in 50's, or oxygen saturation around 90% (85 -95%)

Three CPAP weaning methods

M1: Taken ‘OFF’ CPAP with the view to stay ‘OFF’

M2: Cycled on and off CPAP with incremental time ‘OFF’.

M3: As with M2, cycled on and off CPAP but during ‘OFF’ periods were supported by 2 mm nasal cannula at a flow of 0.5 l/min.

Arch Dis Child Fetal Neonatal Ed published online May 18, 2012

Methods of weaning preterm babies <30 weeks gestation off CPAP: a multicentre randomised controlled trial

	M1 (n=56)	m^2 (n=69)	M3 (n=52)	Sig
Time of wean‡	11.3±0.8	16.8±1.0*	19.4±1.3*	p<0.0001
Total days CPAP	24.4±0.1	38.6±0.1*	30.5±0.1*	p<0.0001
CGA OFF CPAP	31.9±0.1	34.1±0.1*	32.8±0.2*	p<0.0001
Oxygen duration‡	24.1±1.5	45.8±2.2*	34.1±2.0*	p<0.0001
BPD	7/56 (12.5%)	29/69 (42%)†	10/52 (19%)	p=0.011
Length of Admission	58.5±0.1	73.8±0.1*	69.5±0.1*	p<0.0001
CGA at D/C#	35.8±0.1	36.9±0.1*	36.9±0.1*	p<0.0001

CGA: corrected GA;

Arch Dis Child Fetal Neonatal Ed published online May 18, 2012

Nasal CPAP
Discontinued

- No tachypnea or retraction
- No apnea and bradycardia
- FiO_2 is room air

Nasal CPAP
Complications (1)

- Nasal obstruction from secretions or improper application of nasal prongs
- Gastric distention from swallowing air, abdominal distention,especially in infants on aminophylline or caffeine
- Nasal septum erosion or necrosis
- Fluctuating FiO_2
- Air leak: <5%, usually occurs during acute phase

Nasal CPAP
Complications (2)

- Pneumothorax, if occurs, usually occurs within the first few days of use, not after a week. Furthermore, pneumothorax is generally less severe and less frequent in infants on CPAP compared to intubated infants on mechanical ventilation.
- Most of complications are preventable
- The majority of the problems can be attributed to inappropriate use, wrong device or a lack of training and experience


WARNING


SUSAN

Feeding on CPAP

Baby may feed at breast

Babies on NIV have adequate aerodigestive reflexes to prevent aspiration.

Concern over increased incidence of GERD is unfounded

Safety and efficacy of oral feeding in infants with BPD on nasal CPAP

Dysphagia. 2015 Apr. 30(2): 121-7

Hanin M, Nuyhakki S, Malkar MB, Jadeherla SR

395 gms , On CPAP since birth

CPAP
Novel Application

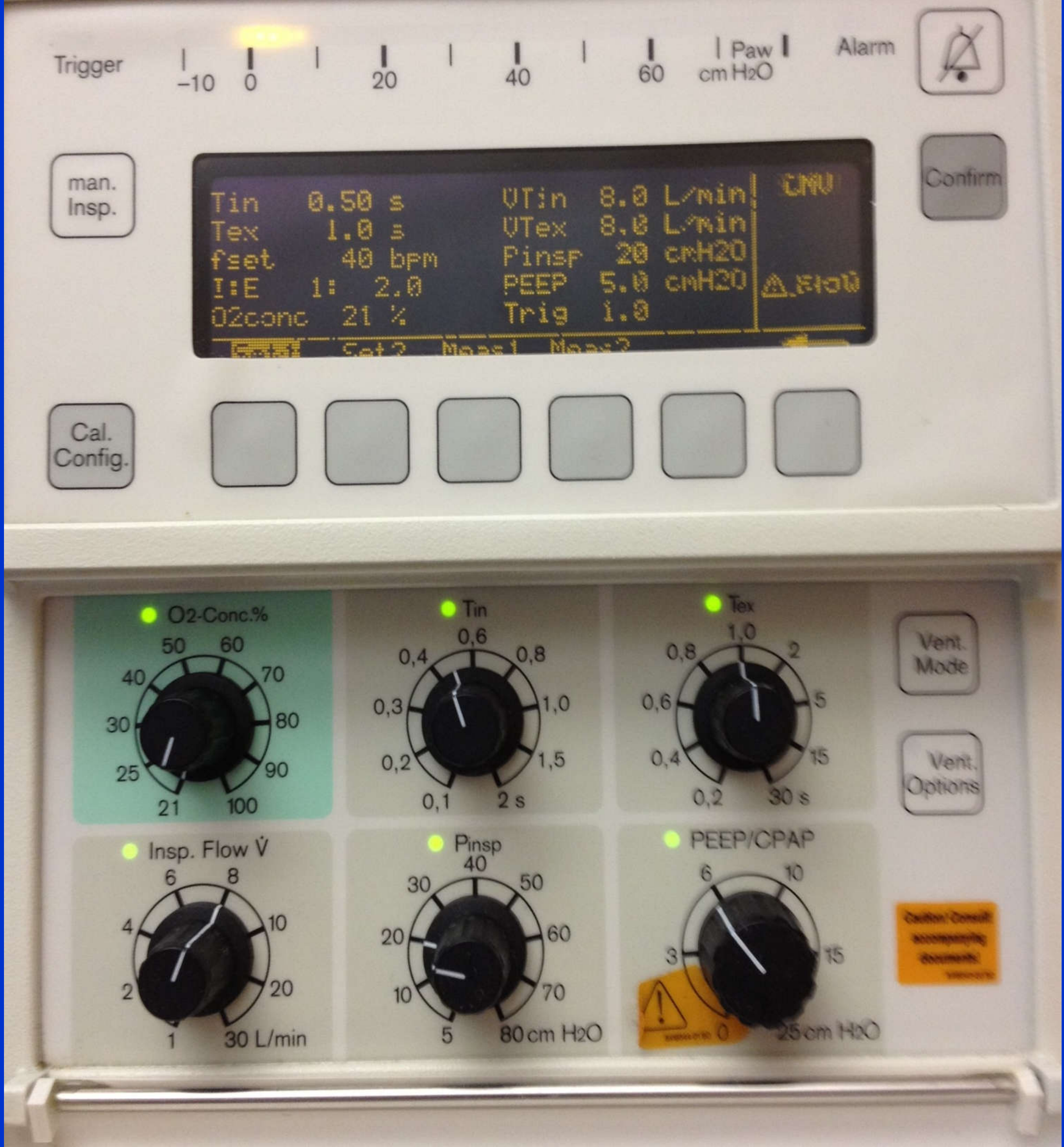
- Mechanical ventilation via nasal CPAP cannulae
- Preferably in SIMV, A/C or pressure support mode. Infant Star Sync is not available anymore.

  (using Servo i with NAVA).
- PIP: 15-20 cmH_2O, PEEP: 5 cmH_2O
- Indications:

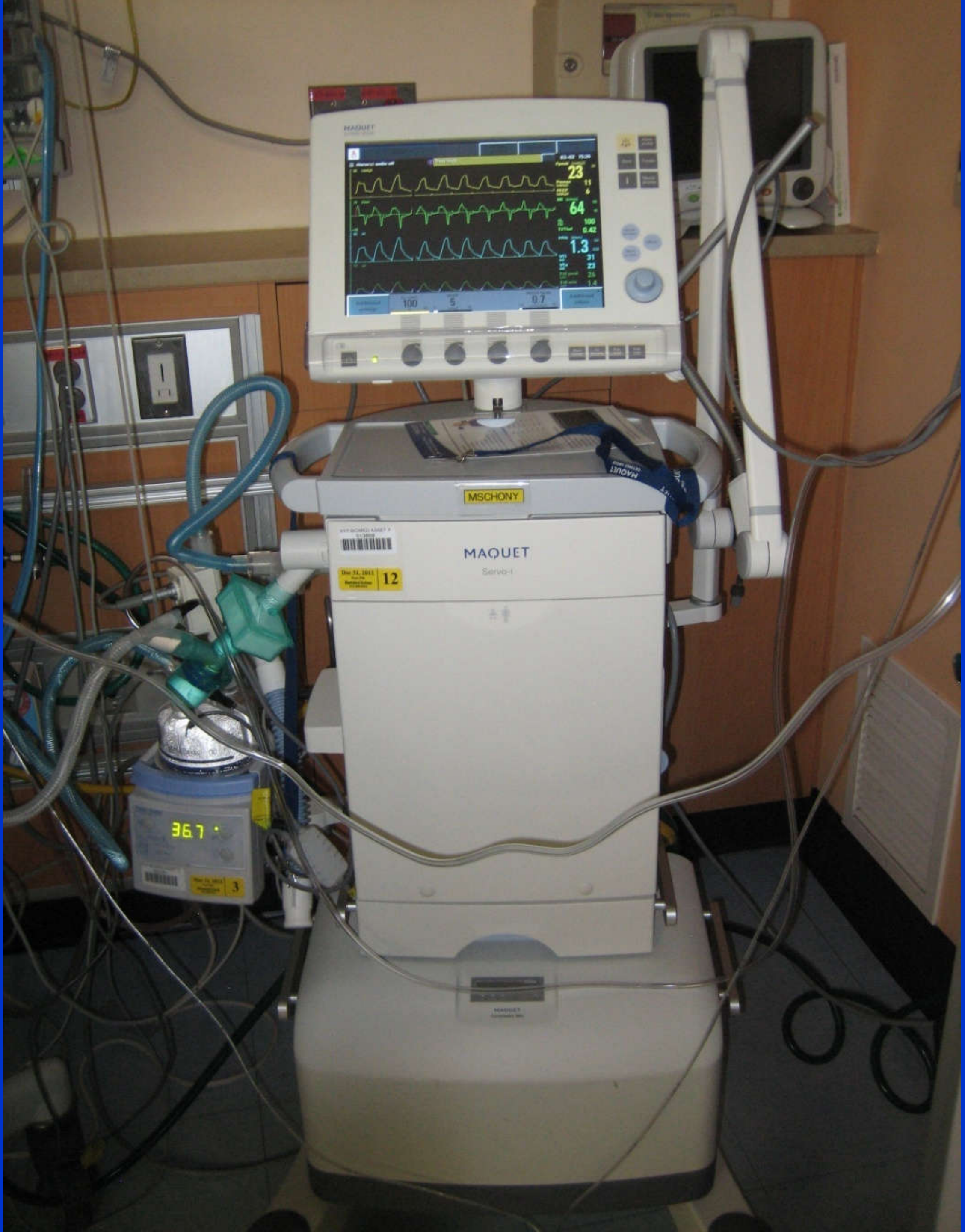
✓ Frequent A&B

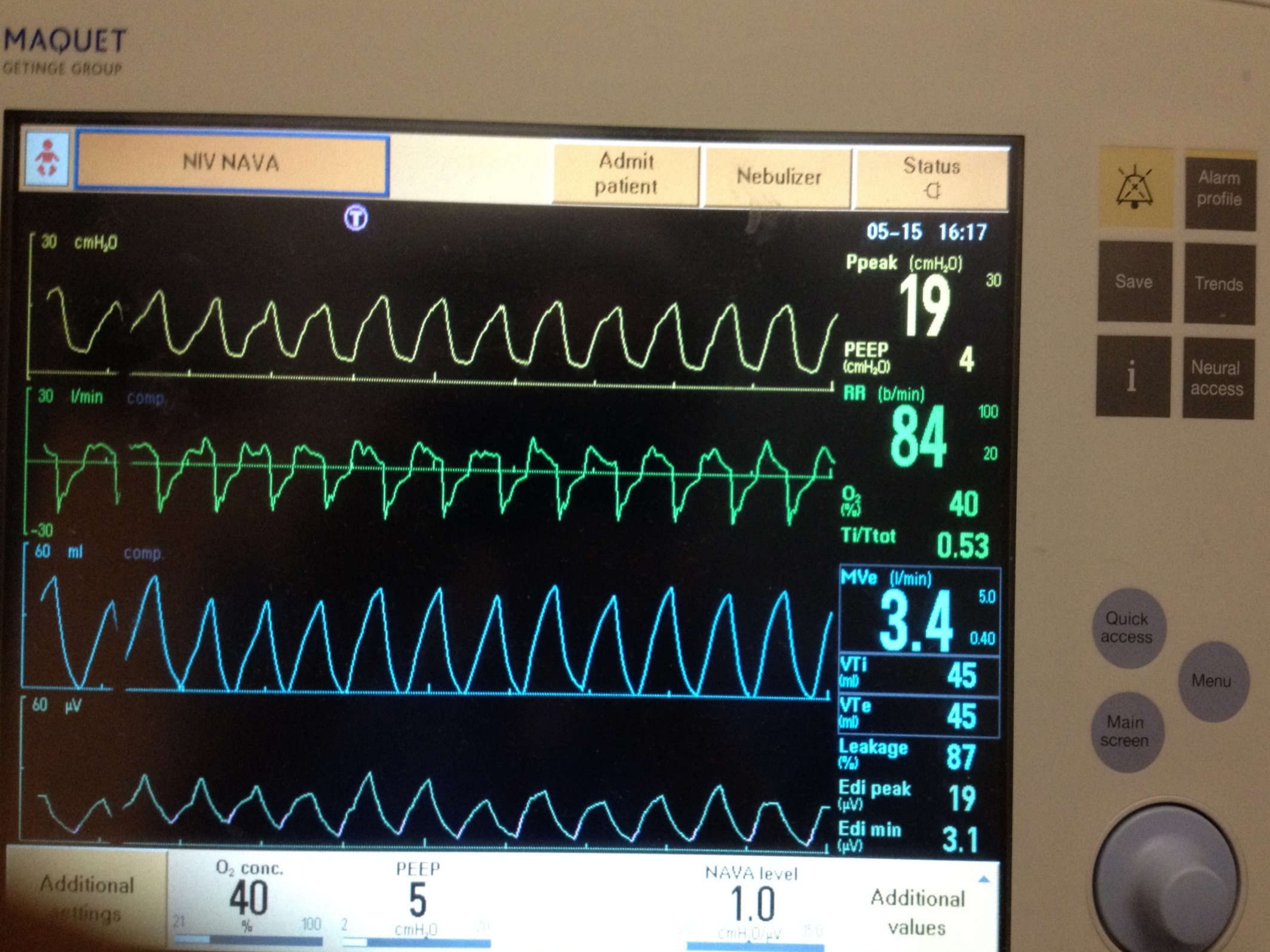
✓ High $PaCO_2$

✓ Laborious breathings



Trigger
–10 0 20 40 60
Paw
cm H2O
Alarm
man. Insp.
Tin 0.50 s
Tex 1.0 s
fset 40 bpm
I:E 1: 2.0
O2conc 21 %
VTin 8.0 L/min
VTex 8.0 L/min
Pinsp 20 cmH2O
PEEP 5.0 cmH2O
Trig 1.0
CMV
Confirm
Cal. Config.
O2-Conc.%
21 25 30 40 50 60 70 80 90 100
Tin
0,1 0,2 0,3 0,4 0,6 0,8 1,0 1,5 2 s
Tex
0,2 0,4 0,6 0,8 1,0 2 5 15 30 s
Vent. Mode
Vent. Options
Insp. Flow V̇
1 2 4 6 8 10 20 30 L/min
Pinsp
5 10 20 30 40 50 60 70 80 cm H2O
PEEP/CPAP
0 3 6 10 15 25 cm H2O


MSCHONY
MAQUET
Servo-i


MAQUET
GETINGE GROUP
NIV NAVA
Admit patient
Nebulizer
Status
05-15 16:17
30 cmH2O
Ppeak (cmH2O)
19
30
PEEP (cmH2O)
4
30 l/min comp.
-30
RR (b/min)
84
100
20
O2 (%)
40
Ti/Ttot
0.53
60 ml comp.
MVe (l/min)
3.4
5.0
0.40
VTi (ml)
45
VTe (ml)
45
60 µV
Leakage (%)
87
Edi peak (µV)
19
Edi min (µV)
3.1
Alarm profile
Save
Trends
i
Neural access
Quick access
Menu
Main screen
Additional settings
O2 conc.
40
21 % 100
PEEP
5
2 cmH2O
NAVA level
1.0
Additional values


0 1 2 3 4 5 6 7 8
cm
CPAP
SIZE 2
1250-2000g
CANNULAIDE®
INFANT CPAP
NASAL SEAL
Reorder CA102
1
Lot 20031001
May 2005
For use by or on order of a licensed physician only.
For single use only.
Beevers Mfg & Supply
503-472-9055
Rev C 2003 09 30

Mechanical Ventilation

Indications

1. Marked retractions on CPAP (not due to nasal obstruction)
2. Frequent apnea and bradycardia on CPAP
3. PaO_2 < 50 mm Hg with FiO_2 > 60%
4. $PaCO_2$ > 70 mm Hg (except 1st ABGS)
5. Intractable metabolic acidosis (BD > 10 meq/L after Rx with $NaHCO_3$)
6. Other (Cardiovascular collapse, Neuromuscular disorder, Congenital diaphragmatic hernia, or for Surgery, MRI, Cardiac catheterization, etc.)

The Columbia Experience with CPAP

Morgan Stanley Children's Hospital of NewYork-Presbyterian
Columbia University Medical Center

The Columbia Experience (1997-1999)

A retrospective database review for a cohort of all live inborn VLBW infants (BW 500-1500g) born between Jan 1, 1997 and Dec 31, 1999 (three calendar years).

- 320 infants were divided into three groups :

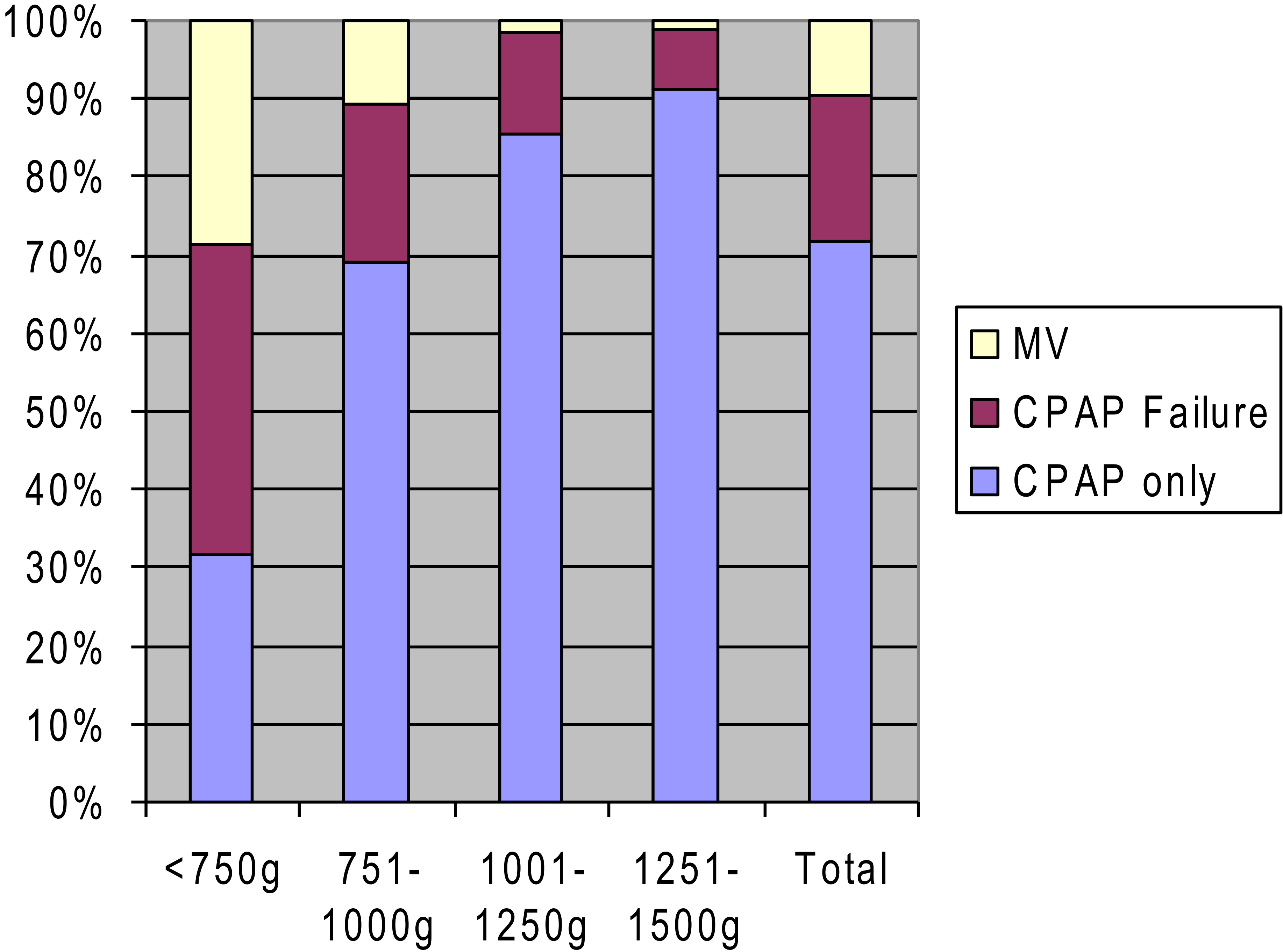
1) <u>CPAP only group</u> (n = 230): received only bubble NCPAP for respiratory support during the first 24 hrs of life.

2) <u>CPAP failed group (n = 60)</u>: Infants managed initially with NCPAP who required intubation within 24 hrs of birth.

3) <u>Vent only group (n = 30)</u>: Infants requiring intubation immediately following birth.

The Columbia Experience (1997-1999)

BW(gm)	CPAP Only(%)	CPAP/ IMV(%)	IMV (%)	Total	Expired (%)
500-750	21(31.8)	26(39.4)	19(28.8)	66	11(16.7)
751-1000	58(69)	17(20.2)	9(10.7)	84	6(7.1)
1001-1250	59(85.5)	9(13)	1(1.4)	69	0
1251-1500	92(91)	8(7.9)	1(1)	101	7(6.9)
Total	230(71.9)	60(18.8)	30(9.4)	320	24(7.5)


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
<750g
751-1000g
1001-1250g
1251-1500g
Total
MV
CPAP Failure
CPAP only

BPD
(Required oxygen suplement at 36 wks PCA)

BW(gm)	CPAP only	CPAP/IMV	IMV	Total
500-750	0/21	1/26	3/19	4/66
751-1000	1/58	0/17	0/9	1/84
1001-1250	0/59	0/9	0/1	0/69
1251-1500	1/92	1/8	0/1	2/101

Intraventricular Hemorrhage
(IVH Grade III-IV)

BW(gm)	CPAP only	CPAP/IMV	IMV	Total
500-750	1/21	3/26	4/19	8/66
751-1000	0/58	0/17	0/9	0/84
1001-1250	1/59	0/9	0/1	1/69
1251-1500	0/92	1/8	0/1	1/101

Retinopathy of Prematurity
(ROP Stage 3-4)

BW(gm)	CPAP only	CPAP/IMV	IMV	Total
500-750	4/21	5/26	3/19	12/66
751-1000	0/58	0/17	0/9	0/84
1001-1250	0/59	0/9	0/1	0/69
1251-1500	0/92	0/8	0/1	0/101

Mortality before Discharge

BW(gm)	CPAP only	CPAP/IMV	IMV	Total
500-750	0/21	3/26	8/19	11/66
751-1000	1/58	3/17	2/9	6/84
1001-1250	0/59	0/9	0/1	0/69
1251-1500	3/92	3/8	1/1	7/101

NICU Quality and Outcome, 2013

501 – 1500g

	MSCH (Columbia)	Vermont Oxford
Incidence of BPD	7.7%	34.6%
Nosocomial infection	5.8%	13.4%
Incidence of IVH	13.5%	25.9%
Incidence of Severe ROP	6.3%	7.8%
Incidence of NEC	5.5%	6.7%
Neonatal Mortality rate	9.5%	15.0%

The strategy of

Early nasal CPAP therapy first and

Surfactant replacement only for rescue

does not jeopardize outcome of very low birth weight infants

CURPAP study

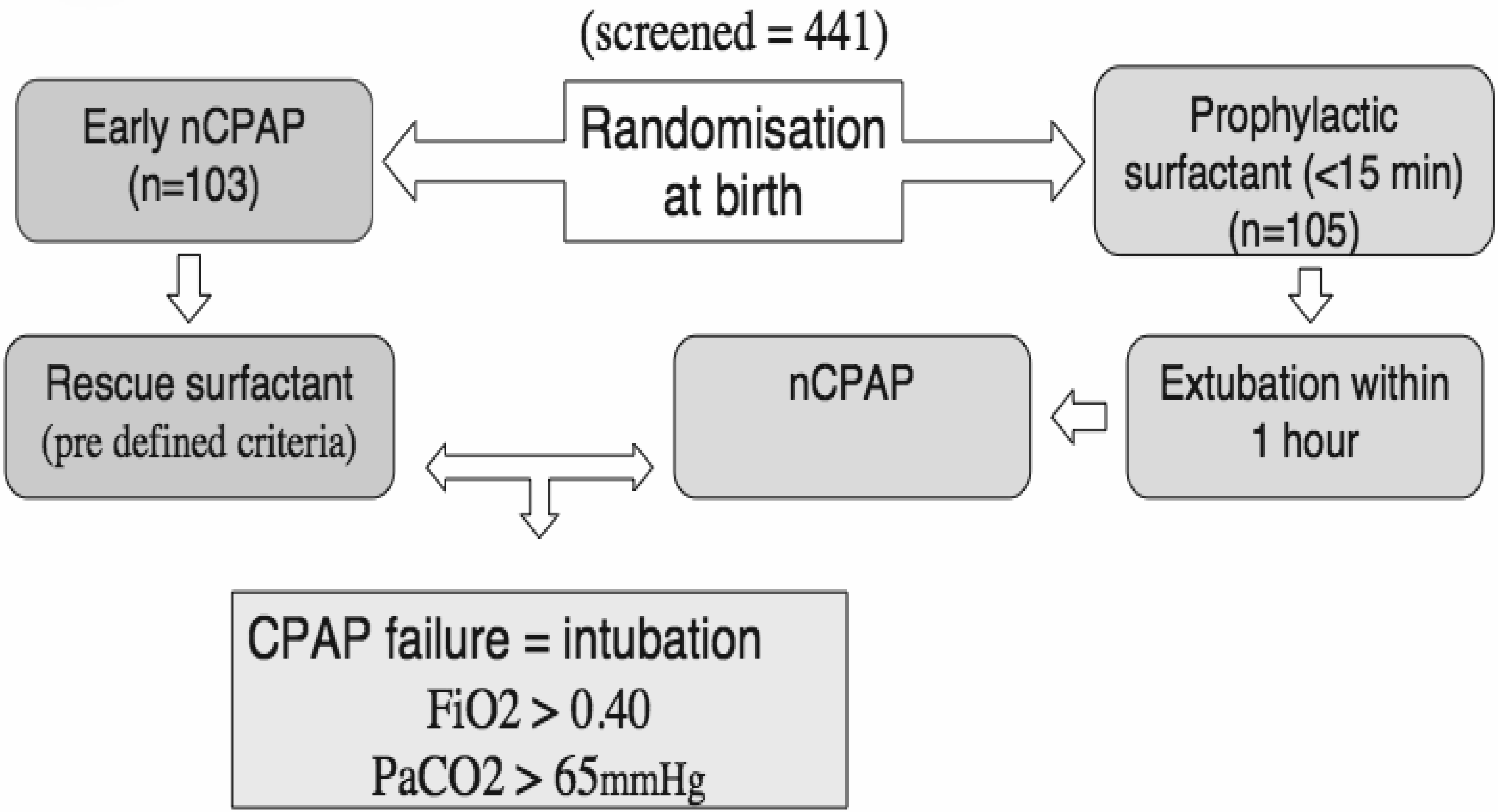
(R Plavka, U Simeoni et al. ESPR: Arch Dis Child 2008;93(Suppl II):A34)

- **Question**: is the prophylactic administration of surfactant superior to early rescue treatment in spontaneously breathing infants supported on nCPAP, in reducing the need for mechanical ventilation, during the first 5 days of life?
- **Population**: 25-28 weeks infants (European multicentre, n=24)
- **Outcome**:

. Duration of mechanical ventilation during the first 5 days of life

. Mortality, pulmonary and neurological morbidity

CURPAP study: method



CURPAP study: preliminary results

Parameter	nCPAP	CURPAP
Gestational age (median in weeks)	27	27
Birth weight (g)	913 ± 200	967 ± 221
Antenatal steroids	98%	96%
CPAP failure => mechanical ventilation	**31%**	**33%**
Pneumothorax	**1%**	**6.7%***
Mortality	10.7%	8.6%
BPD	22%	23.8%

50% rescue surfactant
(median =240 min of age)

Summary of the CURPAP study

- Prophylactic surfactant is **<u>not</u>** superior to early rescue surfactant therapy after CPAP
- Surfactant was halved in the nCPAP group
- Outcome was really good in both arms

Do not brand a form of therapy as useless,

when in reality it was only inappropriately applied.

Reasons for different results in previous CPAP studies

- The difference in devices used and experiences
- The difference in criteria of CPAP failure
- Studies did not show significant reduction of BPD because CPAP therapy was discontinued too early to take advantage of stimulation of lung growth.

Key strategies for the successful use of nasal CPAP therapy

1. Choose the right nasal CPAP device
2. Familiarize caregivers with the device
3. Learn to use nasal CPAP correctly, Gain experience, increase in the comfort level of Staff and Team work
4. Maintain nasal CPAP with meticulous airway care & Pay attention to details
6. Initiate nasal CPAP as early as possible
7. Tolerate $PaCO_2$ up to 65 mmHg & FiO_2 up to 60%
8. Extended use of nasal CPAP till on room air without respiratory distress to enhance the growth of the premature lung