BMC Emergency Medicine

RESEARCH Open Access

# Oxygen accumulation and associated dangers in rescue helicopters

Lisa Marie Kohler[1], Andrea Köhler[1], Fabian Perschinka[1], Bernhard M. Benda[1], Michael Joannidis[1] and Frank Hartig[1*]

## Abstract

**Background** At the time of the COVID-19 pandemic, devastating incidents increased due to frequent oxygen administration to patients. The dangers associated with the use of oxygen, especially through local enrichments and formation of "oxygen clouds", have been well understood for years. Nevertheless, dramatic incidents continue to occur, since fire hazard increases exponentially with oxygen concentrations above 23%. Rescue helicopters are at a particular high risk, because of technical reasons such as oxygen use in a very small space, surrounded by kerosene lines, electronic relays and extremely hot surfaces.

**Methods** In this study three different sized rescue helicopter models (Airbus H135, H145 and MD902) were examined. Oxygen enrichment in the cabin was measured with an oxymeter during a delivery rate of 15 l/min constant flow for 60 min. Furthermore, the clearance of the enriched atmosphere was tested in different situations and with different ventilation methods. To make the airflow visible, a fog machine was used to fill the helicopter cabin.

**Results** Oxygen accumulation above 21% was detected in every helicopter. After 10–15 min, the critical 23% threshold was exceeded in all three aircrafts. The highest concentration was detected in the smallest machine (MD902) after 60 min with 27.4%. Moreover, oxygen clouds persisted in the rear and the bottom of the aircrafts, even when the front doors were opened. This was most pronounced in the largest aircraft, the H145 from Airbus Helicopters. Complete and rapid removal of elevated oxygen concentrations was achieved only by cross-ventilation within 1 min.

**Conclusions** Oxygen should be handled with particular care in rescue helicopters. Adapted checklists and precautions can help to prevent oxygen accumulation, and thus, fatal incidents. To our knowledge, this is the first study, which analyzed oxygen concentrations in different settings in rescue helicopters.

**Keywords** Oxygen enrichment, Oxygen accumulation, Oxygen administration, Oxygen clouds, Rescue helicopter, Fire hazard, Explosion, Prevention

*Correspondence:
Frank Hartig
Frank.Hartig@tirol-kliniken.at
[1]Division of Intensive Care and Emergency Medicine, Department of Internal Medicine I, Medical University Innsbruck, Innsbruck, Austria

## Background

Oxygen is a highly reactive and oxidizing agent that is involved in many combustion and corrosion processes. It is a colorless and odorless gas that makes up 20.9% of air. The fire triangle or combustion triangle is a simplified model for understanding the necessary ingredients for most fires. It illustrates the three elements a fire needs to ignite: heat, fuel, and oxygen. A fire naturally occurs when the elements are present and combined in the right mixture. In contrast, a fire can be prevented or extinguished by removing any one of the three elements in the fire triangle. Oxygen reduces the flash point, combustion point and ignition temperature. Moreover, it increases the rate of combustion, the combustion temperature and the explosiveness, thus functioning as a fire accelerator. This means that in an oxygen-enriched atmosphere even materials that would not burn under normal conditions like metals or fireproof clothing, will start to burn [1, 2]. Additionally, materials that would normally only burn, may burn vigorously or even explode. Therefore, the higher the oxygen content, the greater the risk of fire or explosion [1, 3].

An oxygen content of 23–24% is assumed as the threshold above which the risk is increasingly rising [1–4]. Although oxygen caused fire incidents in the medical field are rare, they are devastating events when they happen [5]. By analyzing accident events, the main causes of oxygen enrichment are leaks caused by damaged, poorly maintained or manufactured connections as well as the intentional or unintentional opening of valves. Other causes are the use of excess oxygen during application (e.g. medical oxygen therapy, welding or cutting) and inadequate ventilation in areas where oxygen is used. Since oxygen has a slightly higher density than air, it sinks to the bottom and forms "clouds" [1, 4]. Consequently, the gas settles very well in clothing, fabrics or even in beards, especially when there is poor ventilation.

Rescue helicopters are exposed to a particular high risk. They are equipped almost like an intensive care unit, but everything is housed in a very small cabin. Free-flowing oxygen in such a small room volume increases the oxygen content in the atmosphere much faster than in a large room. Due to the higher density, oxygen sinks into cavities, clothing and fabrics like rescue bags etc. Moreover, oxygen administration is usually very generous in rescue helicopters. Since primarily very seriously ill or injured patients are transported, they are likely to have an increased oxygen requirement. In addition, the oxygen partial pressure drops due to high altitude rescue sites in the mountains and/or the flight altitude so that this drop must be compensated for some patients by administering oxygen. Finally, the helicopter environment consists of lots of electronics, extremely hot surfaces, hydraulics, oil, fuel lines and medical equipment that contribute to the risk of fire (Airbus Helicopters employee, personal communication, April 2023). Electronic devices like a defibrillator, which is frequently needed during transport, can generate sparks and be a source of ignition [1, 2, 6–8]. To note, sparks can also be caused by friction and grinding of equipment or by pressing switches [1]. Electrical overload or short-circuits would be another hazard, but is more likely to play a role in older equipment and therefore can be prevented [2]. In conclusion, all three factors of the fire triangle can be found in a rescue helicopter and thus, precautionary and prevention measures are important.

In addition to the technical risks, people also play an important role. Due to the challenging and stressful situations during a rescue operation, the rescue crew may forget to close the oxygen valve when the patient is unloaded from the helicopter. Free-flowing oxygen can then accumulate in the cabin over time and when the crew gets back on board oxygen may get sucked into the turbine. Indeed, according to the CIRS (critical incident reporting system) of some rescue helicopter companies the forgotten closure of the oxygen valve after disconnecting the mask-hose and unloading the patient is a frequent scenario.

The increased fire incidents in intensive care units during the COVID-19 pandemic show that there is a serious risk of fire in any area where oxygen therapy is used [2]. Consequently, there is a need to investigate the potential risks of oxygen use in rescue helicopters, since in contrast to ambulance vehicles they are smaller and surrounded by potentially dangerous technical structures. However, despite high flight safety requirements, there are still no studies on oxygen enrichment in medical rescue helicopters, although several oxygen-caused accidents in aircrafts have already happened [9–11].

In this study three common rescue helicopter models with different cabin volumes were examined. The Airbus H135 model is the most used rescue helicopter worldwide with a share of 24%. Its total cabin volume is exactly 6.00 $m^3$. Loading of patients is done through the side door [12]. The Airbus H145 model is larger than the H135 and has a cabin volume of 8.07 $m^3$. Patients are loaded from two rear doors (Airbus Helicopters employee, personal communication, April 2023). The MD902 helicopter is smaller than the Airbus H135 and H145 models and has a cabin volume of only 4.90 $m^3$ [13]. Patients are loaded from the side. The aim of this study was to analyze the potential risk and differences of oxygen enrichment in helicopter cabins of different sizes and designs. In addition, the intention of this study was to develop simple and easy-to-implement solution strategies to prevent incidents. To our knowledge, this is the first study, which analyzed oxygen accumulation in different settings in rescue helicopters.

## Methods

### Helicopters

The study was carried out at Heli Austria GmbH / Martin Flugrettung in Tyrol. The three common rescue helicopter models, Airbus H135, H145 and MD902, are represented in this aviation company and could be used for this study to collect the measurement data.

### Devices

The oxygen concentrations were measured using the GOX 100 oxygen measuring device from GHM Messtechnik GmbH Kompetenz-Center Greisinger. The device was always stored free of moisture and away from direct sunlight. It has a measuring range between 0.0 and 100.0% oxygen concentration and a measuring frequency of one measurement per second. The sensor accuracy is +/-0.5% to 25 vol% and +/-1.0% above [14]. The device was 2-point calibrated before each measurement. The default working temperature and storage temperature of the sensor and device were never exceeded at any time. The ETEC FOG 400 fog machine was used to make the air flows visible. The fog fluid used is harmless to health and technology, is biodegradable and leaves no residue [15].

### Methods

The measurements were carried out in the same way in all three helicopters. Standardized measuring points were defined to be able to compare the results appropriately. Five measuring points at different heights and locations of the cabin were defined, which are listed in Table 1. The points examined were all in the immediate vicinity of the patient, where many technical devices and fabrics such as the transport bag are located. To note, all interventions are carried out directly at the injured or ill person as soon as it is necessary. These include defibrillation or cardioversion, suction for airway management and others.

An external oxygen cylinder was used for delivering 15 l/min for 60 min so that the oxygen of the ready-to-go rescue helicopter was not depleted. 15 l are the standard dosage for severely injured or ill patients. A nasal cannula was used to simulate the outflow at the level of the built-in oxygen connection.

First, the helicopter was well ventilated by opening all doors to ensure fresh normal ambient air. Then the oxygen cylinder was drained at 15 l/min for 1 h in the closed cabin. This scenario simulates the situation where the oxygen valve hasn´t been closed e.g. after unloading the patient. It also simulates oxygen administration on a long flight. An interval of 60 min was selected to cover flights of different durations and distances. The measurements were taken in fine, windless weather or in the hangar. The oxygen concentrations were measured every five minutes with the oxymeter at the previously defined points. The measurements were repeated three times under the same conditions and then the mean value was calculated.

For comparison, oxygen concentrations were measured in an open space resuscitation scenario in the shock room. Therefore, oxygen concentrations were measured with 50 cm distance around the head of a person lying on a stretcher and breathing 15 l/min oxygen administered via a nasal cannula.

**Table 1** Oxygen measuring points

| Measuring point | Location |
|---|---|
| 1 | device console patient compartment |
| 2 | floor between stretcher and seat |
| 3 | height of the patient's navel |
| 4 | rear back top |
| 5 | height of the patient's shins |

#### *Oxygen gas clearance*

A distinction was made between oxygen clearance and fog clearance. After 60 min with oxygen free-flow, the time for return to normal oxygen level was measured in the three cabin sections. Different situations were analyzed depending on the helicopter type (description below).

In a further step, with running rotor the cabins were filled with fog to visualize the air conditions and the draught as soon as the doors were opened. A concern of the rescue helicopter crew was that the enriched air would be drawn upwards towards the hot turbine. Time for complete visual clearance was measured for every cabin section (see below).

#### *Simulated cabin situations for oxygen and fog clearance trials*

Basically, the cabin was divided into three equally sized areas: the cockpit, the patient compartment, and the rear third of the helicopter. All scenarios were repeated twice on the stationary helicopter with rotors switched off. The measurements were carried out in similar weather conditions and at temperatures above zero degrees Celsius. The following three situations represent real-life conditions during rescue operations in the different helicopter models.

In situation 1 the flight rescuer exits at the front left and opens the left sliding door after ten seconds. The other doors remain closed. This scenario represents the usual situation in the H135 and MD902 aircraft. In situation 2, the flight rescuer exits at the front left door, opens the left sliding door after ten seconds and after one minute, the emergency doctor exits by opening the right-hand sliding door. Situation 3 is exact like situation 2, but also the rear doors are opened after a total of two minutes. Scenarios 2 and 3 are common in the H145 aircraft. The pilot's right front door stays always closed, since the pilot usually

**Table 2** Oxygen concentrations at different measuring points (MP) in the Airbus H135

| time (min) | MP 1 O2 (%) | MP 2 O2 (%) | MP 3 O2 (%) | MP 4 O2 (%) | MP 5 O2 (%) |
|---|---|---|---|---|---|
| 0 | 20,8 | 20,7 | 20,7 | 20,7 | 20,5 |
| 5 | 21,2 | 21,0 | 21,1 | 20,7 | 20,6 |
| 10 | 22,1 | 22,3 | 22,2 | 21,6 | 21,5 |
| 15 | 23,2 | 23,2 | 23,0 | 22,3 | 22,0 |
| 20 | 23,5 | 23,6 | 23,6 | 22,6 | 22,5 |
| 25 | 23,9 | 24,1 | 24,1 | 23,2 | 23,0 |
| 30 | 24,3 | 24,7 | 24,5 | 23,6 | 23,5 |
| 35 | 24,7 | 25,1 | 24,9 | 23,9 | 23,7 |
| 40 | 25,0 | 25,5 | 25,2 | 24,0 | 23,6 |
| 45 | 25,1 | 25,5 | 25,3 | 23,9 | 23,8 |
| 50 | 25,4 | 25,9 | 25,5 | 24,4 | 24,1 |
| 55 | 25,7 | 26,2 | 25,9 | 24,8 | 24,6 |
| 60 | 25,9 | 26,5 | 26,0 | 25,0 | 24,6 |

**Table 3** Oxygen concentrations at different measuring points (MP) in the Airbus H145

| time (min) | MP 1 O2 (%) | MP 2 O2 (%) | MP 3 O2 (%) | MP 4 O2 (%) | MP 5 O2 (%) |
|---|---|---|---|---|---|
| 0 | 20,5 | 20,5 | 20,4 | 20,5 | 20,4 |
| 5 | 21,7 | 21,5 | 21,5 | 21,5 | 21,5 |
| 10 | 22,6 | 22,6 | 22,5 | 22,3 | 22,1 |
| 15 | 23,1 | 23,1 | 23,0 | 22,7 | 22,6 |
| 20 | 23,5 | 23,5 | 23,3 | 23,2 | 23,1 |
| 25 | 23,9 | 23,9 | 23,8 | 23,6 | 23,5 |
| 30 | 24,2 | 24,3 | 24,2 | 24,1 | 24,0 |
| 35 | 24,7 | 24,9 | 24,6 | 24,7 | 24,6 |
| 40 | 25,0 | 25,0 | 25,0 | 25,0 | 25,0 |
| 45 | 25,2 | 25,5 | 25,4 | 25,5 | 25,4 |
| 50 | 25,6 | 25,6 | 25,6 | 25,6 | 25,6 |
| 55 | 25,9 | 25,9 | 25,9 | 26,1 | 26,0 |
| 60 | 26,5 | 26,6 | 26,5 | 26,5 | 26,5 |

**Table 4** Oxygen concentrations at different measuring points (MP) in the MD902

| time (min) | MP 1 O2 (%) | MP 2 O2 (%) | MP 3 O2 (%) | MP 4 O2 (%) | MP 5 O2 (%) |
|---|---|---|---|---|---|
| 0 | 20,7 | 20,8 | 20,7 | 20,8 | 20,8 |
| 5 | 21,4 | 22,1 | 21,4 | 21,5 | 21,3 |
| 10 | 21,9 | 22,8 | 22,2 | 22,2 | 22,0 |
| 15 | 22,7 | 23,6 | 22,8 | 22,8 | 22,7 |
| 20 | 23,5 | 24,3 | 23,5 | 23,3 | 23,3 |
| 25 | 23,9 | 24,8 | 24,0 | 23,8 | 23,8 |
| 30 | 24,3 | 25,3 | 24,5 | 24,4 | 24,2 |
| 35 | 24,7 | 25,5 | 25,0 | 24,7 | 24,5 |
| 40 | 25,3 | 26,0 | 25,7 | 25,3 | 25,2 |
| 45 | 25,8 | 26,5 | 26,0 | 25,8 | 25,6 |
| 50 | 26,2 | 26,8 | 26,3 | 26,1 | 26,0 |
| 55 | 26,4 | 27,1 | 26,7 | 26,4 | 26,3 |
| 60 | 26,8 | 27,4 | 27,0 | 26,8 | 26,7 |

does not exit the aircraft, or at least only at a very late stage when the helicopter has landed at the home base after the rescue operation.

In a further trial, the stationary helicopter was filled with fog with the rotor on. The left front door was opened first, followed by the left sliding door and finally the rear doors were opened. In this trial the right sliding doors were not opened. Attention was paid to where the fog was drawn. The time was measured until the fog was no longer visible. This trial was recorded on video for more precise analysis and evaluation of the results (see Additional File 1).

## Results

### Oxygen accumulation

The accumulated oxygen concentrations at the different measuring points within the three helicopter models are listed in Tables 2, 3 and 4. The highest oxygen concentrations in all helicopters were detected at measuring point 2, the floor next to the stretcher. Due to the slightly higher density, oxygen sinks directly to the bottom and forms clouds after exiting the nasal cannula [1, 4]. At the other measuring points we found less high concentrations, where the oxygen obviously mixes better with the ambient air.

A comparison of the oxygen concentrations at point 2 of the three helicopter models is shown in Fig. 1. The curve shows that the critical threshold of 23% was exceeded after 10 to 15 min in each aircraft. The strongest increase was detected in the MD902 Explorer with 27.4%. It is the smallest of the three aircrafts and therefore has less volume. The Airbus H135 and H145 helicopters were close behind with 26.5% and 26.6% respectively. However, they also have a larger cabin and therefore more volume in which the oxygen can distribute better.

### Oxygen concentration in open space (resuscitation scenario)

Oxygen concentrations lateral of the head of the person never exceeded 21% oxygen in a distance of 50 cm. In contrast, measurements on the chest in 50 cm distance to the nasal cannula showed an increased oxygen concentration of 22.5–23.5% after 3–5 min, but remained stable afterwards. To note, the closer the measurement was to the nasal cannula, the higher the oxygen concentration increased. Oxygen concentrations at the position of the defibrillation pads (20 cm distance) reached almost 30%.

### Oxygen clearance

Oxygen clearance was tested with the corresponding situations that occur under real conditions during a rescue operation (see materials and methods, simulated cabin situations). The oxygen clearance of the H135 model was tested with situation 1, as this helicopter unloads

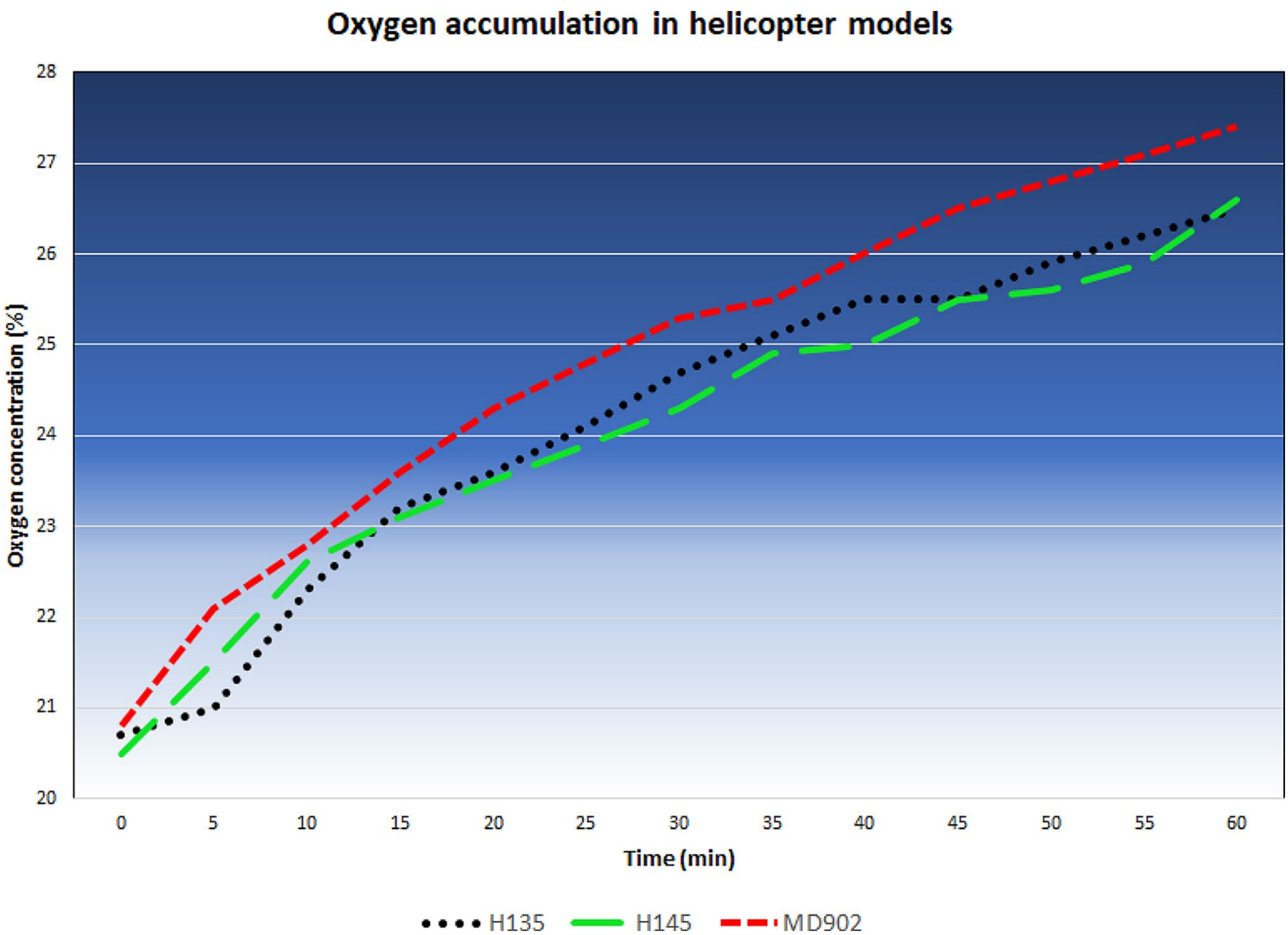


**Fig. 1** Oxygen accumulation in the three helicopter models H135, H145 and MD902 at measuring point 2

patients only through the left side door. The oxygen concentration in the front two thirds of the cabin dropped back to normal 21% after about 30 s. In the rear third, however, an increased concentration was detectable for about 5–8 min until it dropped back to the normal concentration.

The oxygen clearance of the Airbus H145 was tested with situation 2 and 3, as, in contrast to the H135 and MD902, patient loading and unloading takes place only from the rear. The results show that the O2 concentration in the front two thirds changed considerably slower over the first two minutes with an oxygen reduction of only 1–2%. A rapid decrease and normalization only occurred when the two rear doors were opened (situation 3). Ambient air values were then reached within less than a minute.

In the MD902, the clearance was tested with situation 1 again, as patients are loaded and unloaded from the side. In the cockpit and in the middle section of the helicopter, the concentration dropped back to the normal 21% oxygen after just 40 s. However, in the rear section the concentration remained almost constantly high for over 5 min and dropped only by a maximum of 1%. For this reason, the decision was made to also open the rear doors (situation 3). As soon as these doors were opened, the concentration dropped constantly within one minute to ambient air levels.

### Fog clearance

Fog clearance was measured twice for each helicopter model and the time was recorded in minutes until no more fog was visible. The cabin sections were divides into thirds (1 - front, 2 - middle and 3 - rear section). The results of the fog clearance on the stationary helicopter with rotors switched off are shown in Table 5.

### Fog clearance with running rotor

The Airbus H135 and H145 helicopters showed similar data with the rotor running. The aircraft was filled with fog, and then the left front door was opened first and a few seconds later the left sliding door followed. After approximately 1 min, no more fog was visible in the front and middle section. However, in the rear section the fog was stuck like a cloud (see Fig. 2). However, all fog could be removed quickly after the rear doors were opened.

**Table 5** Fog clearance time in the H135, H145 and MD902

| Cabin section | Situation 1 (min) | Situation 2 (min) | Situation 3 (min) |
|---|---|---|---|
| | **H135** | | |
| front | 01:54 | 01:58 | 01:19 |
| middle | 04:16 | 03:06 | 02:19 |
| rear | 05:36 | 05:47 | 02:27 |
| | **H145** | | |
| front | 00:48 | 00:43 | 00:50 |
| middle | 01:34 | 01:34 | 01:20 |
| rear | 05:29 | 03:01 | 02:13 |
| | **MD902** | | |
| front | 01:44 | 01:21 | 01:10 |
| middle | 01:37 | 01:25 | 01:17 |
| rear | 02:36 | 02:36 | 02:14 |

The situation was different with the MD902. Probably due to the small size, not only the cockpit and middle section were quickly cleared of fog after opening the doors, but even the rear section of the cabin. In this helicopter no persistent fog clouds could be detected. However, a turbulence and suction of fog upwards in the direction of the turbines was observed after opening of the side doors.

## Discussion

Every year, a large number of oxygen-caused accidents occur [5]. Fires in oxygen-enriched atmospheres ignite particularly easily and burn very intensely. If people are affected, they often suffer very serious burns that frequently lead to death. The danger increases with every percent of oxygen and even a few percent more can have great consequences. Therefore, care must always be taken to ensure that no excess oxygen unnecessarily increases the concentration in the environment.

This study investigated the potential risks of oxygen enrichment in three different rescue helicopters. To our knowledge, this is the first study on this topic although oxygen therapy is used regularly in this dangerous environment. Even the Airbus Helicopters manufacturing company was unable to provide any data (Airbus Helicopters, personal communication, April 2023). It was shown that oxygen accumulation exceeded the dangerous threshold in every tested helicopter. The highest concentration of oxygen was measured with 27.4% after 60 min. Our data show that oxygen accumulation and clearance are dependent on cabin size and design. Persistent oxygen clouds were found especially in the rear section and could only be removed by cross-ventilation with opening of the rear doors.

The oxygen clearance and fog clearance trials showed that in the front two thirds of the cabin, the accumulation disappeared within 30 s to 2 min. In contrast, in the rear section oxygen clouds settled for several minutes or were even persistent. These clouds remained even when the front doors were opened. Rapid normalization was only achieved when also the rear doors were opened and cross-ventilation and a draught was ensured.

A comparison of the oxygen and fog trials shows for both substances a faster normalization in the front two thirds of the cabin. However, due to their different properties it is not possible to draw conclusions from one substance to another. In the largest aircraft examined, the H145, the fog cloud in the rear was clearly visible and the oxygen cloud was detectable using an oximeter. Both clouds were only detectable as long as the rear doors were closed. After opening, any excess substance was then eliminated within 30–60 s by air draught. This air exchange also occurs when patients are loaded or unloaded from the rear, as during a rescue operation. The situation was similar in the H135 aircraft with persistent fog and oxygen clouds in the rear. However, with this helicopter the rear doors are not supposed to be opened as patient loading/unloading takes please from the side. These doors are only opened in special situations, e,g. when unloading certain bags that are required during operations. An increased O2 concentration as well as a fog cloud could be detected in the rear even after 5–8 min. To note, the front doors were always open. This means that this helicopter model is at particular risk for persistent oxygen clouds in the rear section, since cross-ventilation through opening of the rear doors is not routine.

A difference between fog and oxygen distribution was only seen in the MD902. The fog had disappeared from the entire helicopter with both closed or opened rear doors within less than 3 min, which is attributed to the small tail and therefore smaller volume. The oxygen concentration, however, was detectable for much longer and could only be normalized by opening the rear doors. The explanation for this lies probably in the interior lining of the model. In contrast to the other two Airbus helicopters, the ceiling of the MD902 is not made of plastic, but of a fabric lining. This confirms the well-known phenomenon that oxygen is easily trapped in fabrics and can pass through them, forming a reservoir [16].

Cross-ventilation leads to fast oxygen clearance, however, during real operations the doors are often closed again immediately due to the cold temperatures in winter, the strong winds outside, to avoid draught and, above all, noise inside. This means that there is usually very little air exchange and almost no cross-ventilation. The fog clearance trials also showed that the mist was being drawn from the side doors up to the rotor and turbine. However, the percentage of oxygen that actually reaches the hot surfaces of the turbine could not be measured due to the safety risk. Presumably, the oxygen enriched


**Fig. 2** Fog clouds in the rear section of the H145 helicopter

cabin air mixes immediately with ambient air, but further studies are needed to address this issue.

An enrichment of approximately 27% may not seem much, but the potentially dangerous environment of a rescue helicopter (hot surfaces, oil/kerosine lines, defibrillation etc.) increases the risks of accidents significantly. Even the 2021 ERC (European Resuscitation Council) guidelines advocate certain precautionary measures for defibrillation during oxygenation therapy. Safe defibrillation is recommended by moving the oxygen mask at least 1 m away from the patient's body or by keeping the system closed with an endotracheal tube [17]. To note, these are recommendations for resuscitation in open space. Defibrillation in the confined space of a helicopter with oxygen accumulation around the patient could have serious consequences for both the patient and the crew. Moreover, due to of the COVID-19 pandemic, new methods have been developed to minimize the risk of contagion during transport of infected patients. RUAG LTD, for example, invented a partition wall for the H135 aircraft between the patient compartment and cockpit, which is designed to prevent infection through virus exchange [18]. This cockpit separation reduces the cabin volume even further. In addition, COVID patients often have a high oxygen need, which in combination may lead to a particularly high oxygen enrichment in the aircraft. To reduce the danger of on-board oxygen, some companies like Metro Aviation Inc. (USA) sell oxygen systems where the liquid oxygen is completely stored outside the helicopter cabin [19]. However, such systems are not used in German-speaking countries, and they do not reduce oxygen accumulation inside the cabin during patient treatment.

### Precautionary measures

As oxygen is not perceptible to the human senses, an increase in concentration cannot be detected by crew member [2, 20]. Although measuring devices could be installed to detect increased concentrations, this costs time and money and at the same time offers no protection against an enriched atmosphere [1]. However, a simple checklist, which must be completed before each take-off, can help to ensure that the oxygen valve is closed and secure. Moreover, cross-ventilation is recommended as often as possible for at least 1 min to eliminate any accumulated oxygen, especially after patient transport with oxygen therapy. These simple actions can significantly improve flight safety in this area.

In the MD902 Explorer, the inner fabric lining could also be replaced. A material should be used that neither allows oxygen to pass through or build a reservoir. As there are many different cables and switching relays behind the cover, shielding the oxygen would be particularly important here. Finally, an automatic shut-off valve could be invented that stops outflow immediately as soon as the O2 hose is disconnected.

### Limitations

The test setting of 15 l/min oxygen flow for 60 min was chosen to cover both longer transport flights and a longer oxygen free-flow during a stopover. Even though most flights in Austria are completed in less than the tested time, it must be kept in mind that the oxygen continues to flow in the helicopter if the problem is not recognized. Since several oxygen cylinders are mounted and connected together in the cabin, all of them can be emptied at once. However, there are also countries that are less densely populated with helicopters and may well require 60 min or more of operation time. The system can also leak at any time due to defects in the equipment or errors during assembly. To note, oxygen free-flow in the tested helicopter models would last 130–200 min until the cylinders are empty. Moreover, some patients need more than 15 l/min oxygen during transport. For example, 25–50 l/min are regularly administered via nasal high-flow oxygen therapy. Therefore, the study should be repeated with higher and longer oxygen flows.

As the dangers of oxygen are well known, the tests were carried out in stationary helicopters and not in flight due to safety concerns. A special setting would be required for in-flight tests, which would have gone beyond the scope of this study. There may be even less oxygen enrichment due to decreasing cabin pressure or leaks in the cabin and thus cross-ventilation.

Finally, the oxygen clearance test was carried out without the rotor running, as sucking oxygen-enriched air into the hot turbine could have potentially serious consequences. A thorough test setup would be necessary to answer this question. Furthermore, oxygen measuring devices are not always 100% accurate and are sensible to strong winds or pressure differences.

## Conclusions

This study shows that in every tested helicopter model the threshold of 23% oxygen was exceeded after 10–15 min, which is associated with a significantly increased fire risk. Moreover, cabin size and cabin design play a major role in the oxygen accumulation process and the formation of persistent oxygen clouds. We have shown that oxygen accumulation tends to settle at the rear section of the cabins. The oxygen clouds remain particularly persistent when the rotor is not running and the doors are closed. Oxygen clearance is still incomplete if only the doors of the front sections are opened. Cross-ventilation through opened rear doors is crucial, leading to a rapid stabilization of normal ambient air. The fog clearance trials also showed that the mist was being drawn from the side doors up to the rotor and turbine. However, the percentage of oxygen that actually reaches the hot surfaces of the turbine could not be measured due to the safety risk. In conclusion, there is an increased risk of fire in rescue helicopters due to oxygen accumulation. To improve flight safety, further studies are needed to investigate the potential dangers of oxygen in more detail.

## Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12873-024-01066-y.

**Supplementary Material 1**: Fog clearance. Fog clearance.mov, https://doi.org/10.6084/m9.figshare.25108541. Fog clearance with running rotor in the Airbus H145. This footage shows the fog clearance with running rotors after the left and rear doors were opened

**Acknowledgements**

The authors acknowledge the company of Heli Austria and the crew members of Martin Flugrettung for allowing and helping them to conduct oxygen measurements in their helicopters.

**Author contributions**

LK and FH conceived the study and designed the trial. LK performed data collection. AK drafted the manuscript and LK, FH, FP, BB and MJ contributed substantially to its revision. All authors agree to be accountable for the content of the work.

**Funding**
The authors declare that no financial support was received for the research, authorship, and/or publication of this article. The study was supported by Martin Flugrettung / Heli Austria, which provided the helicopters for the measurements.

**Data availability**
All data generated during this study are included in this published article and its supplementary video footage is available in the figshare repository (https://doi.org/10.6084/m9.figshare.25108541).

## Declarations

**Ethics approval**
As no patients and sensitive data were processed in the study, no ethical review and approval was necessary.

**Consent for publication**
Consent for publication has been obtained from the people shown in the supplementary video.

**Competing interests**
The authors declare no competing interests.

Received: 23 January 2024 / Accepted: 1 August 2024
Published online: 13 August 2024

**References**
1. EIGA. Fire hazards of oxygen and oxygen enriched atmospheres. 2018. https://www.eiga.eu/uploads/documents/DOC004.pdf [Accessed April 18, 2023].
2. Wood MH, Hailwood M, Koutelos K. Reducing the risk of oxygen-related fires and explosions in hospitals treating Covid-19 patients. Process Saf Environ Prot. 2021;153:278–88. https://doi.org/10.1016/j.psep.2021.06.023
3. Health and Safety Executive. Oxygen use in the workplace: Fire and explosion hazards. 2013. https://www.hse.gov.uk/pubns/indg459.pdf [Accessed April 18, 2023].
4. Linde Gas GmbH. Kurz-Unterweisung: Umgang mit Sauerstoff. 2020. https://www.linde-healthcare.at/de/images/kurzunterweisung_o2_20200423_at_tcm549-589232.pdf [Accessed April 18, 2023].
5. Jones TS, Black IH, Robinson TN, Jones EL. Operating Room Fires Anesthesiology. 2019;130(3):492–501. https://doi.org/10.1097/aln.0000000000002598
6. Seifert PC, Peterson E, Graham K. Crisis Management of Fire in the OR. AORN J. 2015;101(2):250–63. https://doi.org/10.1016/j.aorn.2014.11.002
7. Kezze I, Zoremba N, Rossaint R, Rieg A, Coburn M, Schälte G. Risks and prevention of surgical fires. Anaesthesist. 2018;67(6):426–47. https://doi.org/10.1007/s00101-018-0445-2
8. Daly S, Milne HJ, Holmes DP, Corfield AR. Defibrillation and external pacing in flight: incidence and implications. Emerg Med J. 2014;31(1):69–71. https://doi.org/10.1136/emermed-2012-202028
9. Oxygen System Installation Cited In Fire Aboard Bell 206L-3. Flight Safety Foundation 1999. https://flightsafety.org/hs/hs_jul_aug99.pdf, https://asasi.org/wp-content/uploads/2021/05/Oxygen-Fire-in-an-EMS-helicopter.pdf
10. USAF RC-135V Rivet Joint Oxygen Fire. Aerossurance 2015. https://aerossurance.com/safety-management/usaf-rj-oxygen-fire/
11. Fires in P3 Aircraft Oxygen Systems. Journal of Testing and Evaluation, Sept 2006 Paper ID: 13562, https://ntrs.nasa.gov/api/citations/20080026076/downloads/20080026076.pdf
12. Airbus Helicopters. Life saving. 2022. https://mediaassets.airbus.com/pm_38_576_576175-fcvdo47a06.pdf [Accessed April 17, 2023].
13. MD Helicopters. Technical Description MD 902 Explorer. 2014. https://www.mdhelicopters.com/files/Models/MD902_Tech_Desc.pdf [Accessed April 20, 2023].
14. GHM Messtechnik GmbH Kompetenz-Center Greisinger. Sauerstoffmessgerät Betriebsanleitung GOX 100. https://www.greisinger.de/files/upload/de/produkte/bda/GOX100_DE.pdf [Accessed April 20, 2023].
15. ETEC Professional. ETEC Professional Nebelfluid 5 Liter Heavy. 2023. https://www.etec-professional.de/product_info.php?products_id=1694 [Accessed August 7, 2023].
16. Linde Gas GmbH. Sicherheitshinweise: 4 - Sauerstoffanreicherung. 2020. https://www.linde-healthcare.at/de/images/sh_04_at_v120_nq_tcm549-589235.pdf [Accessed April 18, 2023].
17. Soar J, Böttiger BW, Carli P, Couper K, Deakin CD, Djärv T, et al. Erweiterte Lebensrettende Maßnahmen für Erwachsene. Notfall + Rettungsmedizin. 2021;24(4):406–46. https://doi.org/10.1007/s10049-021-00893-x
18. RUAG LTD. EASA certified COVID-19 separation wall for Airbus H135 Series helicopters. 2020. https://ruag-ch.picturepark.com/v/7iMhS6qO/ [Accessed October 12, 2023].
19. Metro Aviation Inc. Helicopter flight manual supplement 135 M-7 for Eurocopter Helicopter Corporation. 2010. https://downloads.regulations.gov/FAA-2015-0726-0001/attachment_2.pdf [Accessed October 12, 2023].
20. EIGA. Hazard! Oxygen Enrichment. 2018. https://www.eiga.eu/uploads/documents/SL002.pdf [Accessed April 18, 2023].