Emergency Medical Teams

Operational Support

COVID-19 Basic Manual on oxygen supply systems in EMTs and AMCS

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Contents

1. Introduction

The purpose of this document is to provide recommendations to ensure oxygen supply capacity for oxygen therapy in emergency medical team (EMT) and alternative medical care site (AMCS) clinical modules. The document includes basic knowledge on the different types of oxygen therapy systems, as well as guidance for EMT operational support staff to adapt their equipment in order to most effectively meet the clinical needs of COVID-19 patients.

In order to meet the oxygen demand required for the clinical management of patients with COVID-19, especially in the hospitalization of severe and critical cases,[1] EMTs must adapt their designs and procedures to adequately meet these needs.

Additional challenges occur when EMTs expand clinical capacities by adapting structures to serve as alternative health care sites. Since these facilities do not have the installed capacity to supply medical oxygen, they need to be transformed in ways that include the design and installation of an oxygen network (8).

1. The definition of patients in this document follows the algorithm for the management of patients with suspected COVID-19 infection at the first level of care and in remote areas of the Region of the Americas (1).

2. Basic concepts

This manual focuses on the design and installation of oxygen systems. In order to understand oxygen in the context of an EMT or AMCS, it is first important to understand the nature of medical gases such as oxygen. In addition, this chapter will describe the working conditions and parameters for using oxygen, as well as the regulations governing systems that supply and distribute oxygen in health-related settings.

2.1 Medical gases

<table>
<tr><th colspan="3">These are products consisting of one or more gaseous components that come into direct contact with the human body.
They are used in inhalation therapy, anesthesia, "in vivo" diagnosis, and––when they come into direct contact with them––to preserve and transport organs, tissues, and cells intended for transplantation.</th></tr>
<tr><th>Medical gases used as medication</th><th>Medical gases used as health products</th><th>Other types of gases</th></tr>
<tr><td>Their actions are:
• Pharmacological
• Immunological
• Metabolic
They contain properties designed to prevent, diagnose, treat, alleviate, or cure diseases or ailments.</td><td>Act through pharmacological, immunological, and/or metabolic means.</td><td>These do not come into contact with the patient, but support the use of medical gases, as well as the operation of equipment used in care and treatment of diseases.</td></tr>
<tr><td>Examples
• Oxygen
• Nitrogen protoxide
• Medicinal air
• Nitric oxide (O_2/nitrogen protoxide mixture)
• Helium (and its mixtures)</td><td>Examples
• Carbon dioxide (CO_2) for use in laparoscopy</td><td>Examples
• Compressed air to operate surgical tools.
• Nitrogen for powering surgical tools.
• Compressed air used with Venturi for the extraction of anesthetic gases from operating rooms.</td></tr>
</table>

2.2 Medical parameters of O_2

Oxygen at atmospheric pressure is a colorless gas that is odorless, non-flammable, and tasteless. Its liquefaction temperature is -18°C. Chemically, it is a highly active gas, due to its oxidizing nature. It is a necessary component in the formation of other compounds that form exothermic reactions. It requires special care, since it facilitates spontaneous combustion and detonation. It is mainly employed as the basic constituent of mixtures for inhalation and respiratory uses.

The oxygen supplied to the patient should be controlled, with a flow rate based on the type of patient and oxygen requirements, ranging from 0.2 l/min to 60 l/min. Since the oxygen concentration can be reduced significantly by high relative humidity, this should be taken into account. The concentration should be no less than 82%.

For children under 5 years of age, humidification is not necessary when the oxygen is administered at low flow rates of up to 2 l/min using nasal prongs or catheters. In tropical climates, humidification may also be unnecessary when oxygen is administered with a concentrator rather than a cylinder, since concentrators deliver oxygen at room temperature whereas cylinders deliver it cold.

Humidification may be required when the need for high oxygen flow exceeds 2 l/min or if the oxygen does not pass through the nose, for example with a nasopharyngeal catheter or tracheal cannula.

2.3 Regulation

EAll countries have regulations governing medical gas piping systems and their equipment. These regulations may have their own national specifications or may refer to international standards for local application.

The main international standards are NFPA 99 (2), which is prevalent in the Region of the Americas, and UNE-EN7396-1 (3), which is used mainly in Europe and its surrounding area. The following table compares these standards:

Table 1: Comparison of UNE-EN7396-1 and NFPA99 regulations

Parameters	International System (Europe)	United States (the Americas)
Medical gas piping systems : • Supply sources • Copper piping • Intermediate pressure regulators • Monitoring and alarm systems	UNE-EN7396-1	NFPA 99
Pressure regulators	UNE EN ISO 10524-1:2007	
Flexible tank connections	UNE EN ISO 407:2005	
Piping with markings	UNE EN ISO 5359:2008	
Low pressure flexible connection pipes		

3. Sources of oxygen for medical use

Oxygen sources are technologies that provide gas to the distribution networks of healthcare facilities and/or directly to patients or devices.

Oxygen can be dispensed from various sources, in different formats, with the type of supply depending on the healthcare facility, and on variables such as:

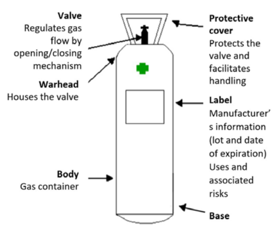
- Amount of O_2 to be consumed by the EMT/AMCS
- Logistics for supplying the product
- Availability of space and access in the EMT/AMCS

Selection of the most appropriate source of O_2 for an EMT or AMCS must also consider the specific context of the response, the cost-effectiveness of the chosen alternative, and the availability of the product.

The sources of O_2 evaluated in this manual are indicated in the table below (6):

Table 2: Comparison of oxygen sources

Type of source	Stored O_2		Generated O_2	
	Compressed O_2 in cylinders	Cryogenic liquefied O_2	O_2 concentrators (7)	Oxygen-producing plants (12)
Characteristics	2 types of supply: • Individual - supplied directly to the patient • Series of large cylinders connected together (16 to 18 cylinders) Presented as 0.5 l - 50 l	• O_2 is supplied through the delivery system, from the cryogenic tank (fixed or mobile) to the points of use • Capacity of the tanks is 1,500 l - 40,000 l	• Medical device that concentrates O_2 by passing air through molecular sieves • Concentrations for clinical use, 82% - 95.5% • Two types • Stationary (2 to 5 patients) • Portable (individual)	• Pressure swing absorption (PSA) system. The air passes through O_2 generators with zeolite molecular sieves that adsorb nitrogen • Concentration of 93% - 95%
Advantages	• Easy to manage and use	• Greater autonomy and safer delivery of the product • Savings in time, space, and gas	• Sustainable and cost-effective source • High reliability and low cost compared with other sources	• Molecular sieves are fully regenerative – with an indefinite lifetime • Easily scalable • Relatively low cost of operation • Permanent availability

Type of source	Stored O_2		Generated O_2	
	Compressed O_2 in cylinders	Cryogenic liquefied O_2	O_2 concentrators (7)	Oxygen-producing plants (12)
Disadvantages	• Requires strict replacement plans • Requires considerable storage space • Challenging transportation logistics	• Greater autonomy and safer delivery of the product • Savings in time, space, and gas	• Requires constant electric power supply for operation	• Purity level and product flow can vary • Dependent on location, climatic conditions, and ambient air quality • Presence of impurities such as Argon
Components		Minimum components: • Enclosure to house the equipment • Cryogenic tank • Gasification system • Control panel for the gas supply • Electric panel for discharging tanks • Lighting • Water supply	Minimum components: • O_2 concentrator • Control panel • Alarm system • Flowmeter • Humidifier • Accessories: pipe and/or mask 	Minimum components: • Air compressor • Prefilter • Filtration • Compressed air tank • Oxygen generator • Auxiliary tank • O_2 receiver tanks
Safety	• Avoid mechanical damage (shocks, falls) or physical damage (excessive heating, electrical shorts) • Always keep cylinders in a vertical position • Dedicated storage areas (dry, ventilated, marked, protected from sunlight) • Workflows clearly established	• Handling by specialized personnel • Use of cryogenic gloves and transparent face masks • The container or pipe containing cryogenic gases must never be touched without appropriate PPE • Only specific containers should be used • Minimum distances should be maintained	• Periodic maintenance (every three to four months) • Confirm that O_2 concentration is within the limits of operation	• Management by specialized personnel • Continuous monitoring of concentration and level of purity

Type of source	Stored O_2		Generated O_2	
	Compressed O_2 in cylinders	Cryogenic liquefied O_2	O_2 concentrators (7)	Oxygen-producing plants (12)
EMT /AMCS use recommended	Low to moderate O_2. • EMT triage • EMT 1 and 2 • AMCS not for COVID-19 patients	High O_2 consumption • EMT SARI • EMT TYPE 3 • AMCS for COVID-19 patients	Low to moderate O_2 consumption • EMT triage • EMT 1 and 2 • AMCS not for COVID-19 patients	High O_2 consumption • EMT SARI • EMT type 3 • AMCS for COVID-19 patients (moderate to severe)

4. Oxygen systems for medical use

Image 1: Oxygen facilities in a SARI EMT (EMT SARI MoH Ecuador).

Initially, EMTs were primarily focused on trauma response; therefore, they used individual oxygen systems with cylinders or concentrators that allowed them sufficient oxygen for their operations. However, total consumption during their response missions was limited.

The impact of the COVID-19 pandemic has increased the amount of medical oxygen needed for EMT response. Respiratory failure in the severe and critical phases of the disease requires high-consumption oxygen therapy. As a result, hospitals, AMCS, and EMTs are all expected to be able to identify and monitor patients and provide sufficient oxygen to treat patients admitted to these centers. A definition of COVID-19 is provided in Annex 1.

The design and preparation of medical oxygen systems for EMT and AMCS response must be adapted to the logistic and budgetary context and capacities of the EMT or AMCS team, and must be planned prior to deployment. This planning can be one of the most complex tasks in decision making; thus, throughout this chapter and the following one, the necessary information will be given to facilitate the choice of the type of oxygen facility to be deployed in an EMT. The following table summarizes what will be presented.

Table 3: Appropriate systems, based on type of EMT or AMCS

Typology	Individual oxygen systems	Centralized oxygen systems
EMT1	Lighter, portable. Can be carried from headquarters. Better adapted to temporary patients who are not going to be admitted. Assembly is quick and easy, and maintenance and management can also be performed by medical staff.	Not recommended.

Typology	Individual oxygen systems	Centralized oxygen systems
EMT2	Can be used on missions where a small percentage of patients require oxygen therapy. Also suited to missions where liquid oxygen (LOX) or PSA tanks are not available. It is advisable to have them as a backup if centralized systems are used, or for relocations.	Recommended for missions with a long deployment time, and/or with hospitalized patients requiring oxygen therapy upon admission (justifying the effort of assembling the equipment).[2] An existing source of oxygen at the deployment site is necessary, and the supply must be reliable. A qualified and sometimes certified operational support team is required.
EMT3	It is advisable to have them merely as support, or for relocations.	Recommended for this type of EMT. With an ICU, a high number of inpatients, and two operating rooms, the management of numerous individual systems would be too complicated. An existing source of oxygen at the deployment site is necessary, and the supply must be reliable. A qualified and sometimes certified operational support team is required.
EMT SARI	If the admitted patients are in moderate condition, and/or are recovering from a severe/critical phase (known as step-down), its use may be acceptable. However, it may be complicated to manage if the number of patients on oxygen therapy increases and oxygen gas cylinders are the source. It is advisable to have them as a backup or for relocations if centralized systems are chosen.	Recommended for this type of EMT, especially if housing severe and/or critical patients. An existing source of oxygen at the deployment site is necessary, and the supply must be reliable. A qualified and sometimes certified operational support team is required.
AMCS	It will depend on the type of services to be provided. If these services do not require hospitalization of severe and/or critical patients requiring oxygen therapy, and the number of moderate patients requiring oxygen therapy is not very high, the use of this type of facility may be acceptable. It is advisable to have them as a backup or for relocations if centralized systems are chosen.	Recommended for this type of EMT, especially if housing severe and/or critical patients. An existing source of oxygen at the deployment site is necessary, and the supply must be reliable. A qualified and sometimes certified operational support team is required.

2. Oxygen distribution kits are available for quick transport and installation with the possibility of connection to various types of sources, allowing oxygen distribution to 1-10 patients, reducing cost and assembly time.

The following section will explain the types of systems that can be installed in EMTs or AMCS, as well as the components that comprise them. The objective is to establish an effective design, as will be detailed in the final chapter.

4.1 Individual O_2 systems

Individual O_2 systems are those in which oxygen goes directly from the source to a single patient, through individual cylinders and concentrators. These systems are the simplest to deploy and the least expensive in terms of investment. However, operation of this type of facility requires considerable effort in overseeing cylinder changes and has certain limitations in terms of the flow of oxygen supplied; in addition, precautions must be taken with the electrical system when using individual concentrators.

O_2 sources for individual systems are usually placed close to the point of consumption, i.e., adjacent to a patient's bed; certain precautions should therefore be taken to ensure that they have been installed correctly and operate safely. (9) These precautions vary depending on the type of O_2 source available.

4.1.1 Individual cylinders

When using individual oxygen cylinders, the following components are required, as shown in Figure 1.

Three main recommendations should be considered for these systems:

- For COVID-19 patients, oxygen consumption is usually continuous and high-flow (5). This means that, depending on the size of the cylinders, they should be changed every three to four hours or even more frequently; extensive planning of the cylinder changes is therefore necessary.
- The cylinders should be located in such a way as to facilitate access for the described changes, inspections, etc., so that the logistics team can access the source point without affecting patients or clinical operations.

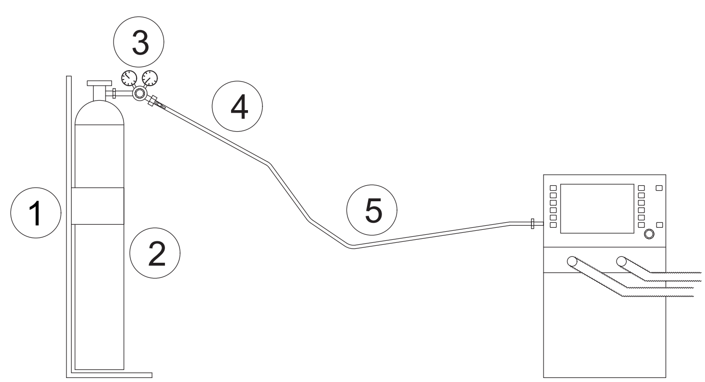


Figure 1: Parts of an individual facility, from tank to respirator: 1. Fixed location of tank; 2. Oxygen tank; 3. Pressure regulator (if it does not have a flow/pressure gauge, then a flow meter should be attached); 4. Humidifier (optional, not included in the illustration); 5. Pipeline (usually made of flexible plastic).

- The use of double pressure reducer systems (manifolds) is recommended; this requires advance preparation for changing cylinders, in order to avoid causing drops in the flow supplied to patients, which could case hypoxia.

4.1.2 Individual concentrators

Figure 2 shows the design of an individual system with a mobile oxygen concentrator.

These systems are the easiest to handle. Nevertheless, the following actions are recommended:

- Oxygen concentrators require a continuous supply of energy; it is essential that there be no power cuts, as this would be fatal for the patients connected to them. For this reason, a UPS[3] is recommended, thereby allowing battery operation when outages occur, and, in addition, making it possible to regulate the voltage to the devices. This is highly important when electrical generators are used to supply electricity to a deployed EMT/AMCS.
- For more information on oxygen concentrators, please consult the List of Priority Medical Devices in the context of COVID-19 (4), which contains information on the minimum standards, technical description, and specifications of oxygen concentrators (and other medical devices) that have been recommended for the management of patients with suspected or confirmed SARS-CoV-2 infection at the various levels of complexity of care.

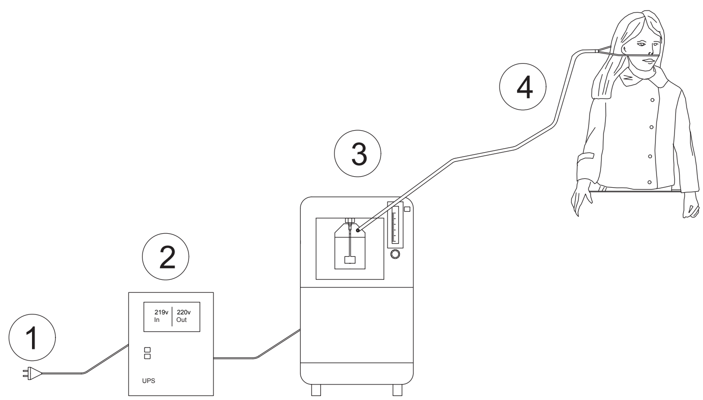


Figure 2: Individual facility with portable oxygen concentrator: 1. Power outlet; 2. UPS unit; 3. Portable oxygen concentrator; 4. Pipeline (usually made of flexible plastic.

4.2 Centralized O_2 systems

Centralized systems are those that supply oxygen to several patients or oxygen therapy devices, with distribution lines channeled centrally from a single source. Sources vary according to the context in which a facility is created. The main sources are liquid oxygen (LOX) tanks, PSA production tanks, dual

3. Uninterruptible power supply (UPS) is a device with batteries or other energy storage elements that can provide electrical power for a limited time to all connected devices during a power outage.

concentrators, and linked oxygen gas cylinders. All of these have been discussed in the previous chapter (see Chapter 3).

The initial investment for this type of installation is usually high, with similarly high complexity in installation and maintenance. However, they are capable of supplying high oxygen flows in a more efficient way; in medium- to long-term responses and responses where high oxygen consumption is required, they are the optimal solution, provided that installation is possible.

Centralized systems are the most technically complex and contain a larger set of controlling and regulating parts to manage the oxygen supply. These networks and sources must be calculated and installed by specialized technicians who are qualified to install them at the point of assembly. In the following subchapters, the component parts of these systems will be explained.

4.3 Components

4.3.1 Pipes and fittings

Oxygen is transmitted from source to patient (or to the electromedical device) through pipes, usually made of copper.[4] Polyamide pipes are used for short distances––generally from the outlets (copper-pipe connections) to the electromedical devices, and from the machinery to masks and other devices that require it. While these are flexible, light, and better adapted to the environment, they are more susceptible to cuts, punctures, crushing, etc.

Copper pipes are available in coils or bars, and although they are thermally and/or mechanically malleable, they sometimes need fittings for bends (elbows), and for T-joints and reduction points. The joints between pipes and between pipes and fittings are generally soldered (using heat), with a material to provide capillary action – i.e., after being cleaned and added the flux two pieces of copper are heated and a filling wire is added; this is distributed by capillary action in the space between the two pieces to be joined. Soldering may be either soft or hard.

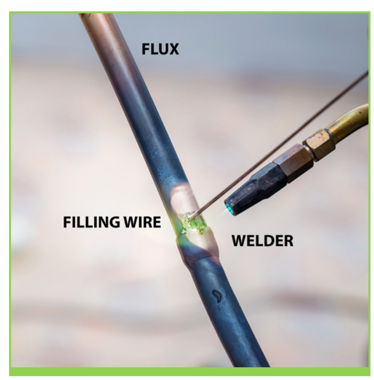


Image 2: Picture of copper brazing and components.

Soft soldering is carried out at temperatures below 450° C, and the filling wire is usually tin. Brazing is performed at temperatures above

4. The standards in the Americas are specific to each country, but are usually influenced by the NFPA99 standard. In Europe this is UNE-EN7396-1. See chapter 2.

450° C and the filler material is usually a copper or tin-silver alloy (brazing can be performed without filler, using the appropriate temperature).

Materials to maintain in the EMT for working on copper:

- Pipe cutter with chip cleaner
- Scouring pad
- Rags or cleaning material
- Filling wire
- Flux material
- Heater (soldering lamp, soldering gun, bi-gas torch)
- ½", ¼" copper piping, splice sockets, Ts, reduction sockets from ¾" to ½", and from ½" to ¼".

Copper piping for gas should be marked and/or painted with the color indicated by the standards of each country (in countries whose standards are based on NFPA99, oxygen piping is marked in green; however, in countries whose standards are based on ISO, oxygen piping is marked in white). This color must be visible to maintenance and repair workers, since it is necessary to know which pipes carry this gas.

In the case of a centralized facility with copper piping in an EMT or AMCS, the piping must be protected from the weather and from impacts and be elevated from the ground. The pipes must be well fixed to avoid bending, which could cause breaks at some point, as shown in image 3.

Image 3: Copper oxygen piping on the outside of a tent. The pipes are marked in green and fixed with metal supports. They are elevated from the ground and set under the tent's guy wires to avoid impacts (EMT SARI CSS Panama).

If the copper pipelines are run inside an enclosure, it is safer to run them at ceiling height to avoid accidental impacts and to have a direct view of the piping (to quickly detect possible leaks).

Polyamide pipes are usually much more flexible and are usually supplied in coils. They are connected to devices to other types of piping, and to each other by fittings.

Materials to have on hand at the EMT for working on polyamide.

Materiales para llevar en el EMT para trabajar poliamida:

- Cutter.
- Screwdriver set.
- Small wrench, and/or pliers or thread-tightening pliers.
- Polyamide tubing of various diameters (1/4" to 1/8"). Union and derivation accessories (couplings, Ts, Ys) for the above diameters.

It is important that the pipes, whether copper or polyamide, are perfectly clean inside; in particular, they should be free of oil or grease.

Polyamide pipes usually come clean from the factory, without grease or other chemical products; however, copper pipes may have them, so it is recommended to wash them prior to installation, or when storing them prior to deployment if, after washing and drying, plugs are installed to prevent dirt from getting inside them again. Cleaning should be done with an alkaline solution (sodium carbonate or trisodium phosphate) in hot water, followed by drying by blowing with nitrogen or with dry, grease-free compressed air.

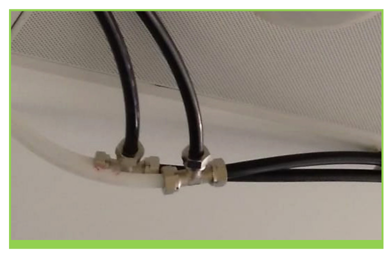


Image 4: Two polyamide oxygen lines with T-joints.

4.3.2 Sockets and connectors

Sockets and connectors are the medical gas connections equivalent to sockets and plugs in electricity. Sockets (or "females") are usually placed at the end of copper piping, while connectors (or "males") are attached to polyamide tubing or other tubing connected to a machine, a mask, or any other device using oxygen. These are plugged into the sockets.

Medical gas intakes usually have shut-off mechanisms that prevent gas from escaping from the piping system through the intakes when no appliances are connected to them. They also generally have trapping mechanisms so that the connectors do not accidentally come loose. The shapes of the sockets and connectors, and their cutting and clamping mechanisms, are very numerous and depend on the country in which they are distributed, as well as on the particular oxygen distribution company. This often leads to problems of compatibility, and therefore of operability, if the EMT equipment has connectors that are not appropriate for the existing sockets at the deployment site.

Image 5: Photo of various medical gas intakes.

To solve this problem, it is highly recommended that (when deployed), EMTs using oxygen supply devices connected to centralized networks carry with them sockets and connectors to be installed in existing or new networks.

Materials an EMT should have on hand to install oxygen sockets:

- Sockets for quick connection of oxygen, attached to copper pipe for soldering into existing network.
- Connectors compatible with the sockets being brought to the site .
- Materials for working with copper and polyamide (see previous section).

4.3.3 Valves, manifolds, regulators, and flowmeters

Medical gas lines, including oxygen, must have control and regulation mechanisms to open and close the gas flow, and to control the gas pressure inside the pipes to avoid damaging them or the equipment they supply.

To achieve this control, several types of accessories are available: valves, regulators, manifolds, flowmeters, etc. Many of them have similar functions, though they have various names, depending on the location or the purpose for which they are used.

Valves. These are usually placed at the inlets and outlets of the pipes and their branches; their function is to allow or stop the flow of fluids/gases (types of shut-off valves: ball valves, flap valves, gate valves, and non-return valves), or to regulate pressure (pressure-regulating valves). They can be manually or automatically operated; however, shut-off valves are generally not used or operated in gas systems, except in the case of breakdowns and maintenance. Valves must always be inserted in protective covers or boxes that protect the valve from accidental action, and they usually have pressure gauges attached to check that the gas pressure is correct, as shown in Figure 3.

Regulators. Regulators are also valves. They serve both to open and close the air flow, and to regulate the flow rate through the fitting. The term “regulator,” or “pressure reducer” is usually associated with an accessory that is connected to the outlet of the cylinders, or to the outlet of the connectors that are inserted into the inlets, determining the final flow rate to be supplied to the mask or electromedical device.

The regulators or pressure reducers connected to oxygen or other gas cylinders or tanks are linked by a threaded system to ensure that the reducer does not accidentally shoot out in the event of incorrect assembly Sometimes there are two pressure gauges, making it possible to view the cylinder outlet pressure (before the regulator) and the pressure at the inlet of the tube (after the regulator).

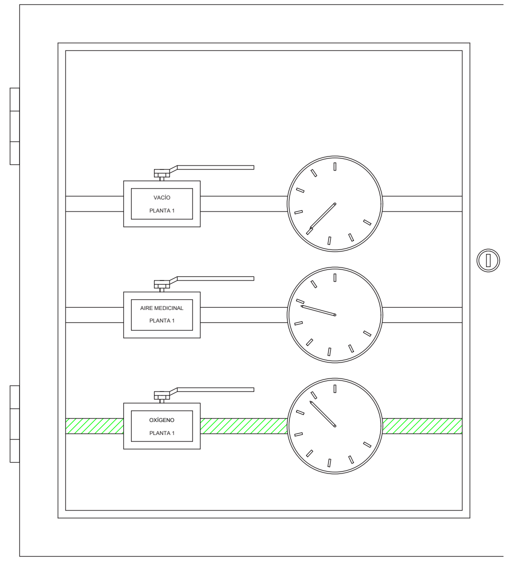


Figure 3: Protective cover with shut-off valves and pressure gauges.

Each type of gas has cylinders designed for its use, as well as a specific outlet for that gas (marked with different letters); thus, the coupling between the regulator and the cylinder must be correct. The coupling used for cylinders to be used for oxygen is type F (metric W22.91 14 threads/right, inches R5/8”). (10)

Imagen 5: Oxygen regulator for gas cylinder. The cylinder valve regulates the gas coming out of the cylinder (pressure gauge closest to the cylinder) and the regulator controls the gas entering the circuit (pressure gauge on the left). This picture shows how the polyamide tube is connected directly to the regulator.

Flowmeters. These are measuring devices that indicate the flow of air passing through them and help control the flow of air supplied to the patient through biomedical equipment or directly to a mask. They are usually attached to a regulator so that, by combining the two, the flows can be controlled or regulated.

Oxygen concentrators have built-in flowmeters, so it is not necessary to purchase them separately. However, for other oxygen sources with variable pressures (such as cylinders, O_2 distribution networks, and PSA tanks), it is important that the flowmeters be placed downstream of the oxygen regulator, i.e. on the low-pressure side.

Manifolds. Manifolds are devices that generally combine oxygen-cylinder connectors, shut-off valves, and pressure regulators; they regulate the flow of gas and avoid pressure fluctuations when several gas cylinders are connected at the same time––both when they are all in use and when some of the cylinders are changed once the gas in them has been consumed.

The use of manifolds is recommended when several cylinders are used, or when oxygen is supplied directly to patients who require a high flow rate and their health depends on a constant supply, such that numerous cylinder changes need to be made during the patient's treatment. The manifold makes it possible to extend the time between cylinder changes, and to do so in a way that is safe for the patient.

Imagen 7: Group of cylinders connected through a manifold.

There are various models of manifolds: automatic, semi-automatic, manual. Depending on the needs of use of the EMT, as well as maintenance capacities and cost, the most appropriate option can be chosen.

4.3.4 Gasifiers

Gasifiers or vaporizers are devices designed to transform liquid oxygen into gaseous oxygen. They usually comprise a series of tubes through which oxygen flows. Through temperature exchange with the outside air, O_2 is vaporized and expands.

Image 8: Gasifier with ice on the outside.

These devices are used at the outlet of the cryogenic oxygen tanks and allow the oxygen to be converted into gas. After passing through a pressure regulator, the gas then enters the oxygen distribution network at the appropriate pressure.

Gasifiers are usually sized and installed by the same companies that supply the cryogenic oxygen and they are installed inside the enclosure where the liquid oxygen tank will be placed. The supplier is responsible for maintaining the gasifiers and will instruct the EMT or AMCS technicians in the necessary cleaning (ice) and basic maintenance tasks.

4.3.5 Filters

By definition, a filter is a porous element through which a fluid (in this case, a gas) is passed in order to clarify or purify it. In hospitals, hygroscopic devices are often referred to as "humidifying filters" for patients undergoing respiratory and anesthesia therapy who require humidity and heat exchange and gas retention.

Filters are defined according to their capacity to "clarify" or "purify" unwanted particles in fluids. Achieving these levels of purification involves certain working characteristics such as flow rate, fluid pressure, direction of flow, etc.

Image 9: Top: In-line particulate filter for placement in polyamide tube (or similar). Bottom. Humidifying filter.

In this guide, which is directed at EMTs and AMCS, the explanation will focus on three main types of filters:

- **In-line particulate filters.** These filters are placed in the oxygen supply line, usually close to the point of consumption, in the polyamide tubing. They are generally used for the removal of bacteria and viruses, as well as any other particles that may flow through the oxygen, in order to prevent them from reaching the patient.
- **Particulate filters for oxygen concentrators.** These prevent unwanted particles in the air that are being concentrated and sent through an oxygen line from reaching the patient. These filters are, of course, placed inside the concentrator.
- **Humidifying filters.** Although they are not true filters, most of them bring the air to the desired humidity to prevent damage to the patient's mucosa. They consist of a distilled-water tank with oxygen flowing into the humidifier through the inlet port. This raises the relative humidity and the oxygen exits the outlet port to the patient.

All of these filters should be included in the EMT or AMCS equipment to be deployed, in order to ensure safe oxygen therapy for patients during the mission.

5. Design and installation

Before continuing with the final chapter of this guide, it is important to emphasize that this document offers recommendations and does not deal with calculations. Calculating the appropriate piping for fluids (especially oxygen) and installing it is a job for a specialized engineering team; in many countries, this must be done by certified professionals. This manual, however, is intended to help EMT/AMCS managers and their operational support teams understand what is needed to establish an optimal, adequate design for EMT or AMCS facilities and the personnel working there.

For a suitable design and assembly, it is necessary to analyze all of the variables in several steps, namely: calculation of consumption, environmental analysis, source selection, distribution system, and network management. These steps are detailed below.

5.1 Calculation of consumption

When calculating the oxygen consumption required for an EMT or AMCS, the first step is to determine which medical services, types of patients, and quantities are involved.

Example:[5]

Here, the intention is to create a type 2 EMT that includes, among other services, an operating room, recovery area, resuscitation capability, and emergency room, allowing for inpatient capacity (20 beds) such that six beds have the capacity for non-invasive oxygen therapy treatment. An initial table can be constructed to aid in calculating daily consumption.

Area	Oxygen therapy	No. of patients	Flow per patient	Hours per day
Triage	No	0	0	0
Outpatient consultations	No	0	0	0
Pediatrics	No	0	0	0
Emergencies	Yes	4	10 l/min	4
Operating room	Yes	1	60 l/min	12
Resuscitation room	Yes	1	20 l/min	12
Hospitalization	Yes	6	20 l/min	24
Obstetrics	No	0	0	0

5. The data presented here are an example designed to clearly show the key points for performing the calculation.

Area	Oxygen therapy	No. of patients	Flow per patient	Hours per day
Physiotherapy	No	0	0	0
Trauma care	No	0	0	0

Although there are tables for calculating the quantities or flows to be supplied according to the type of patient, it is useful, when completing this table, to compare the figures with the number of EMT or AMCS specialists in each area who will be providing oxygen therapy to patients (emergency physicians, anesthesiologists, etc.). Using the following formula, daily oxygen consumption for each area can be calculated:

Daily oxygen consumption by area = No. of patients x flow per patient x 60 min/h x h/day

By adding the consumption for each area, the daily consumption of an EMT or AMCS can be obtained. This figure is then multiplied by the number of days of the mission to obtain the total estimate of O_2 required.

Returning to the example:

Area	Daily consumption (l/day)
Triage	0
Outpatient consultations	0
Pediatrics	0
Emergencies	9,600
Operating room	43,200
Resuscitation room	14,400
Hospitalization	172,800
Obstetrics	0
Physiotherapy	0
Trauma care	0
Total per day	240,000

Thus, **240 m^3 of O_2 per day** are needed in our example of a type 2 EMT. An environmental analysis, as outlined in the following section, will be needed to determine how to supply these quantities.

5.2 Environmental analysis

When analyzing the pre-deployment environment and assessing the feasibility of deployment, oxygen supply must be taken into account. Experience tells us that this rarely occurs, since the vast majority of EMTs have been focused primarily on trauma management response during naturally occurring events in which an analysis of the O_2 environment was less critical. However, as previously mentioned, the onset of the COVID-19 pandemic has made this analysis key to the success or failure of a mission.

As with all analyses or assessments, advance preparation of checklists will provide for a more efficient assessment. These checklists should include:

1. **Information on suppliers of gases, especially O_2**. It is critical to understanding how gases are supplied in the area or country where they are to be deployed. This may be in cylinders, as cryogenic oxygen, or with concentrators. Suppliers and contact telephone numbers should be located; information should be obtained on whether there is sufficient (or insufficient) supply, time frames, quantity and quality, payment methods, transport options, etc.
2. **Examining the existing** systems will help to better understand the preceding point, not only in terms of supply (source) but also with regard to analyzing the existing intakes or piping, for better preparation of the material to be brought to the site. In addition, if the existing systems have a stock of certain spare parts, if the system to be used is similar to the existing one, and if there is mutual cooperation, this will allow for faster repair of breakdowns in the EMT or AMCS facility. This will, in turn, reveal whether there are trained personnel capable of working safely with oxygen in the deployment area or whether a specialist will need to be included in the team to be deployed. (This is recommended).
3. **Local regulations.** Existing local regulations will give an overview of the technical, quality, and safety requirements to be met in designing the systems.
4. **Facilities and spaces for location.** Analysis of the deployment site should include distances, spaces for piping, safe places for installing sources, access to the site, etc.
5. **Local health care workers.** Consulting with the health personnel will help determine whether the oxygen supplied is of good quality, free of particles, or, for example, requires prior filtration.

All of this information, together with the estimate of O_2 consumption required by the EMT or AMCS, will help shape the final design of the EMT O_2 facility.

5.3 Choice of source

An EMT/AMCS can have a single source or several sources, depending on the estimated consumption in each area (the distance between areas also influences the decision) and the local supply capacity.

The simplest and safest source to install consists of portable oxygen concentrators (see section 4.1.2 of this manual). Concentrators, especially portable ones, can be moved from place to place and require a power supply to operate. Many have batteries that allow them to operate without connection to the power grid for several minutes; however, if they travel a long distance (as may be the case if the vehicle does not have a power supply), this would not be the appropriate supply system. Concentrators usually have a supply flow of between 5 l/min and 10 l/min and are very practical for providing supply over a long period of time.[6]

The next simplest source in terms of set-up consists of oxygen cylinders (see point 3 of this manual). Individual cylinders can be used as the primary supply or as backup in case of a power outage; they can also be used as a connected series of in-line cylinders to serve as a centralized supply. The main challenge in using cylinders is that their supply is exhausted very quickly if the flow of oxygen to be dosed is high; it is essential to have a proven system for changing cylinders, in order to avoid gaps or delays. To calculate how often to change cylinders, the following formulas should be considered:

Cg = Vc x Pg

Cg = Quantity of gas (liters)

Vc = Geometric capacity of the gas cylinder (liters)

Pg = Pressure of the gas inside the cylinder (bar)

AS = Cg/Qs

As = Cylinder supply autonomy (minutes)

Cg = Quantity of gas (liters)

Qs = CFlow rate of the supply in (liters/min)

If individual cylinders are to be used, they need to be securely fastened where they are placed, with access that allows them to be transported safely. When batteries or a series of cylinders are used, they must be installed away from the movement of personnel and patients, so as to avoid accidents. Likewise, the site must have adequate access to be able to change cylinders safely.

5. The range indicated is the one recommended in the specifications for oxygen concentrators in the LDMP for COVID-19. There are oxygen concentrators with higher capacity, but they lose the advantage of portability and suffer from lower oxygen quality (concentrations of 90% plus or minus 3%). (4)

When EMTs need to be highly mobile or where O_2 consumption is not too great, portable concentrators and cylinders are most commonly used and easiest to obtain. O_2 cylinders are usually obtained in the field, while concentrators are generally among the team's equipment that is transported from the base location. However, for EMTs deployed for a very long deployment in one place, AMCSs based in a fixed location, or EMTs that require large consumption of O_2, as in responding to COVID-19, it is more practical and common to install PSA or liquid oxygen tanks.

For PSA tanks, which require an installation plan, a site must first be prepared and other services should be considered, such as access and a reliable electricity supply, so that the tanks can operate normally. These tanks require a large initial investment, so unless they are to be installed in a fixed site, liquid oxygen tanks will be the preferred choice.

Liquid oxygen tanks are ideal for EMTs or AMCS that are going to be deployed for an extended mission and require significant oxygen consumption during the operation. The main problem with this source is that the manufacturer or supplier of liquid oxygen must be capable of refilling the tanks when the supply runs out, with tanks and gasification systems available to install at the EMT or AMCS. The liquid oxygen (LOX) needed at a given EMT can be calculated as approximately 860 liters of O_2 gas per liter of LOX.

5.4 Distribution system

The design of the distribution system will depend on the personnel in charge of scaling the O_2 system, since this will determine both the size of the pipes and the type of network (ring, linear-leg (11).

Points to consider in the design are the cut-off points, locations, and number of taps, meters (flow and pressure gauges), and material and personnel required to deploy the system, as shown in the illustration below:

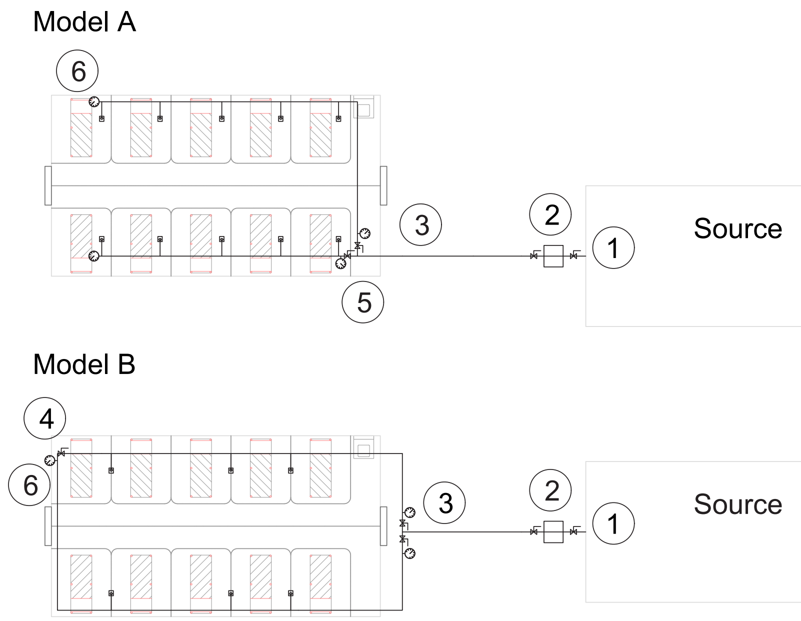


Figure 4: Above (model A) - Example of centralized facility supplying oxygen to an enclosure with a leg pattern. Below (model B) - Example of a centralized system supplying oxygen to an enclosure with a ring system.

- Regardless of whether the network is designed as a ring (Model B) or linear with branches (Model A), shut-off valves must be installed to stop the oxygen supply if leaks are detected (Point 1), or in case of possible modifications and/or repairs (points 2, 3, and 4). Shut-off valves are placed at the beginning of a branch line (point 3), or between ring control points (point 5). They should also be placed before and after key fittings (e.g., on a pressure regulating valve or on a pressure gauge) so that disassembly can be carried out without the risk of leakage (point 2).
- The gauges, especially pressure gauges, make it possible to locate loss of pressure (and leaks) inside the pipeline, or to identify inadequate flow rate. They also prevent excess pressure if the regulating valve fails to work properly, thus avoiding breaks due to excessive pressure. These gauges can be placed at the beginning and end of lines, at the inlet and outlet of pressure regulating valves, etc. (points 3 and 6).
- The location and number of intakes will define the diameter and shape of the pipes, since the oxygen coming out of these intakes will reduce the amount of gas inside them from this point.

Image 10: Indoor oxigen intakes (EMT SARI MoH Ecuador).

- If the personnel that will be assembling the facility in the field do not have sufficient experience and knowledge to assemble complex gas piping networks, the design (including the type of piping to be used) must be adapted to their existing knowledge––for example, by using polyamide piping with quick joints, or using ready-made systems, such as distribution "ramps."

5.5 Managing the network

Imagen 11: Oxygen facilities in a SARI EMT (EMT SARI MoH Ecuador).

In both design and assembly, oxygen supply must be controlled at all times by EMT or AMCS personnel deployed on a mission.

When the supply network is designed, a maintenance and control plan should be established. If possible, this should be translated into checklists, allowing EMT or AMCS personnel to periodically and systematically check that everything is working properly (pressure in the cylinders, piping, leakage control, operation of shut-off valves, etc.). If maintenance and/or repair is also required, this should be recorded in some type of logbook or journal.

If oxygen cylinders are used, a control chart should be constructed, showing when the cylinder was put in place, the size of the cylinder, flow supplied to the patient, and when the supply is expected to be exhausted, so that the cylinder can be replaced. In responses such as those involving COVID-19, this is essential to avoid hypoxia in patients caused by temporary supply outages.

Another action to be taken in managing the network is to establish gas supply and maintenance contracts for the network's components at the deployment site, so that specialized companies can supply the gas, in the case of cylinders or tanks, and perform maintenance on the more complex equipment.

For all of these reasons, it is important to have a training plan for the personnel involved in overseeing the oxygen network.

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Annex 1. Definition of mild, moderate, severe, and critical COVID-19 disease (13)

Mild disease	Symptomatic patients, according to the clinical picture, who meet the COVID-19 case definition criteria and have no signs of viral pneumonia or hypoxia.	
Moderate disease	**Pneumonia**	**Adolescent or adult** with clinical signs of pneumonia (fever, cough, dyspnea, rapid breathing), but without signs of severe pneumonia, including $SpO_2 \geq 90\%$ when breathing room air. **Child** with clinical signs of non-severe pneumonia (cough or shortness of breath + rapid breathing or chest tightness) and no signs of severe pneumonia. • Rapid respiration (measured in breaths/min): <2 months: ≥60; 2-11 months: ≥50; 1-5 years: ≥40. Although the diagnosis can be made clinically, thoracic imaging (radiography, CT, ultrasound) can be useful for diagnosis and can identify or rule out pulmonary complications.
Severe disease	**Severe pneumonia**	• Adolescent or adult with clinical signs of pneumonia (fever, cough, dyspnea, rapid breathing) plus one of the following: respiratory rate >30 breaths/min, severe respiratory distress, or $SpO_2 < 90\%$ when breathing room air. **Child** with clinical signs of pneumonia (cough or shortness of breath) + at least one of the following: • Central cyanosis or $SpO_2 < 90\%$; severe respiratory distress (e.g., rapid breathing, expiratory wheezing, very intense chest tightness); general danger sign: inability to nurse or drink, lethargy or loss of consciousness, or convulsions. • Fast breathing (measure in breathings/min): <2 months: ≥60; 2-11 months: ≥50; 1-5 years: ≥40. Although the diagnosis can be made clinically, thoracic imaging (radiography, CT, ultrasound) can be useful for diagnosis and can identify or rule out pulmonary complications.

Critical disease	**Acute respiratory distress syndrome (ARDS)**	**Onset:** Within one week of a known clinical event (i.e., pneumonia) or the onset of respiratory symptoms or worsening of existing symptoms. **Chest imaging studies (radiography, CT or lung ultrasound):** Bilateral opacities that are not fully explained by volume overload, lobar or lung collapse, or the presence of nodules. **Origin of pulmonary infiltrates:** Respiratory failure not fully explained by heart failure or fluid overload. Objective evaluation (e.g., by echocardiography) is necessary to exclude a hydrostatic cause of the infiltrates or edema if there is no risk factor. **Oxygenation deficit in adults:** • Mild ARDS: 200 mmHg < PaO_2/FiO_2a ≤ 300 mmHg (with PEEP or CPAP ≥ 5 cmH2o)[b] • Moderate ARDS: 100 mmHg < PaO_2/FiO_2 ≤ 200 mmHg (with PEEP ≥ 5 cmH2o)[b] • Severe ARDS: PaO_2/FiO_2 ≤ 100 mmHg (with PEEP ≥ 5 cmH2o)[b] **Oxygenation deficit in children:** Assess OI and OSI.c. Use OI when available. If PaO_2 is not available, turn off FiO_2 to maintain an SpO_2 ≤ 97 % in order to calculate OSI or SpO_2/FiO_2 ratio: • Bi-level system (NIV or CPAP) ≥ 5 cmH2O via full face mask: PaO_2/FiO_2 ≤ 300 mmHg or SpO_2/FiO_2 ≤ 264. • Mild ARDS (with invasive ventilation): 4 ≤ OI < 8 or 5 ≤ OSI < 7.5. • Moderate ARDS (with invasive ventilation): 8 ≤ OI < 16 or 7.5 ≤ OSI < 12.3. • Severe ARDS (with invasive ventilation): OI ≥ 16 or OSI ≥ 12.3.
Critical disease	**Sepsis**	**Adults:** Acute life-threatening organ dysfunction caused by impaired regulation of the patient's response to a suspected or confirmed infection. Signs of organ dysfunction include the following: altered mental state, respiratory distress or rapid breathing, low oxygen saturation, reduced urine output, rapid heart rate, weak pulse, cold extremities, low blood pressure, skin mottling, laboratory signs of coagulopathy, thrombocytopenia, acidosis, elevated lactate, and hyperbilirubinemia. **Children:** Suspected or proven infection and ≥ 2 age-appropriate systemic inflammatory response syndrome (SIRS) criteria, one of which must be abnormal temperature or abnormal white blood cell count.

	Septic shock	**Adults:** hPersistent hypotension despite resuscitation with volume administration, requiring vasopressors to maintain MAP ≥ 65 mmHg and serum lactate concentration > 2 mmol/l. **Children:** Any hypotension value (systolic BP < 5th percentile or > 2 SD below normal for age) or two or three of the following: altered mental state; bradycardia or tachycardia (HR < 90 bpm or > 160 bpm in infants and heart rate < 70 bpm or > 150 bpm in children); prolonged capillary refill (> 2 s) or weak pulse; rapid respiration; mottled or cold skin, or petechial or purpuric rash; elevated lactate; reduced urine output; and hyperthermia or hypothermia.
Other complications that have been described in patients with COVID-19 include acute and life-threatening disorders such as acute pulmonary embolism, acute stroke, acute coronary syndrome, and confusional state (delirium). The degree of clinical suspicion for these complications should be higher when caring for patients with COVID-19, and appropriate diagnostic and treatment protocols should be in place.		

a. If the altitude is of over 1,000 m, the correction factor should be calculated as follows: PaO_2/FiO_2 x barometric pressure /760.

b. When PaO_2 is not available, a value of $SpO_2/FiO_2 \leq 315$ suggests ARDS (also in non-ventilated patients).

c. The oxygenation index (OI) is an invasively determined parameter that indicates the severity of hypoxemic respiratory failure and can be used to predict changes in pediatric patients. It is calculated as follows: percentage fraction of inhaled oxygen multiplied by mean airway pressure (in mmHg), divided by arterial oxygen partial pressure (in mmHg). The oxygen saturation index (OSI) is a noninvasively determined parameter and has been found to be a reliable surrogate indicator of OI in children and adults with respiratory failure. OSI replaces PaO_2 with oxygen saturation measured by pulse oximetry (SpO_2) in the OI equation.

d. The SOFA score takes values between 0 and 24, and includes scores relating to six organ systems: respiratory system (hypoxemia defined by a low PaO_2/FiO_2 value); coagulation (low platelet count); liver (high bilirubin); cardiovascular system (hypotension); central nervous system (low level of consciousness defined by the Glasgow Coma Scale); and urinary system (low urine output or high creatinine). Sepsis is defined by an increase in the SOFA score relative to sepsis of ≥ 2 points. If no data are available, a baseline score of 0 is assumed.

e. SIRS criteria: abnormal temperature (>38.5 °C or <36 °C); tachycardia corresponding to age or bradycardia corresponding to age if the patient is < 1 year old; tachypnea corresponding to age or need for mechanical ventilation; leukocyte count abnormal for age or >10% band cell.

Abbreviations: BP blood pressure; CPAP continuous positive airway pressure; computed tomography (CT); FiO_2 fraction of inspired oxygen; MAP mean arterial pressure; NIV noninvasive ventilation; OI oxygenation index; OSI oxygenation index using SpO_2; PaO_2 partial pressure of arterial oxygen; PEEP positive end expiratory pressure; SAP systolic arterial pressure; SD standard deviation; SIRS systemic inflammatory response syndrome; SOFA sequential organ failure assessment ; SpO_2 oxygen saturation.