TEMEL MEKANİK VENTİLASYON SOLUNUM MEKANİKLERİ

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03.11.2018

Solunum Mekanikleri

- Akciğer fonksiyonlarının basınç, akım ölçümleri ile ifade edilmesi

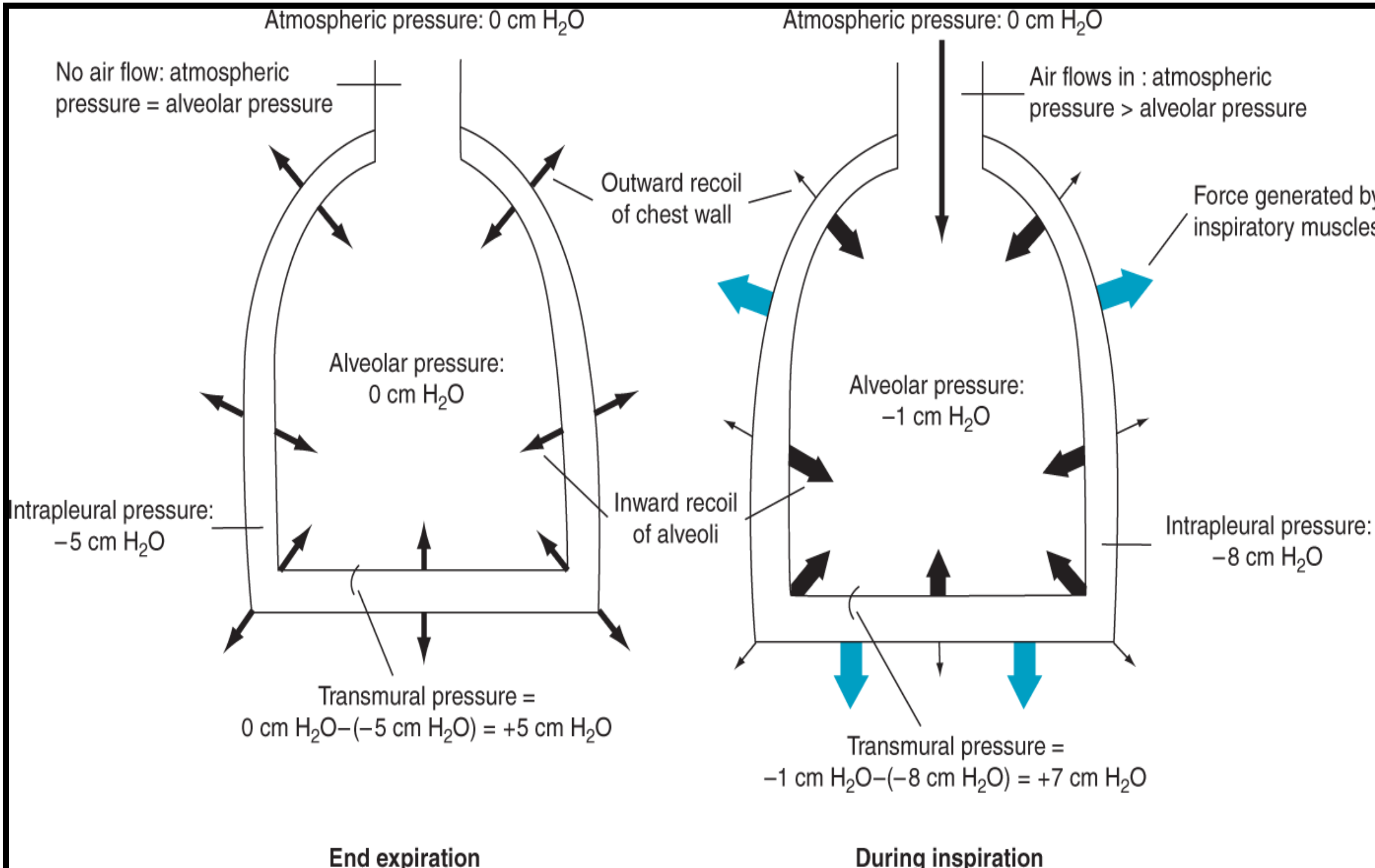
- Bu ölçümlerden pek çok veri elde edilir;
  - Volüm,
  - Komplians-elastans
  - Rezistans
  - WOB

Solunum Mekanikleri

- **Neden önemli?**
  - Akut solunum yetmezliğinin altta yatan patofizyolojisini anlamak
  - Hastalığın durumunu ve seyrini değerlendirmek
  - Tedavi yaklaşımını belirlemek (PEEP, bronkodilatörler, sıvı tedavisi)
  - Hasta ventilatör uyumunu sağlamak
  - Ventilatör ilişkili komplikasyonları önlemek
  - Mekanik ventilasyonun sonlandırılmasına karar verebilmek

Solunum Mekanikleri

- **Başlıca gaz kanunları;**
  - Gazlar sıkışabilir
  - Basınç farkı yönünde akarlar
  - Direnç artarsa akış azalır
  - Hava bağımsız olarak difüze olan gazların karışımıdır
  - Her bir gazın karışım içinde bir kısmi basıncı vardır (Pgaz)



Source: Levitzky MG: *Pulmonary Physiology, Eighth Edition*: www.accessmedicine.com

Transpulmoner P(P_L): P_A-P_{pl}

alveolar havalanmadan sorumludur.

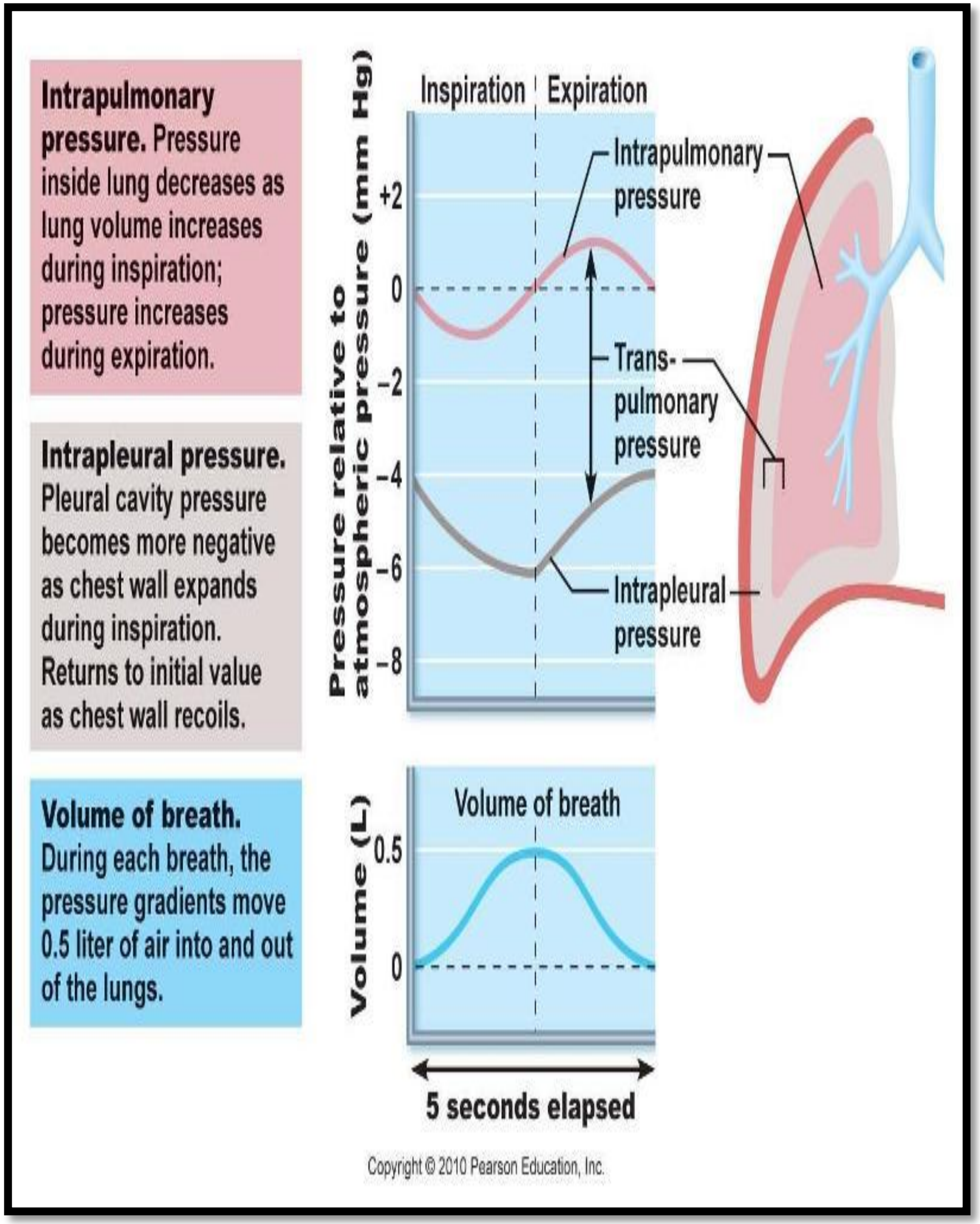
Mekanik ventilatörler transpulmoner basıncı arttırarak fonksiyon görürler

Negatif basınçlı ventilatörler;

P_{pl}'ını azaltır

Pozitif basınçlı ventilatörler;

P_A'ı artırır



Kaynak: *Pilbeam SP. Basic terms and concepts of mechanical ventilation.,in Mechanical Ventilation:Physiological and Clinical Applications ed 4, St Louis 2006, Mosby*

Solunum Mekanikleri

- **Ventilasyonu etkileyen faktörler:**
  - Komplians
    - Göğüs duvarı
    - Akciğer
  - Elastans
  - Rezistans
    - Hava yolu çapı
      - Bronkokonstriksiyon
      - Bronkodilatasyon
    - Hava yolu direnci- müköz engelleme

Solunum Mekanikleri

- **Komplians:**

  Volüm değişikliği / Basınç değişikliği

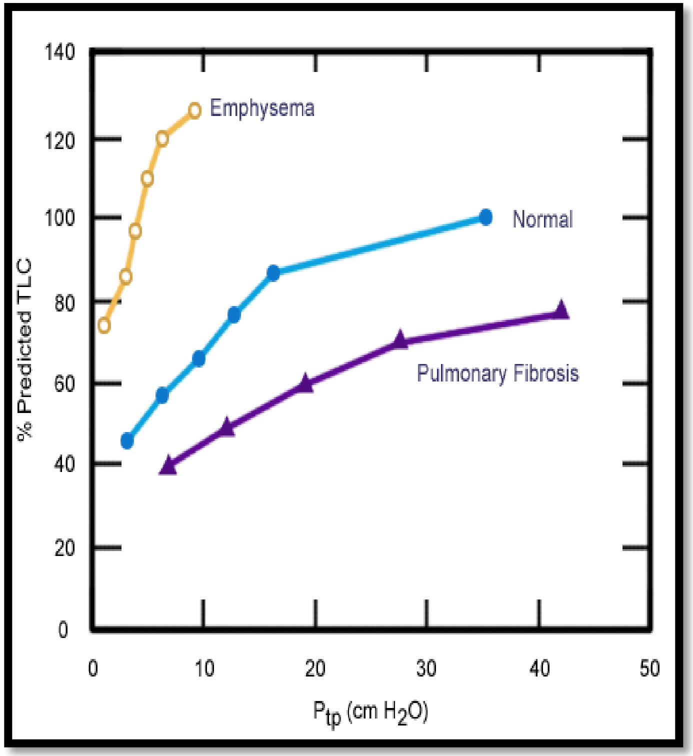
  - «Akciğerin genişleyebilme kolaylığı»
  - Belirli bir basınç artışına bağlı olarak oluşan hacim artışının ölçüsü (1/elastans)

- Normal toplam komplians: (akciğer+göğüs duvarı)= 200 ml/cm H20
  - Basınç 1 cmH2O arttığında akciğerler 200ml genişler

- **Elastans (1/komplians);**

  Basınç değişikliği/Volüm değişikliği

  - «Gerilen akciğerlerin eski şekline dönebilmesi»
  - Akciğerin elastik özellikleri (1/3)
  - Sıvı içeriğinin yüzey gerilimi (2/3)

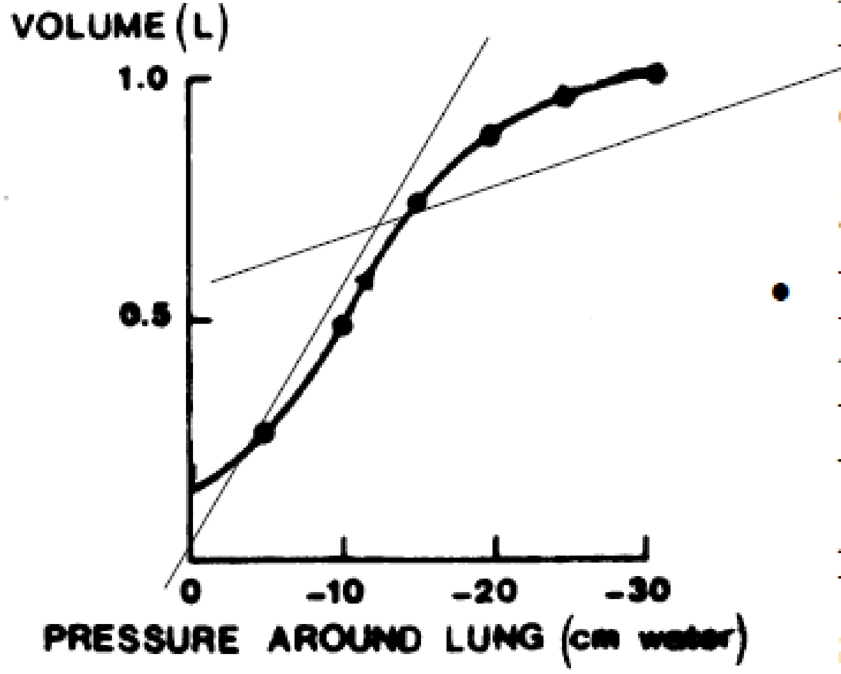


Pilbeam SP. Basic terms and concepts of mechanical ventilation.,in Mechanical Ventilation:Physiological and Clinical Applications ed 4, St Louis 2006, Mosby

Solunum Mekanikleri

- **Komplians:**
  - **Statik komplians;**
    - İnspiratuar gaz akımının olmadığı, 2-5 sn inspiratuar duraklama sonrası dengede ölçülen komplians
    - Cstat= V_T/Pplat-PEEP
    - Bu duraklamayı yapmak zor
  - Kısa süreli (0.5-1sn) lik duraklama sonrası ölçülen komplians **"quasistatic" «yarı-statik»**
    - Cqs= VT/Pqs-PEEP
  - Sağlıklı insanda Cstatik, Cqs birbirine yakındır ama KOAH, ARDS'de böyle değildir.
  - **Dinamik komplians;**
    - Cdyn=VT/Ppeak-PEEP

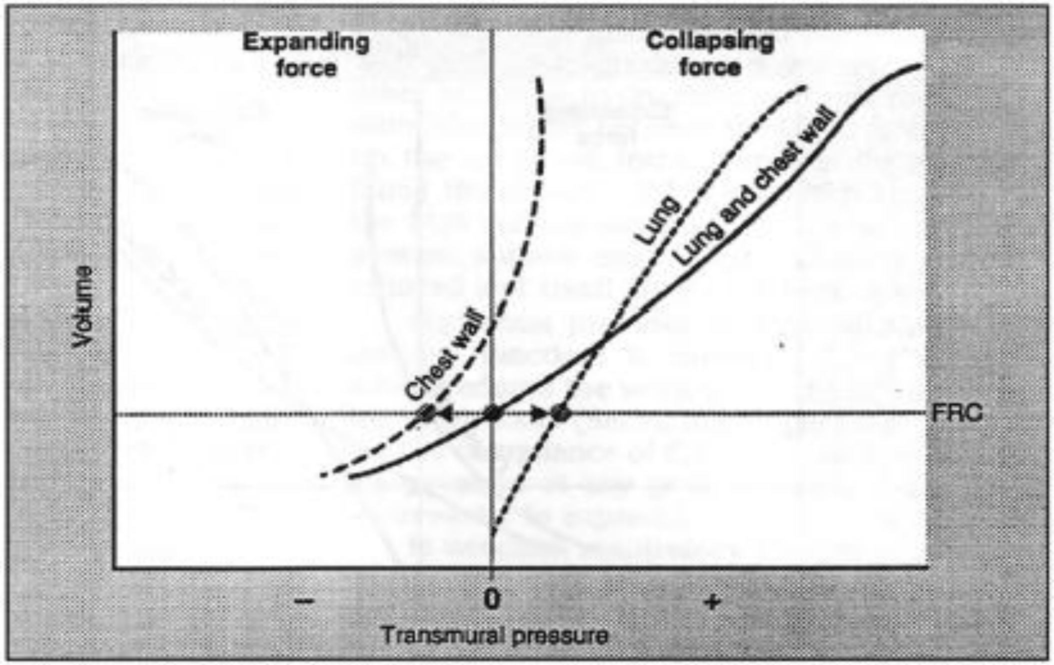
AC'lerin kompliyansı



- Eğrinin dik olması yüksek kompliyansı, yatık olması düşük kompliyansı gösterir.
- Dolayısıyla AC kompliyansı yüksek volümlerde en düşük, rezidüel volüm seviyelerinde en yüksek noktasındadır.

Komplians

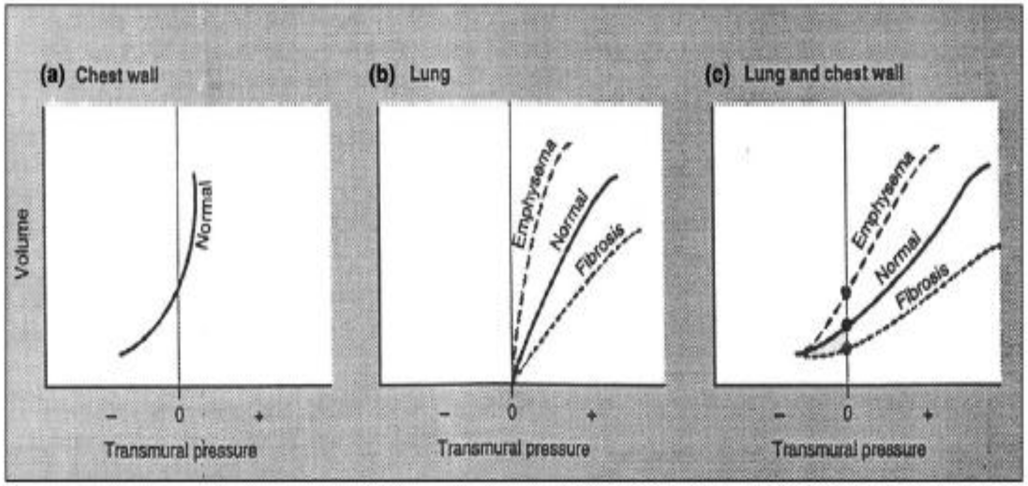
Figure 2



Compliance of the lungs, chest wall, and the combined lung–chest wall system. At the functional residual capacity, the forces of expansion and collapse are in equilibrium. Reprinted from [3] with permission from Elsevier.

Komplians

Figure 3



Compliance in emphysema and fibrosis. Shown are changes in the compliance of the inspiratory limb of the pressure−volume curve with respect to **(a)** chest wall, **(b)** lungs, and **(c)** combined lung-chest wall system in patients with emphysema and fibrosis. The functional residual capacity (FRC), represented on the vertical axis at a transmural pressure of 0, is elevated in emphysema, which can lead to dynamic hyperinflation. Reprinted from [3] with permission from Elsevier.

Komplians

Table 1

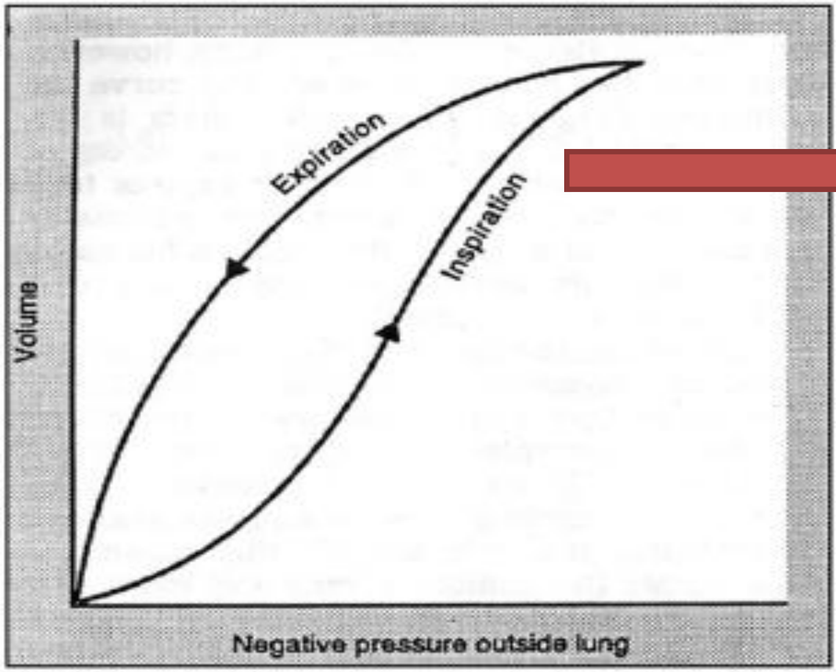
Causes of decreased intrathoracic compliance

Causes of decreased measured chest wall compliance	Causes of decreased measured lung compliance
Obesity	Tension pneumothorax
Ascites	Mainstem intubation
Neuromuscular weakness (Guillain–Barre, steroid myopathy, etc.)	Dynamic hyperinflation
Flail chest (mediastinal removal)	Pulmonary edema
Kyphoscoliosis	Pulmonary fibrosis
Fibrothorax	Acute respiratory distress syndrome
Pectus excavatum	Langerhans cell histiocytosis
Chest wall tumor	Hypersensitivity pneumonitis
Paralysis	Connective tissue disorders
Scleroderma	Sarcoidosis
	Cryptogenic organizing pneumonitis
	Lymphangitic spread of tumor

Shown are the causes of decreased intrathoracic compliance, partitioned into causes of decreased measured chest wall compliance and causes of decreased measured lung compliance.

Critical Care October 2005 Vol 9 No 5 Grinnan and Truwit

Komplians-PV Eğrisi

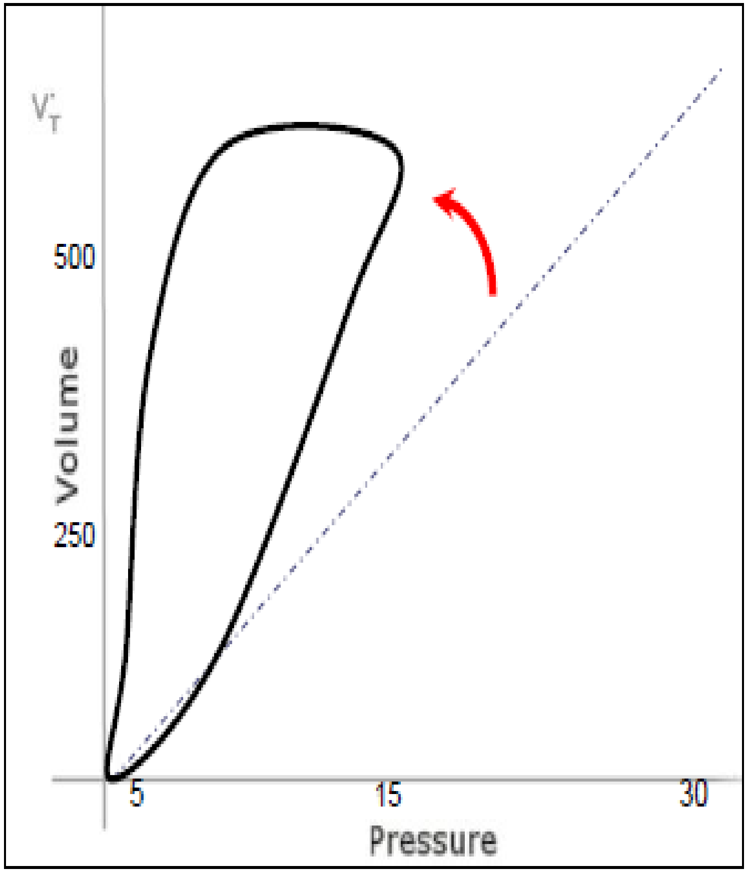


Pressure–volume curve. Shown is a pressure–volume curve developed from measurements in isolated lung during inflation (inspiration) and deflation (expiration). The slope of each curve is the compliance. The difference in the curves is hysteresis. Reprinted from [3] with permission from Elsevier.

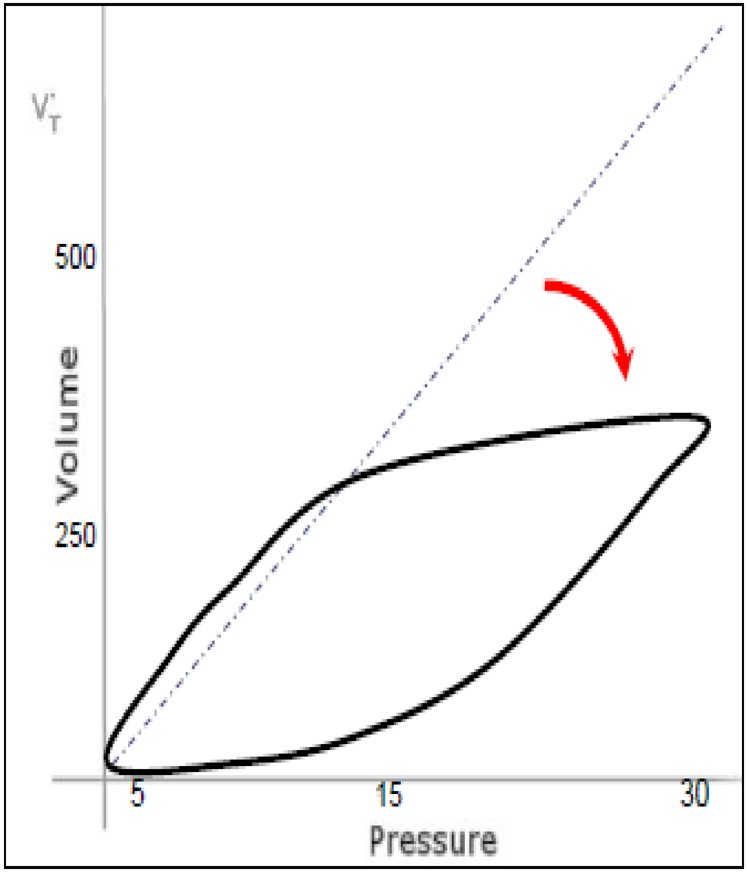
Histerezis; elastik yapılarda uygulanan kuvvet sonrası oluşan volüm değişikliğinin kuvvet ortadan kalktıktan sonra belirli bir zaman korunması

P-V Eğrisi- Eğrinin eğimi kompliansı verir

ARTMIŞ KOMPLİANS

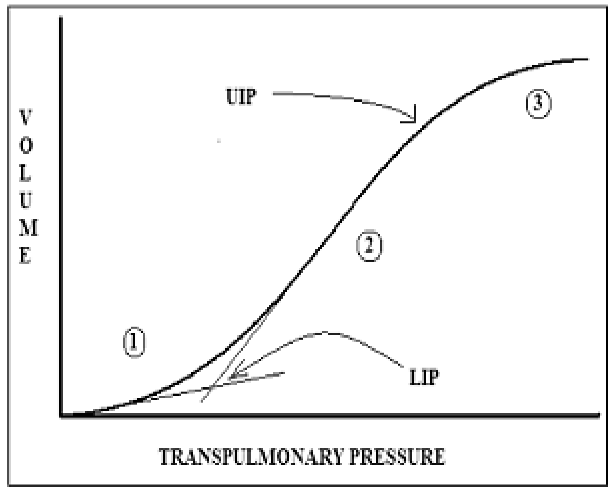


AZALMIŞ KOMPLİANS



Komplians- PV Eğrisi

Figure 5



The inspiratory limb of the pressure–volume curve (dark line) divided into three sections. Section 1 (low compliance) and section 2 (high compliance) are separated by the lower inflection point (LIP). Section 2 (high compliance) and section 3 (low compliance) are separated by the upper inflection point (UIP). In this example, the LIP is marked at the point of crossing of the greatest slope in section 2 and the lowest slope of section 1. The UIP is marked at the point of 20% decrease from the greatest slope of section 2 (a calculated value).

Critical Care October 2005 Vol 9 No 5 Grinnan and Truwit

Komplians- PV Eğrisi

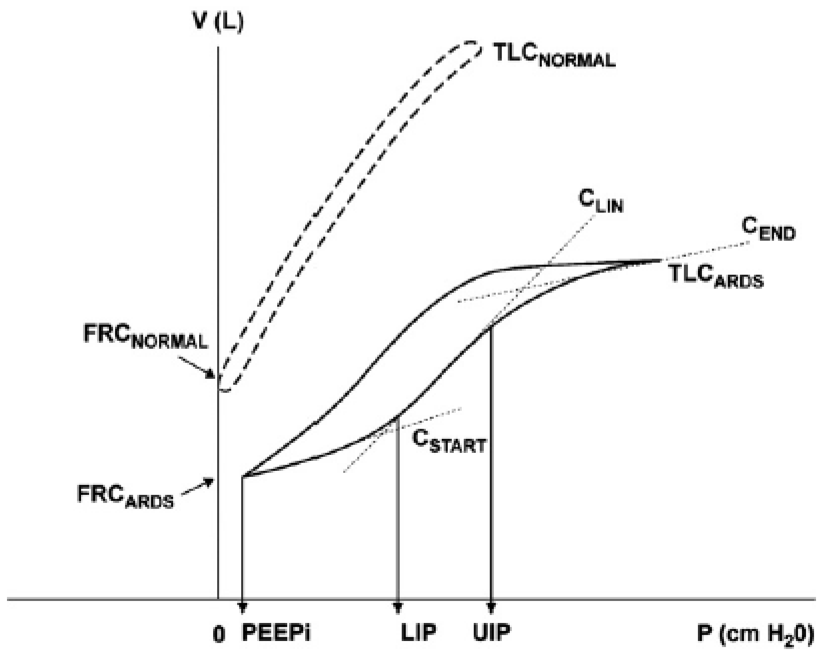
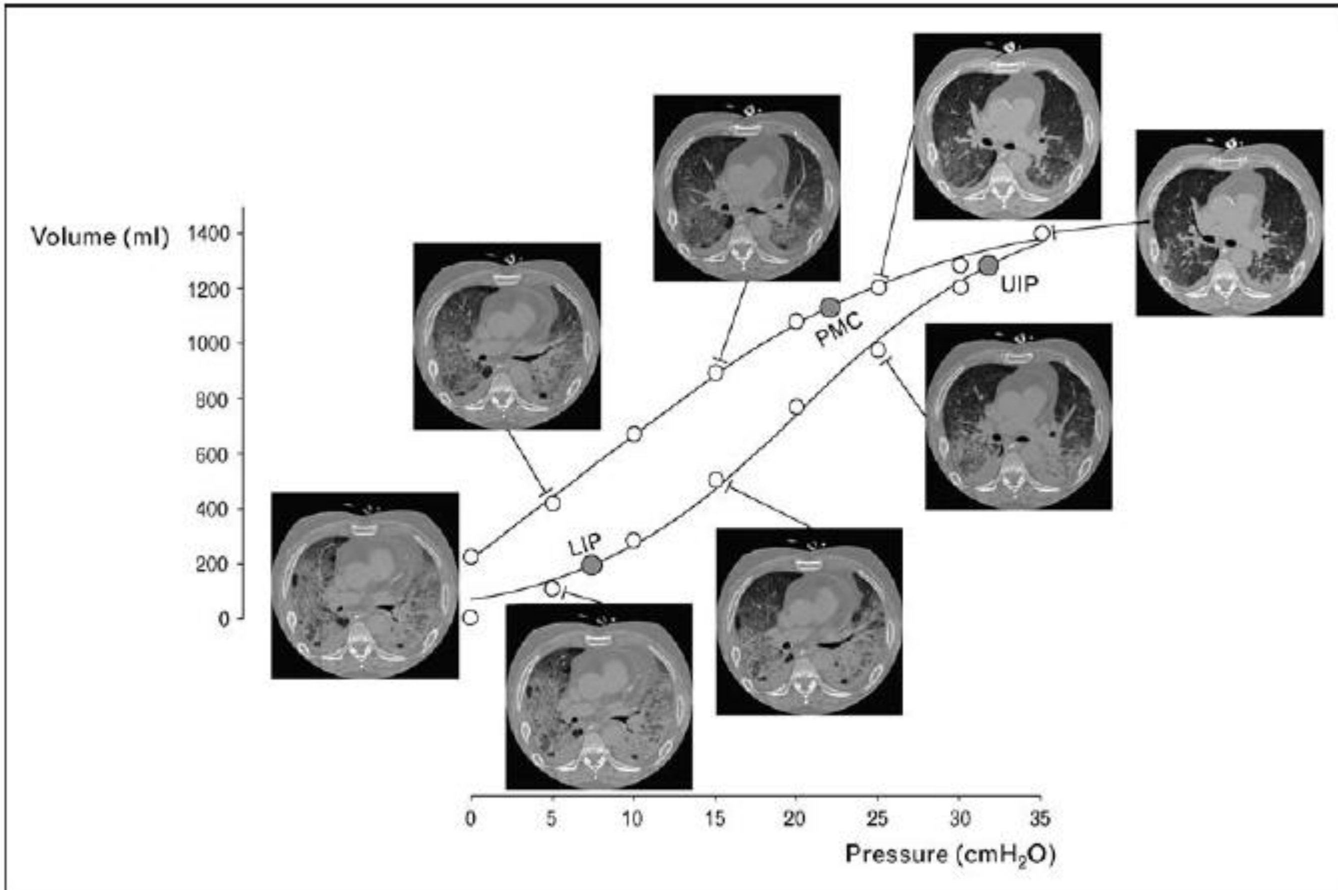


Fig. 8. Pressure–volume (PV) loops for both normal subjects and those with acute respiratory distress syndrome (ARDS). Both functional residual capacity (FRC) and total lung capacity (TLC) are decreased in ARDS. Additionally, the static PV loop for ARDS appears to demonstrate three distinct phases of compliance—starting compliance (C_{START}), a phase of linear compliance (C_{LIN}) and end compliance (C_{END}). The transitions between these three compliances are referred to as the lower inflection point (LIP) and the upper inflection point (UIP).

W.R. Henderson, A.W. Sheel / Respiratory Physiology & Neurobiology 180 (2012) 162–172

Figure 1 Lung recruitment and derecruitment along the pressure-volume curve in a patient with early acute respiratory distress syndrome

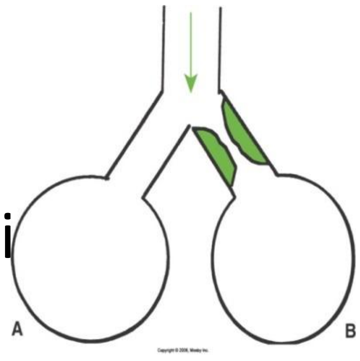


Computed tomographic scan images were obtained while tracing the curve in static conditions. Note that recruitment only starts when airway pressure is higher than the lower inflection point (LIP) of the inspiratory limb and continues up to the maximum pressure reached, even above the upper inflection point (UIP). There is, however, no derecruitment when airway pressure decreases from this level to the expiratory point of maximum curvature (PMC). With pressures below this point, derecruitment starts and continues along the rest of the expiratory limb of the curve.

Current Opinion in Critical Care 2008, 14:80–86

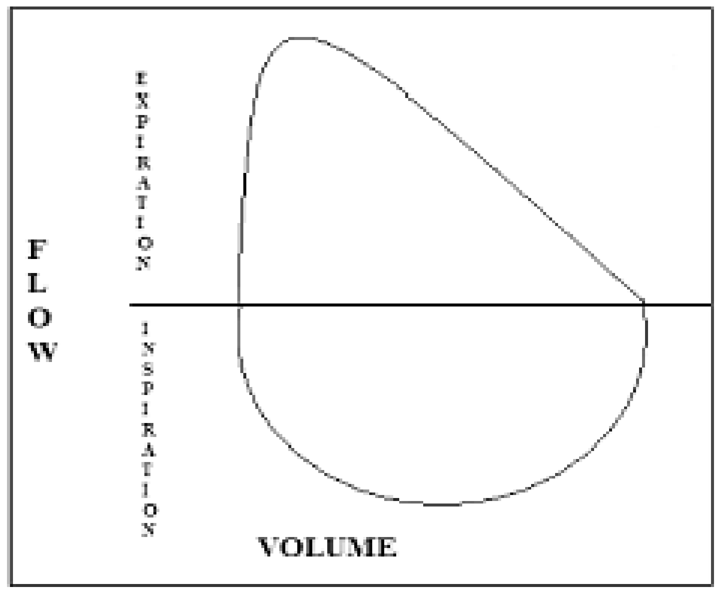
Solunum Mekanikleri

- **Rezistans: «Akıma karşı direnç»**
  - İletici hava yolları sorumludur
    - Akım Hızı: Tidal Volüm / İnspirasyon süresi
    - **Rezistans: Ppeak-Pplato/ Akım Hızı**
  - **Raw (cmH20/L/sn):**
    - Entübe olmayanlarda: 0.6-2.4 cmH20/L/sn
    - Entübelerde ≥ 6cmH20/L/sn
    - **Endotrakeal tüp** rezistans artışında önemli!!
    - Tüp ne kadar küçük olursa, rezistans o kadar fazla olur
    - Hava yolu hastalıkları rezistansı artırır



Pilbeam SP. Basic terms and concepts of mechanical ventilation.,in Mechanical Ventilation:Physiological and Clinical Applications ed 4, St Louis 2006, Mosby

Solunum Mekanikleri-
Akım Volüm Eğrisi



Flow–volume loop. A flow–volume loop is shown, with exhalation above the horizontal axis and inspiration below.

Solunum Mekanikleri-
Akım Volüm Eğrisi

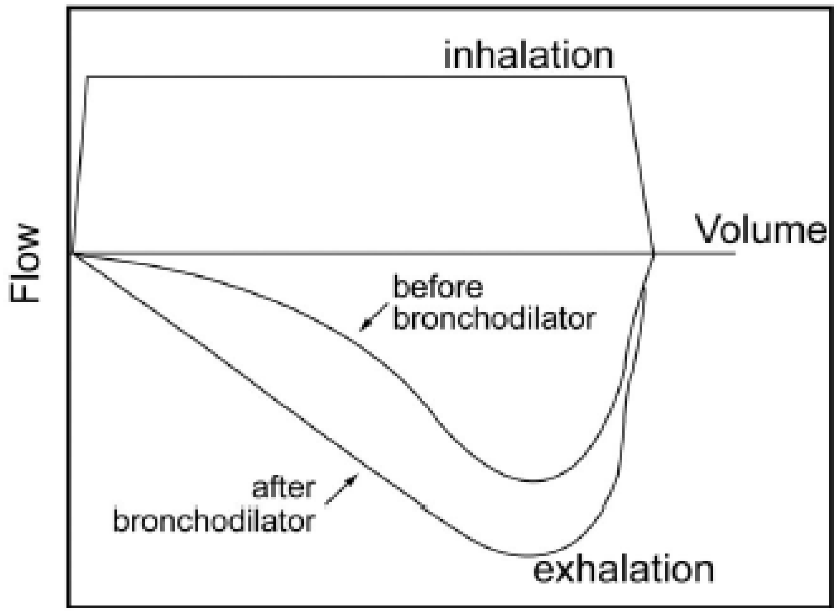


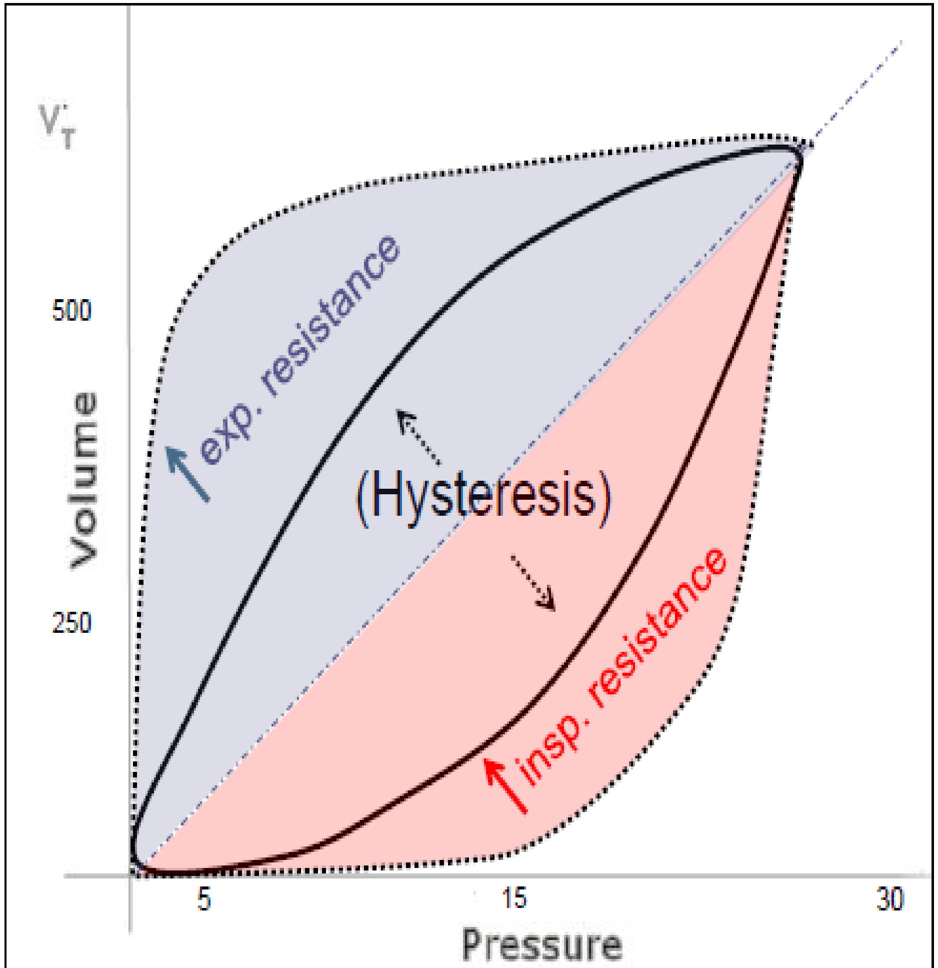
Fig. 22. Flow-volume curve illustrating response to broncho-dilation in a patient with obstructive lung disease.

RESPIRATORY MECHANICS DURING MECHANICAL VENTILATION

RESPIRATORY CARE • NOVEMBER 2014 VOL 59 NO 11

PV Eğrisi

Increased expiratory resistance: secretions, bronchospasms, etc.

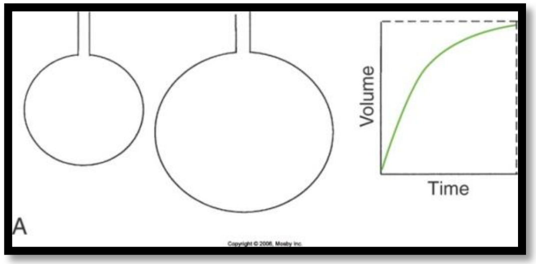


Increased inspiratory resistance: kinked ET tube, patient biting tube

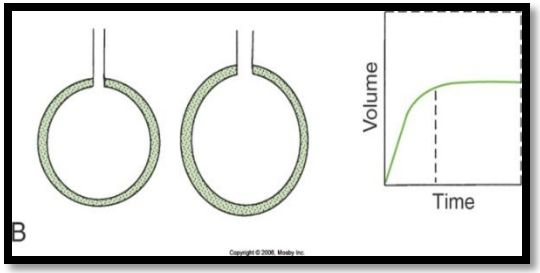
Solunum Mekanikleri

Zaman Sabiti: Komplians x Rezistans

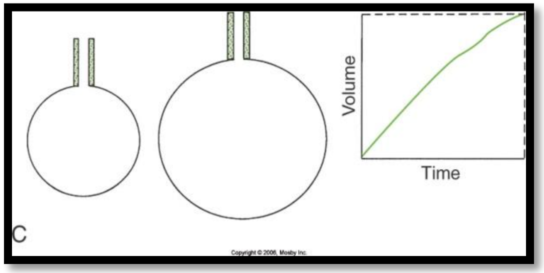
A: Normal AC



B: Düşük komplians;
alveoller hızlıca dolar ama daha az hava girer
(Kısa zaman sabiti; örn ARDS)



C: Artmış rezistans;
alveoller yavaş dolar, daha yavaş boşalır.
(Uzun zaman sabiti; örn KOAH)



Solunum Mekanikleri

Pozitif Basınçlı Ventilasyonda Gaz Akımı Temel Denklemi

= (Ventilatör tarafından oluşturulan pozitif basınç)+ (inspiratuar kaslar tarafından oluşturulan negatif plevral basınç)

= P elastans + P resistive

=(Elastans x Volüm)+(Rezistans x Akım)

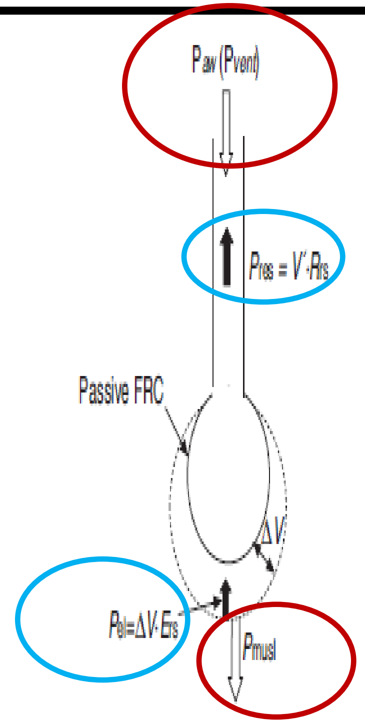


Fig. 1. – Schematic representation of pressures acting on the respiratory system during assisted mechanical ventilation. Pressure generated by inspiratory muscles (P_{mus}) and ventilator (P_{aw}) drive inspiratory flow (V') into the lungs (open arrows), which is opposed by resistive (P_{res}) and elastic (P_{el}) pressures (closed arrows). R_{rs}: resistance of respiratory system; FRC: functional residual capacity; ΔV: change in volume; E_{rs}: elastance of the respiratory system.

Ptot (t)= Pmus(t)+Paw(t)=V'(t).Rrs+VT(t).Ers+PEEPi

Pilbeam SP. Basic terms and concepts of mechanical ventilation.,in Mechanical Ventilation:Physiological and Clinical Applications ed 4, St Louis 2006, Mosby

Solunum Mekaniklerinin Yatak Başında Değerlendirilmesi

- **İnspiratory Hold Manevrası;**

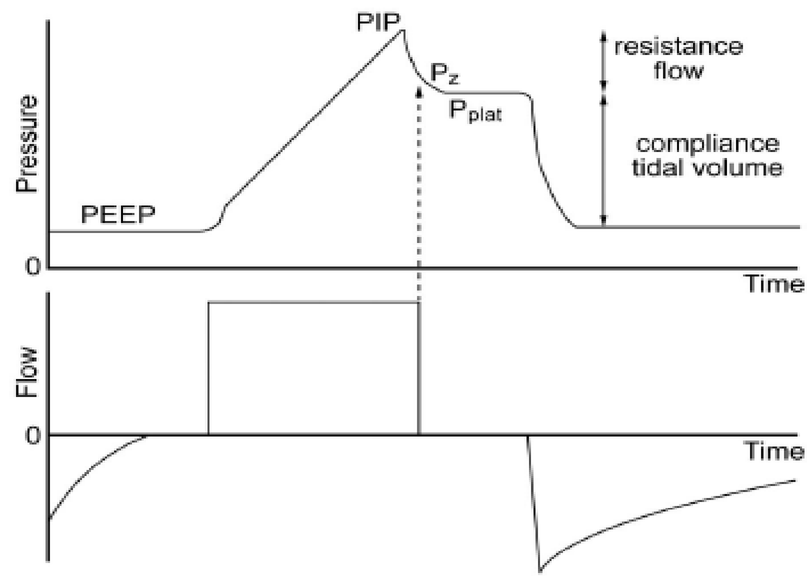


Fig. 1. Airway pressure and flow waveforms during constant flow volume control ventilation, illustrating the effect of an end-inspiratory breath-hold. With a period of no flow, the pressure equilibrates to the plateau pressure (P_{plat}). P_{plat} represents the peak alveolar pressure. The difference between P_z and P_{plat} is due to time constant inhomogeneity within the lungs. The difference between the peak inspiratory pressure (PIP) and P_{plat} is determined by resistance and flow. The difference between P_{plat} and PEEP is determined by tidal volume and respiratory system compliance. P_z = pressure at zero flow.

Respiratory Mechanics in Mechanically Ventilated Patients
Dean R Hess PhD RRT FAARC
Respiratory Care • November 2014 Vol 59 No 11

Solunum Mekaniklerinin Yatak Başında Değerlendirilmesi

- **Ekspiratory hold manevrası**

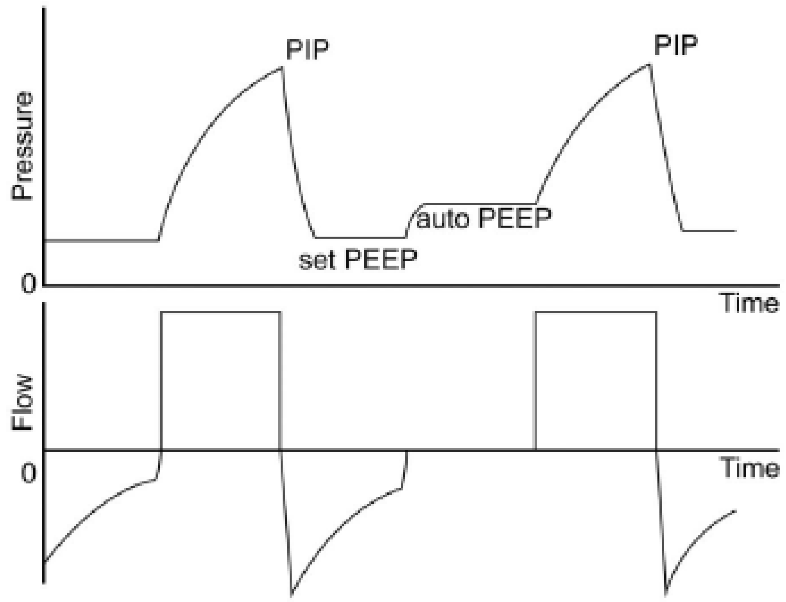


Fig. 2. Applying an end-expiratory breath-hold allows measurement of end-expiratory alveolar pressure. The difference between PEEP set and the pressure measured during this maneuver is the amount of auto-PEEP. PIP = peak inspiratory pressure.

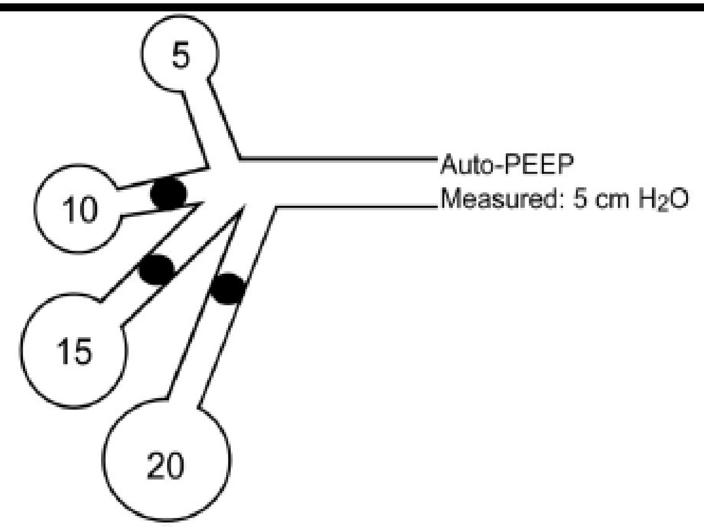


Fig. 3. As illustrated here, the measured auto-PEEP can be considerably less than the auto-PEEP in some lung regions if airways collapse during exhalation.

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Solunum Mekaniklerinin Yatak Başında Değerlendirilmesi

Restrepo et al

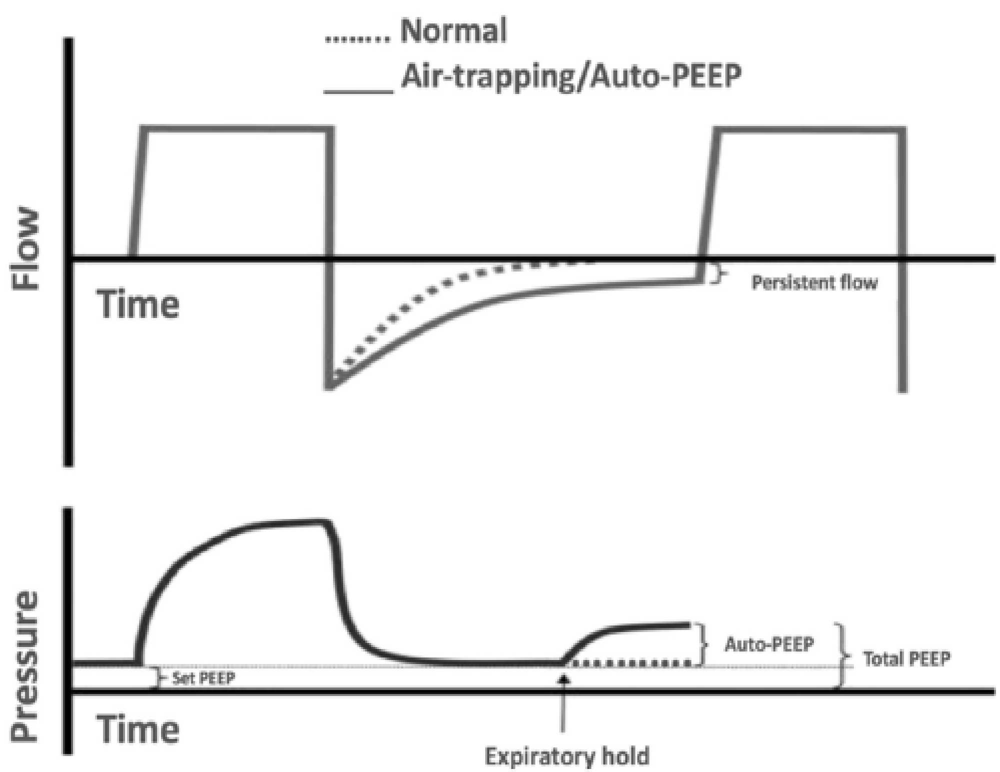
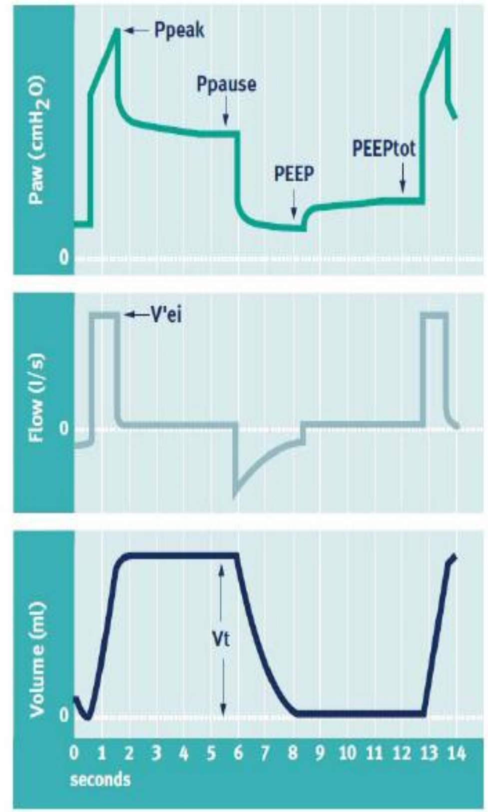


Fig. 4. Flow-time scalar (*top*) indicating persistency of expiratory flow at the end of the breath, indicating air trapping. The end-expiratory alveolar pressure is obtained after applying an end-expiratory pause. The difference between the pressure measured during this maneuver (total PEEP) and the level of PEEP selected by the operator is the amount of auto-PEEP. The pressure-time scalar (*bottom*) displays the end-expiratory alveolar pressure obtained after applying an end-expiratory pause.

Solunum Mekanikleri

- **Peak İnspiratuar Basınç (PIP):**
  - İnspiratuar fazdaki en yüksek basınç
  - Belirleyen faktörler
    - AC-Göğüs duvarı kompliansı
    - Havayolu rezistansı
    - Verilen tidal volüm
    - İnspiratuar akım hızı
    - End ekspiratuar basınç(PEEP)
    - Solunum iş yükü (WOB)
- **İnspiratuar pause:**
  - Amaç: AC'de havanın dağılımını düzeltmek
  - Optimum V/Q uyumunu sağlamak
  - VD/VT oranını azaltmak



In ventilated adults with normal airway resistance, Ri,max is usually 5-8 cmH2O/l/s (including the effect of an unobstructed endotracheal tube of appropriate size)
The clinical interpretation of measurements of respiratory system compliance is easier when referred to the ideal body weight (normal value: 1 –1.2 ml/cmH2O/kg)

Ppeak = peak airway pressure
Ppause = static end-inspiratory pressure
PEEP = positive end-expiratory pressure
PEEPtot = total intrapulmonary PEEP
V'ei = end-inspiratory flow
Vt = tidal volume

$$Ri,max = \frac{Ppeak - Ppause}{V'ei}$$

$$Cqs = \frac{Vt}{Ppause - PEEPtot}$$

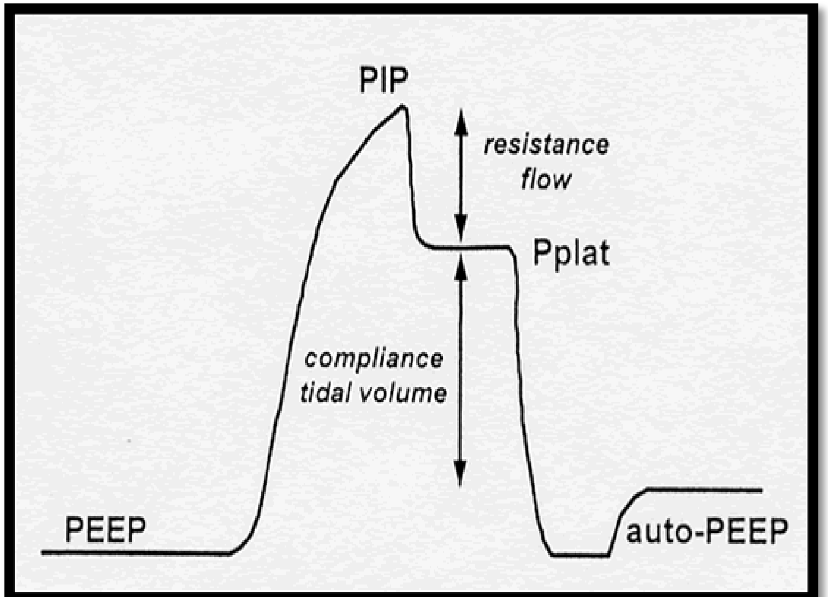
$$RC = Ri,max \cdot Cqs$$

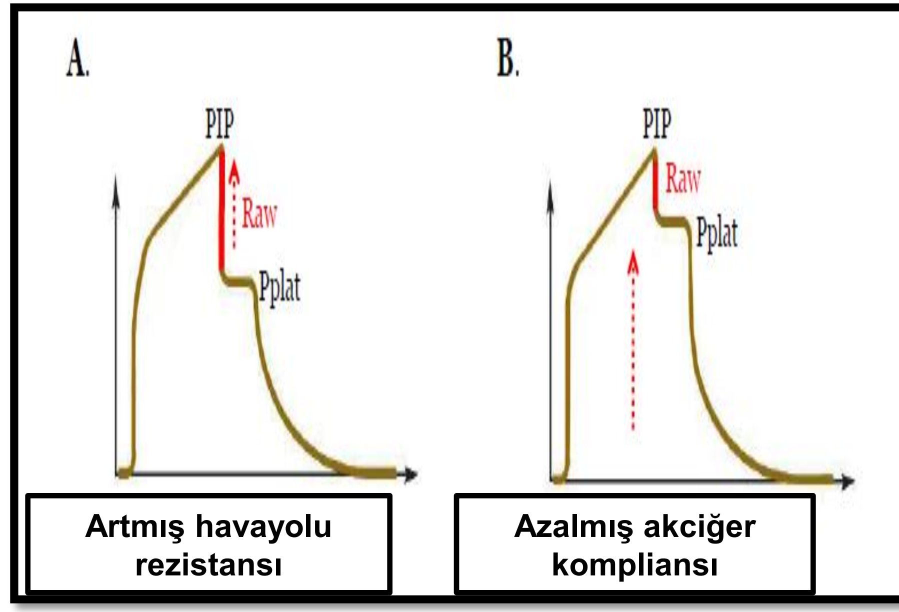
$$PEEPi = PEEPtot - PEEP$$

Frozen curves during passive VCV with constant inspiratory flow and double hold manoeuvre, for manual measurement of passive respiratory system mechanics

ESICM PACT- Mechanical Ventilation Skills and techniques. Patroniti N, Update 2011

Solunum Mekanikleri





$$C_{strs} = \frac{V_T}{P_{plat} - PEEP_{total}} \qquad R_{aw} = \frac{PIP - P_{plat}}{\dot{V}_i}$$

Pplato ≤ 30cmH20 tutulmalı

Benjamin D. Singer, MD; Thomas C. Corbridge, MD South Med 2009;102(12):12381245.

Solunum Mekaniklerinin Yatak Başında Değerlendirilmesi

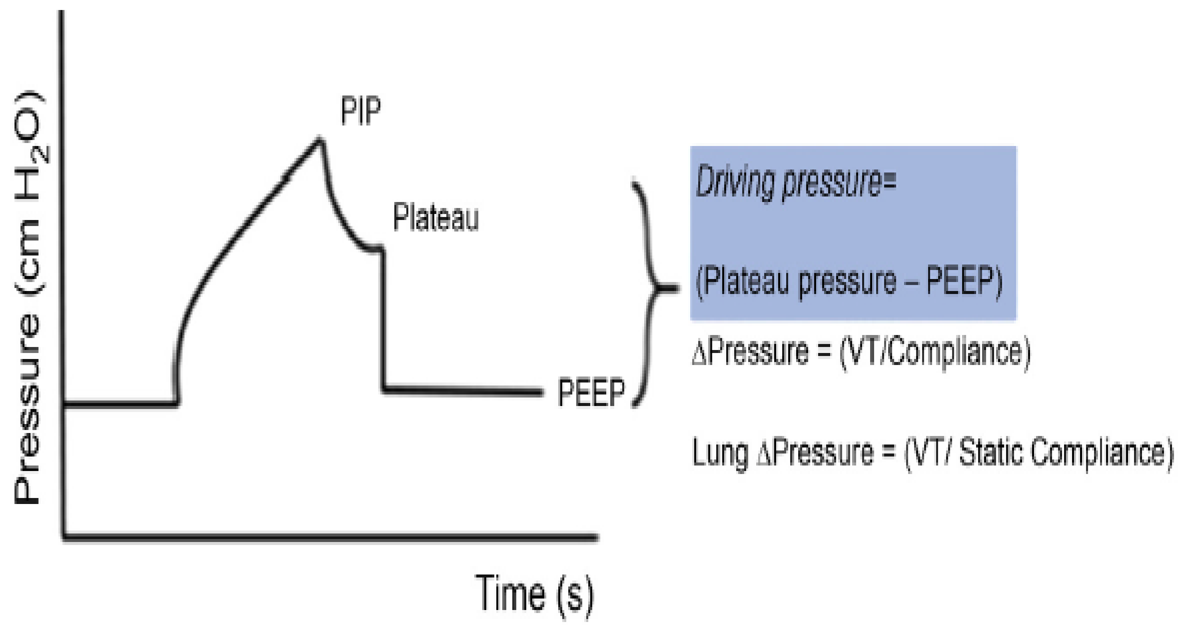
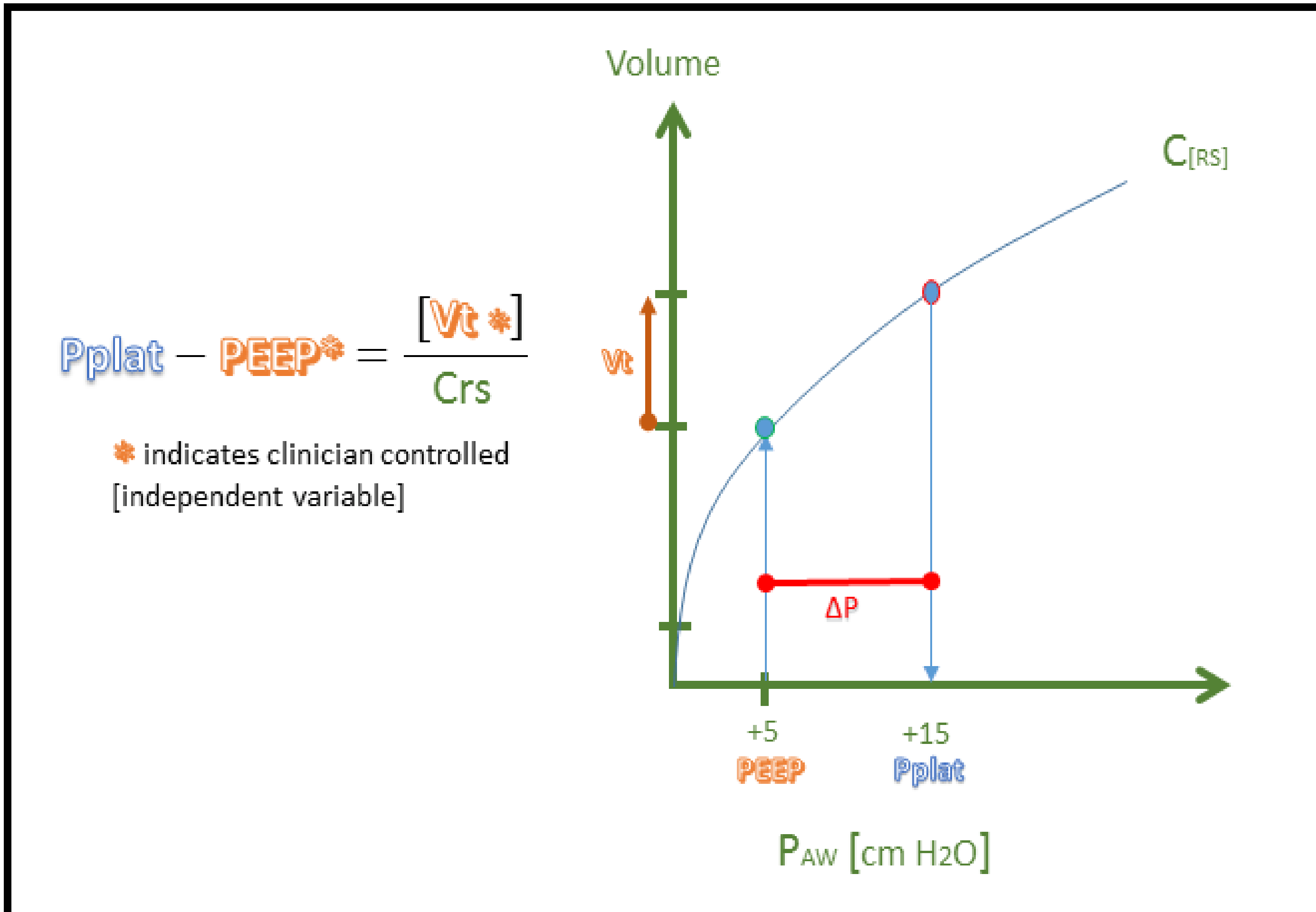


Fig. 21. DP is the difference between P_{plat} and PEEP, and is a correlate of the ratio between VT and the compliance of the respiratory system.

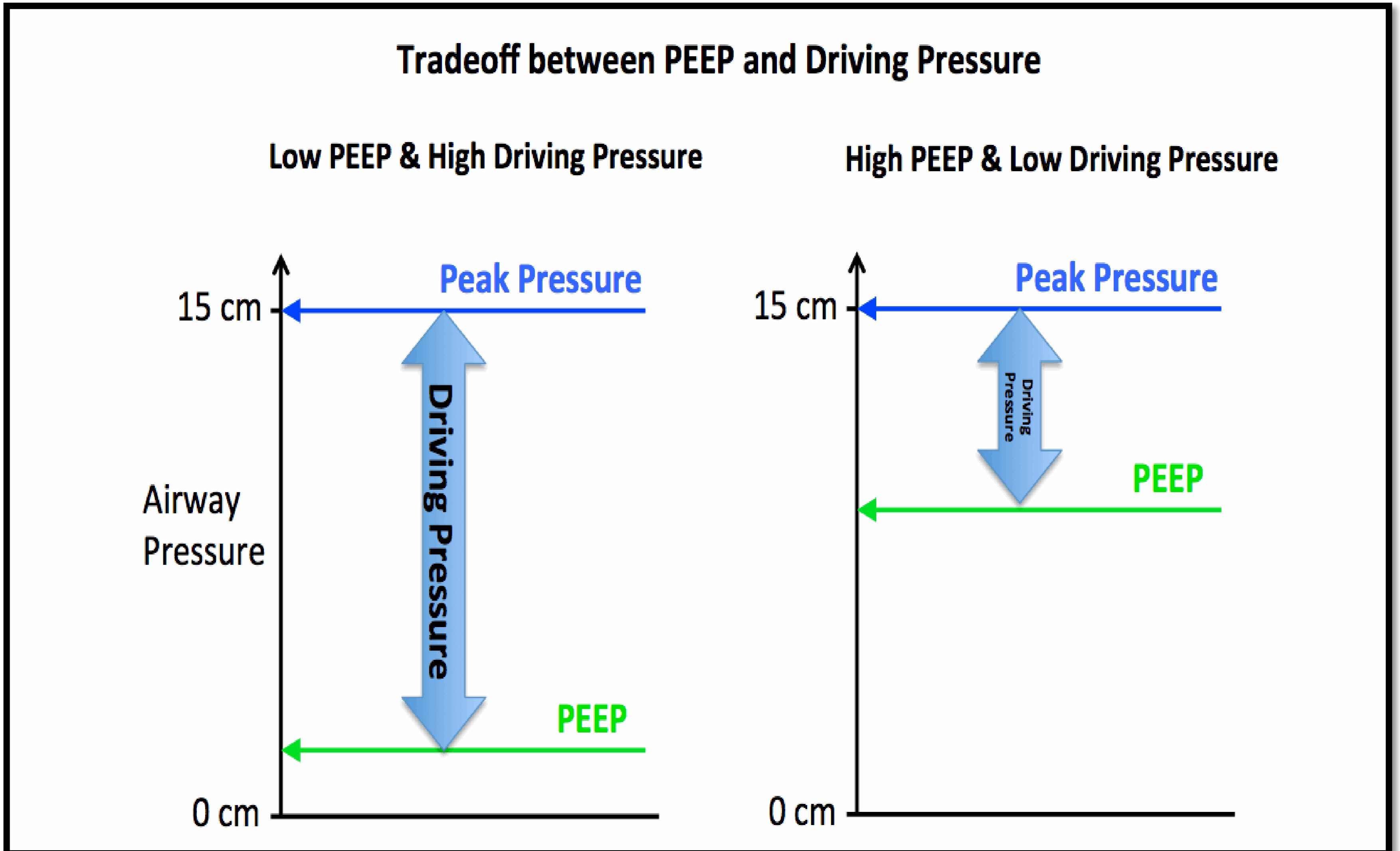
Driving Pressure-Plato Pressure

- **ΔP (Driving Pressure);**
  - Tidal volumun akciğerde ne kadar mekanik bozulma (dinamik strain) yarattığını tahmin eder,
- **Plato basıncı (Pplato);**
  - Akciğere uygulanan basıncı (akciğer stresi) yansıtır.
- Her ikisi de barotravma riskini ölcer.

Driving Pressure



Driving Pressure



Stres İndeks

- Sabit akımlı volüm kontrol ventilasyon sırasında basınç zaman eğrisinin şekli değerlendirilerek elde edilir

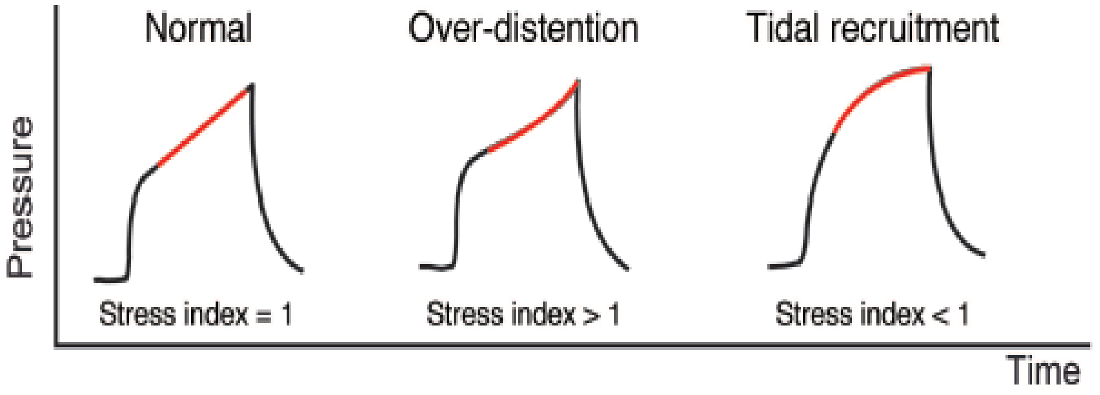


Fig. 10. Normal stress index, stress index with over-distention, and stress index with tidal recruitment.

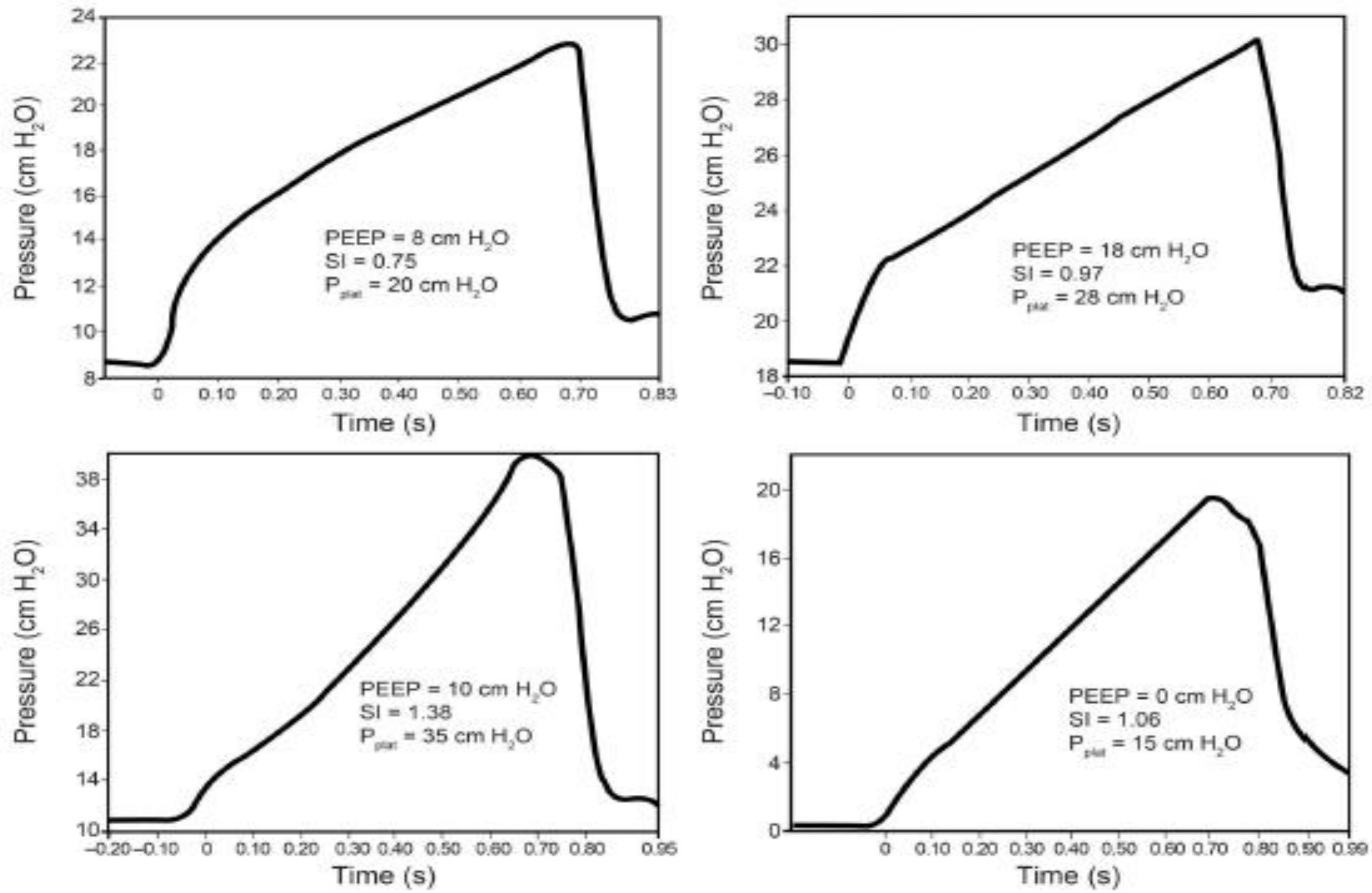


Fig. 11. Top: Stress index (SI) in a patient early in the course of ARDS. In this case, the stress index improved as PEEP was increased. Bottom: Stress index in a patient late in the course of ARDS. In this case, the stress index improved as PEEP was decreased. P_{plat} – plateau pressure. From Reference 31.

Solunum Mekaniklerinin Yatak Başında Değerlendirilmesi

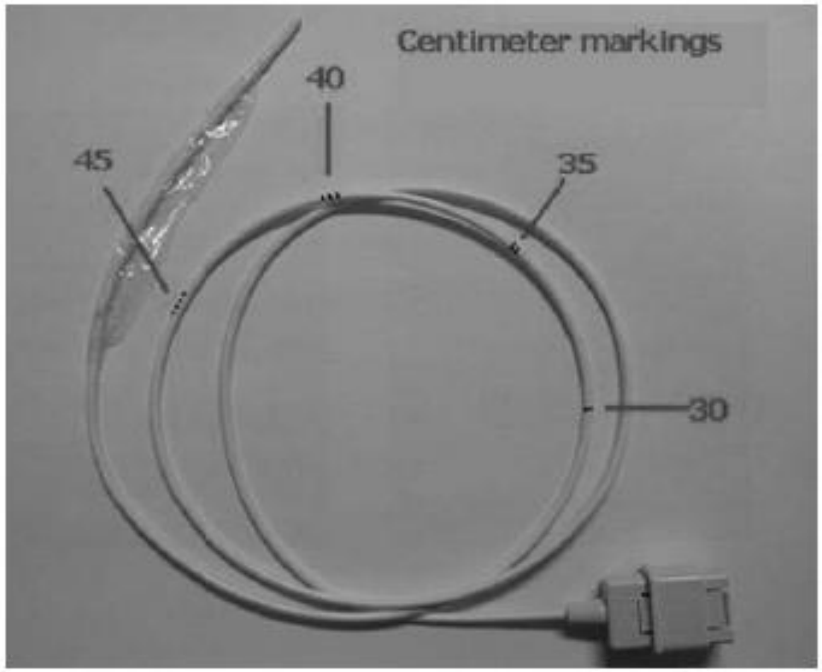


Fig. 1. Picture of an esophageal manometer demonstrating the size and position of the balloon, as well as the depth markings in centimeters.

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Solunum Mekaniklerinin Yatak Başında Değerlendirilmesi

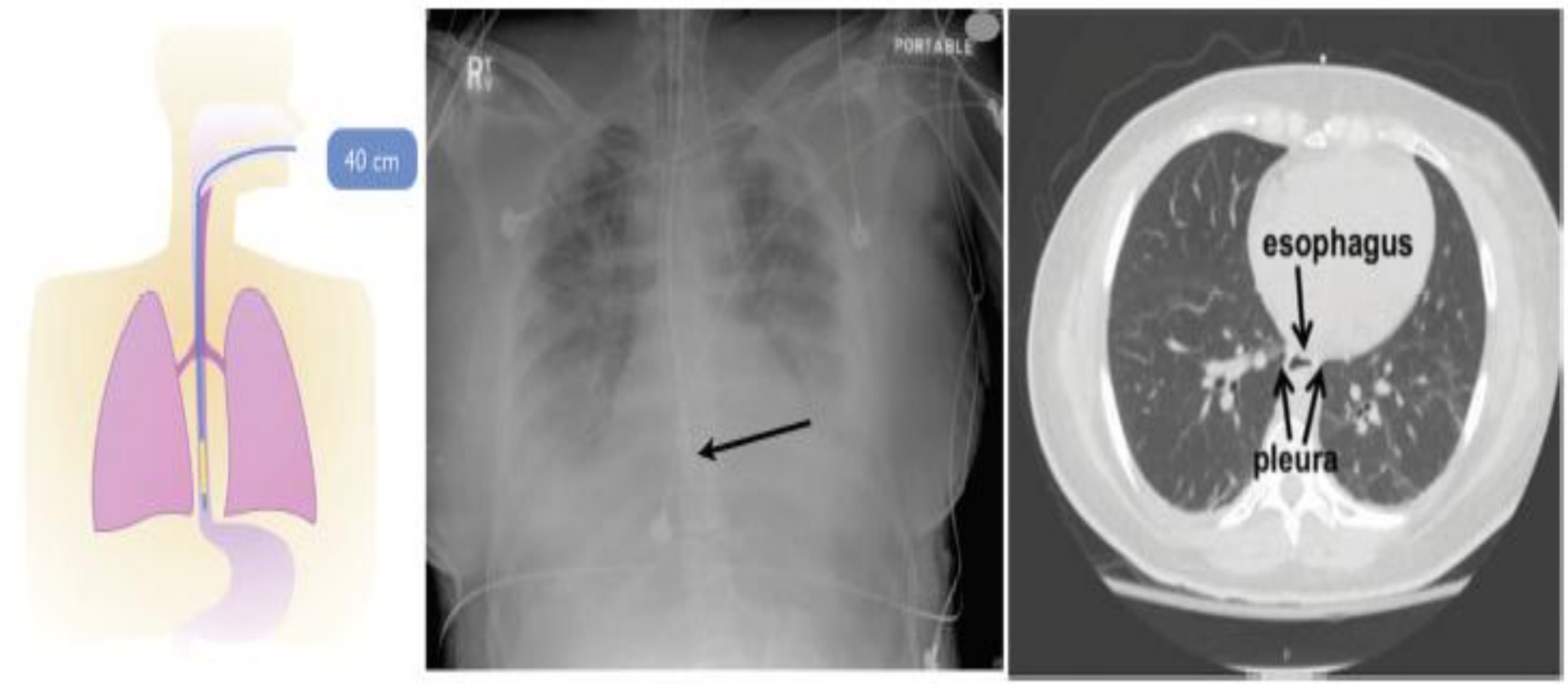


Fig. 6. Left: Correct positioning of the esophageal balloon, ~40 cm from the lips. Center: Chest radiograph showing correct balloon placement (arrow). Right: Note that the esophagus borders the pleural space in the mid-thorax (arrows). Left and center images from Reference 19.

Pes

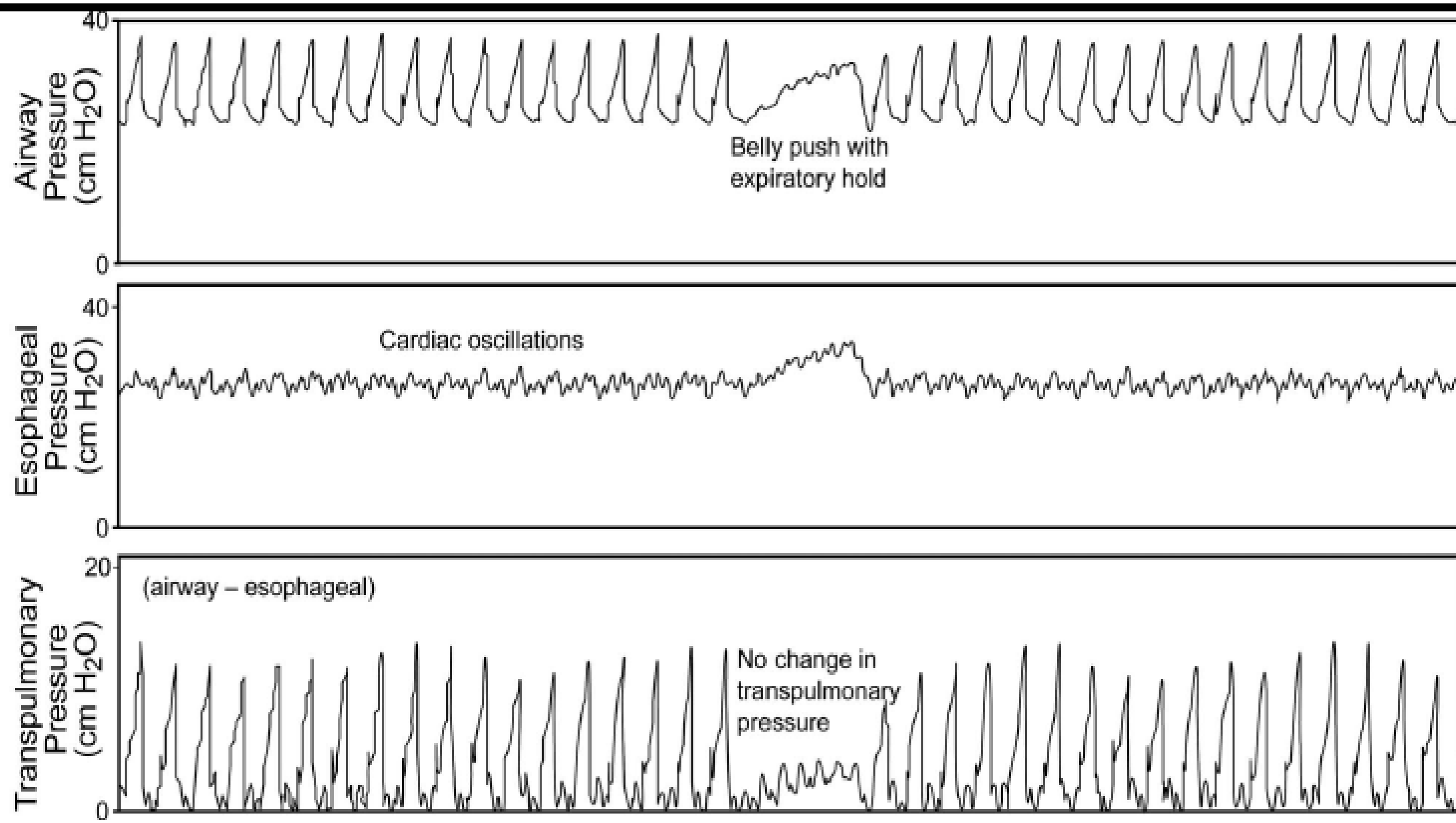


Fig. 5. Illustrated here are several features used to determine that the esophageal balloon is correctly placed in the esophagus. Notice the presence of cardiac oscillations on the esophageal pressure waveform. Also note that there is no change in transpulmonary pressure when pressure is applied to the abdomen.

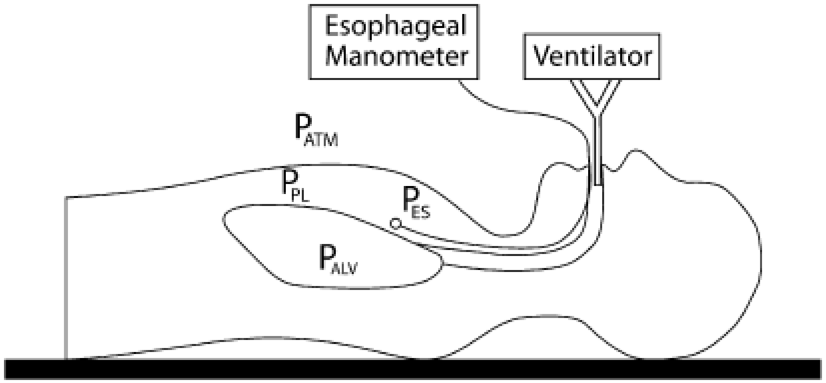


Fig. 3. Diagram depicting the pressure measures useful in partitioning pulmonary mechanics. The clinician can directly measure atmospheric pressure (P_{ATM}) and airway pressure (P_{AW}). Esophageal pressure (P_{ES}) may also be directly measured and used as a surrogate for pleural pressure (P_{PL}). With these pressures measured, several additional pressures may be derived: respiratory system pressure (P_{RS}) - $P_{ALV} - P_{ATM}$, trans-pulmonary pressure (P_{TP}) - $P_{ALV} - P_{PL}$, and chest wall pressure (P_{CW}) - $P_{PL} - P_{ATM}$.

- Prs (solunum sistemi basıncı) = Palv-Patm
- Ptp (transpulmoner basınç)= Palv-Ppl
- Pcw (göğüs duvarı basıncı)=Ppl-Patm

Pes-Ptp

- Hasta başında transpulmoner basınç ölçümünün iki amacı vardır:
  - hava yolu basıncı üzerine göğüs duvarının etkisini belirlemek
  - akciğeri açık tutacak basıncı belirlemek

- Ayrıca, özofagus basıncı hasta eforunu göstermede önemlidir.

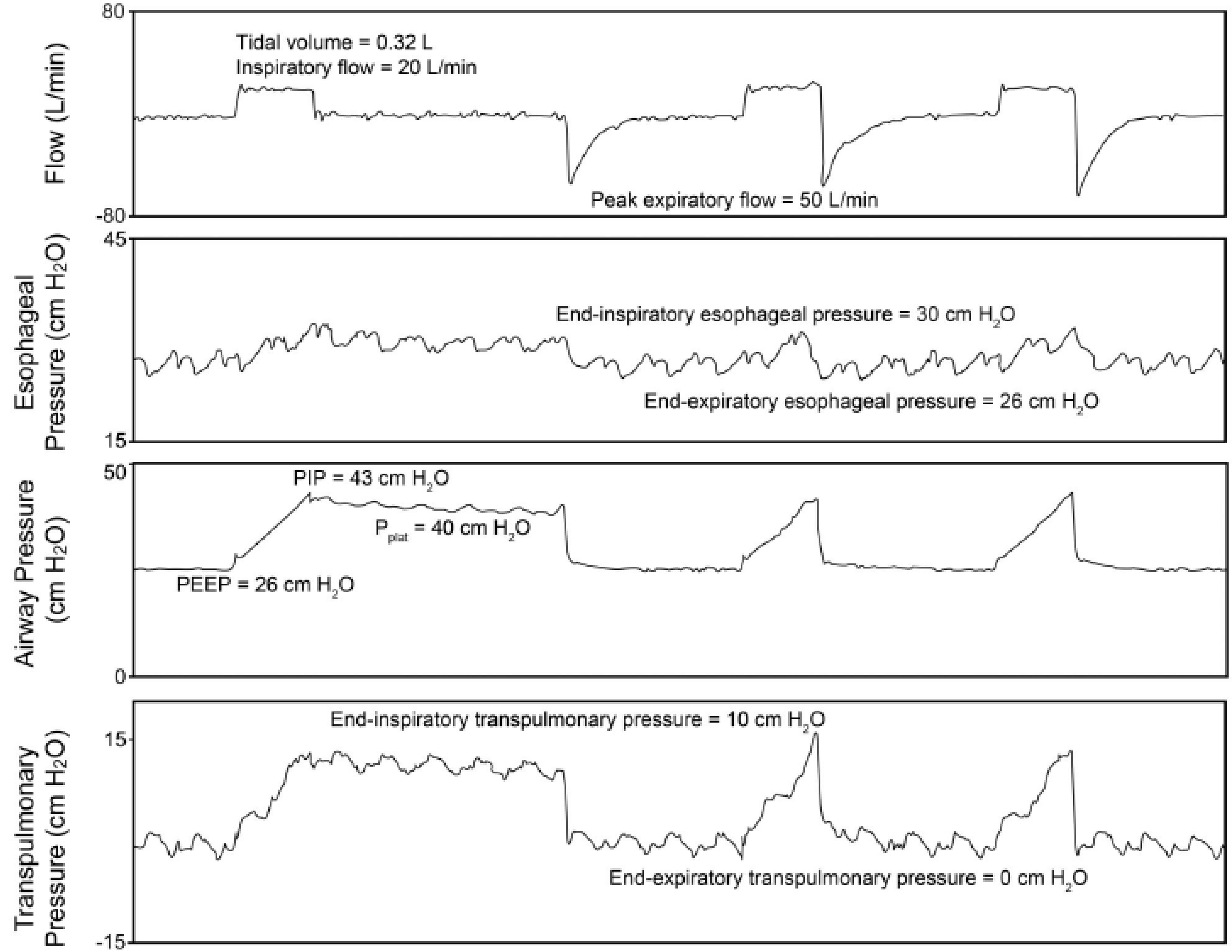
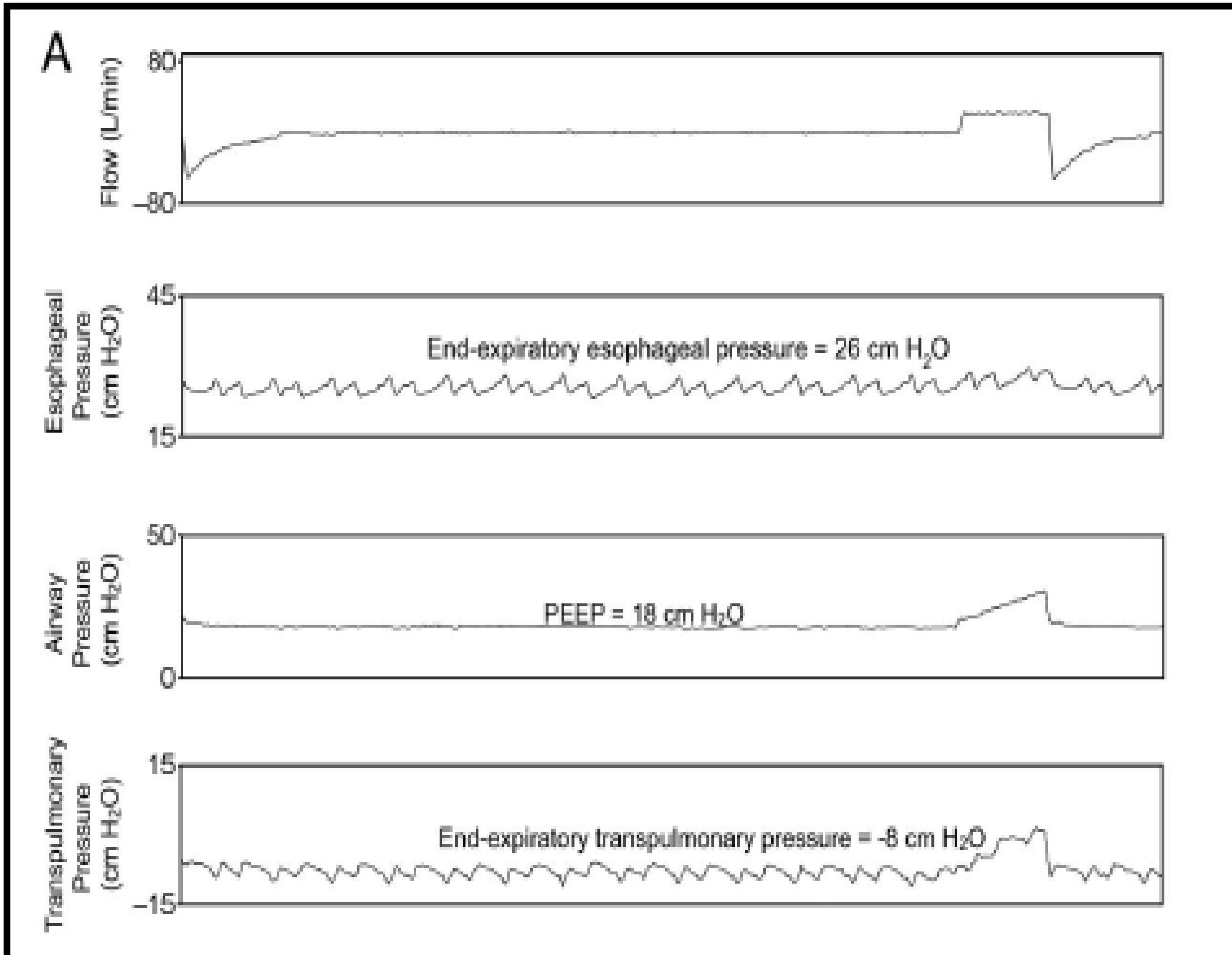
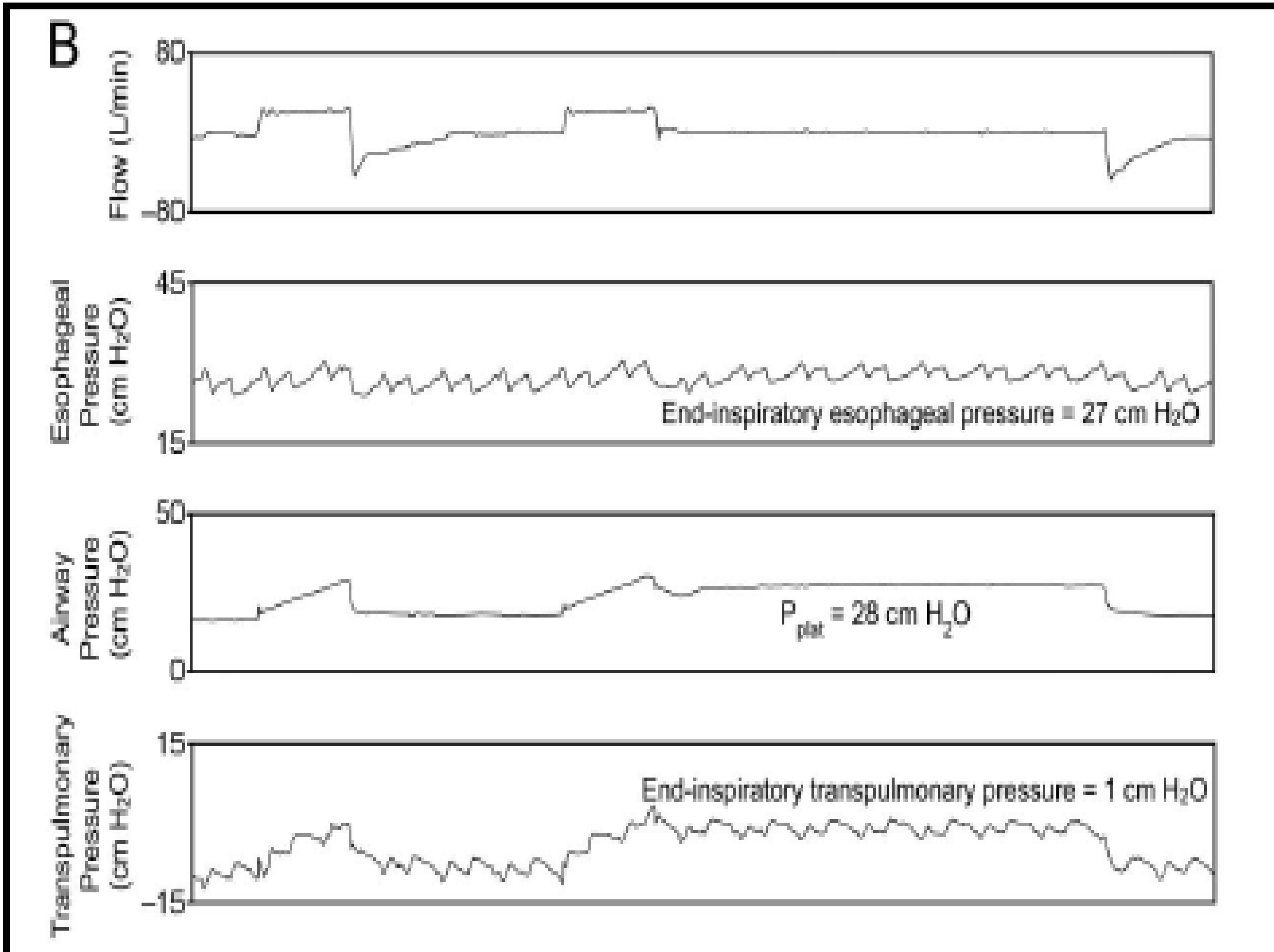


Fig. 17. Flow, esophageal pressure, airway pressure, and transpulmonary pressure can be used to calculate respiratory system compliance, chest-wall compliance, lung compliance, inspiratory airway resistance, and expiratory airway resistance. See text for details. PIP = peak inspiratory pressure; P_{plat} = plateau pressure.


A
Flow (L/min)
80
-80
Esophageal Pressure (cm H2O)
45
15
End-expiratory esophageal pressure = 26 cm H2O
Airway Pressure (cm H2O)
50
0
PEEP = 18 cm H2O
Transpulmonary Pressure (cm H2O)
15
-15
End-expiratory transpulmonary pressure = -8 cm H2O



B
80
Flow (L/min)
−80
45
Esophageal Pressure (cm H2O)
15
End-inspiratory esophageal pressure = 27 cm H2O
50
Airway Pressure (cm H2O)
0
Pplat = 28 cm H2O
15
Transpulmonary Pressure (cm H2O)
−15
End-inspiratory transpulmonary pressure = 1 cm H2O

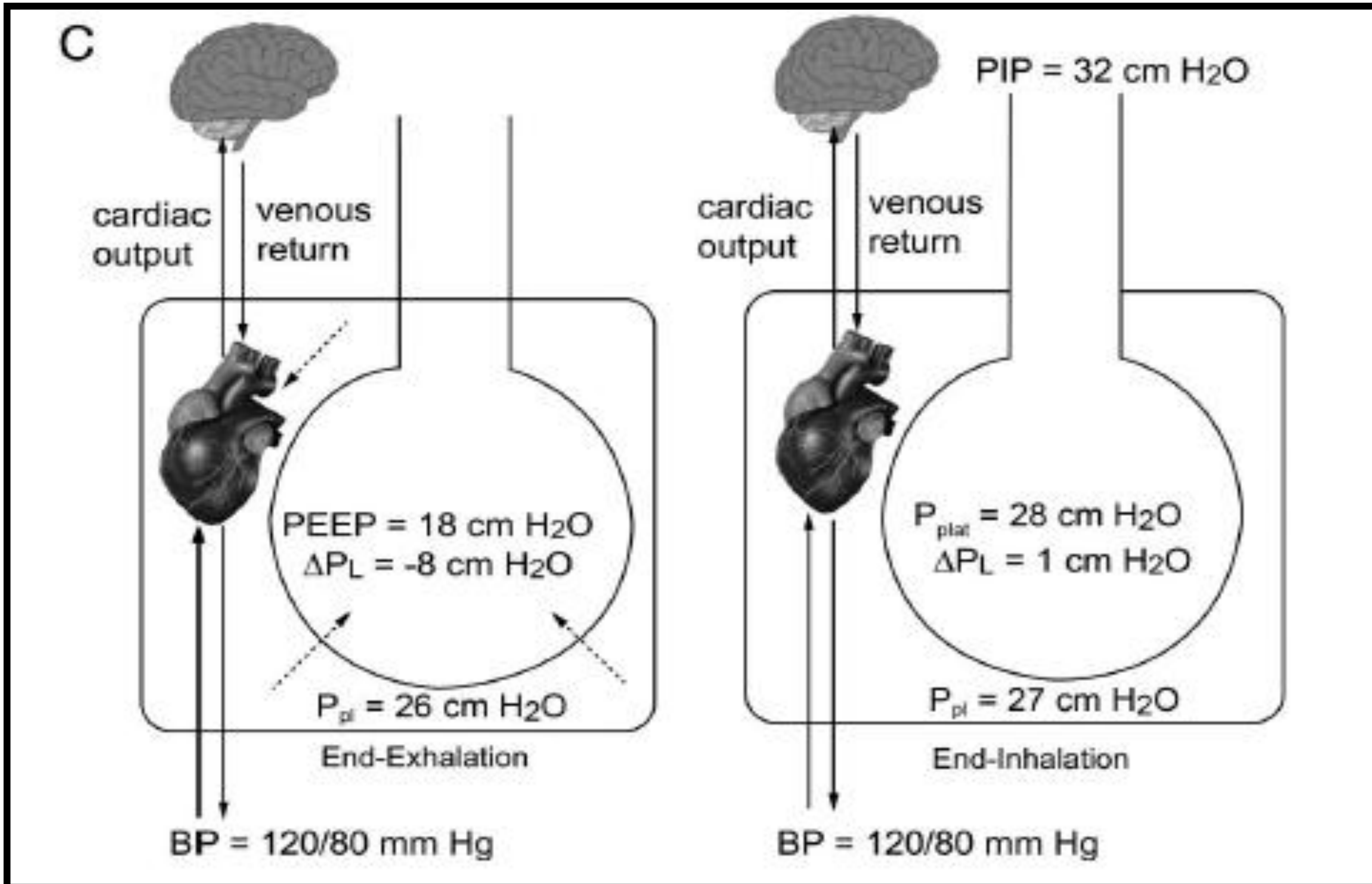
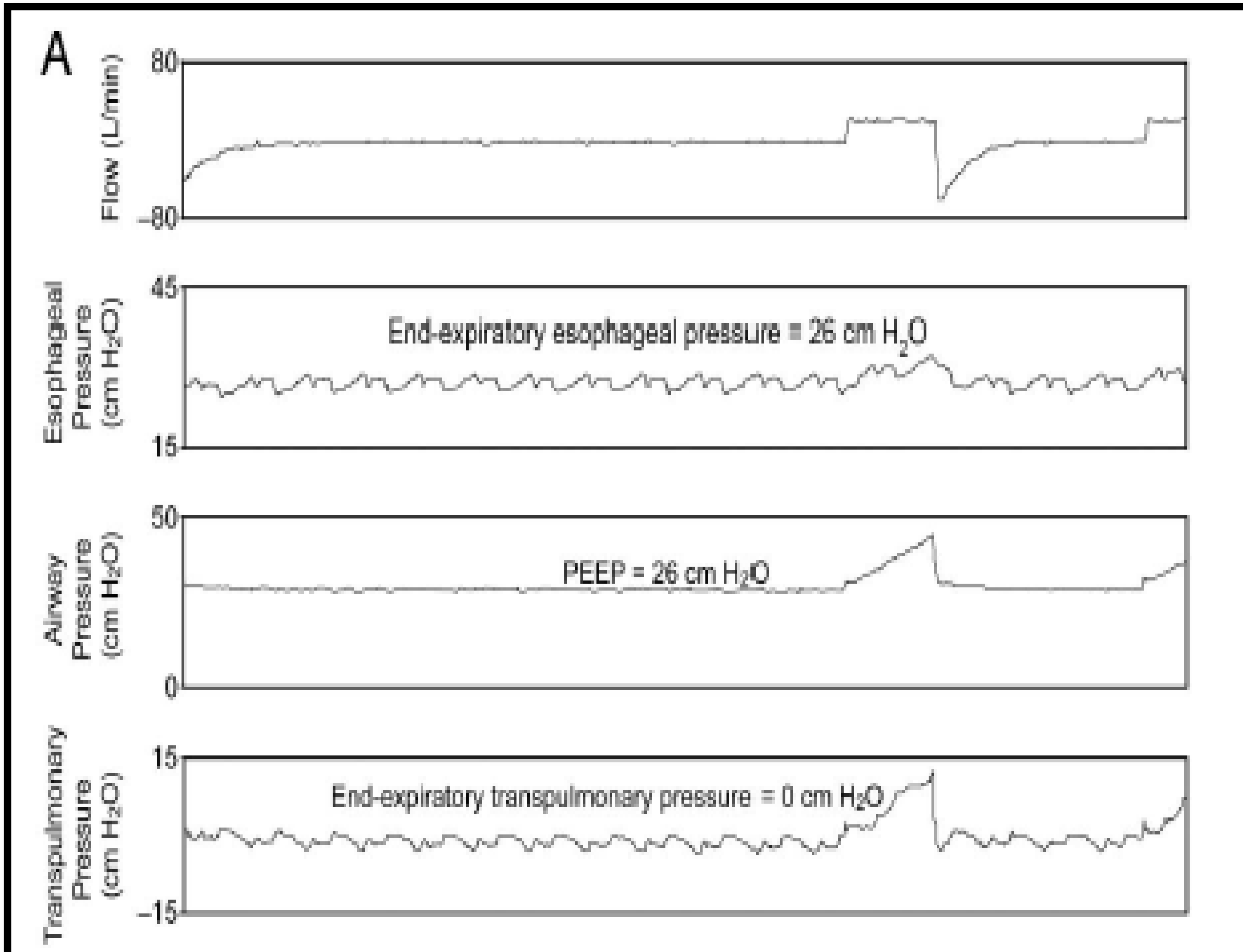
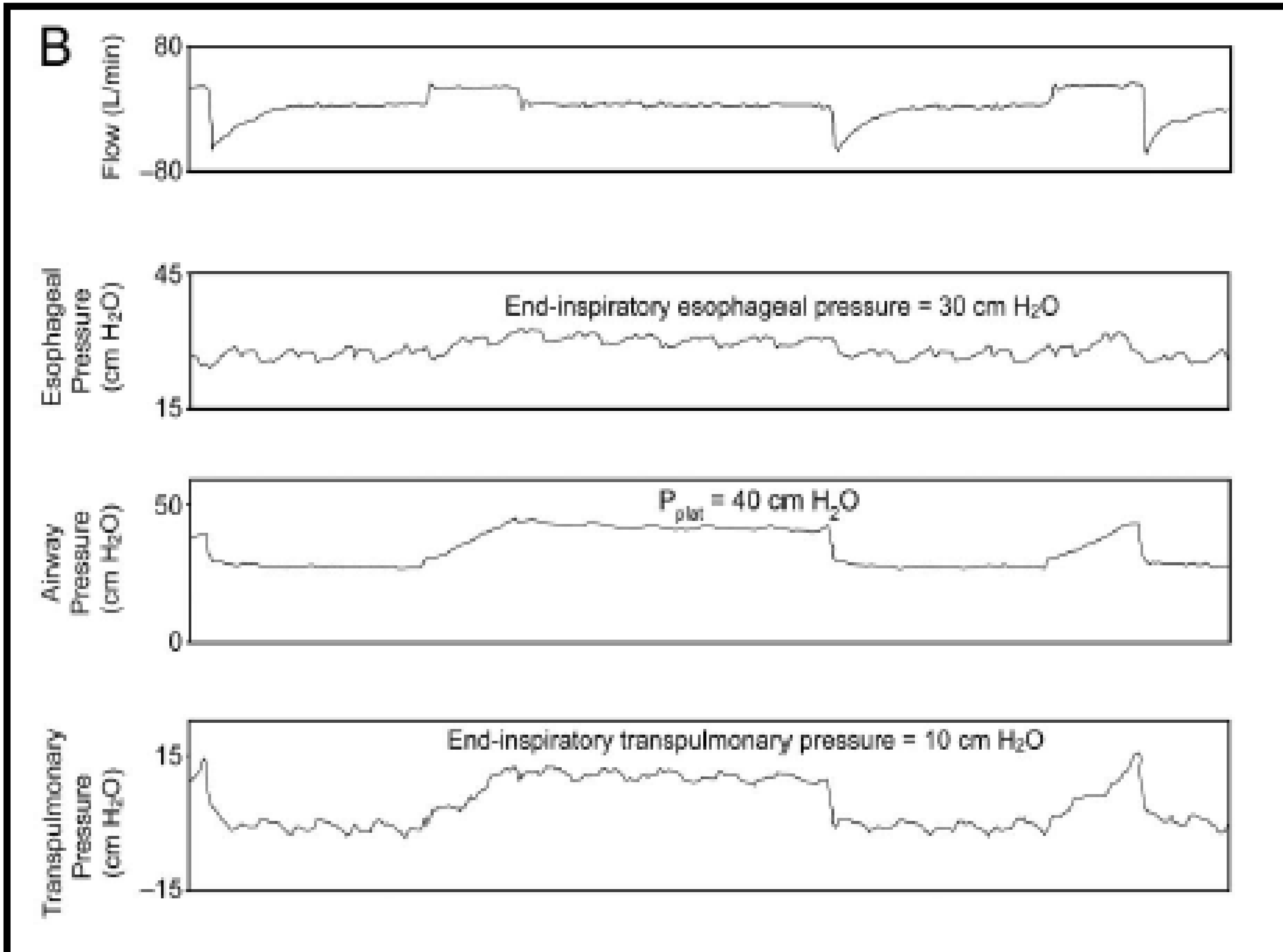


Fig. 24. Esophageal pressure, airway pressure, and transpulmonary pressure (P_L) with PEEP set at 18 cm H_2O. A: During expiratory pause. B: During inspiratory pause. C: As shown in the cartoon, there is a net collapsing pressure on the lungs, heart, and central circulation at the end of exhalation. At the mid-thoracic level (position of the esophageal balloon), the end-inspiratory P_L is slightly positive. P_{plat} = plateau pressure; PIP = peak inspiratory pressure; P_{pl} = pleural pressure; BP = blood pressure.


A
80
Flow (L/min)
−80
45
Esophageal Pressure (cm H2O)
End-expiratory esophageal pressure = 26 cm H2O
15
50
Airway Pressure (cm H2O)
PEEP = 26 cm H2O
0
15
Transpulmonary Pressure (cm H2O)
End-expiratory transpulmonary pressure = 0 cm H2O
−15


B
Flow (L/min)
80
−80
Esophageal Pressure (cm H2O)
45
15
End-inspiratory esophageal pressure = 30 cm H2O
Airway Pressure (cm H2O)
50
0
Pplat = 40 cm H2O
Transpulmonary Pressure (cm H2O)
15
−15
End-inspiratory transpulmonary pressure = 10 cm H2O

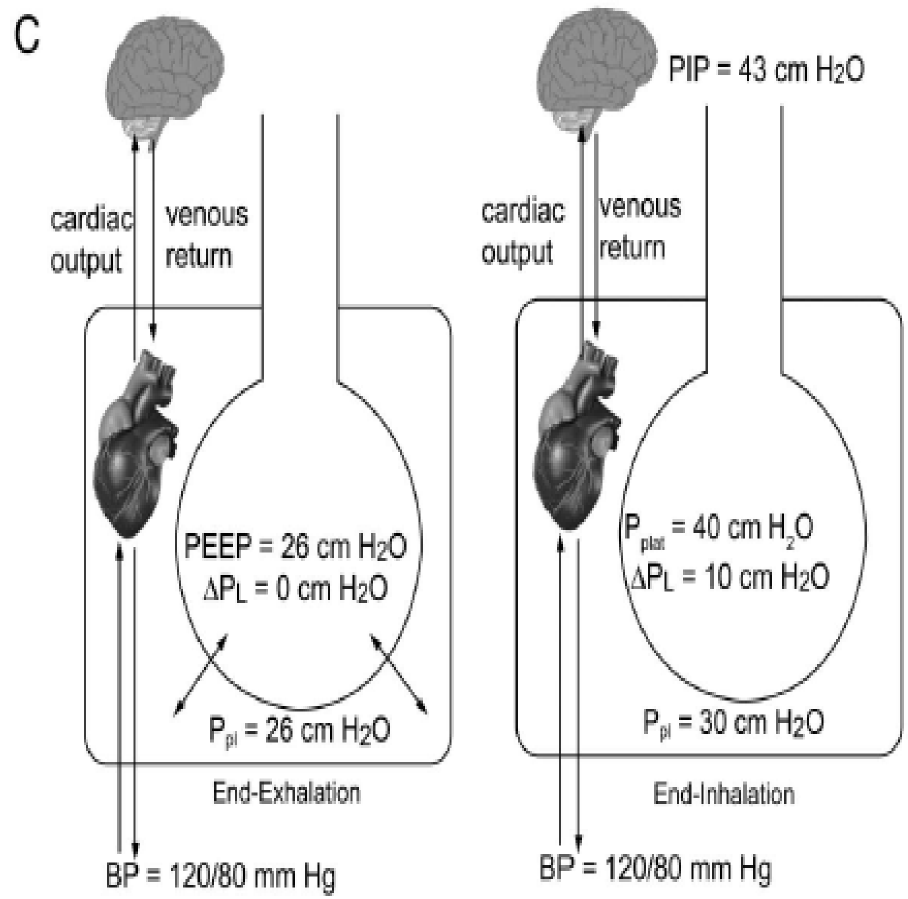


Fig. 25. Esophageal pressure, airway pressure, and transpulmonary pressure (P_L) with PEEP set at 26 cm H_2O (same patient as Fig. 24). A: During expiratory pause. B: During inspiratory pause. C: as shown in the cartoon, the PEEP counterbalancs the P_{es} (pleural pressure [P_{pl}]). Note that the same pressure is exerted on the heart and central circulation at the end of exhalation. At the mid-thoracic level (position of the esophageal balloon), the end-inspiratory P_L is 10 cm H_2O, which is likely safe, despite a plateau pressure (P_{plat}) of 40 cm H_2O. Note that blood pressure (BP) is not affected because there is no increase in P_{pl} with the addition of PEEP. PIP = peak inspiratory pressure; Ppl = pleural pressure; BP = blood pressure.

Solunum Mekanikleri

- **Work of breathing**
  - WOB= P X V (ventilasyonu gerçekleştirecek akımın başlaması için gereken enerji)

Table 2. – Determinants of work of breathing in ventilator-dependent patients

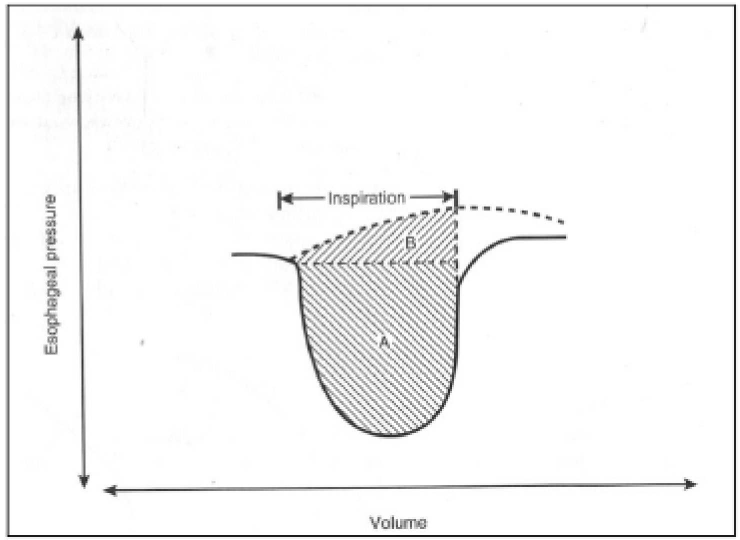
Patient's abnormal mechanics
Low compliance
High flow resistance
PEEPi
Diameter of the endotracheal tube
Ventilator circuit, valves and devices
Ventilatory pattern
*V*T and *V'*E
Inspiratory flow rate and waveform.

PEEPi: intrinsic positive end expiratory pressure; *V*T: tidal volume; *V'*E: minute ventilation.

Eur Respir Mon, 2005, 31, 195–206. Printed in UK - all rights reserved. Copyright ERS Journals Ltd 2005.

Solunum Mekanikleri-WOB

Figure 8



Calculating the work of breathing during spontaneous ventilation using an esophageal balloon. Area A represents the work to move air into and out of the lungs. Area B represents the work to expand the chest wall and is calculated from a pressure–volume curve in a passive patient receiving a mechanically generated breath. The sum of A and B represents the total work of breathing, and it can be determined through integration of the product of esophageal pressure and flow. Reprinted from [1] with permission from Elsevier.

Pes-PTP

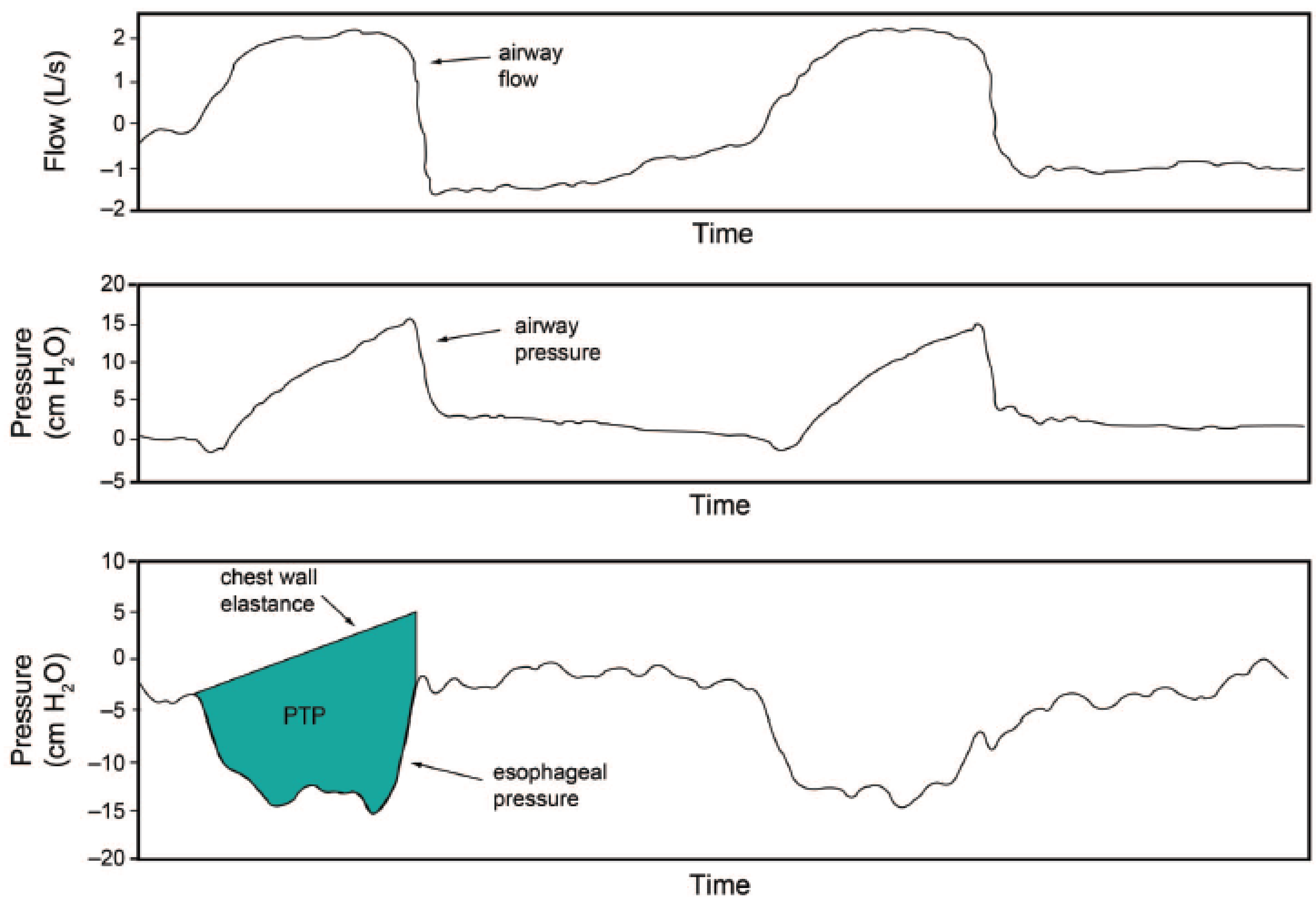


Fig. 23. Illustration of the determination of pressure-time product (PTP). PTP is shown in the shaded area.

Table 1 Case-scenarios in which esophageal and transpulmonary pressure monitoring could be of help at the bedside

Case-scenario	Relevant Pes-derived measure[a]	Clinical significance	Clinical recommendation
Passively ventilated patient	Tidal ΔP_L	Measure of the tidal stress applied to lung parenchyma	Possibly keep below 10–12 cmH_2O in ARDS patients
	End Inspiratory P_L	Measure of the total stress applied to lung parenchyma	Possibly keep below 20–25 cmH_2O in ARDS patients
	End expiratory P_L	Negative value possibly indicating tendency of the alveoli and/or airways to collapse	Possibly keep above 0 cmH_2O in ARDS patients
	Transmural pulmonary vascular pressure	Effective pressure driving blood flow in intrathoracic vascular structures	Consider delta between CVP and end-expiratory Pes rather than CVP per se to better understand volume status of the patient
	Periodically interspersed negative Pes swings after passively delivered ventilator breaths	Detection of reverse triggering	Consider paralysis or modify sedation (reduce sedation to let the patient trigger)
Ventilated patient with active breathing	Transmural pulmonary vascular pressure	Effective pressure across intrathoracic vascular structures	Consider delta between CVP and end-expiratory Pes rather than CVP per se to better understand volume status of the patient
	End inspiratory P_L	Measure of the tidal stress applied to lung parenchyma	Possibly keep below 20–25 cmH_2O in ARDS patients
	Pmus	Measure of the pressure generated by the patient's inspiratory muscles	Normal values are between 5 and 10 cmH_2O
	Work of breathing	Measure of patient's total work during the respiratory cycle	Normal values are around 0.35 or 2.4 $J\ min^{-1}$
	PTPes	Measure of patient's respiratory muscles effort to breathe	Normal values are around 100 $cmH_2O\ s\ min^{-1}$
	Negative Pes swings without ventilator pressurization	Ineffective effort	Titrate PEEP and/or decrease support and/or consider NAVA
	Pes inspiratory time longer than ventilator inspiratory time	Double triggering or premature cycling	Increase ventilator Ti up to 0.8–1.0 s or consider switching to NAVA or PAV. Rule out non-ventilatory causes (metabolic acidosis, encephalopathy, etc.)
	No Pes swing prior to ventilator pressurization	Auto-triggering	Check for leaks, trigger settings, ventilator tubing (water in circuits) and/or decrease sedation
	Increasing PTPes and/or Pes swings along spontaneous breathing trial	High likelihood of failure to wean	Differentiate whether resistive or elastic workload increased and treat consequently. Reconnect to ventilator

ARDS Acute respiratory distress syndrome, *CVP* central venous pressure, *NAVA* neurally adjusted ventilatory assist, *PAV* proportional assist ventilation, *PEEP* positive end-expiratory pressure, *Pes* esophageal pressure, P_L transpulmonary pressure, ΔP_L change in transpulmonary pressure, *Pmus* inspiratory muscle pressure, *PTPes* esophageal pressure–time product, *Ti* inspiratory time.

[a] The end expiratory P_L is the absolute value. The end inspiratory P_L can be measured with the elastance method or the absolute value. They do not give the same results, the absolute value being generally lower

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