Comparison of Portable Oxygen Concentrators and Inspired Oxygen Levels Using a COPD Patient Simulation Model

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Article

Comparison of Portable Oxygen Concentrators and Inspired Oxygen Levels Using a COPD Patient Simulation Model

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Abstract: Background: There is a lack clinical efficacy of portable oxygen concentrators (POC) among patients with chronic obstructive pulmonary disease (COPD) across various respiratory rates. **Methods**: This study used a lung simulator to simulate a COPD patient's lungs for 15 breaths per minute (bpm), 20 bpm, 30 bpm, and 40 bpm. POC devices were compared to control devices, including wall oxygen and a standalone oxygen concentrator on settings 2, 3, 5 and 6. One-way analysis of variance (ANOVA) tests were used to determine differences between devices. **Results**: Most respiratory rate scenarios for settings 2 and 5, the wall oxygen obtained a higher measured FiO2 compared to all POCs. However, on setting 2 for 40 bpm, the Caire FreeStyle Comfort with autoSat on Sensitivity 5 achieved a higher FiO2 than the wall oxygen and all other POCS (F=208.91, df=11, p<0.01). Excluding the control group, the Inogen G4 obtained a higher FiO2 on setting 2 for 20 bpm compared to the other POCs (F=20.331, df=9, p<0.01). However, the Caire FreeStyle Comfort with autoSat and Caire FreeStyle Comfort without autoSat achieved a higher FIO2 for all other breathing scenarios on settings 2 and 5 compared to the other POCs. **Conclusions**: While the wall oxygen delivered higher oxygen levels on most respiratory rate scenarios, differences exist among POCs for COPD lung scenarios.

Keywords: portable oxygen concentrators; chronic obstructive pulmonary disease; home oxygen therapy; respiratory care; oxygen therapy; obstructive lung disease

1. Introduction

Approximately 1.5 million Americans use home oxygen therapy as supplemental treatment for advanced lung disease.1 Traditional in-home oxygen therapy previously required large oxygen tanks that were heavy for patients to transport, requiring most patients to be homebound. New technologies, such as portable oxygen concentrators (POCs), have improved the quality of life for patients needing home oxygen therapy. POCs are generally lightweight and enable patients to be ambulatory, improving quality of life for patients with advanced lung disease.[1, 2]

POCs can administer oxygen through pulse-delivery systems or continuous flow mechanisms. Pulse-delivery systems sense patient breaths through trigger sensitivities (usually adjustable) and only administer oxygen when sensing individual patient breaths. Typically, for most pulse-delivery systems, the bolus size decreases as the patient's respiratory rate increases. A new technology called autoSat (used by Caire devices), delivers a fixed bolus of oxygen, at a given setting up until the point that the patient's rate multiplied by the bolus volume exceeds the maximum oxygen production capacity of the POC. Other devices, including the GCE Zen-O Lite (in pulse mode) and the SimplyGo Mini, also use this fixed bolus design. It is critical to evaluate the impact of POC oxygen delivery technology to ensure patient oxygen demand is adequately met through these emerging technologies.

POCs have shown mixed efficacy in delivering adequate oxygen for various patient scenarios. Additionally, there is a lack of research on comparing POCs' efficacy across different respiratory rates, specifically using COPD patient models. These differences in respiratory rates approximate various breathing scenarios for COPD patients, including at rest and during sleep (15 bpm and 20 bpm) compared to exertion with higher respiratory rates (30 bpm and 40 bpm). This research

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contributes to the gap in knowledge by: 1) examining differences in delivered FiO2 among a larger and more diverse sample of POCs compared to previous research, 2) including POCs with fixed bolus volume technology, 3) determining differences in delivered FiO2 among POCs at varying respiratory rates (15, 20, 30, and 40), and 4) examining differences in delivered FiO2 among POCs and control group oxygen delivery devices (wall oxygen and standalone oxygen concentrator) using a COPD patient lung simulator, specific to the airway resistance, compliance, and lung mechanics of a COPD patient (accounting for airway dead space).

2. Materials and Methods

This bench study was conducted using the IngMar Medical Active Servo Lung 5000 (IngMar Medical, Pittsburgh, Pennsylvania) attached to flexible tubing (double-lumen endotracheal tube) to simulate an adult patient's nares. The IngMar Lung Simulator consists of a computer-controlled, piston-operated device that accomplishes motion based on gas exchange in a spontaneously breathing patient. An oxygen analyzer (Maxtec Handi+, Maxtec, Salt Lake City, Utah) was connected to the corrugated tubing 6 inches below the nares to estimate the inspired oxygen concentration at the adult trachea (Figure 1). The 6 inches of corrugated tubing, the Handi+ oxygen analyzer (attached to a small, air-tight connecting piece, and the 12 inches of corrugated tubing simulated the airway deadspace of the trachea and bronchi. A nasal cannula (Salter Labs 7-foot 16SOFT Nasal Cannnula, SunMed, El Paso, TX) was placed in the simulated patient nares, also attached to each POC. The IngMar Lung simulated a COPD patient at the following respiratory rates: 15 breaths per minute (bpm), 20 bpm, 30 bpm, and 40 bpm. Oxygen levels were compared between POC devices and control groups. The control groups consisted of oxygen delivered via a wall outlet (99.999% pure oxygen) and a standard oxygen concentrator (Caire Companion oxygen concentrator with 87-95.5% oxygen purity). The POCs included the Caire FreeStyle Comfort (with autoSat), Caire FreeStyle Comfort (without autoSat), Inogen G4, Inogen G5, Phillips SimplyGo Mini, GCE Zen-O lite, Drive Medical iGo2, and Kingon POCs. All POCs were new in the box and each were tested to determine use as intended by the manufacture. Each POC and control device was randomized for the following breathing scenarios (15 bpm, 20 bpm, 30 bpm, and 40 bpm). The breathing rate scenarios ran for 3 minutes over a total of 3 repetitions for 3 randomizations, resulting in 9 data points per POC device for each respiratory rate scenario.

All devices were compared at settings 2 and 5. Only two devices were compared at setting 3 (Inogen G3 and wall oxygen) and setting 6 (Inogen G5 and wall oxygen). Settings 3 and 6 only included the Inogen G3 and Inogen G5 because these were subgroup analyses. The purpose of these analyses was to examine the maximum setting for each of these devices compared to the wall oxygen. The other devices had maximum settings of 5 and thus were compared against all other POCs. Additionally, we compared all POC devices and the control group devices on setting 2. The Caire FreeStyle Comfort was tested at both sensitivity settings 2 and 5 to determine if differences existed with respect to the delivered FiO2 in this model.

A target tidal volume of 400 mL was used to simulate COPD patients for each breathing rate. The lung simulator self-adjusted the lung mechanics for the 15 and 20 bpm scenarios to achieve the target tidal volume. The higher breathing rates of 30 and 40 bpm required us to manually change the settings on the lung simulator to achieve the 400 mL tidal volumes. These measurements and settings are displayed in Table 1.

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Table 1. Lung measurement settings for the IngMar ASL 5000 simulating an unassisted COPD patient and a target achieved tidal volume of 500 mL.

Respiratory Rate Scenario	Compliance	Resistance trachea (in/out)	Inspiratory Muscle Pressure	iTime	I:E Ratio	Peak inspiratory flow
15 breaths per minute	66 mL/cmH20	12 cmH20/L/s 25 cmH20/L/s	17 cmH20	1	0.5	23.5 L/min
20 breaths per minute	66 mL/cmH20	12 cmH20/L/s 25 cmH20/L/s	17 cmH20	1	0.5	23.5 L/min
30 breaths per minute	66 mL/cmH20	12 cmH20/L/s 25 cmH20/L/s	26 cm H20	0.828	0.71	41.5 L/min
40 breaths per minute	66 mL/cmH20	12 cmH20/L/s 25 cmH20/L/s	36 cm H20	0.623	0.71	54.7 L/min

Note. I:E ratio is defined as inspiratory to expiratory ratio.

Data Analysis

Means and standard deviations were calculated for descriptive purposes. Multiple groups were compared using one-way analysis of variance (ANOVAs) tests. ANOVAS were also conducted to examine the differences in FiO2 between the POCs, excluding the control groups. These analyses were conducted with the control devices included and without the control devices to isolate differences between the POCs. Independent samples T-tests compared Inogen G4 for setting 3 to wall O2, and Inogen G5 for setting 6 to wall O2. All assumptions for statistical tests were evaluated and deemed adequate. Statistical significance is set at $P<0.05$. All analyses were conducted in SPSS version 25.

3. Results

Setting 2

Descriptive statistics for each respiratory rate, setting, and device are presented in Table 1. Table 2 presents the results for setting 2, 3, 5, and 6 for all POC devices, including the control groups of wall-delivered oxygen and standalone oxygen concentrators. The control devices delivered statistically significantly higher FiO2 compared to the POC devices for most scenarios (Table 2). There was a noticeable decrease for FiO2 as the respiratory rate increases across all settings and devices. On 2 liters per min (LPM) specifically, the wall O2 achieved a mean FiO2 of 0.281 (15 bpm), 0.276 (20 bpm), 0.257 (30 bpm), and 0.243 (40 bpm). On setting 2, this was the highest FiO2 achieved except for the 40 bpm scenario. For this specific scenario (setting 2 on 40 bpm), the highest FiO2 achieved was the Caire FreeStyle Comfort (with autoSat at sensitivity 5) (FiO2 0.25). Therefore, the Caire FreeStyle Comfort achieved statistically significantly higher FiO2 measurements compared to the oxygen delivered via the wall outlet and all other POCs ($F=208.91$, $df=11$, $p<0.01$). The comparisons among all POCs excluding control groups are presented in Table 3. While the wall oxygen and the standalone oxygen concentrator all delivered higher FiO2 levels for the other respiratory rate scenarios on setting 2 (15, 20, and 30 bpm), the Caire FreeStyle Comfort with autoSat on sensitivity setting 5 achieved higher FiO2 than all other POCs for 15 bpm (0.244) (8.720, (9), $p<0.01$) and for the 30 bpm scenario (0.248) (80.18, (9), $p<0.01$). The Inogen G4 obtained the highest FiO2 for the 20 bpm scenario compared to all other POCs (0.244) (20.331, (9), $p<0.01$).

Table 2. Comparison of Measured Inspired Oxygen Means among Portable Oxygen Concentrators (POC) in a Simulated Patient Model with Chronic Obstructive Pulmonary Disease (COPD).

Breath Rate	Setting	Wall O2	CAIRE FSC sens. 2	CAIRE FSC sens. 5	CAIRE FSC (w/o autoSAT)	Caire SOC	Inogen G4	Inogen G5	SimplyGo Mini	GCE Zen-O Lite (Pulse Model)	GCE Zen-O Lite (Eco Model)	Drive iGo2	Kingon P2	F or T, (*df*), *p*-value
Mean FiO2 at 15 BPM	2 or 2 LPM	0.281	0.244	0.244	0.241	0.278	0.238	0.241	0.228	0.234	0.234	0.232	0.239	82.55, (*11*), *p*<0.01
Mean FiO2 at 20 BPM	2 or 2 LPM	0.276	0.235	0.235	0.236	0.268	0.244	0.242	0.242	0.237	0.239	0.228	0.228	155.79, (*11*), *p*<0.01
Mean FiO2 at 30 BPM	2 or 2 LPM	0.257	0.243	0.248	0.236	0.250	0.235	0.235	0.236	0.243	0.232	0.226	0.232	154.82, (*11*), *p*<0.01
Mean FiO2 at 40 BPM	2 or 2 LPM	0.243	0.248	0.250	0.229	0.243	0.230	0.229	0.231	0.231	0.223	0.223	0.229	208.91, (*11*), *p*<0.01
Mean FiO2 at 15 BPM	3 or 3LPM*	0.321	--	--	--	--	0.267	--	--	--	--	--	--	-23.78, (*16*) *p*<0.01
Mean FiO2 at 20 BPM	3 or 3LPM*	0.312	--	--	--	--	0.271	--	--	--	--	--	--	-73.92, (16), p<0.01
Mean FiO2 at 30 BPM	3 or 3LPM*	0.285	--	--	--	--	0.251	--	--	--	--	--	--	-34.47, (16), p<0.01
Mean FiO2 at 40 BPM	3 or 3LPM*	0.264	--	--	--	--	0.242	--	--	--	--	--	--	-28.50, (16), p=0.01
Mean FiO2 at 15 BPM	5 or 5LPM	0.403	0.290	0.266	0.316	0.396	--	0.286	0.286	0.284	0.274	0.259	0.284	430.55, (10), p<0.01
Mean FiO2 at 20 BPM	5 or 5LPM						--							157.44, (10), p<0.01

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		0.379	0.297	0.292	0.291	0.365		0.303	0.292	0.296	0.280	0.285	0.253	
Mean FiO2 at 30 BPM	5 or 5LPM	0.361	0.275	0.279	0.275	0.319	--	0.274	0.270	0.265	0.267	0.267	0.256	9.74, (10), p<0.01
Mean FiO2 at 40 BPM	5 or 5LPM	0.320	0.256	0.259	0.261	0.294	--	0.256	0.251	0.251	0.254	0.237	0.253	422.43, (10), p<0.01
Mean FiO2 at 15 BPM	6 or 6LPM*	0.451	--	--	--	--	--	0.304	--	--	--	--	--	-55.59, (16), p<0.01
Mean FiO2 at 20 BPM	6 or 6LPM*	0.411	--	--	--	--	--	0.313	--	--	--	--	--	-37.10, (16), p<0.01
Mean FiO2 at 30 BPM	6 or 6LPM*	0.361	--	--	--	--	--	0.287	--	--	--	--	--	-50.51, (16), p<0.01
Mean FiO2 at 40 BPM	6 or 6LPM*	0.320	--	--	--	--	--	0.268	--	--	--	--	--	-66.00, (16), p<0.01

Note. *=independent samples t-test conducted due to n=2 groups.

Table 3. Comparison of Measured Inspired Oxygen Means among Portable Oxygen Concentrators (POC) in a Simulated Patient Model with Chronic Obstructive Pulmonary Disease (COPD) without control groups (Wall O2 and CAIRE SOC).

Breath Rate	Setting	CAIRE FSC sens. 2	CAIRE FSC sens. 5	CAIRE FSC (w/o autoSAT)	Inogen G4	Inogen G5	SimplyGo Mini	GCE Zen-O Lite (Pulse Model)	GCE Zen-O Lite (Eco Model)	Drive iGo2	Kingon P2	F or T, (*df*), *p*-value
Mean FiO2 at 15 BPM	2 or 2 LPM	0.244	0.244	0.241	0.238	0.241	0.228	0.234	0.234	0.232	0.239	8.720, (9), *p*<0.01
Mean FiO2 at 20 BPM	2 or 2 LPM	0.235	0.235	0.236	0.244	0.242	0.242	0.237	0.239	0.228	0.228	20.331, (9), *p*<0.01
Mean FiO2 at 30 BPM	2 or 2 LPM	0.234	0.248	0.236	0.235	0.235	0.236	0.243	0.232	0.226	0.232	80.18, (9), *p*<0.01

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Mean FiO2 at 40 BPM	2 or 2 LPM	0.248	0.250	0.229	0.230	0.229	0.231	0.231	0.223	0.223	0.229	225.87, (*9*), p<0.01
Mean FiO2 at 15 BPM	5 or 5LPM	0.290	0.266	0.316	--	0.286	0.286	0.284	0.274	0.259	0.284	39.02, (*8*), p<0.01
Mean FiO2 at 20 BPM	5 or 5LPM	0.297	0.292	0.291	--	0.303	0.292	0.296	0.280	0.285	0.253	22.39, (*8*), p<0.01
Mean FiO2 at 30 BPM	5 or 5LPM	0.275	0.279	0.275	--	0.274	0.270	0.265	0.267	0.267	0.256	1.68, (*8*), p=0.12
Mean FiO2 at 40 BPM	5 or 5LPM	0.256	0.259	0.261	--	0.256	0.251	0.251	0.254	0.237	0.253	48.90, (*8*), p<0.01

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Setting 3

The Inogen G4 and the wall O2 were compared per protocol for setting 3. The wall O2 achieved a statistically significantly higher FiO2 than the Inogen G4 for all respiratory rate scenarios. Specifically, the wall O2 achieved a measured FiO2 of 0.321 for 15 bpm, 0.312 for 20 bpm, 0.285 for 30 bpm, and 0.264 for 40 bpm, while the Inogen G4 obtained a measured FiO2 of 0.267 for 15 bpm, 0.271 for 20 bpm, 0.251 for 30 bpm, and 0.242 for 40 bpm.

Setting 5

On setting 5, the wall O2 achieved a higher FiO2 for each respiratory rate scenario compared to all other POCs and the other control group (standalone oxygen concentrator). The FiO2 levels achieved for the wall O2 were 0.403 for 15 bpm, 0.379 for 20 bpm, 0.361 for 30 bpm, and 0.320 for 40 bpm. After excluding the control groups for 15 bpm setting, the Caire FreeStyle Comfort without autoSat achieved a higher FiO2 compared to all other POCs (0.316), which was statistically significant ($F= 39.02$, ($df= 8$), $p<0.01$). For 20 bpm, the Inogen G5 achieved a higher FiO2 compared to the other POCs (excluding the control group) at 30.3%, which was statistically significant ($F= 22.39$, ($df=8$), $p<0.01$). For the 30 bpm scenario, the Caire FreeStyle Comfort with autoSat on sensitivity setting 5 achieved a higher FiO2 compared to all other POCs (0.279). This difference was not statistically significant, however ($F=1.68$, ($df=8$), $p=0.12$). Lastly, the Caire FreeStyle Comfort without autoSat achieved a higher FiO2 for the 40 bpm scenario compared to all other POCs (0.261) ($F=48.90$, ($df=8$), $p<0.01$).

Setting 6

On setting 6, the Inogen G5 and the Wall O2 were the only devices compared per the protocol. The wall O2 achieved higher FiO2 measurements for all breathing rate scenarios for 15 bpm, 20 bpm, 30 bpm, and 40 bpm (0.451, 0.411, 0.361, and 0.320, respectively). The Inogen G5's FiO2 measurements for 15 bpm were 0.304, 0.313 for 20 bpm, 0.287 for 30 bpm, and 0.268 for 40 bpm. The wall O2's measurements were statistically significantly higher than Inogen G5 for each scenario.

4. Discussion

This study contributes important findings to the literature by expanding on previous bench work with POCs[3-9] by incorporating COPD lungs as patient simulations with higher respiratory rates (40 bpm) compared to other studies.[6] Consistent with previous research, the wall O2 provided higher FiO2 measurements compared to all POCs for most scenarios.[6] However, for setting 2 on 40 bpm, the Caire FreeStyle Comfort (with autoSat at sensitivity 5) achieved a statistically significant higher FiO2 compared to the wall O2 and all other POCs. While the comparison between the Caire FreeStyle Comfort with autoSat and the wall O2 was not clinically significant, some comparisons between the POCs and the Caire FreeStyle Comfort with autoSat were clinically significant. For example, the Caire FreeStyle Comfort with autoSat actually achieved a higher FiO2 by 2-3 percentage points compared to several other POCs (including the Kingon P2, GCE Zen-O Lite Eco Model, and the Drive iGo2). This finding is likely due to the bolus size of the autoSat setting holding constant across all breaths, regardless of respiratory rates. As mentioned previously, the majority of pulse dose POCs have a decreasing bolus size for increasing respiratory rates. For COPD patients, this is a clinically significant finding because the autoSat delivers higher FiO2 compared to POCs without a fixed bolus design.

Similarly to our study, Chatburn and Williams conducted a bench examination in 2010 among 4 portable oxygen concentrators (Invacare XPO2, Respironics EverGo, AirSep FreeStyle, and Inogen One).[6] Across various respiratory rate scenarios, the POC with the largest oxygen pulse volume (Invacare XPO2) achieved the highest FiO2 in this study.[6] The oxygen purity of the control delivery devices is important as the wall outlet O2 at 99.999% exceeds the oxygen purity delivered by the Caire SOC and other POCs (87-95.5%), which could represent a clinically significant reduction in oxygen delivery.

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Other breathing scenarios also showed a superior finding for Caire FreeStyle Comfort across settings 2 and 5. However, for the 20 bpm scenario, the Inogen POC obtained higher FiO2 measurements for both settings 2 and 5. Additionally, at the higher respiratory rates (i.e., 30 bpm and 40 bpm) and higher settings, the pulse dose POCs consistently delivered higher FIO2 compared to the continuous flow POCs, which is consistent with the increasing respiratory rate causing decreases in FiO2 concentrations in the trachea with increases of air entrainment.

Although our findings for setting 2 on 40 bpm were clinically significant for the Caire FreeStyle Comfort with autoSat, many of the other comparisons (specifically among the few POCs that consistently achieved the higher FiO2 levels) were not deemed clinically significant. Although most findings reached statistical significance, these FiO2 differences were only significant by 0.1-0.2 for the top several POCs. Some of the POCs, including the Kingon P2 and the Drive iGo2, were consistently lower than the leading POCs by several percentage points. These differences would indeed be clinically significant. Clinical providers should consider the various impacts of respiratory rates on delivered FiO2 when assisting patients to select an optimal POC.

Bolus sizes per breath can also provide insight into our findings. The bolus sizes per respiratory rate among the selected POCs that were tested are displayed in Table 4. For example, the Kingon P2 and Simply Go Mini had smaller bolus sizes at the higher respiratory rates, consistent with our findings on settings 2 and 5. However, for devices with similar bolus sizes, there were still discrepancies in our findings by FiO2 measurements. We hypothesize that this finding was due to missed breaths and inadequate trigger sensitivities for some of the devices. Since the goal of this study was not to investigate the specific trigger sensitivities and missed breaths, more research is needed to investigate discrepancies in POC's trigger sensitivities. Additionally, providing oxygen bolus sizes per breath may be a more informative way to display oxygen delivery information for both providers and patients. While most of this information is located in the technical appendices and manuals for POCs, manufacturers should consider making this information more obvious and apparent to consumers.

Table 4. Pulse dose bolus sizes (mL) per breath by respiratory rate among selected portable oxygen concentrators.

Setting	Device	10 bpm	15 bpm	17 bpm	20 bpm	25 bpm	30 bpm	40 bpm
1	CAIRE FreeStyle Comfort (without AutoSat)	---	14	---	10.5	8.4	7	5.3
	CAIRE FreeStyle Comfort with AutoSat	---	10.5	---	10.5	10.5	10.5	10.5
	Inogen G4	21	---	---	10.5	8.4	---	---
	Inogen G5	21	---	12	---	8	7	---
	Simply Go Mini	---	11	---	11	8.8	73	5.5
	GCE Zen-O Lite Pulse	---	11	---	11	11	11	11
	GCE Zen-O Lite Eco	---	11	---	10.5	8.4	7	5.25
	Drive iGo2	26	---	---	13	10.4	---	---
	Kingon P2	21	14	---	10.5	8.4	7	5.3
2	CAIRE FreeStyle Comfort (without AutoSat)	---	28	---	21	16.8	14	10.5
	CAIRE FreeStyle Comfort with AutoSat	---	21	---	21	21	21	21
	Inogen G4	42	---	---	21	16.8	---	---
	Inogen G5	42	---	25	---	17	14	---
	Simply Go Mini	---	22	---	22	17.6	14.7	11
	GCE Zen-O Lite Pulse	---	22	---	22	22	22	22
	GCE Zen-O Lite Eco	---	22	---	19.8	15.8	13.2	9.9
	Drive iGo2	44	---	---	22	17.6	---	---

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	Kingon P2	42	28	---	21	16.8	14	10.5
3	CAIRE FreeStyle Comfort (without AutoSat)	---	42	---	31.5	25.2	21	15.8
	CAIRE FreeStyle Comfort with AutoSat	---	31.5	---	31.5	31.5	31.5	26.3
	Inogen G4	63	---	---	31.5	25.2	---	---
	Inogen G5	63	---	37	---	25	21	---
	Simply Go Mini	---	33	---	33	26.4	22	16.5
	GCE Zen-O Lite Pulse	---	33	---	33	33	33	33
	GCE Zen-O Lite Eco	---	33	---	31.5	25.2	21	15.75
	Drive iGo2	72.5	---	---	36.3	29	---	---
	Kingon P2	63	42	---	31.5	25.2	21	15.8
4	CAIRE FreeStyle Comfort (without AutoSat)	---	56	---	42	33.6	28	21
	CAIRE FreeStyle Comfort with AutoSat	---	42	---	42	42	35	26.3
	Inogen G4	---	---	---	---	---	---	---
	Inogen G5	84	---	49	---	34	28	---
	Simply Go Mini	---	44	---	44	35.2	29.3	22
	GCE Zen-O Lite Pulse	---	44	---	44	44	44	44
	GCE Zen-O Lite Eco	---	44	---	42	33.6	28	21
	Drive iGo2	88	---	---	44	35.2	---	---
	Kingon P2	84	56	---	42	33.6	28	21
5	CAIRE FreeStyle Comfort (without AutoSat)	---	70	---	52.5	42	35	26.3
	CAIRE FreeStyle Comfort with AutoSat	---	52.5	---	52.5	42	35	26.3
	Inogen G4	---	---	---	---	---	---	---
	Inogen G5	105	---	62	---	42	35	---
	Simply Go Mini	---	55	---	50	40	33.3	25.0
	GCE Zen-O Lite Pulse	---	55	---	55	55	55	50
	GCE Zen-O Lite Eco	---	55	---	52.5	42	35	26.25
	Drive iGo2	101.4	---	---	50.7	40.6	---	---
	Kingon P2	100	66.7	---	50	40	33.3	25
6	CAIRE FreeStyle Comfort (without AutoSat)	---	---	---	---	---	---	---
	CAIRE FreeStyle Comfort with AutoSat	---	---	---	---	---	---	---
	Inogen G4	---	---	---	---	---	---	---
	Inogen G5	126	---	74	---	50	42	---
	Simply Go Mini	---	---	---	---	---	---	---
	GCE Zen-O Lite Pulse	---	66	---	66	66	57	50
	GCE Zen-O Lite Eco	---	66	---	59.4	47.5	39.6	29.7
	Drive iGo2	---	---	---	---	---	---	---
	Kingon P2	---	---	---	---	---	---	---

While bench studies can provide insights into exact FiO2 measurements under simulated conditions, clinicians should also account for patient-based studies when recommending POCs. Several studies have examined the performance of different POCs among patients with lung disease undergoing a 6-minute walk test. Previous research comparing the Inogen One G2 and EverGo against compressed oxygen cylinder found no significant differences in oxygen saturation (SpO2)

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between devices during 6-minute walk tests among individuals with interstitial lung disease.[3] LeBlanc and colleagues also found that among COPD patients and patients with pulmonary fibrosis, the POC with the largest bolus of oxygen resulted in the highest SpO2 achieved by patients during a 6-minute walk test.[5]

While the current bench study cannot directly extrapolate to patient results, example differences in PAO2 measurements are displayed in Table 5 based on the POC FiO2 measurements. These differences in PAO2 measurements can highlight the major variations in Fio2 findings across POC devices. For example, the difference in PAO2 between the GCE Zen-O Lite (eco setting) and the Caire FreeStyle Comfort with autoSat on sensitivity 5 is nearly 20 mmHg (128.3 vs. 109.0, respectively). Calculating differences in PAO2 based on these Fio2 measurements can be useful for clinicians when deciding the best device for patients, especially those who are sensitive to PAO2 fluctuations. Additionally, these PAO2 comparisons are helpful for those patients with worse diffusion rates who may need a higher alveolar oxygen level in order to have an acceptable arterial oxygen level.

Table 5. Comparison of Example PAO2 using the Alveolar Air Equation and Measured Mean FiO2 among Portable Oxygen Concentrators (POC).

Breath Rate	Setting	Wall O2	CAIRE FSC sens. 2	CAIRE FSC sens. 5	CAIRE FSC (w/o autoSAT)	Caire SOC	Inogen G4	Inogen G5	SimplyGo Mini	GCE Zen-O Lite (Pulse Model)	GCE Zen-O Lite (Eco Model)	Drive iGo2	Kingon P2
Mean FiO2 at 15 BPM	2 or 2 LPM	150.4	124.0	124.0	121.8	148.2	119.7	121.8	112.6	116.8	116.8	115.4	120.4
Mean FiO2 at 20 BPM	2 or 2 LPM	146.8	117.6	117.6	118.3	141.08	124.0	122.5	122.5	119.0	120.4	112.6	112.6
Mean FiO2 at 30 BPM	2 or 2 LPM	133.2	123.3	126.8	118.3	128.3	117.6	117.6	118.3	123.3	115.4	111.1	115.4
Mean FiO2 at 40 BPM	2 or 2 LPM	123.3	126.8	128.3	113.3	123.3	114.0	113.3	114.7	114.7	109.0	109.0	113.3
Mean FiO2 at 15 BPM	3 or 3LPM*	178.9	--	--	--	--	140.4	--	--	--	--	--	--
Mean FiO2 at 20 BPM	3 or 3LPM*	172.5	--	--	--	--	143.2	--	--	--	--	--	--
Mean FiO2 at 30 BPM	3 or 3LPM*	153.2	--	--	--	--	129.0	--	--	--	--	--	--
Mean FiO2 at 40 BPM	3 or 3LPM*	138.2	--	--	--	--	122.5	--	--	--	--	--	--
Mean FiO2 at 15 BPM	5 or 5LPM	237.4	156.8	139.7	175.3	232.3	--	153.9	153.9	152.5	145.4	134.7	152.5

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Mean FiO2 at 20 BPM	5 or 5LPM	220.2	161.8	158.2	157.5	210.2	--	166.0	158.2	161.0	149.6	153.2	130.4
Mean FiO2 at 30 BPM	5 or 5LPM	207.4	146.1	148.9	146.1	177.4	--	145.3	142.5	139.0	140.4	140.4	132.5
Mean FiO2 at 40 BPM	5 or 5LPM	178.2	132.5	134.7	136.0	159.6	--	132.5	129.0	129.0	131.1	119.0	130.4
Mean FiO2 at 15 BPM	6 or 6LPM*	271.6	--	--	--	--	--	166.8	--	--	--	--	--
Mean FiO2 at 20 BPM	6 or 6LPM*	243.0	--	--	--	--	--	173.2	--	--	--	--	--
Mean FiO2 at 30 BPM	6 or 6LPM*	207.3	--	--	--	--	--	154.6	--	--	--	--	--
Mean FiO2 at 40 BPM	6 or 6LPM*	178.2	--	--	--	--	--	141.1	--	--	--	--	--

Note. Alveolar air equation assumed 747 mmHg of barometric pressure, 40 mmHg PaCO2, and an average of 0.80 respiratory quotient for an average diet/patient.

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COPD patients have reported improved quality of life from using POCs compared to traditional, heavy in-home oxygen tanks.[10, 11] However, COPD patients have expressed concerns with running out of oxygen while using POCs. This concern is magnified if POCs aren't obtaining the target FiO2 that the patient needs, and the patient is requiring a higher setting on the POC. Therefore, selecting a POC that obtains the highest FiO2 on a patient's prescribed setting will optimize oxygen preservation and may help mitigate patient's concerns about oxygen depletion during outings.[10]

5. Conclusions

While the wall O2 delivered significantly higher FiO2 across most scenarios, POCs drastically improve the quality of life of COPD patients and other patients requiring home oxygen therapy. The Caire FreeStyle Comfort POC with the autoSat setting delivered consistently higher FiO2 compared to other POCs in most scenarios. Additionally, the Caire FreeStyle Comfort POC with autoSat even delivered higher FiO2 compared to the wall oxygen in the 40 bpm scenario on setting 2. This is likely due to the autoSat consistently delivering the same bolus size of oxygen, regardless of increasing respiratory rates. However, it should be noted that other devices with fixed bolus delivery systems did not achieve high FiO2 measurements like the Caire FreeStyle Comfort POC. This may be due to missed breaths and various trigger sensitivities of POCs. Future research should investigate the association between missed breaths, trigger sensitivities, and FiO2 measurements.

Clinicians should consider the efficacy of the POC device when making recommendations to patients. Additionally, clinicians should consider the variability in FiO2 obtained with various trigger sensitivities depending on respiratory rate needs and level of activity and exertion for individual patients. Patients and clinicians would benefit from seeing easily digestible and clear information on oxygen bolus size, type of pulse delivery system, and minute volume maximum capabilities. Examples of oxygen bolus sizes by breath rates may be helpful for patients to evaluate a standardized measure across POCs. This information is critical to helping patients select the optimal POC device, especially for patients with higher FiO2 needs and increased respiratory rate demands.

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References

1. Jacobs SS, Lederer DJ, Garvey CM, Hernandez C, Lindell KO, McLaughlin S, et al. Optimizing Home Oxygen Therapy. An Official American Thoracic Society Workshop Report. Ann Am Thorac Soc 2018;15(12):1369-1381.
2. Martin DC. Contemporary portable oxygen concentrators and diverse breathing behaviours -- a bench comparison. BMC Pulm Med 2019;19.
3. Khor YH, McDonald CF, Hazard A, Symons K, Westall G, Glaspole I, et al. Portable oxygen concentrators versus oxygen cylinder during walking in interstitial lung disease: A randomized crossover trial. Respirology 2017;22(8):1598-1603.
4. Yanez AM, Prat JP, Alvarez-Sala JL, Calle M, Diaz Lobato S, Garcia Gonzalez JL, et al. Oxygenation With a Single Portable Pulse-Dose Oxygen-Conserving Device and Combined Stationary and Portable Oxygen Delivery Devices in Subjects With COPD. Respir Care 2015;60(3):382-387.
5. Leblanc CJ, Lavallee LG, King JA, Taylor-Sussex RE, Woolnough A, McKim DA. A comparative study of 3 portable oxygen concentrators during a 6-minute walk test in patients with chronic lung disease. Respir Care 2013;58(10):1598-1605.
6. Chatburn RL, Williams TJ. Performance comparison of 4 portable oxygen concentrators. Respir Care 2010;55(4):433-442.

7. Chen JZ, Katz IM, Pichelin M, Zhu K, Caillibotte G, Finlay WH, et al. In Vitro-In Silico Comparison of Pulsed Oxygen Delivery From Portable Oxygen Concentrators Versus Continuous Flow Oxygen Delivery. Respir Care 2019;64(2):117-129.
8. Fischer R, Wanka ER, Einhaeupl F, Voll K, Schiffl H, Lang SM, et al. Comparison of portable oxygen concentrators in a simulated airplane environment. Respir Med 2013;107(1):147-149.
9. Bunel V, Shoukri A, Choin F, Roblin S, Smith C, Similowski T, et al. Bench Evaluation of Four Portable Oxygen Concentrators Under Different Conditions Representing Altitudes of 2438, 4200, and 8000 m. High Alt Med Biol 2016;17(4):370-374.
10. AlMutairi HJ, Mussa CC, Lambert CT, Vines DL, Strickland SL. Perspectives From COPD Subjects on Portable Long-Term Oxygen Therapy Devices. Respir Care 2018;63(11):1321-1330.
11. Moretta P, Molino A, Martucci M, Fuschillo S, De Felice A, Guida P, et al. Subject Preferences and Psychological Implications of Portable Oxygen Concentrator Versus Compressed Oxygen Cylinder in Chronic Lung Disease. Respir Care 2021;66(1):33-40.