RESISTANCE AND COMPLIANCE

by

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RESISTANCE AND COMPLIANCE

BEHAVIORAL OBJECTIVES

UPON COMPLETION OF THE READING MATERIAL, THE PRACTITIONER WILL BE ABLE TO:

1. Define compliance.
2. List the factors affecting elastic resistance.
3. Define airway resistance.
4. List the factors affecting airway resistance.
5. Compare and contrast laminar and turbulent flow.
6. Define static compliance.
7. Define dynamic compliance.
8. Calculate dynamic and static compliance.
9. Interpret compliance results.
10. Clinically apply the $C_{dyn}$ & $C_{stat}$ values.

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INTRODUCTION

Confusion often exists when defining compliance and elastance. Here we will explain these concepts in simple terms, and go into detail later in this course.

Compliance is the measure of the ease of inflation, the ease of distensibility, or the ease with which the lungs can stretch. The compliance number symbolizes the ease with which the lungs can inflate. The normal value for compliance is 100 to 200 ml/cm H$_2$O. Keeping in mind that a normal value is always best, remember that:

- Increasing compliance means the lungs are more easily inflating with air, which is generally medically desirable.
- Decreasing compliance means the lungs are getting stiffer.
- If compliance is decreasing, elastance is increasing (meaning stiffer lungs)

Elastance is the reciprocal (counterpart) of compliance, but not the term commonly used clinically. Elastance is a measure of lung stiffness - increased elastance indicates stiffer lungs. Elastance (also called elastic resistance) is the resistance of the lungs and chest wall to being stretched. The definition of elastance makes the concept of elastance confusing to some. The definition of elastance is “the ability to return to the resting shape after being distorted by a force” (describing the recoiling force of the lungs). To make elastance simple, remember that: elastance is opposite of compliance, and increased elastance means stiffer lungs:

- Increased elastance equates with decreased compliance (meaning stiffer lungs).
- Decreased elastance equates with increased compliance (meaning more easily inflatable lungs).

Compliance is a deceptively simple concept, yet many practitioners have difficulty understanding it’s theory. Another merit in using the compliance computation is that it indicates the energy cost of breathing. Compliance can be calculated on any patient with the proper equipment. On nonintubated spontaneously breathing patients, an esophageal balloon must be in place to record intrathoracic pressure changes. However, we will restrict this discussion to patient's receiving mechanical ventilation. Compliance is easily measured on these patients by recording volume and pressure changes.

The calculation of compliance is very simple. The difficult part is applying what the number means and knowing what factors affect that number. For the former, I like to use an analogy we are all familiar with, the miles per gallon (MPG) calculation for a car. The MPG calculation indicates the work performed (miles traveled) using one unit of energy (gallon). MPG is calculated by dividing distance traveled (miles) by the amount of gas used (gallons). One divides the change in miles by the change in gallons. This tells one how efficiently the car is working. When MPG increases, more work is performed and the car is operating more
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efficiently. When MPG decreases, less work is performed and the car is less efficient.

Lets say the compliance calculation is simply the “MPG” rating for the lungs. We merely replace the miles portion of the equation with volume (ml) and the gallon portion with pressure (cm H₂O). As one gallon is the constant in the MPG calculation, one cm of H₂O pressure is the constant in the compliance calculation. When the efficiency of the lungs decreases, we accomplish less work using the same amount of energy, in cm of H₂O. That is, we move less volume using the same pressure. The compliance decreases exactly like MPG decreases when your car becomes less efficient. As the lungs become more efficient, the opposite occurs. If compliance is increasing, the energy cost of breathing is decreasing and so the lungs are improving (becoming more distensible). If compliance is decreasing, the energy cost of breathing is increasing and the lungs are deteriorating (becoming stiffer or less distensible).

For example, if the patient’s initial compliance is 100 ml/cm H₂O and later in the day it is 50 ml/cm H₂O, we know the efficiency of the lungs has decreased, and the lungs are getting stiffer. The lungs are only moving half as much air with the same pressure as before. Or, put another way, the patient is getting less work accomplished using the same amount of energy. They are moving less volume (50 ml/cm H₂O) with the same pressure. Obviously, the reverse is also true. If the lungs become more efficient at moving gas in and out of the lungs, the compliance number increases. This means the patient accomplishes more work with the same amount of energy.

CALCULATION OF COMPLIANCE

Compliance is calculated by dividing the patient's exhaled tidal volume by the pressure needed to provide that same tidal volume. If the measured exhaled tidal volume is 500 ml and the pressure observed is 10 cm H₂O, one divides 500 by 10. This gives a compliance of 50 ml per cm H₂O. One measures the change in exhaled volume (Vₜ) and divides it by the change in pressure (cm H₂O). Normal compliance on spontaneously breathing healthy adult, measured via esophageal balloon is approximately 200 ml/cm H₂O. Intubation reduces this number to approximately 100 ml/cm H₂O.

\[
\text{COMPLIANCE} = \frac{\text{EXHALED VOLUME CHANGE}}{\text{PRESSURE CHANGE}}
\]

EXAMPLE: \[
\frac{500 \text{ ml}}{10 \text{ cm H}_2\text{O}} = 50 \text{ ml/cm H}_2\text{O}
\]

Clinically, one is obtaining compliance for a patient and ventilator circuit. This requires that tidal volume be corrected to account for the compliance of the ventilator circuit being used and the gas volume that remains in the ventilator circuit after each breath. Tubing compliance factor (disposable tubing) is generally 2 to 4 ml per cm H₂O. Tubing compliance factor (Cₜ) is multiplied by the peak pressure and the value subtracted from the exhaled tidal volume. This number represents "lost" volume as a result of tubing expansion when the circuit is pressurized on inspiration. The patient does not receive this amount of the tidal volume. It merely stretches...
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the tubes. For example, if tubing compliance is 3 ml/cm H2O and peak pressure is 50 cm H2O, 150 ml (3 ml x 50 cm H2O) stretches the tubes and accounts for the volume loss. Therefore, 150 ml does not enter the lungs and is subtracted from the exhaled tidal volume before calculation of compliance.

\[ V_T \text{ corrected} = V_T - (\text{PIP} \times C_T) \]

\[ \text{COMPLIANCE} = \frac{V_T \text{ corrected}}{\text{Peak Pressure}} \]

\[ \text{EXAMPLE:} \]

\[ \frac{500 \text{ ml} - 150 \text{ ml}}{10 \text{ cm H}_2\text{O}} = \frac{350}{10} = 35\text{ml/cm H}_2\text{O} \]

FACTORS AFFECTING COMPLIANCE

To move gas between the atmosphere and the blood one must move a volume of gas through an extensive system of airways and stretch the alveoli and chest. Anything that affects flow through the airways affects compliance. Anything that impedes expansion of the alveoli (or chest) affects compliance. The causes affecting flow will be called airway resistance (flow) and those that impede expansion of the chest will be called elastic resistance in this discussion.

Simply put:

Airway resistance occurs due to excess secretions, bronchospasms, or similar problems that increase the peak pressure. The solution is usually suction and/or a bronchodilator.

Elastic resistance refers to a stiffening chest wall that causes increased peak pressures. One must further evaluate the patient to find the cause and solution. (This will be discussed in detail later).

This is a very simplified discussion on the factors affecting lung distensibility. In a pure academic sense, there are three factors relating to lung expansion. They are: elastance, resistance, and inertia. Elastance is the resistance of the lungs and chest wall to being stretched. This is also referred to as "elastic resistance".

Resistance is the frictional opposition offered by the airways to flow and the tissues to being displaced. Flow/airway resistance is 80% of the total frictional resistance, so I am using the term “airway resistance”. Inertia is the resistance any resting body has to movement or flow.
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Clinically, inertia is minor and generally ignored.

The amount of airway resistance and elastic resistance determines how much mechanical work is required to breathe. There is also "metabolic" work associated with breathing. This is measured by the O₂ cost of breathing.

The discussion first begins with the factors of airway resistance, then the factors of elastic resistance. The course concludes with a discussion of dynamic and static compliance as diagnostic tools. Monitoring of dynamic and static compliance helps determine whether the patient has an airway resistance problem or elastic resistance problem. In summary, airway resistance and elastic resistance affect the work of breathing.

AIRWAY RESISTANCE (Raw)

The factors affecting airway resistance are: viscosity and density of the gas mixture; length, lumen radius of artificial and patient’s airways; ventilator flow rate and flow pattern. (These are mathematically related to airway resistance in Poiseuille's Law). The length of the patient’s airways also is considered a constant and ignored. However, excessive endotracheal tube length should be trimmed to minimize airway resistance. I’ll confine the following discussion to the most clinically significant variables: flow rate, flow pattern, and lumen radius.

In cases of extreme airway resistance, helium-oxygen mixtures have been used to minimize gas density. Heliox mixtures are less dense than nitrogen-oxygen mixtures so they may help improve distribution of inspired gas and oxygenation for severe asthmatics. The following discussion is confined to the most clinically significant variables: flow rate, flow pattern, and lumen radius.

Flow rate, flow pattern, and lumen radius are important to cover in detail. The clinician has some degree of control over these. Therefore, one can influence the amount of airway resistance the patient experiences. As stated previously, we are discussing patients who are intubated and mechanically ventilated. This means, to a degree, we determine the flow rate that the patient receives. To minimize the amount of airway resistance, one should use the lowest flow rate possible. It should be pointed out that flow rate always must be high enough to meet patient peak inspiratory flow rate requirements. If not, the patient's work of breathing may actually increase from gasping for more air. One should use the lowest flow rate possible, while still meeting or exceeding patient demand. For patients in distress, the lowest flow rate possible may be quite high. The higher the flow, the greater the amount of turbulence and turbulence increases airway resistance. Conversely, a slow flow rate minimizes turbulence and airway resistance. This provides more uniform distribution of the inspired air.

The effect of a high flow rate and turbulence on uniform ventilation can be easily demonstrated. Try to fill a glass with water by turning the faucet on as far as it will go. You know what will happen? You’ll get soaked and the glass will never fill completely. If the flow is decreased, the glass fills smoothly and completely. And you don’t make a mess! The lungs are similar, the
slower the flow rate, the more even the ventilation. Slow flow rates minimize turbulence and therefore decrease airway resistance.

There are two basic flow patterns, laminar and turbulent. Laminar flow consists of orderly concentric rings of gas molecules traveling in straight lines. Flow is “cone-shaped” with the molecules in the center of the lumen traveling slightly faster than those near the airway walls. Friction with the airway wall slows the outer molecules down. Laminar flow is possible in a straight tube with no obstructions and slow flow rates.

Turbulent flow is chaotic. Gas molecules are traveling in random directions and speeds. They collide with one another and the airway wall. Turbulent flow occurs with fast flow rates, at bifurcations, and at obstructions. Increased gas density and decreased tube radius also can produce turbulence.

In the lungs, both patterns exist but one must strive to minimize turbulent flow. One has little control over lung bifurcations but one can remove obstructions and adjust flow rate to decrease turbulence.

**TURBULENT FLOW CAUSED BY:**

- Obstructions
- Excessive flow rates
- Bifurcations

**LAMINAR FLOW PRODUCED BY:**

- Removal of obstructions
- Correct flow rates

The final clinically significant factor relating to airway resistance is the lumen radius. The clinician has more control of this variable than one might think. It begins with selection of the artificial airway. When the airway lumen is smaller, there is greater airway resistance and vice versa. Airway resistance and lumen radius are exponentially related to the fourth power. This means any change in the radius causes a tremendous change in the airway resistance. For example, if the radius is cut in half airway resistance doesn’t just double. It increases by a factor of $2 \times 2 \times 2 \times 2$ (16 times). If the radius increases 2 times, airway resistance decreases by the same factor of 16.

Because of this relationship any small amount of bronchospasm, secretion accumulation, in the endotracheal tube, water in the ventilator tubing, or other obstruction considerably increases airway resistance. Conversely, a very small amount of bronchodilation, secretion removal or relief of obstruction considerably decreases airway resistance. This is why a patient may
complain of a severe increase in the work of breathing when there is only a minimal change in breath sounds. The narrowing may not produce much “noise” but it can seriously increase the patient’s work. Patient relief from a bronchodilator also can be far out of proportion to clinical improvement. The improvement may be difficult to detect but the patient notices the decrease in work of breathing.

If the inspiratory flow is constant and known with accuracy, then the airway resistance may be estimated according to the following formula:

\[
\text{Estimated Raw (cm H}_2\text{O/Liters/sec)} = \frac{(\text{PIP} - \text{Pplat})}{V \ (L/\text{sec.})}
\]

Normal adult airway resistance ranges from approximately 0.5 to 2.5 cm H\textsubscript{2}O/L/sec. In a healthy adult intubated with an 8.0 mm ET tube, we would expect airway resistance to be 4 to 6 cm H\textsubscript{2}O higher than this normal range due to the additional resistance imposed by the tube. An increase in Raw above 15 cm H\textsubscript{2}O/L/sec in an intubated patient with otherwise normal lungs, signals abnormal airway narrowing due to such factors as increased secretions, bronchospasm, or partial occlusion of the airway.

**AIRWAY RESISTANCE AFFECTED BY:**

<table>
<thead>
<tr>
<th>Patient Causes</th>
<th>Mechanical Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secretions</td>
<td>Viscosity and density of gas</td>
</tr>
<tr>
<td>Bronchospasm</td>
<td>Airway length</td>
</tr>
<tr>
<td>Partial airway obstruction</td>
<td>Flow rate</td>
</tr>
<tr>
<td></td>
<td>Flow pattern</td>
</tr>
<tr>
<td></td>
<td>Lumen radius</td>
</tr>
</tbody>
</table>

**ELASTIC RESISTANCE**

Elastic resistance is much simpler to explain than airway resistance. One component is the impedance offered by the alveoli to being stretched. The second component is the opposition existing between the interstitium and chest wall in being moved. Anything that prevents the alveoli from stretching or prevents the interstitium and chest from expanding increases elastic resistance (decreases compliance). Examples include: fibrosis of the alveoli or interstitium, loss of surfactant, chest wall deformities, trauma, pain, splinting, chest dressings, fluid or air accumulation within alveoli or pleural spaces and atelectasis. Abdominal organs also have to be moved to breathe. Therefore, conditions preventing diaphragm excursion, such as obesity, ascites, pregnancy and air in the patient’s stomach or abdomen also affect elastic
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resistance.

A simple change in position affects the elastic resistance. Elastic resistance decreases when one is upright. It is much easier to expand the lungs upright than in a supine position. One can decrease elastic resistance simply by elevating the head of the bed. Conversely, elastic resistance increases from an upright to supine position. Therefore, it takes more energy (pressure) to breathe lying down than sitting upright or standing. These minor changes, such as a change in position or insertion of a nasogastric tube to relieve abdominal distension due to air, should not be confused with changes in the patient’s lung status when interpreting compliance changes. All compliance measurements must be made under the same conditions and using the same technique (same patient position, standardized calculation, etc.) for valid interpretations.

It is important to remember that the measurement of elastic resistance is performed under static (no air flow) conditions: therefore, elastic resistance changes only effect static compliance. Think of elastic resistance as the synonym for static compliance. This might make things less confusing. Also remember elastic resistance is referring to the lungs ability to expand. A similar statement is used to define static compliance.

DECREASES IN ELASTIC RESISTANCE ARE AFFECTED BY:

- Decrease Chest Wall Expansion
- Interstitium Fibrosis
- Alveoli Fibrosis
- Patient Position
- Abdominal organs
- Atelectasis
- Loss of Surfactant
- Trauma
- Pain
- Splinting

DYNAMIC AND STATIC COMPLIANCE

Dynamic compliance monitors both elastic and airway resistance. Dynamic compliance is the total impedance to inflation and represents the sum of all forces opposing movement of gas into the lung. In order to ventilate the lungs, we must use pressure to push gas
through the airways and stretch the alveoli and chest. During this procedure if proper measurements are documented the practitioner can measure dynamic compliance. Static compliance, often referred to as effective static compliance, monitors elastic resistance only. To understand this better, one may think of the static compliance as indicative of the “lungs” (plateau pressure), and dynamic compliance as indicative of the “lungs and airway resistance” (peak pressure).

Airway resistance is a factor only when there is flow in the airways. Elastic resistance however, is a constant. It is present whether there is flow or not. The peak inspiratory pressure (PIP) is reflected on the pressure manometer in cm H₂O. The PIP indicates the energy needed to overcome the elastic and airway resistance. Diagram 1 is an illustration of how airway/frictional resistance can be determined by the difference between peak inspiratory pressure (PIP) and plateau pressure.

For example, to ventilate the lungs with 750 ml the pressure might rise to 20 cm H₂O. If we were to perform an inspiratory hold maneuver on the patient and not allow expiration to occur, flow ceases. At this point of zero flow, no energy is needed to overcome airway resistance. Observing the pressure manometer, the pressure drops and "plateaus" at a specific pressure. The plateau pressure indicates the pressure needed to overcome the elastic resistance, or it should be considered a reasonable reflection of transalveolar pressure and used to estimate the collective distention of lung units.

The compliance calculation is the change in volume (V₁) divided by the change in pressure (cm H₂O). If we use the PIP as the denominator of our equation for our calculation, we obtain the dynamic compliance of the patient. It is called "dynamic" because this implies motion or flow. The dynamic compliance indicates the total amount of work accomplished (volume moved) per unit of energy used (pressure). If we use the plateau pressure as the denominator of our equation...
RESISTANCE AND COMPLIANCE

for our calculation, we can calculate the static compliance. So named because we stop flow and take a "static" measurement. This gives information on the resistance of the alveoli, interstitium, and chest wall only. It does not consider the airways.

DYNAMIC COMPLIANCE = CORRECTED TIDAL VOLUME \( \frac{\text{Exhaled } V_T - \text{Compressed Volume loss}}{\text{PEAK INSPIRATORY PRESSURE (PIP) - PEEP}} \)  

or

Total Impedance

Dynamic compliance monitors both elastic and airway resistance. Therefore, the total pressure (PIP) is used for the calculation.

STATIC COMPLIANCE = CORRECTED TIDAL VOLUME \( \frac{\text{Exhaled } V_T - \text{Compressed Volume loss}}{\text{PLATEAU PRESSURE - PEEP}} \)

or

Effective Compliance

Static compliance monitors elastic resistance only. Therefore, the plateau pressure is used for the calculation.

Note: Corrected \( V_T = \) Expired \( V_T \) (ml) – Compressed Volume loss.  
Compressed Volume (volume lost in ventilator circuit, or tubing). In general the accepted figure used as a correcting factor for disposable tubing is 3 ml/cm H\(_2\)O.

Example: \( \text{PIP (cm H}_2\text{O)} \times 3 \text{ ml/ cm H}_2\text{O} = \text{compressed volume loss} \)  
\( 30 \text{ cm H}_2\text{O} \times 3 \text{ ml/cm H}_2\text{O} = 90 \text{ ml} \)

Measured on a regular basis the effective static compliance can help establish trends in pulmonary status, and guide the application of PEEP or CPAP.

PEAK AND PLATEAU PRESSURES

The maximum value of airway pressure at the airway opening during a ventilatory cycle is routinely monitored in the ICU. Peak airway pressure greater than 50 cm H\(_2\)O is generally discouraged, because high values of \( P_{\text{peak}} \) carry increased risk of barotrauma and hypotension. An increase in \( P_{\text{peak}} \) must result from increased resistive pressure and/or increased elastic pressure from decreased lung or chest wall compliance. Measurement of end-inspiratory plateau pressure (\( P_{\text{plat}} \)) differentiates the resistive and elastic components. The \( P_{\text{plat}} \) level should be monitored for all ventilated patients. The \( P_{\text{plat}} \) levels should not exceed 30 to 35 cm H\(_2\)O because higher levels not only would indicate decreased compliance but also could expose the lungs to the risk of ventilator-induced lung injury.

It should be noted that when peak and plateau pressures are increasing, compliance is decreasing.

PEEP

The dynamic/static compliance calculation is the change in exhaled volume divided by the change in pressure. If PEEP is being used, the actual change in pressure is the difference between the PEEP level and the peak/plateau pressures. Therefore, the PEEP pressure
must be subtracted from the peak and plateau pressures before calculating compliance (dynamic and static). For example:

The exhaled tidal volume is 500 ml, peak pressure is 15 cm H\textsubscript{2}O, plateau pressure is 10 cm H\textsubscript{2}O, and PEEP is 5 cm.

**Dynamic Compliance**

\[
\text{Dynamic Compliance} = \frac{500 \text{ ml} - (15 \text{ cm H}_2\text{O} \times 3 \text{ ml/cm H}_2\text{O})}{15 \text{ cm H}_2\text{O} - 5 \text{ cm H}_2\text{O}}
\]

\[
= \frac{500 \text{ ml} - 45 \text{ ml}}{10 \text{ cm H}_2\text{O}}
\]

\[
= 455 \text{ ml}
\]

\[
= 45.5 \text{ ml/cm H}_2\text{O}
\]

**Static Compliance**

\[
\text{Static Compliance} = \frac{500 \text{ ml} - (15 \text{ cm H}_2\text{O} \times 3 \text{ ml/cm H}_2\text{O})}{10 \text{ cm H}_2\text{O} - 5 \text{ cm H}_2\text{O}}
\]

\[
= \frac{500 \text{ ml} - 45 \text{ ml}}{5 \text{ cm H}_2\text{O}}
\]

\[
= 455 \text{ ml}
\]

\[
= 91.0 \text{ ml/cm H}_2\text{O}
\]

**INTERPRETATION OF RESULTS**

A n increase in compliance indicates a decrease in elastic alveolar resistance (lung parenchyma). Therefore, if compliance increases it is easier to ventilate the patient. If the patient is on a set volume, it is delivered with less pressure. If the patient is on a set pressure, more volume is delivered. On spontaneous breaths, the patient’s work of breathing is less and they have to generate less pressure when compliance increases. They achieve their desired tidal volume (V\textsubscript{T}) using less energy. Obviously, the reverse is true. A decrease in compliance indicates an increase in alveolar resistance. Decreased compliance means it takes more pressure to achieve a set volume and the patient must work harder for each breath.

**NOTE:** It is very important to note the inverse relationship between compliance and pressure. If peak or plateau pressure increase (and volume remains constant) compliance has decreased, which is interpreted as a worsening in the patients condition, since the lungs are becoming more difficult to expand. If the peak or plateau pressure decreases (and volume remains constant) compliance has increased, which is interpreted as an improvement in the patients condition, since the lungs are becoming easier to expand. Resistance and compliance also are inversely related.
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When compliance (effective static) goes up there is improvement in the lung parenchyma. When airway resistance (can be measured as the difference between PIP and Plateau Pressure) goes down there is improvement in the airways and vice versa.

Obviously, we must calculate both static and dynamic compliance to monitor a patient. Once we have a baseline measurement we can watch for changes or trends to develop. When there is a change, we can more easily pinpoint where the pathology is taking place if both compliances are being monitored. One must remember that dynamic compliance (total impedance) monitors the whole lung system, both airway and elastic resistance. If dynamic compliance changes, we can simply say there is a change in either the airway or elastic resistance. We cannot be more specific. We then look at the static compliance (lung parenchyma) numbers. If they are unchanged, we have localized the problem to the airways. If there had been a change in the elastic resistance (lung parenchyma), the static compliance would have changed.

Both airway and elastic resistance (lung parenchyma) often change, resulting in a change in both dynamic and static compliance. We then must look at the degree of change in the specific compliances to pinpoint the primary problem. For example, if there is a significant change in the dynamic compliance (total impedance) and a minor change in the static, one can assume the primary problem is a change in the airway resistance. Secretion accumulation is one such problem. Secretions narrow airway lumen thereby increasing airway resistance and increasing dynamic compliance. Secretions do not affect elastic resistance (lung parenchyma) so the static compliance is unaffected.

Contrast this with increasing alveolar consolidation, which affects both dynamic and static compliance. Increasing consolidation causes a significant change in the dynamic compliance, and also, consolidation increases elastic resistance (lung parenchyma) so the static compliance changes significantly. Remember that any change in airway resistance changes dynamic compliance. Determining static compliance and comparing it to previous numbers helps determine whether the change is in the airways or lung parenchyma.

Sometimes it is very difficult to decide the primary problem based upon compliance alone. Other data has to be gathered. However, the fact that the compliance has changed may be the first indicator of more serious changes to come, such as, worsening ABG’s. Changes in compliance should always be correlated with the clinical condition of the patient. They alert the clinician to investigate potential problems or to monitor the patient more closely.

SUMMARY OF RESISTANCE AND COMPLIANCE INTERPRETATION

Six probable groupings of increasing or decreasing static and dynamic lung compliance exist. Each has its own possible basis and are covered sequentially. The patient must be passive on the ventilator for the measured values to be precise. Check two or three breaths for increased accuracy. Let the patient have a normal breath or two between each of the peak and plateau pressure measurement breaths.
1. **Decreased dynamic compliance with stable static compliance**
   Decreased dynamic compliance with stable static compliance is noticed as an increase in peak pressure with an unchanged plateau pressure. It is caused by an increased airway resistance (secretions, bronchospasm, etc.). Correcting the underlying problem results in the peak pressure returning to the original level.

2. **Increased dynamic compliance with stable static compliance**
   Increased dynamic compliance with stable static compliance is noticed as a decrease in peak pressure with an unchanged plateau pressure. This represents an improvement in the patient’s airway resistance from the original condition. Secretions can be diminished, mucous plugs cleared, bronchospasm corrected, and so on.

3. **False decreased dynamic compliance with true decreased static compliance**
   False decreased dynamic compliance with true decreased static compliance is noticed as an increase in both the peak and plateau pressure. This is seen when the patient’s lung-thoracic compliance worsens. The plateau pressure is elevated and the static compliance is decreased.

   As an artifact of the stiffer lungs, the peak pressure is also elevated, and the dynamic compliance is decreased. However, the difference between the peak and plateau pressures remains the same. This demonstrates that there is no real increase in the patient’s airway resistance.

4. **True decreased dynamic compliance with true decreased static compliance**
   True decreased dynamic compliance with true decreased static compliance is noticed as an increase in both the peak and plateau pressure. This is seen with the combination of a decreased lung compliance and an increased airway resistance.

5. **False increased dynamic compliance with true increased static compliance**
   False increased dynamic compliance with true increased static compliance is noticed as a decrease in both the peak and plateau pressure. This is seen when the patient’s lung-thoracic compliance improves. The plateau pressure decreases, and as an artifact, the peak pressure also decreases.

6. **True increased dynamic compliance with true increased static compliance**
   True increased dynamic compliance with true increased static compliance is also noticed as a decrease in both the peak and plateau pressure. This is seen when both the airway resistance and lung-thoracic compliance improve. When the plateau pressure has decreased, it’s indicating more compliant lungs.
WAVE FORMS

ASSESSING COMPLIANCE

**Figure 1** shows a typical pressure-volume loop. If the inspiratory curve maintains the shape shown at A, then the slope (steepness) of the loop indicates changes in compliance. A shift toward the vertical volume axis (B) indicates an increase in compliance, while a shift toward the horizontal pressure axis indicates a decrease (C) **Figure 2**.

**Figure 3** shows a pressure-volume loop during a mandatory breath in which the inspiratory curve flattens (A), indicating lung overdistension. Lung overdistension is evident when pressure continues to rise with little or no corresponding rise in volume.
RESISTANCE AND COMPLIANCE

ASSESSING RESISTANCE

Figure 4 shows another pressure-volume loop. An inspiratory curve with a bow shape (A), and a slope leaning toward the horizontal axis (B), indicates increased resistance.

CLINICAL APPLICATION OF RESISTANCE AND COMPLIANCE

TRACKING DYNAMIC AND STATIC COMPLIANCE AND WHAT IT MEANS TO THE CLINICIAN

EXAMPLE #1

<table>
<thead>
<tr>
<th>Exhaled Corrected Tidal Volume (VT)</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Pressure (P_{peak})</td>
<td>20</td>
<td>25</td>
<td>30</td>
<td>35</td>
</tr>
<tr>
<td>Plateau Pressure (P_{plat})</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>PEEP</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

Calculate the difference between P_{peak} & P_{plat}:

1. _____ 2. _____ 3. _____ 4. _____

This figure may be used as a clinical estimation of RAW, an indicator to provide treatment with a bronchodilator, a baseline pressure support level.
**Resistance and Compliance**

Graph the $P_{\text{peak}}$ & $P_{\text{plat}}$:

<table>
<thead>
<tr>
<th>35cm</th>
<th>30cm</th>
<th>25cm</th>
<th>20cm</th>
<th>15cm</th>
<th>10cm</th>
<th>5cm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A    B    C    D

Notice that the difference between the pressures is increasing. This indicates an obstructive condition increasing resistance. This is generally due to:

- small endotracheal tube
- bronchospasm
- secretions

Calculate the Dynamic and Static Compliance for the above example and insert below:

Dynamic Compliance ($C_{\text{dyn}}$)  5._____ 7._____ 9._____ 11._____  
Static Compliance ($C_{\text{stat}}$)    6._____ 8._____ 10._____ 12._____  

Notice that the dynamic compliance is decreasing, but the static compliance remains constant.

**Example #2**

<table>
<thead>
<tr>
<th>Exhaled Corrected $V_T$</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td></td>
</tr>
</tbody>
</table>

$P_{\text{peak}}$  
20 25 30 35

$P_{\text{plat}}$  
15 20 25 30

PEEP  
5 5 5 5

Calculate the difference Between $P_{\text{peak}}$ & $P_{\text{plat}}$:  13._____ 14._____ 15._____ 16._____
Graph the $P_{peak}$ & $P_{plat}$:

35cm
30cm
25cm
20cm
15cm
10cm
5cm

E    F    G    H

Notice that the difference between the pressures is constant, but both the pressures are increasing. This lets the clinician know that there is a restrictive force at work.

Compliance is decreasing and the ability to observe this gives the clinician an alert to the following conditions:

- Fibrosis
- Pleural effusion
- Consolidation
- Tension pneumothorax
- Mainstem intubation
- Congestive heart failure (CHF)
- Adult Respiratory Distress Syndrome (ARDS)
- Atelectasis
- Hyperinflation
- Abdominal distension

Calculate the $C_{dyn}$ and $C_{stat}$ for the above example and insert below:

$C_{dyn}$: 17.____ 19.____ 21.____ 23.____

$C_{stat}$: 18.____ 20.____ 22.____ 24.____

Notice that both the dynamic and static compliances are decreasing.
EXAMPLE #3:

<table>
<thead>
<tr>
<th></th>
<th>I</th>
<th>J</th>
<th>K</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exhaled Corrected VT</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>$P_{\text{peak}}$</td>
<td>20</td>
<td>30</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>$P_{\text{plat}}$</td>
<td>15</td>
<td>22</td>
<td>30</td>
<td>35</td>
</tr>
<tr>
<td>PEEP</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

Calculate the difference between $P_{\text{peak}}$ & $P_{\text{plat}}$: 25.  26.  27.  28.

Graph the $P_{\text{peak}}$ & $P_{\text{plat}}$:

As you can see, not only is the difference between the peak and plateau pressures increasing, but the pressures are increasing as well.

Calculate the $C_{\text{dyn}}$ and the $C_{\text{stat}}$ for the above example and insert below:

$C_{\text{dyn}}$: 29.  31.  33.  35.
$C_{\text{stat}}$: 30.  32.  34.  36.

Note that compliance is decreasing and resistance is increasing. This trend gives the clinician the distinct conclusion that there are restrictive and obstructive processes at work.

Work of breathing (WOB) increases with increased airway resistance and decreased lung compliance. Minute volume ($V_E$) also increases the work of breathing. The more aware we are of these processes, the better we can fine-tune the ventilator, our care and assessment to achieve better outcomes for our patients.
RESISTANCE AND COMPLIANCE

CLINICAL COMPLIANCE CALCULATIONS

To obtain mechanical (tubing) compliance:

1. Put known volume into a closed circuit and record the pressure at that volume.
2. Divide the volume by the pressure.

$$C_{mech} = \frac{V}{P}$$

Note: Normal is approximately 3 ml/cmH$_2$O

To obtain lost volume due to $C_{mech}$:

1. Multiply $C_{mech}$ by $P_{peak} - PEEP$

Lost volume = $C_{mech} \times (P_{peak} - PEEP)$

To correct $V_T$ for lost volume:

1. Subtract lost volume from exhaled volume.

Corrected $V_T = $ Exhaled $V_T - $ (Lost $V_T$)

Dynamic compliance:

1. $C_{dyn}$
2. Air is moving, measured at peak inspiratory pressure ($P_{peak}$)

$$C_{dyn} = \frac{\text{Measured (corrected if not already done by ventilator)}}{P_{peak} - PEEP}$$

Static compliance:

1. $C_{stat}$
2. Air is not moving, measured during an inspiratory pause (hold, $P_{plat}$)

$$C_{stat} = \frac{\text{Measured (corrected if not already done by ventilator)}}{P_{plat} - PEEP}$$

*BOTH SHOULD BE MEASURED ON THE SAME BREATH*
RESISTANCE AND COMPLIANCE

CLINICAL APPLICATION ANSWER SHEET

EXAMPLE #1

1. 5
2. 10
3. 15
4. 20
5. 33
6. 50
7. 25
8. 50
9. 20
10. 50
11. 17
12. 50

EXAMPLE #2

13. 5
14. 5
15. 5
16. 5
17. 33
18. 50
19. 25
20. 33
21. 20
22. 25
23. 17
24. 20

EXAMPLE #3

25. 5
26. 8
27. 10
28. 15
29. 33
30. 50
31. 20
32. 29
33. 14
34. 20
35. 11
36. 17
RESISTANCE AND COMPLIANCE

CLINICAL PRACTICE EXERCISE

The following practice exercise is discussed at the end of the course. (All tidal volumes in the practice exercises should be considered exhaled volume).

1. The patient is a 30-year-old trauma victim with right-sided pneumothorax and hemothorax. He is being mechanically ventilated with a VT of 800 ml, PIP of 45 cm H₂O, plateau pressure of 39 cm H₂O. Chest tubes are inserted on the right. The right lung has been expanded and breath sounds are clear bilaterally. What is the dynamic and static compliance if tubing compliance is 3 ml per cm H₂O?

______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________

2. The PIP has been gradually increasing over the past several hours. PIP is now 52 cm H₂O. Dynamic compliance is now 12.4 ml/cm H₂O. Static compliance is unchanged. There are slight crackles heard on the right. What are possible explanations for the increase in PIP and decrease in dynamic compliance?

______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________

3. What do you recommend to reverse the above trend?

______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________

4. On the following day, PIP is 30 cm H₂O, plateau pressure is 25 cm H₂O, VT remains at 800 ml. What is the dynamic and static compliance and what can be said about the patient’s elastic and airway resistance?

______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________
SUMMARY

In summary, the compliance calculation is simply to divide the change in volume by the change in pressure. If PEEP is being used, it must be subtracted prior to compliance calculation. Compliance is an indicator of the work of breathing. It is an “efficiency rating” for the lungs. It is affected by the amount of airway resistance and elastic resistance.

The factors of airway resistance are: viscosity and density of the gas mixture, length of the airways, flow rate, flow pattern, and lumen radius. The factors of elastic resistance are anything preventing alveolar or chest expansion. Examples include: alveolar or interstitial fibrosis, atelectasis, chest trauma, pain, splinting, fluid accumulation in alveolar or pleural spaces, and loss of surfactant, to name a few.

To aid pinpointing pathology, we calculate dynamic and static compliance. Dynamic compliance is a reflection of both airway and elastic resistance and is calculated by using the peak pressure. Static compliance is obtained by using the plateau pressure obtained at a point of zero flow. It reflects elastic resistance only. Standard technique must be followed when doing the compliance measurement. Any changes in compliance should be caused by the patient’s condition, not by a difference in technique by the staff. A simple thing, such as a change in the patient’s position between measurements, may alter the results.

Peak airway pressure greater than 50 cm H2O is generally discouraged, because high values of P\text{peak} carry increased risk of barotrauma and hypotension. The P\text{plat} level should be monitored for all ventilated patients. The P\text{plat} levels should not exceed 30 to 35 cm H2O because higher levels not only would indicate decreased compliance but also could expose the lungs to the risk of ventilator-induced lung injury.

PRACTICE EXERCISE DISCUSSION

1. A tubing compliance of 3 ml/cm H2O and PIP of 45 result in a lost volume of 135 ml (45 X 3 = 135). The corrected V\text{T} is therefore 665 ml. Dividing 665 ml by 45 cm H2O gives a dynamic compliance of 14.78 ml/cm H2O. Dividing 665 ml by 39 cm H2O gives a static compliance of 17.05 ml/cm H2O (Most practitioners and institutions would round these off to 15 and 17 ml/cm H2O.) If V\text{T} is not corrected for lost volume, dynamic compliance is 17.78 ml/cm H2O and static compliance is 20.51 ml/cm H2O.

2. An increase in PIP and decrease in dynamic compliance simply indicate an increase in resistance. This could be an increase in elastic or airway resistance. Since static compliance reflects elastic resistance and it is unchanged, one can assume that airway resistance has increased. Secretions and bronchospasm are the most common causes of increased airway resistance. Crackles auscultated on the right indicate secretions as a possible cause of the increased airway resistance and decreased dynamic compliance.

3. Suctioning is indicated.
4. A decrease in ventilating pressures with the same $V_T$ indicates a decrease in resistance. Dynamic compliance is now 23.67 ml/cm H$_2$O and static compliance is 28.4 ml/cm H$_2$O (using a corrected $V_T$). Both dynamic and static compliance have increased from previous levels. Therefore, both airway and elastic resistance have decreased.
RESISTANCE AND COMPLIANCE

SUGGESTED READING AND REFERENCES


2. Bone R., MONITORING VENTILATORY MECHANICS IN ACUTE RESPIRATORY FAILURE, Respiratory Care, May 1983, Vol 28, #5 pp 597-603


RESISTANCE AND COMPLIANCE

POST TEST

DIRECTIONS: IF COURSE WAS MAILED TO YOU, CIRCLE THE MOST CORRECT ANSWERS ON THE ANSWER SHEET PROVIDED AND RETURN TO: RCECS, 16781 VAN BUREN BLVD, SUITE B, RIVERSIDE, CA 92504-5798 OR FAX TO: (951) 789-8861. IF YOU ELECTED ONLINE DELIVERY, COMPLETE THE TEST ONLINE – PLEASE DO NOT MAIL OR FAX BACK.

1. By definition, compliance is a measurement of:
   a. Change in volume divided by change in pressure.
   b. Change in dead space divided by tidal volume.
   c. Change in pressure divided by change in volume.
   d. None of the above.

2. Static compliance is reflected in the plateau pressure, and dynamic compliance is reflected in the peak pressure.
   a. True
   b. False

3. ELASTIC RESISTANCE changes will affect:
   a. Dynamic compliance alone.
   b. Static compliance alone.
   c. Both dynamic and static compliance.

4. Which of the following will affect the ELASTIC RESISTANCE?
   a. Radius of airway lumen
   b. Tracheal stenosis
   c. Alveolar fibrosis
   d. All of the above
RESISTANCE AND COMPLIANCE

5. The respiratory therapist reviews the ventilator flow sheet for a patient who is being mechanically ventilated. The ventilator settings have not been changed. The plateau and peak pressures are recorded below.

<table>
<thead>
<tr>
<th>Time</th>
<th>Plateau Pressure (cm H₂O)</th>
<th>Peak Pressure (cm H₂O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:00 p.m.</td>
<td>30</td>
<td>35</td>
</tr>
<tr>
<td>9:00 p.m.</td>
<td>34</td>
<td>39</td>
</tr>
<tr>
<td>10:00 p.m.</td>
<td>39</td>
<td>45</td>
</tr>
<tr>
<td>11:00 p.m.</td>
<td>44</td>
<td>50</td>
</tr>
</tbody>
</table>

Which of the following is indicated by this information?

a. Static effective lung compliance is increasing  
b. The patient is ready to begin weaning from the ventilator  
c. Static effective lung compliance is decreasing  
d. Airway resistance is decreasing

6. If plateau pressure is 30 cm H₂O and the corrected Vₜ is 900 ml, what is the static compliance?

a. 30 ml/cm H₂O  
   b. 35 ml/cm H₂O  
   c. 40 ml/cm H₂O  
   d. None of the above

7. If the peak pressure is 25 cm H₂O, corrected exhaled Vₜ is 600 ml, and PEEP pressure is 5 cm H₂O, what is the dynamic compliance? (3ml/cm H₂O volume loss factor)

a. 21 ml/cm H₂O  
   b. 35 ml/cm H₂O  
   c. 30 ml/cm H₂O  
   d. 25 ml/cm H₂O

8. Plateau pressure is used to compute:

a. Static compliance.  
b. Total impedance.  
c. Both total impedance and static compliance.
RESISTANCE AND COMPLIANCE

9. If the dynamic compliance value (total impedance) decreases from 50 ml/cm H₂O to 40 ml/cm H₂O, the work of breathing has:
   a. Increased.
   b. Decreased.
   c. Stayed the same.

10. Total impedance is defined as:
   I. Using peak airway pressure (PIP) in the calculation
   II. A measurement which reflects airway and frictional resistance
   III. A measurement which reflects the resistance of the alveoli
   IV. The difference between PEEP and Pₚ₉ₙ₉ are used in calculation
   a. I, II, III
   b. II, III, IV
   c. I, II, IV
   d. I, & II only

11. Static compliance is defined as:
   I. Corrected V_t exhaled ÷ Pₚ₉₉₉ – PEEP
   II. A calculation with flow stopped
   III. A measurement which gives us information on the resistance of the alveoli, interstitium and chest wall only
   IV. A measurement which gives us information on the resistance in the airways
   a. I, II, III
   b. I & II only
   c. I, II, IV
   d. All of the above

12. Which of the following will affect the static compliance?
   a. Pneumonia
   b. Pulmonary emphysema
   c. Obesity
   d. All of the above
13. Once the patient is suctioned and the tubing drained, the patient exhibits a continued decrease in compliance and increased resistance in their airways. Possible remedies to this problem include:

I. Listen for additional secretions and suction again if indicated
II. Administer a nebulizer in-line with a bronchodilator
III. Bypass the humidifier
IV. Administer a metered dose inhaled in-line with Albuterol

a. I, II, III
b. II, III, IV
c. I, II, IV
d. All of the above

14. Laminar flow may be achieved by:

I. Placing the largest size artificial airway possible
II. Appropriate flow rate adjustment
III. Suctioning of the patient airway
IV. Draining the ventilator tubing

a. I, II, III
b. II, III, IV
c. III & IV only
d. All of the above

15. Turbulent flow is caused by:

I. High flow rates
II. Obstructions to gas flow
III. Lung bifurcations
IV. Water in the tubing

a. I, II, III
b. I, II, IV
c. II & III only
d. All of the above
RESISTANCE AND COMPLIANCE

ANSWER SHEET

NAME____________________________________ STATE LIC #_______________________

ADDRESS_________________________________ AARC# (if applic.)___________________

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1. a b c d
2. a b
3. a b c
4. a b c d
5. a b c d
6. a b c d
7. a b c d
8. a b c
9. a b c
10. a b c d
11. a b c d
12. a b c d
13. a b c d
14. a b c d
15. a b c d

KM: Test Version H
RESISTANCE AND COMPLIANCE

EVALUATION FORM

NAME:________________________________________ DATE:__________________

AARC # (if appl.)________________________ STATE LICENSE #:__________________

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Were the objectives of the course met? ______ ______

Was the material clear and understandable? ______ ______

Was the material well-organized? ______ ______

Was the material relevant to your job? ______ ______

Did you learn something new? ______ ______

Was the material interesting? ______ ______

Were the illustrations, if any, helpful? ______ ______

Would you recommend this course to a friend? ______ ______

What was the most valuable portion of the material?
________________________________________________________________________

What was the least valuable portion of the material?
________________________________________________________________________

Suggestions for future courses: ____________________________________________

Comments: ______________________________________________________________
________________________________________________________________________

What is your specialty area?________________________ Credentials?________

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