TECHNICAL SPECIFICATION

ISO/TS 16976-4

Second edition
2019-03

Respiratory protective devices — Human factors —

Part 4: Work of breathing and breathing resistance: Physiologically based limits

Appareils de protection respiratoire — Facteurs humains — Partie 4: Travail de respiration et de résistance à la respiration: limites physiologiques

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Foreword

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This document was prepared by Technical Committee ISO/TC 94, *Personal safety — Personal protective equipment*, Subcommittee SC 15, *Respiratory protective devices*.

This second edition cancels and replaces the first edition (ISO/TS 16976-4:2012), which has been technically revised. The main changes compared to the previous edition are as follows:

a) adjustment of key-points in Figures 3, 4 and 7 to correspond with the 50 %-reference line;

b) adjustment of keys in Figures 3, 4, 7 and 8;

c) adjustment of Figures 3, 4 and 6;

d) clarification on flow resistance and elastic load given in 7.4.

A list of all parts in the ISO/TS 16976 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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Introduction

A respiratory protective device (RPD) is designed to offer protection from the inhalation of hazardous substances. However, this protection requires extra effort by the respiratory muscles as they need to generate higher pressures to overcome the associated respiratory loads imposed by the RPD.

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Respiratory protective devices — Human factors —

Part 4: Work of breathing and breathing resistance: Physiologically based limits

1 Scope

This document describes how to calculate the work performed by a person's respiratory muscles with and without the external respiratory impediments that are imposed by RPD of all kinds, except diving equipment. This Document describes how much additional impediment people can tolerate and contains values that can be used to judge the acceptability of an RPD.

NOTE These calculations are explained in some textbooks on respiratory physiology (in the absence of an RPD), but most omit them or are incomplete in their explanations.

2 Normative references

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The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 16972, *Respiratory protective devices — Definitions of terms pictograms*

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3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 16972 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
body temperature pressure saturated
BTPS
standard condition for the expression of ventilation parameters

Note 1 to entry: Body temperature (37 °C), ambient pressure and water vapour pressure (6,27 kPa) in saturated air.

3.2
compliance
change in volume of the human lung that results from a change in pressure

Note 1 to entry: The compliance is measured in l/kPa.

Note 2 to entry: This term is the typical term for the elastic behaviour of the lungs and chest. Compliance is the inverse of elastance.

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3.3
elastance
change in pressure that results from a given volume change of the human lung

Note 1 to entry: The elastance is measured in kPa/l.

Note 2 to entry: This term is the typical term for the elastic behaviour of an RPD. Elastance is the inverse of compliance.

3.4
relaxation volume
lung volume when respiratory muscles are relaxed, i.e. the volume at the beginning of an inspiration, also known as functional residual capacity (FRC) and expiratory reserve volume (ERV)

3.5
tidal volume
V_T
volume of a breath

Note 1 to entry: The tidal volume is measured in litres BTPS.

3.6
vital capacity
VC
volume of the largest breath a person can take, i.e. the volume difference between a maximum inspiration and a maximum expiration

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Note 1 to entry: The vital capacity is measured in litres BTPS.

3.7
work of breathing
WOB
work required for an entire breathing cycle

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Note 1 to entry: The work in breathing is measured in Joules.

3.8
work of breathing per tidal volume
WOB/V_T
normalized WOB (equivalent to volume-averaged pressure)

Note 1 to entry: The work in breathing per tidal volume is measured in Joules per litre = kPa.

4 Symbols and abbreviated terms

BTPS	body temperature pressure saturated
ERV	expiratory reserve volume
FRC	functional residual capacity
RPD	respiratory protective device
VC	vital capacity
WOB	work of breathing

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p_{el} pressure required to overcome the elastance

p_{aw} pressure required to overcome the flow resistance of the airways

$p_{i,ext}$ pressure required to overcome the inspiratory flow resistance of the RPD

5 Pressure and volume changes during breathing

5.1 Pressure and volume changes in the absence of an RPD

During an inspiration the inspiratory muscles contract which makes the chest expand and the diaphragm flatten. This action causes the lungs to expand to a larger volume. Even in the absence of flow resistance, it takes a certain pressure to expand the chest and lungs. The term used in respiratory physiology for this elastic behaviour is compliance. The term compliance is also used in laws and regulations; to avoid confusion with this use of the word, the remainder of this document will use the term elastance instead. See Note 2 to entry of 3.3, "elastance is the inverse of compliance". Elastance describes how much an elastic material changes when a force or a pressure is applied.

Figure 1 shows the lungs (item 1) inside the chest wall (item 2) and diaphragm (item 3). The lungs are connected to the airway (item 4). The elastance of the lungs tries to act to shrink them (shown by the arrows), similarly to a stretched balloon trying to shrink in volume. The elastance of the chest acts by trying to expand it. Thus, in the absence of muscle effort, the forces on the chest and lungs oppose each other and will, at some volume, be equal and opposite and come to a position of rest. The lung volume at which this happens is referred to as the relaxation volume. During an inhalation the chest wall expands and the diaphragm (item 3) moves downwards.

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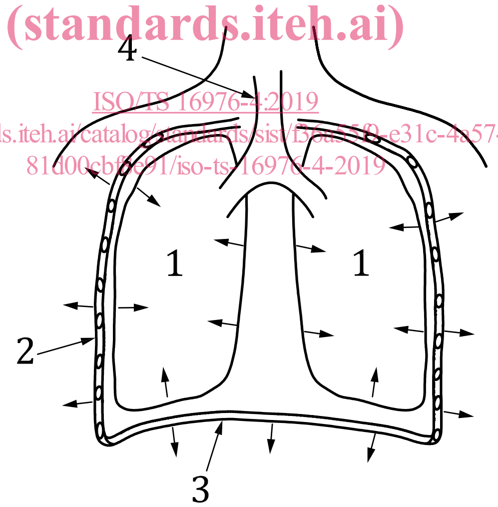

Key

1 lungs

2 chest wall

3 diaphragm

4 airway

Figure 1 — Schematic cross-section of a person's chest and lungs

Figure 2 illustrates/defines changes in breathing. An inspiration is shown to start at point A and the lung volume increases until it reaches its end, point B, where the following expiration starts. The volume difference between points A and B is the size of the breath, referred to as the tidal volume.

A maximum inspiration is shown at point C and a maximum expiration at point D. The volume difference between these two points is the maximum volume change achievable and is referred to as the vital capacity, VC. The range of VC varies from 3 l to 6 l and depends on a person's age, height and gender.

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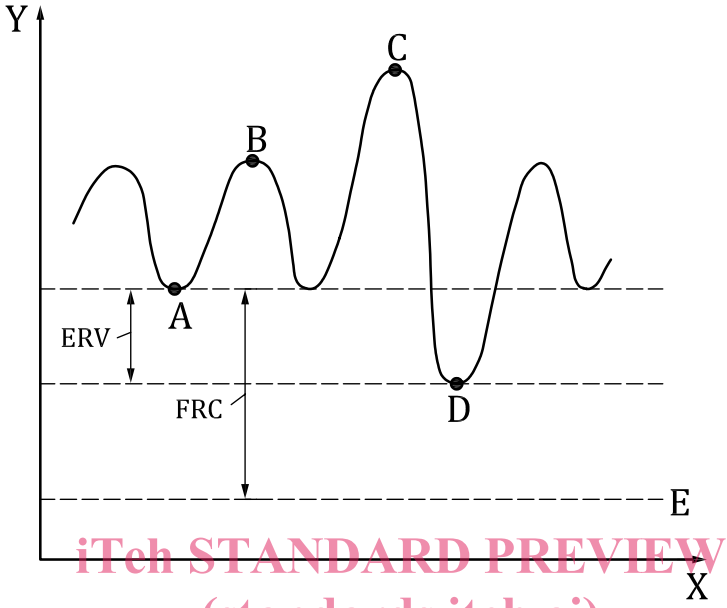
Even with a maximum expiratory effort some volume remains in the lungs. Had the lungs been able to be emptied completely the volume illustrated by line E would have been reached.

Point A is the point where the respiratory muscles are relaxed and that volume is referred to as "relaxation volume". Another term used for this point is "expiratory reserve volume", ERV, which can be calculated as the difference between points A and D. A third term used is "functional residual capacity", FRC, which is the volume difference between points A and E.



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Key

X time
Y lung volume
A start of an inspiration
B end of an inspiration and start of the following expiration
C maximum inspiration
D maximum expiration
E lungs and chest completely empty

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Figure 2 — Definitions of volume changes

In order to inhale, effort is required to overcome the combined elastance of the chest and lungs, as well as the flow resistance in the airways. Figure 3 illustrates the pressure generated and the resulting volume changes.

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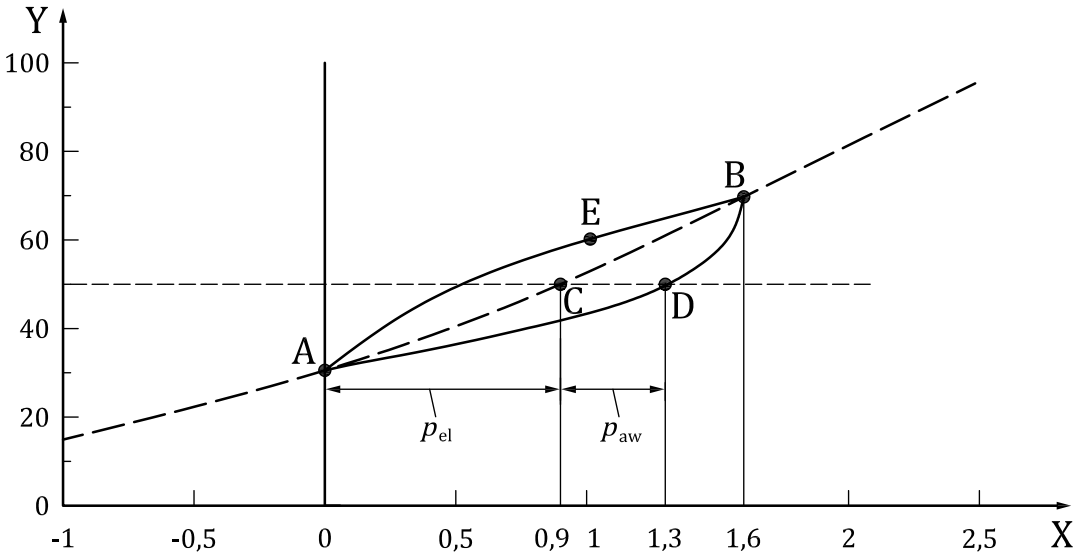

Key

X alveolar pressure, in kPa

Y volume, in percent of VC

A start of an inspiration and end of the previous expiration

B end of an inspiration and start of the following expiration

C point on the elastance line partway through an inspiration

D point on the combined elastance and pressure drop line during an inspiration

E point on the combined elastance and pressure drop line during an expiration

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NOTE The interrupted line is not a straight line but becomes less steep at low and high volume.

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Figure 3 — Lung volume versus pressure in the absence of an RPD

For a person, the muscles generate the pressure which in turn generates a change in lung volume. Therefore, the pressure is the independent variable and the volume is the dependent one. It is the opposite for an RPD, for which it is the change in volume in the lungs (i.e. gas flow) that generates pressure across a flow resistance. At the beginning of the inspiration (point A in Figure 3) no pressure is generated, i.e. it is the relaxation volume. At the end of the inspiration (point B) the greatest volume has been achieved, called the tidal volume, V_T. The interrupted line shows the interaction of the pressures and volumes from the combined elastance of the chest and lungs. For example, at point C the volume has changed from about 30 % of VC (at point A) to about 50 % of VC. The volume change could then be 0,9 l. With a typical textbook value for elastance of 1 kPa/l, the elastance requires a pressure change of about 0,9 kPa. The lower solid line ADB shows the total pressure (elastance plus pressure due to flow resistance) generated by the respiratory muscles and the resulting change in volume during the inspiration. The expiration follows the upper solid line BEA. To reach the volume of 50 % VC during inspiration (point D), a total pressure of about 1,3 kPa is required. This is the sum of the pressure of about 0,9 kPa required for the total elastance, p_{el}, and an additional 0,5 kPa (approximately) for the flow resistance of the airway, p_{aw}. Towards the end of the inspiration the flow slows down and the pressure drop due to flow resistance decreases and the inspiration ends at point B where there is no flow. Thus, the pressure at point B is only due to the elastance. The tidal volume becomes 70 % VC – 30 % VC = 40 % VC, giving a resulting pressure of (0,40 × 4) l × 1 kPa/l = 1,6 kPa. The inspiratory and expiratory curves combine to form a volume-pressure loop.

At the end of the inspiration (point B) pressure is stored due to the total elastance. During low breathing rates this pressure is sufficient to move the gas out during the following expiration. Thus, such an expiration is said to be passive because the expiratory muscles are inactive. However, the inspiratory muscles are active by controlling the flow. When more ventilation is desired, the pressure due to elastance is not sufficient and the expiratory muscles take an active part.

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