



SHORT COMMUNICATION

# Comparison of portable oxygen concentrators in a simulated airplane environment



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Received 13 August 2012; accepted 2 October 2012

Available online 22 October 2012

## KEYWORDS

Altitude;  
Airplane;  
Travel;  
COPD

## Summary

Portable oxygen concentrators (POC) are highly desirable for patients with lung disease traveling by airplane, as these devices allow theoretically much higher travel times if additional batteries can be used. However, it is unclear whether POCs produce enough oxygen in airplanes at cruising altitude, even if complying with aviation regulations.

We evaluated five frequently used POCs (XPO2 (Invacare, USA), Freestyle (AirSep C., USA), Evergo (Philipps Healthcare, Germany), Inogen One (Inogen, USA), Eclipse 3 (Sequal, USA)) at an altitude of 2650 m (as simulated airplane environment) in 11 patients with chronic obstructive lung disease (COPD) and compared these POCs with the standard oxygen system (WS120, EMS Ltd., Germany) used by Lufthansa.

Oxygen was delivered by each POC for 30 min to each patient at rest, blood gases were then drawn from the arterialized ear lobe. All POCs were able to deliver enough oxygen to increase the PaO<sub>2</sub> of our subjects by at least 1.40 kPa (10 mmHg). However, to achieve this increase, the two most lightweight POCs (Freestyle and Invacare XPO2) had to be run at their maximum level. This causes a significant reduction of battery life. The three other POCs (EverGo, Inogen One, Eclipse 3) and the WS120 were able to increase the PaO<sub>2</sub> by more

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than 2.55 kPa (20 mmHg), which provides extra safety for patients with more severe basal hypoxemia.

When choosing the right oxygen system for air travel in patients in COPD, not only weight, but also battery life and maximum possible oxygen output must be considered carefully.

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The number of patients with lung diseases is increasing and so is the number of people with impaired lung function wanting to travel by airplane. However, liquid oxygen is prohibited during air travel and standard compressed oxygen steel cylinders with oxygen-conserving devices allow only relatively short travel time. For these reasons portable oxygen concentrators (POC) are highly desirable, as these devices allow theoretically much higher travel times if additional batteries can be used. Before a POC can be used during air travel three main questions need to be answered:

- 1.) Does the POC comply with aviation regulations?
- 2.) Does the POC produce enough oxygen at altitudes up to 2500 m? and
- 3.) Does the POC deliver enough oxygen for patients with impaired lung function in an in-flight situation?

**The first question** is generally answered by the flight authorities and depends mostly on compliance with radio frequency unresponsiveness. The POCs approved by the federal aviation administration (FAA) of the United States can be found at the FAA website.<sup>1</sup> All POCs tested in this study are commonly used in Germany (Invacare XPO2 (Invacare, Elyria, Ohio), Freestyle (AirSep C., Buffalo, New York), Evergo (Philipps Healthcare, Hamburg, Germany), Inogen One (Inogen, Goleta, CA), Eclipse 3 (Sequal, Ball Ground, GA)) and were FAA approved.

**The second question** was evaluated during a technical test performed in Hintertux, Austria at four different altitudes (1500 m, 2100 m, 2605 m and 3250 m). For the test, each POC was connected to an artificial lung system (ASL5000, IngMar Medical Ltd, Pennsylvania, USA) with a flow analyzer (PF300, imtmedical Corp., Buchs, Switzerland) and easyControl with easyLeak and HME-sensor (SBM-Technology Corp., Wolfratshausen, Germany). To compare the effectiveness of the POCs with a "gold standard", we tested the portable oxygen demand system WS120 (compressed oxygen carbon cylinder with 300 bar and an oxygen conserving device, EMS Ltd., Möhrendorf, Germany) used by Lufthansa for in-flight oxygen delivery for flights up to 14 h.

All POCs maintained an oxygen concentration above 94% up to the highest altitude tested (WS120 delivered 100% oxygen). However, the delivered oxygen bolus was strongly reduced when the POCs were used at higher altitudes (see Table 1). Unfortunately, the Invacare XPO2 could not be tested, as oxygen delivery was not stable enough to be measured by the artificial lung system.

**The third question** was addressed during a study with simulated in-flight conditions. The POCs were compared with the system currently used by Lufthansa (WS120).

We selected patients with chronic obstructive lung disease (GOLD stage II/III) in a stable condition from our outpatient clinic. They were studied at the Schneefernerhaus at 2650 m.

This altitude is comparable to the environment in an airplane at cruising altitude.<sup>2</sup> The local ethics committee approved the study and written informed consent was obtained from all participants.

Baseline evaluation was performed in Munich at an altitude of 540 m and included medical history, spirometry, bodyplethysmography, oxygen saturation, heart rate and capillary blood gases from the arterialized ear lobe.

The patients were brought by cogwheel train to the altitude lab at 2650 m, where they were connected to the reference oxygen system used by Lufthansa during air travel (WS120) delivering an equivalent of 2.8 l O<sub>2</sub>/min via nasal cannula. After 30 min resting in supine position, blood gases were sampled from the arterialized ear lobe.

Then, each patient received oxygen via nasal cannula from one of the POCs. The oxygen delivery rate was chosen according to the results of the technical test to obtain approximately comparable delivery rates of 2.0–2.5 l O<sub>2</sub>/min. The devices were then changed in a random order. We obtained blood gas results and oxygen saturation data from each patient after a steady state period of 30 min with each device. To evaluate the improvement in oxygenation by the devices, each patient was also tested after exposure to room air for 30 min.

During the study period, patients were not allowed any exercise except for the walk to the bathroom, and measurements were only taken after at least 10 min of rest.

Eleven patients (eight male, three female) were included in the study. Mean FEV<sub>1</sub> at baseline in Munich at an altitude of 540 m was 48.3% predicted (range 35%–64%). Baseline SaO<sub>2</sub> was 94.8 ± 1.8%, all patients were in stable condition throughout the study period. The results of the measurements at 2650 m are shown in the Table 1.

## Discussion

Although several companies claim that their POCs can be used during air travel, testing with patients under simulated, realistic in-flight conditions has not been performed systematically. One study was performed in a hypobaric chamber testing POCs in patients with chronic obstructive lung disease (COPD). The use of the FreeStyle (AirSep Corp., Buffalo, New York) resulted in a lower oxygenation compared to continuous flow oxygen via compressed gaseous oxygen with or without an oxygen-conserving device.<sup>3</sup>

In our study all POCs delivered enough oxygen to increase the PaO<sub>2</sub> of our subjects by at least 1.40 kPa (10 mmHg). We chose a difference of 10 mmHg to ensure that the change of pO<sub>2</sub> was meaningful, as repeated measurements of pO<sub>2</sub> from an arterialized ear lobe sample have been found to differ by a mean of 0.99 ± 0.63 mmHg and reflect arterial pO<sub>2</sub> with a mean difference of 0.95 ± 3.05 mmHg.<sup>4</sup> However a patient would need to test

**Table 1** Results of the blood gas measurements at 2650 m and technical data at 2605 m in different POCs and the WS120.

	Room air (at 2650 m)	Freestyle (Airsep)	XPO2 (Invacare)	Inogen One (Inogen)	EverGo (Philipps)	Eclipse 3 (Sequal)	WS120 (EMS)
PO <sub>2</sub> (kPa)	6.93 ± 0.74	8.33 ± 0.89	8.50 ± 1.01	9.48 ± 0.98	9.58 ± 1.17	9.59 ± 1.40	9.54 ± 1.12
PCO <sub>2</sub> (kPa)	4.97 ± 0.56	5.03 ± 0.61	4.96 ± 0.81	4.99 ± 0.68	5.20 ± 0.53	5.12 ± 0.55	5.15 ± 0.68
pH	7.4 ± 0.02	7.4 ± 0.02	7.4 ± 0.03	7.4 ± 0.03	7.4 ± 0.03	7.4 ± 0.03	7.4 ± 0.02
SaO <sub>2</sub> (%)	84.9 ± 5.3	90.9 ± 2.6	91.5 ± 2.9	93.3 ± 2.5	93.7 ± 1.9	93.5 ± 2.1	93.9 ± 2.8
Actual level/max. possible level	—	3/3	4/5	4/5	4/6	3/6	0.7/1.5
Min. O <sub>2</sub> -Bolus (ml)	—	7.9	na	7.6	7.5	11.2	25.2
Max. O <sub>2</sub> -Bolus (ml)	—	16.7	na	39.8	38.4	67.4	75.1
Max. O <sub>2</sub> -concentration (%)	—	94.6	na	94.1	93.2	94.7	99.9
Weight (kg)	—	2.0	2.9	3.2	3.9	8.1	4.5
Weight of additional battery (kg)	—	0.8	0.6	1.3	0.7	1.5	—
Treatment time (h) at actual level	—	2	2.17	2.4	3.1	3.5	14
Treatment time (h) with add. battery	—	4	4.28	4.8	6.2	7	—

Data of PaO<sub>2</sub>, PaCO<sub>2</sub>, pH, SaO<sub>2</sub> are presented as mean ± standard deviation; na denotes not available due to the failure in the technical test. Actual level was the level used at the Schneefernerhaus at 2650 m.

his or her personal oxygen demand according to guidelines to ensure clinical usefulness.<sup>5</sup>

To achieve this increase, the two most lightweight POCs (Freestyle and Invacare XPO2) had to be run at their maximum level, as they contain less zeolite to absorb the atmospheric nitrogen, thus reducing the oxygen concentrating capacity. This causes a significant reduction of battery life which would necessitate additional battery packs adding to the weight carried during intercontinental flights. These POCs could be recommended only in patients with less impaired lung function as effective oxygen delivery is markedly reduced compared to the other three POCs or the WS120.

The three other POCs and the WS120 increased the PaO<sub>2</sub> by more than 2.55 kPa (20 mmHg). This provides extra safety for patients with more severe basal hypoxemia to maintain a minimum in-flight PaO<sub>2</sub> of 7 kPa (50 mmHg) as recommended by current guidelines.<sup>5</sup>

However, the weight of these stronger POCs with the additional batteries is an important consideration limiting their use for air travel, when any additional weight might further reduce the mobility of already impaired patients.

In contrast to the POCs, the WS120 delivers oxygen independent from atmospheric pressure with a stable and precisely adjustable output. However, the overall duration is limited by the capacity of the oxygen cylinders which last in general for 14–18 h. In addition, many airlines charge between 50 and 300 Euro per flight segment, if oxygen supply is required.<sup>6</sup> Compared with these costs, renting of portable oxygen concentrators for e.g. 20 days is much cheaper (appr. 250 Euros).

In conclusion, our study showed that not every POC delivers a comparable oxygen output at an altitude comparable to the in-flight environment, and we found substantial differences in weight and possible duration of use. The noise level emitted by the POCs may be considered as disturbing. Therefore, the choice of the specific type of

oxygen supply during air travel remains an individual preference. Our data may help in choosing the right system.

#### Funding

This study was supported by a grant of German Academy for Aviation and Travel Medicine, [www.flugmed.org](http://www.flugmed.org)

#### Conflict of interest

K. Voll works for the producer of WS120 and performed in part the technical tests.

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