Comparison of Published Pressure Gradient Symbols and Equations in Mechanics of Breathing

David F Wolfe MSEd RRT RPSGT AE-C and Joseph G Sorbello MSEd RRT

In the literature of pulmonary medicine we found dismaying diversity of and inconsistency in terms used to describe physiologic pressure gradients. Standardized terms, definitions, symbols, and equations published by the American Physiological Society, the American College of Chest Physicians, the American Thoracic Society, and the American Association for Respiratory Care have not been consistently used. Rather, researchers have often used their own definitions for transpulmonary pressure, transairway pressure, transthoracic pressure, transrespiratory pressure, and transdiaphragmatic pressure. We describe the variety of definitions and equations we found for those terms. We contend that it would benefit researchers, students, clinicians, and educators to define these terms precisely and use them consistently. *Key words: transpulmonary pressure, transairway pressure, transthoracic pressure, transrespiratory pressure, transdiaphragmatic pressure, terminology, respiratory mechanics/physiology*. [Respir Care 2006;51(12):1450–1457. © 2006 Daedalus Enterprises]

Introduction

A clear understanding of respiratory physiology is critical to the provision of competent respiratory care as well as the scientific advancement of the field. Comprehension of the pressure gradients involved in the mechanics of breathing is an important part of this understanding. There are, however, differences among the definitions, symbols, and equations used to convey this information in the medical literature, including respiratory care texts.

Although a standardized set of definitions, symbols and equations has been published by those who establish such standard terms, various medical authors, including those in respiratory care, have chosen to express these definitions, symbols, and equations differently from that standard. Additionally, the authors differ among themselves in expressing those terms. The differences among various authors have created confusion for many, particularly students, who depend on published standards to guide them in establishing a solid foundation. This foundation helps to achieve understanding of physiology and pathophysiology, from which flows critical components of their professional knowledge and skills.

The purpose of this article is to articulate these differences, as presented in the literature. Armed with this information, the respiratory care community will perhaps come to some consensus on the terminology of breathing mechanics and begin to use this terminology consistently.

The first attempt to document standard respiratory physiologic definitions and symbols was in 1950.[1] In 1964, 1965, and 1986, the American Physiological Society published similar documents.[2,3] In 1975 and 1997 the American College of Chest Physicians and the American Thoracic Society,[4] and American Association for Respiratory Care[5] also published similar documents. Despite these publications, there is still no agreement concerning definitions and symbols used in respiratory physiology, particularly those used to describe mechanics of breathing, among the many authors who publish in the medical literature.

David F Wolfe MSEd RRT RPSGT AE-C and Joseph G Sorbello MSEd RRT are affiliated with the Department of Respiratory Therapy Education, College of Health Professions, State University of New York, Upstate Medical University, Syracuse, New York.

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Correspondence: David F Wolfe MSEd RRT RPSGT AE-C, Department of Respiratory Therapy Education, College of Health Professions, State University of New York, Upstate Medical University, 750 E Adams Street, Syracuse NY 13210-2375. E-mail: wolfed@upstate.edu.

Table 1. Symbols Used in the Medical Literature to Represent Pressures and Pressure Gradients in Mechanics of Breathing

Pressure at a Location	
P_{aw}, P_{ao}, P_{awo}, P_{airway}	airway pressure, airway opening pressure
P_{AW}	flow-resistive pressure in airway
P_{pa}	proximal airway pressure
P_m	mouth pressure
P_{alv}, P_A	alveolar pressure
P_{pl}	pleural pressure
P_{ab}	abdominal pressure
P_{bs}, P_{BS}	body surface pressure
P_b, P_B, P_{ATM}	atmospheric pressure
P_{es}	esophageal pressure
P_{gas}, P_{GA}	gastric pressure
P_{tr}	tracheal pressure
P_E	total pressure in the external ambient
P_{in}	pressure inside a vessel or airway
P_{out}	pressure outside a vessel or airway
Pressure Gradients and Differences	
P_{TA}, P_{aw}, P_{ta}, $P_{transairway}$	transairway pressure, flow-resistive pressure in the airways
P_{TR}, P_{RS}, P_{rs}, P_{tr}, P_{tres}	transrespiratory pressure
P_{trs}, $P_{transrespiratory}$	transrespiratory system pressure
P_{TP}, P_L, P_{tp}, $P_{transpulmonary}$	transpulmonary pressure
$P_{transalveolar}$	transalveolar pressure
P_{TT}, P_W, P_{tt}, $P_{transthoracic}$	transthoracic pressure
P_{Di}, P_{TD}, P_{di}	transdiaphragmatic pressure
P_{RC}	pressure across the rib cage
P_{cw}	across the chest wall
P_{abW}	transabdominal wall pressure
P_{Eq}	pressure across the equipment
$P_{el(L)}$	elastic recoil pressure of the lung (pressure across lung tissue)
P_{tm}, P_{TM}, $P_{transmural}$	transmural pressure

Review of Literature

Symbols

Symbols used in respiratory physiology to identify specific points of reference relating to pressure gradients and the understanding of breathing mechanics are also critical to ensure no impedance to rigorous scientific communication. We offer Table 1 to illustrate the variety of symbols discovered in our literature search. It's our belief that even though it may be acceptable to use different symbols, it's still confusing, especially to students, for whom the concepts of pressure gradients are not fully developed. Our contention is that although different symbols are used and commonly accepted, standardized symbols used by all authors would be beneficial to the field.

Pressure Gradients

A comprehensive review of major textbooks (Table 2) was performed.[6-28] A brief synopsis is also provided below, organized by pressure gradient. One inconsistency we found was that some sources did not define or give equations for many pressure gradients critical in the illustration of respiratory mechanics. One example was the text by Slonim and Hamilton entitled *Respiratory Physiology*, which defined only transpulmonary pressure.[15]

Transpulmonary. Several pressure gradients are encountered in the respiratory system. Transpulmonary pressure (Table 3) is commonly defined as the pressure gradient from the alveolar to the pleural spaces ($P_{alv} - P_{pl}$). Although most agree on the spaces between which this gradient is defined, the text edited by Kacmarek et al[7] reverses the symbols and, therefore, the direction of this gradient ($P_{pl} - P_{alv}$).

Expanding the review to include original peer-reviewed research articles revealed even greater confusion.[29-40] For instance, Davis defined transpulmonary pressure as the difference between airway opening pressure and pleural pressure (as measured via esophageal balloon), rather than the difference between alveolar pressure and pleural pressure.[29] Airway opening and alveolar pressure are equal under static conditions, as may be the case with specific research protocols (under controlled conditions). This is a special scenario, and casual extrapolation of this estimation may confound the reader. Davis's review[29] defined transpulmonary pressure within the context of the measurement of dynamic airway resistance, in which both pressure and flow were dynamic rather than static.

Transairway. Transairway pressure (Table 4) is described alternately as the pressure gradient between the alveolar space and either the mouth or the airway opening ($P_m - P_{alv}$, or $P_{ao} - P_{alv}$).[41,42] The direction of the gradient was reversed in the text for our own course in cardiopulmonary physiology: *Respiratory Care Anatomy and Physiology* by Beachey.[6] Munakata et al describe transairway pressure as the difference between "airway opening and alveolar pressure," without regard to direction.[41] Hicks states that transairway and transrespiratory pressure are synonymous and expressed as $P_{rs} = P_A - P_B$.[28]

Transthoracic. Perhaps the greatest confusion regarding respiratory pressure gradients surrounds transthoracic pressure (Table 5).[32,43-47] The equation for and definition of the transthoracic pressure gradient is inconsistent, even within the same textbook. For example, the equation $P_{pl} - P_{bs}$ appears in Chapter 9 of both the 7th and 8th editions of *Egan's Fundamentals of Respiratory Care*.[12,13] However, Chapter 40 of the 8th edition states that transthoracic pres-

Table 2. Comparison of Pressure Gradient Terms and Equations Used in Respiratory Care Texts

First Author	Pressure Gradients				
	Transairway	Transrespiratory	Transpulmonary	Transthoracic	Transdiaphragmatic
Beachey[6]	"pressure gradient across the airways . . . = $P_A - P_{ao}$"	$P_{rs} = P_A - P_{bs}$	$P_L = P_A - P_{pl}$	$P_W = P_{pl} - P_{bs}$	No equation, definition, or symbol
Kacmarek[7]	"alveolar minus body surface pressure"	"pressure difference across the lung-thorax system . . . alveolar-body surface pressure"	"TPP: the pressure difference across the lung (pleural minus alveolar pressure)"	"pressure difference across the thorax, including chest and diaphragm (pleural-body surface pressure)"	"pressure difference across the diaphragm (abdominal-pleural pressure)"
Martin[8]	"Transairway (pressure) = Pm − Palv = pressure driving air into or out of the lungs"	No equation, definition, or symbol	"Transpulmonary = Palv − Ppl = pressure tending to inflate or deflate the lungs"	"Transthoracic = Palv − Pbs = pressure tending to inflate or deflate the lungs and chest wall together"	No equation, definition, or symbol
Des Jardins[9]	$P_{ta} = P_m - P_{alv}$ $P_m = P_{ao}$	No equation, definition, or symbol	$P_{tp} = P_{alv} - P_{pl}$	$P_{tt} = P_{alv} - P_{bs}$	No equation, definition, or symbol
Cottrell[10]	$P_{ta} = P_m - P_a$	No equation, definition, or symbol	$P_{tp} = P_{alv} - P_{pl}$	Ptt = Ppl − Pbs Pbs = Patm	No equation, definition, or symbol
Pilbeam[11]	$P_{TA} = P_{aw} - P_A$	$P_{TR} = P_{awo} - P_{bs}$	$P_L = P_A - P_{pl}$	$P_W = P_A - P_{bs}$	No equation, definition, or symbol
Ruppel[12]	No equation, definition, or symbol	$P_{rs} = P_{alv} - P_{bs}$ $P_{rs} = P_{alv} - P_{ao}$ in spontaneous breathing	$P_L = P_{alv} - P_{pl}$	$P_W = P_{pl} - P_{bs}$	No equation, definition, or symbol
Ruppel[13]	No equation, definition, or symbol	$P_{rs} = P_{alv} - P_{bs}$ $P_{rs} = P_{alv} - P_{ao}$ in spontaneous breathing	$P_L = P_{alv} - P_{pl}$	$P_W = P_{pl} - P_{bs}$	No equation, definition, or symbol
Op't Holt[14]	$P_{ta} = P_{aw} - P_{alv}$	$P_{tr} = P_{ao} - P_{bs}$	$P_L = P_{alv} - P_{pl}$	P_w or $P_{tt} = P_{bs} - P_{alv}$	No equation, definition, or symbol
Slonim[15]	No equation, definition, or symbol	No equation, definition, or symbol	"pressure difference between alveolar pressure and intrapleural pressure"	No equation, definition, or symbol	No equation, definition, or symbol
Op't Holt[16]	No equation, definition, or symbol	"pressure difference between the alveoli and the mouth"	No equation, definition, or symbol	No equation, definition, or symbol	No equation, definition, or symbol
Grippi[17]	No equation, definition, or symbol	No equation, definition, or symbol	Pl = Palv − Ppl	Prs = Palv − Pbs	Pdi = Pab − Ppl
Loring[18]	Not defined as "transairway pressure"; however, "P_{aw} = flow resistive pressure in the airways; $P_{aw} = P_{ao} - P_{alv}$"	$P_{RS} = P_{ao} - P_{bs}$	P_{TP} or $P_L = P_{ao} - P_{pl}$	Not defined as such; however, P_{CW} is the pressure difference "across the chest wall"; $P_{CW} = P_{pl} - P_{bs}$	$P_{Di} = P_{pl} - P_{ab}$
Chatburn[19]	"$P_{transairway}$ . . . airway opening pressure minus lung pressure."	$P_{transrespiratory} = P_{transairway} + P_{transthoracic}$ "pressure at the airway opening minus the pressure at the body surface"	$P_{transpulmonary} = P_{transairway} + P_{transalveolar}$ "airway opening pressure minus pleural pressure"	(derived) $P_{transthoracic} = P_{transrespiratory} - P_{transairway}$ "lung pressure minus body surface pressure"	No equation, definition, or symbol

(Continued)

Table 2. Continued

First Author	Pressure Gradients				
	Transairway	Transrespiratory	Transpulmonary	Transthoracic	Transdiaphragmatic
MacIntyre[20]	Illustrated as transrespiratory pressure minus transthoracic pressure	"airway pressure minus body surface pressure." Illustrated as transairway pressure plus transthoracic pressure	No equation, definition, or symbol	Illustrated as transrespiratory pressure minus transairway pressure	No equation, definition, or symbol
Matthews[21]	No equation, definition, or symbol	No equation, definition, or symbol	"Transpulmonary pressure $= P_{alveolar} - P_{pleural}$"	No equation, definition, or symbol	No equation, definition, or symbol
Leff[22]	No equation, definition, or symbol	No equation, definition, or symbol	$P_{tp} = P_{alv} - P_{pl}$	Not defined as "transthoracic pressure"; however, $P_{trans\text{-}chest\ wall} = P_{pl} - P_{atmospheric}$	No equation, definition, or symbol
Chatburn[23]	Illustrated as transrespiratory pressure minus transthoracic pressure	Illustrated as transairway pressure plus transthoracic pressure	No equation, definition, or symbol	Illustrated as transrespiratory pressure minus transairway pressure	No equation, definition, or symbol
Culver[24]	No equation, definition, or symbol	Not defined as "transrespiratory pressure"; however transmural pressure of the respiratory system equals "$(P_A - P_{PL}) + (P_{PL} - P_{ATM}) = P_A - P_{ATM}$"	Not defined as "transpulmonary pressure"; however, transmural pressure of the lungs equals "Alveolar pressure (P_A) − pleural pressure (P_{PL})"	Not defined as "transthoracic pressure"; however, transmural pressure of the chest wall equals "P_{PL} − atmospheric pressure (P_{ATM}), or simply P_{PL}"	No equation, definition, or symbol
West[25]	No equation, definition, or symbol	"difference between the inside and outside of the lung"	No equation, definition, or symbol	No equation, definition, or symbol	No equation, definition, or symbol
Levitsky[26]	No equation, definition, or symbol	No equation, definition, or symbol	"equal to the pressure in the trachea minus the intrapleural pressure. Thus, it is the pressure difference across the whole lung."	No equation, definition, or symbol	No equation, definition, or symbol
Drumheller[27]	"(Pta) is the pressure difference between the mouth (Pm), or airway pressure, and the alveolar pressure (Palv)"	No equation, definition or symbol	"(Ptp), or alveolar distending pressure, is the difference between Palv and pleural pressure (Ppl)"	"(Ptt) is the difference between Palv and body surface pressure (Pbs)"	No equation, definition, or symbol
Hicks[28]	$P_{rs} = P_A - P_B$	Stated to be the same as transairway pressure	$P_L = P_A - P_{pl}$	$P_W = P_{pl} - P_B$	$P_{di} = P_{pl} - P_{abd}$

sure is $P_{bs} - P_{alv}$.[14] Other authors add to the confusion by variously defining this gradient as $P_{alv} - P_{bs}$,[9] $P_A - P_{bs}$,[11] and "difference between gastric pressure. . . and the pleural pressure . . . at the end of expiration."[44]

The equation that uses alveolar pressure minus body surface pressure, in its various forms, is the same as that used by other authors to define transrespiratory pressure.[6,7,12,13]

As a summary, we found the following various equations or relationships from the various authors for transthoracic pressure: $P_{pl} - P_{bs}$,[6,10,12,13,18] $P_{alv} - P_{bs}$,[8,9,17] $P_{bs} - P_{alv}$,[14] $P_{transrespiratory} - P_{transairway}$,[20] esophageal pressure

Table 3. Comparison of Transpulmonary Pressure Gradient Symbols, Definitions, and Equations in Published Articles

First Author	Symbol, Definition, and/or Equation (only if included in article)
Davis[29]	"Transpulmonary pressure is defined as the difference between the pressure measured at the airway opening and the pressure measured at the esophagus."
Mundie[30]	Ptp = difference between airway opening pressure (Pao) and esophageal pressure (Pes)
Easa[31]	
Chaunchaiyakul[32]	Transpulmonary pressure: alveolar minus pleural pressure
Permutt[33]	Transpulmonary pressure = "airway pressure relative to pleural pressure"
Murali[34]	"The resistance of the pulmonary circulation is represented by the gradient across the pulmonary vascular bed or the transpulmonary pressure gradient (pulmonary artery mean pressure minus mean pulmonary wedge pressure)."
Sanchez[35]	"Transpulmonary pressure was defined as the difference between the intrapleural and atmospheric pressures."
Schulze[36]; Coates[37]	Ptp
Hobbhahn[38]	"The transpulmonary pressure gradient (TPP) was calculated from MPAP and PCWP."
Gamillscheg[39]	"transpulmonary pressure gradient (CVP − LAP)"
Pelosi[40]	Transpulmonary pressure (PL) is "the difference between Paw and Ppl"

Ptp = transpulmonary pressure
MPAP = mean pulmonary artery pressure
PCWP = pulmonary capillary wedge pressure
CVP = central venous pressure
LAP = left atrial pressure
Paw = airway pressure
Ppl = pleural pressure

Table 4. Comparison of Transairway Pressure Gradient Symbols, Definitions, and Equations in Published Articles

First Author	Definitions, Equations, Symbols (only if included in the article)
Munakata[41]	Transairway pressure (Pta) = "difference between airway opening and alveolar pressure"
Liu[42]	"transairway pressure gradient (P_E − P_A)"

PE = total pressure in the external ambient
PA = total pressure in the alveolar zone

Table 5. Comparison of Transthoracic Pressure Gradient Symbols, Definitions, and Equations in Published Articles

First Author	Definitions, Equations, Symbols (only if included in the article)
Chaunchaiyakul[32]	Transthoracic pressure: pleural minus body surface pressure
Suratt[43]	"Transthoracic pressure is taken as the difference between mouth pressure measured at the proximal pneumotachometer port and body surface (atmospheric) pressure."
Lazenby[44]	"Transthoracic pressure was defined as the pressure difference between the gastric pressure (abdomen) and the pleural pressure (mid-esophagus) at the end of expiration."
Barnas[45]	"Transthoracic pressure (esophageal pressure minus atmospheric pressure)"
Saunders[46]	Pes (esophageal pressure) equivalent to PTT (transthoracic pressure)
Eyal[47]	No definition, equation, or symbol

minus atmospheric pressure,[45] and mouth pressure minus body surface pressure.[43]

Transrespiratory. In the 7th edition of *Egan's Fundamentals of Respiratory Care*, transrespiratory pressure (during spontaneous breathing) was similarly defined in Chapters 9 and 39 as the difference between pressure in the alveoli and the mouth (airway opening or body surface).[12,16] In comparison, the 8th edition had a completely different equation for transrespiratory (and transthoracic) pressure.[14] Chapter 9 of both editions defines transrespiratory pressure as $P_{alv} - P_{bs}$ or as $P_{alv} - P_{ao}$ (for spontaneous breathing),[12,13] and Chapter 40 of the 8th edition defines it as $P_{ao} - P_{bs}$.[14] Chapter 9 of both editions defines transthoracic pressure as $P_{pl} - P_{bs}$[12,13] and Chapter 40 of the 8th edition defines it as $P_{bs} - P_{alv}$.[14] Additionally, other authors state that transrespiratory pressure equals transairway pressure (Table 6).[6,28]

Table 6. Comparison of Transrespiratory Pressure Gradient Symbols, Definitions, and Equations in Published Articles

First Author	Definitions, Equations, Symbols (only if included in the article)
Mundie[30]	Ptr = "difference between Paw and body surface pressure at end-inspiration"
Easa[31]	Transrespiratory system pressure (Ptrs) = "difference between Pao and body surface pressure"
Chaunchaiyakul[32]	"Transrespiratory pressure: alveolar minus body surface pressure"
Loring[48]; Zhang[49]; Suen[50]	No definition, equation, or symbol
Hantos[51]	Prs = airway opening pressure
Hall[52]	Ptr
Taylor[53]	"Transrespiratory pressure (Ptres = alveolar pressure minus body surface pressure)"
Sly[54]	Transrespiratory pressure = airway opening pressure (Pao)
Blease[55]	"Transrespiratory pressure equals change in tracheal pressure minus change in mouse chamber pressure"
Petak[56]	Ptr = tracheal pressure, Pes = esophageal pressure

As we understand these concepts, they may be equivalent in some cases, because pressure at the body surface (P_{bs}) and pressure at the "airway opening" (or "mouth" or "airway") is equivalent in spontaneous breathing. However, this would *not* be true if, for example, an endotracheal tube was in place. In such a case, it would be incorrect to say that the pressure at "the mouth" of this patient is equivalent to "airway" or "airway opening." The pressure in the mouth of this patient would be barometric pressure (P_B) or body surface pressure (P_{bs}). Depending on the text, transairway pressure may *qualitatively* equal transthoracic pressure[9] or transairway pressure may equal transrespiratory pressure.[6,28]

Transdiaphragmatic. One essential gradient, especially in spontaneous breathing mechanics, has rarely been described in textbooks. This is transdiaphragmatic pressure (Table 7), which has been described in only 4 textbooks.[7,17,18,28] Transdiaphragmatic pressure is defined by Kacmarek et al as "the pressure difference across the diaphragm (abdominal – pleural pressure)."[7] Grippi defined transdiaphragmatic pressure as "the pressure generated across the diaphragm during inspiration. It is calculated as the difference between intraabdominal pressure (P_{ab}) and pleural pressure (P_{pl})."[17] Consideration of this pressure gradient is not only beneficial but essential in the description and understanding of breathing mechanics.

Table 7. Comparison of Transdiaphragmatic Pressure Gradient Symbols, Definitions, and Equations in Published Articles

First Author	Symbol, Definition, Equation (only if included in article)
Permutt[33]	Transdiaphragmatic pressure = "a function of the difference between pleural and abdominal pressure"
Saunders[46]	"Transdiaphragmatic pressure (P_{di}) was taken as the difference between P_{es} and P_{ab}"
Pinet[57]	No symbol, definition, or equation
Wanke[58]; El-Kabir[59]	P_{di}
de Torres[60]	$P_{di} = P_{ga} - P_{pl}$
Riou[61]	Pdi = gastric pressure (Pgas) − esophageal pressure (Pes)

P_{es} = esophageal pressure
P_{ab} = abdominal pressure
P_{ga} = gastric pressure
P_{pl} = not defined, but assumed to be pleural pressure

Summary

Our review of the literature exposed great variability in the definition and symbolic representation of pressure gradients among experts and researchers involved in respiratory medicine. The extent of this variability is made evident by conflicting descriptions found in the medical literature and even in chapters of the same textbook. Although the ultimate impact of these discrepancies is not profound, it is our contention that this wide variability is confusing and unnecessary. Agreement among authors and consistent use of these terms will advance the understanding of pressure gradients, improve clarity, and allow for reliable scientific communication among students, clinicians, researchers, and educators.

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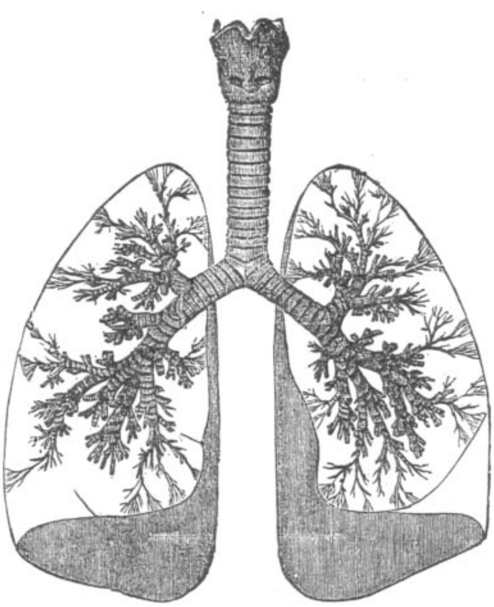

The larynx, trachea, right and left bronchus, and lungs.
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