

Acute and Long-Term Hemodynamic Response to Home Oxygen Therapy: Nasal Prongs Versus Oxygen Saving Devices

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ABSTRACT

BACKGROUND: The Nocturnal oxygen therapy trial and Medical Research Council studies have shown that home oxygen therapy increases survival and offers hemodynamic benefits to hypoxic chronic obstructive pulmonary disease. In recent years, research has been aimed at improving patients' quality of life by introducing portable sources of liquid oxygen and oxygen-saving systems, such as the oxymizer and transtracheal catheters.

PURPOSE: To identify the acute and long-term hemodynamic response to different methods of oxygen saving devices, oxymizer and transtracheal catheter, in chronic obstructive pulmonary disease patients previously oxygenated via nasal prongs.

METHODS: *Acute response.* A minimum of 3 nocturnal pulse-oximetrys were performed with each device (nasal prongs, oxymizer and transtracheal catheter) to find the minimum oxygen flow required to maintain a SpO_2 % > 88% during 95% of the night. With the preset oxygen flow, a radionuclide ventriculography was performed at rest and during exercise to calculate the right and left ventricular ejection fraction. *Long-term response to transtracheal catheter:* Arterial gasometries, hemoglo-

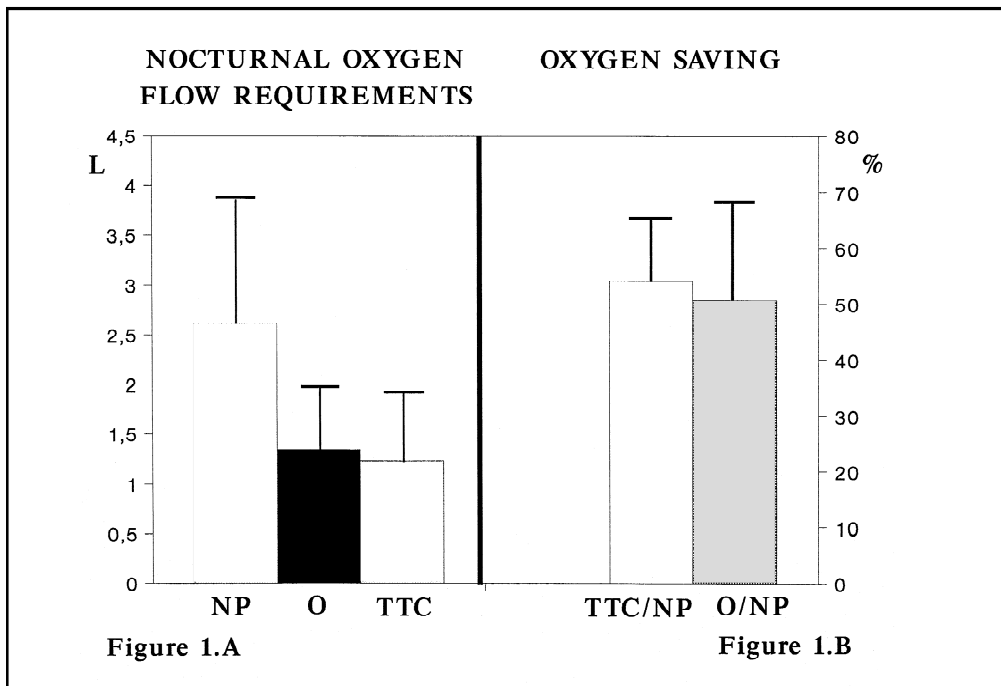


Figure 1. Mean nocturnal oxygen flow requirements (L/min) with every device (A) and percentage of oxygen saving (B).

bin determinations, Pulmonary function testing, echocardiography, radionuclide ventriculography (right and left ventricular ejection fractions, and ventricular volumes), right heart catheterization, 6 minute walking test, and a visual analogue scale score were performed at the beginning of the study and 1 year later in 10 hypoxemic chronic obstructive pulmonary disease.

RESULTS: Acute response. The increment of the left ventricular ejection fraction during maximal exercise with the oxymizer was significantly lower than with nasal prongs or transtracheal catheter and the right ventricular ejection fraction showed a tendency to decrease ($P=0.06$).

Long-term response to transtracheal catheter. At the end of follow-up, decreases were found in hemoglobin (15.2 to 12.9 g/dL) and forced expiratory volume in the first second (0.78 L to

0.62 L) and the Pao_2 (determined with the same oxygen flow via transtracheal catheter) increased (66.8 to 71.0 mm Hg), ($P<0.05$), but the cardiac work, the 6 minute walking test and the visual analogic scale did not deteriorate. Cardiac index, pulmonary capillary wedge pressure, right and left ventricular ejection fraction did not change. Mean pulmonary arterial pressure did not improve but the pulmonary arteriolar vascular resistances and the right ventricle free wall stress index significantly improved at the end of the study. The end-systolic and end-diastolic volumes of the right ventricle determined at rest showed a tendency to decrease ($P=0.06$).

CONCLUSIONS: For patients on home oxygen therapy, who wish to maintain maximal physical activity, the oxymizer is not recommended as an oxygen saving device. Long-term oxygenation, 24 hours

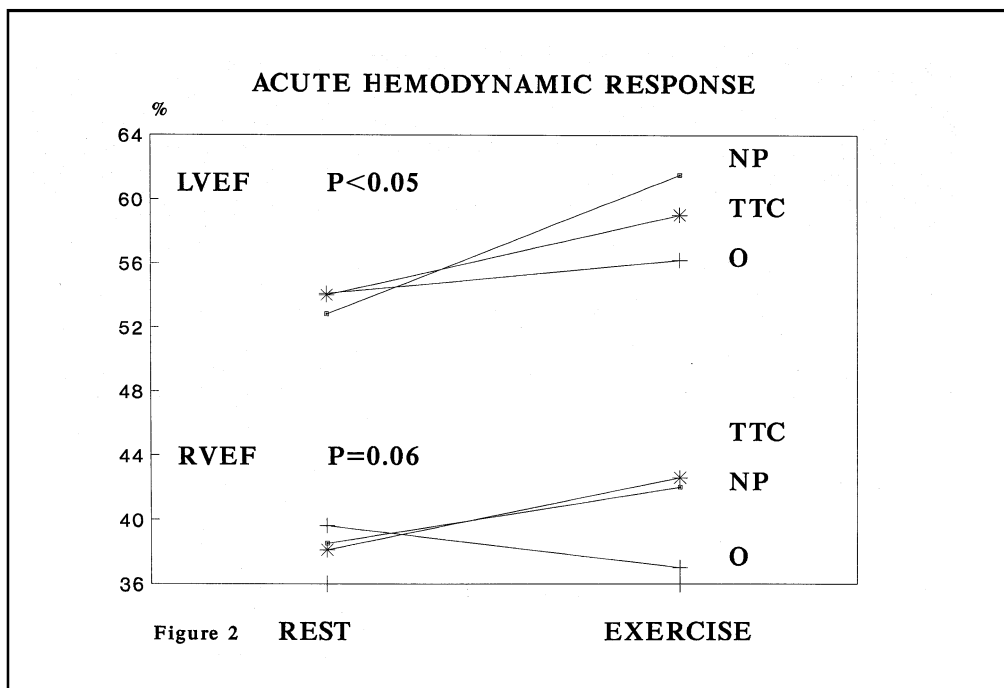


Figure 2. Mean values of the right and left ventricular ejection fraction (RVEF and LVEF) with 3 different devices. At rest no differences were observed. During maximal exercise, the results, when patients were oxygenated via oxymizer (O), were less satisfactory than with nasal prongs (NP) or transtracheal catheter (TTC).

per day with liquid oxygen via transtracheal catheter in hypoxemic patients previously on home oxygen therapy with nasal prongs, who maintained physical activity showed improved oxygenation (hemoglobin values decreased), improved P_{aO_2} and showed hemodynamic benefits (decrease of the post-load). All these results occurred despite the forced expiratory volume in the first second deterioration, maintaining the same degree of dyspnea (unchanged visual analogue scale score) and exercise capacity (no changes in 6 minute walking test).

INTRODUCTION

In 1974,¹ at a meeting of the American Thoracic Society, it was reported that the use of long-term oxygen therapy (LTOT) was steadily increasing in the USA and Europe. However, it was not

conclusively demonstrated that this treatment contributed to lengthening patients' lives. Two major studies, the NOTT^{2,3} and MRC,⁴ were set up as a result. Flenley⁵ stated that in patients with chronic obstructive pulmonary disease (COPD) and chronic hypoxemia, as far as survival is concerned, "no oxygen is bad, oxygen for some of the time is better, but oxygen for most of the time is the best."

From a hemodynamic point of view, the results of the various studies are contradictory; in some cases the hemodynamic benefits derived from LTOT have been demonstrated,^{2,3,6} in other cases, the benefits are not so clear.^{4,7}

In recent years, research has been aimed at improving the patient's quality of life by introducing portable sources of liquid oxygen and oxygen-saving systems, which can be combined, to allow

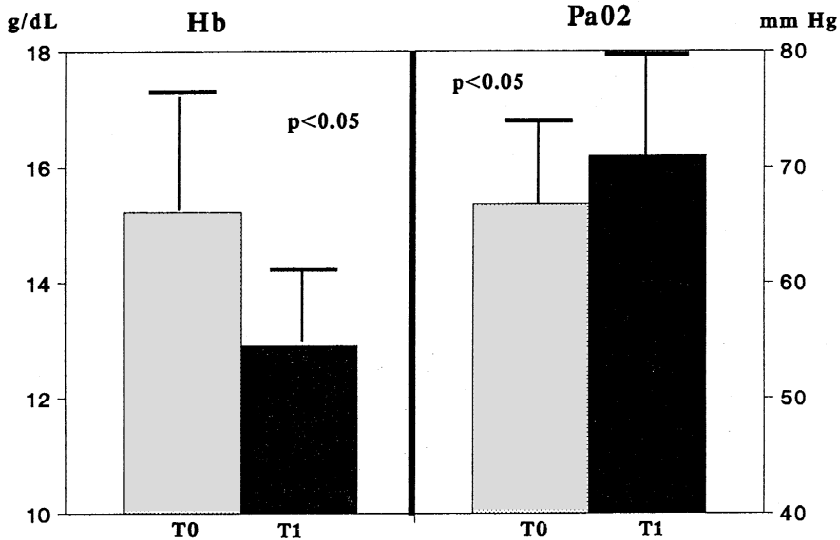


Figure 3.A

Figure 3.B

FEV1 EVOLUTION

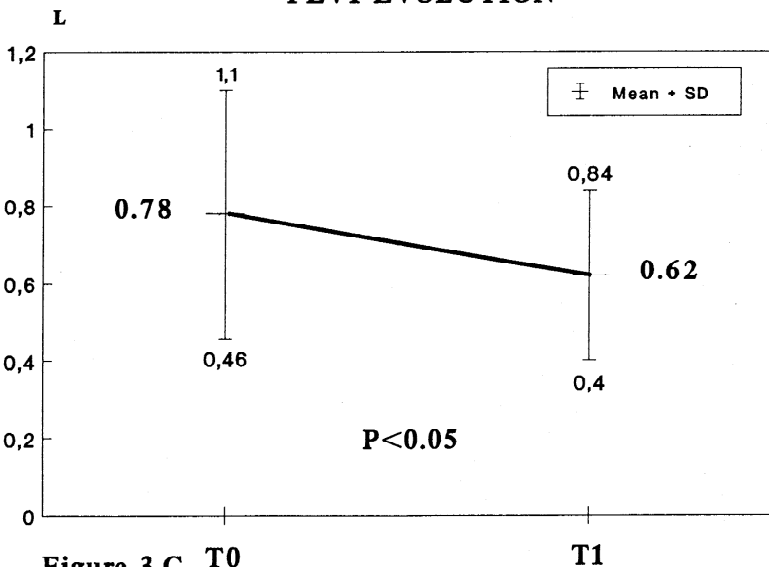


Figure 3.C

Figure 3. These figures show the evolution of Hemoglobin (Hb in g/dL), arterial oxygen (Pao₂ in mm Hg) and Forced Expiratory Volume in the first second (Fev1 in L) during oxygenation via transtracheal catheter (TTC). An improvement in oxygenation (A and B) despite deterioration in spirometric values is observed (C). T0 indicates the beginning of the study and T1, end of follow-up.

patients greater outdoor activity, while maintaining correct oxygenation 24 hours a day.⁸⁻¹¹

The purpose of this study is to ascer-

tain the acute and long-term hemodynamic response of 2 oxygen saving devices, the Oxymizer (Chads Therapeutic, Inc, Woodland Hills, Calif)

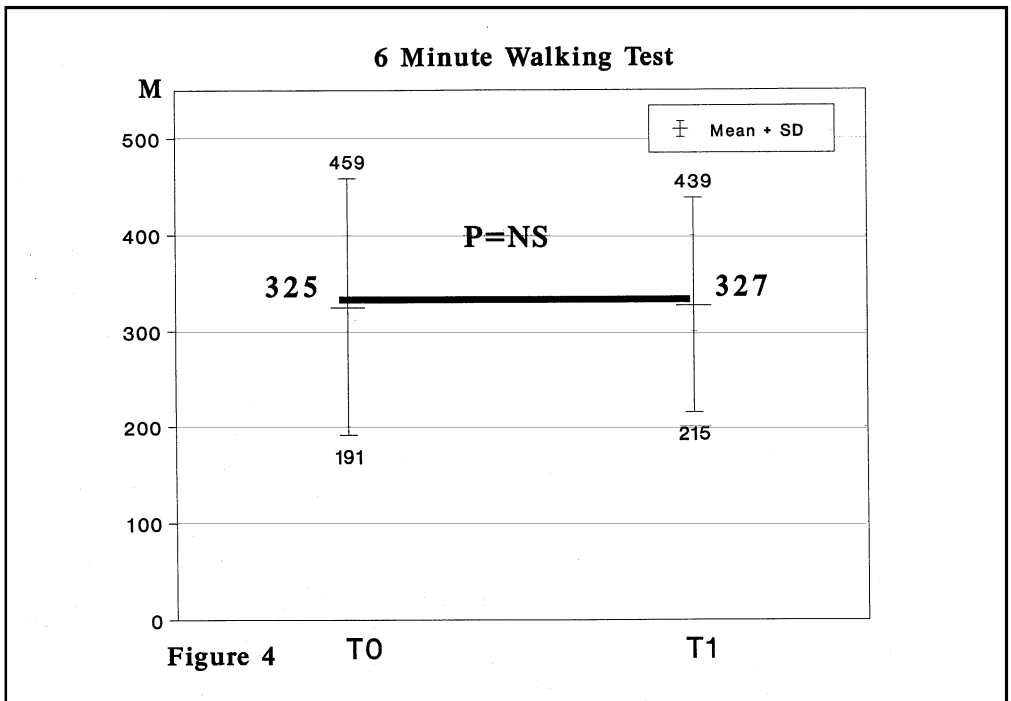


Figure 4. Mean values for the six-minute walking test (6WT) at the beginning (T0) and the end of the follow-up (T1).

and the transtracheal catheter, while maintaining the previously established oxygen saving properties, in a group of patients with COPD, who had previously been treated with LTOT through nasal prongs 18 hours a day.

MATERIALS AND METHODS

We studied a group of 14 patients (13 males and 1 female) with severe COPD and chronic hypoxemia, included in a LTOT program at Germans Trias i Pujol University Hospital in Barcelona. Ten patients (9 males and 1 female, aged 59.9 ± 5.8 years) were able to reach the end of our follow-up (2 died and 2 refused a second catheterization). Patients had received LTOT through nasal prongs 18 hours a day, for a mean period of 26 ± 17 months prior to inclusion in this study and were considered reliable followers of their treatment plan. No patients presented with exclusion criteria for transtracheal catheter

insertion.⁹

PROTOCOL

Before their inclusion in the study, the patients followed a pulmonary rehabilitation program with carefully adjusted medication. After the study procedures were started, patients were not allowed to participate in any other rehabilitation program¹² nor were they allowed to alter the bronchodilating, cardiotoxic, or diuretic medication they were given. The study was performed according to the following steps:

Step 1. At the beginning and at the end of the follow-up, complete pulmonary function testing (PFT_s) were carried out in our pulmonary function laboratory,¹³ which is equipped with automated PFT

EVOLUTION OF THE RV END-SYSTOLIC VOLUME

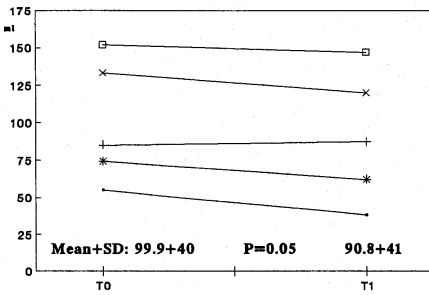


Figure 5.A

EVOLUTION OF THE RV END-DIASTOLIC VOLUME

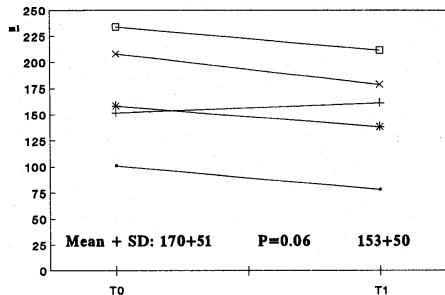


Figure 5.B

mPAP EVOLUTION

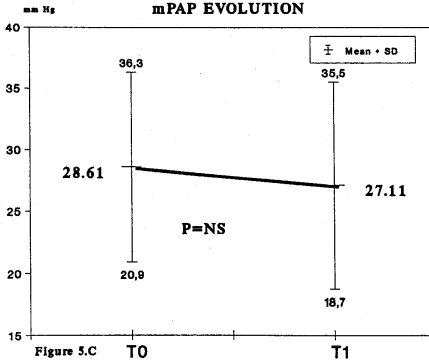


Figure 5.C

PAVR EVOLUTION

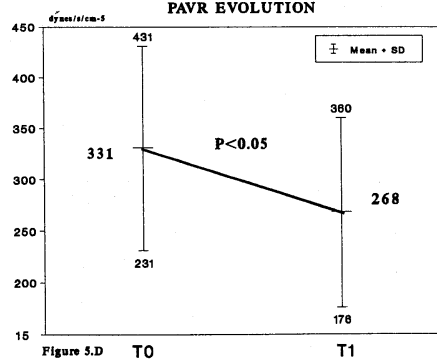


Figure 5.D

Figure 5. Figures 5A and 5B show the tendency of the right end-systolic (RVESV) and end-diastolic volumes (RVEDV) determined at rest to decrease after 1 year oxygenation 24-hours a day with liquid oxygen via transtracheal catheter. Figure 5D shows the decrease of the post-load despite the mean pulmonary arterial pressure (mPAP in mm Hg) (Figure 5C).

equipment (Sensor Medics, Anaheim, Calif) for pulmonary volume and diffusion, and spirometric tests with the following components: a dry-piston rolling-seal spirometer with horizontal displacement and potentiometer; a pulmonary volume module by helium dilution; an IBM XT personal computer; and an automated plethysmographic cabin for pulmonary volume and airway resistance tests (Spectramed, Holland).

Step 2. The oxygen flow required for a correct oxygenation with the oxymizer and transtracheal catheter was determined during rest and during exercise in the following way¹⁴:

- A minimum of 3 nocturnal pulse-oximetrys (Oxyshuttle, Sensormedics)

with oxygen administered through nasal prongs, oxymizer, and transtracheal catheter, were performed which allowed us to calculate the minimum oxygen flow needed to keep oxygen saturation (SaO_2) > 88% during 95% of the time measured with each device¹⁴

- Arterial gasometries (Corning 178 gasometer, Izasa) were performed on room air and with oxygen flow through nasal prongs and transtracheal catheter, while the patient was awake, were obtained at the beginning and end of the study.¹²
- Oximetric monitoring of patients was performed when they were examined as outpatients.
- A 6-minute walking test was per-

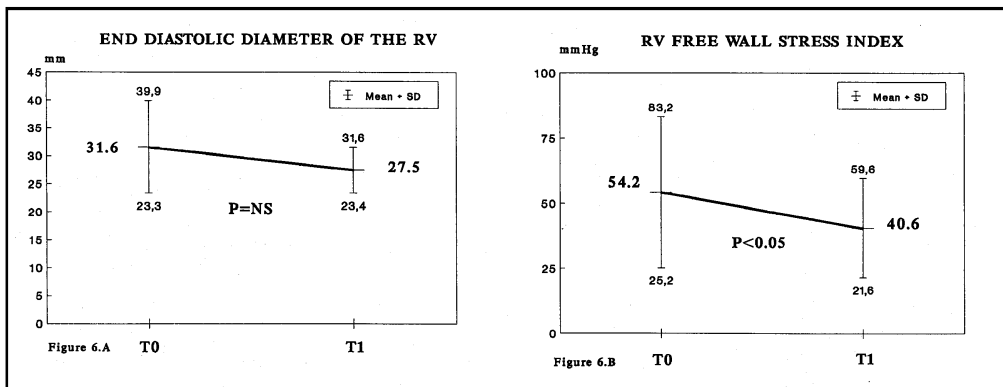


Figure 6A and 6B. Observe the tendency for the end-diastolic diameter of the right ventricle (EDDRV in mm) to decrease and a significant decrease in the right ventricle free wall stress index (RVFWSI in mm Hg) illustrating the better physiologic situation of the right ventricle after 1 year oxygenation 24 hours a day with liquid oxygen via transtracheal catheter (TTC).

formed at the beginning and end of the follow-up period. Patients received liquid oxygen via transtracheal catheter delivered by a stroller, which the patients pulled, of liquid oxygen (Vital Aire-SEO) under oximetric control, to ascertain that the administered oxygen flow allowed correct oxygenation. The walking distance was measured and dyspnea assessed by a visual analogue scale (VAS). Moreover, we attempted a correlation between these variables and pulmonary vascular resistances (PVR), pulmonary arteriolar vascular resistances (PAVR), RV ejection fraction (RVEF), and LV ejection fraction (LVEF).

Step 3. Hospital-based patients were fitted with a transtracheal catheter (Oxycath, Smad-Proclinics), using the previously described procedure.⁹ The first transtracheal catheter was replaced before the patient was discharged, and from then on they were replaced in our center on a weekly basis for 8 to 10 weeks after discharge. After being trained in transtracheal catheter replacement and the use of portable oxygen sources, patients were again included in

the COPD-monitoring procedures of our department, and received no further special care.¹⁵⁻¹⁶

Step 4. Physical activity was monitored. An anamnesis aiming to specify whether the patients stayed away from home for 4 hours or more every day was performed by interviewing the patient and the patient's relatives without the patient present at every outpatient examination.

Step 5. Studies were performed to evaluate the acute hemodynamic response. Isotopic ventriculography with the equilibrium technique and the radiopharmaceutical metastable Technetium-99 (99mTc), with a 6-hour average life and a 140 KeV photon activity were used. This study was carried out with the patient in decubitus position and perpendicular to the Picker 4/15 gamma camera. Twenty mCi of 99mTc, in a volume of 1 cm³ of blood, were injected through an antecubital vein. The ejection fraction (EF) in each beat was calculated by the formula:

$$EF = \frac{\text{Diastolic count} - \text{Systolic count}}{\text{Diastolic count}}$$

The isotopic ventriculography was performed on the patient, while on an ergonomic bicycle and receiving oxygen through nasal prongs, oxymizer, and transtracheal catheter, both at rest, and during exercise at a subjective maximum rate. In each case, the oxygen flow was that preset by nocturnal pulse-oximetry. Blood pressure and heart rate were measured, thus, making it possible to calculate the cardiac work (systolic blood pressure x cardiac rate) at rest and exercise.

Step 6. The long-term hemodynamic response to 24-hour oxygenation with liquid oxygen via transtracheal catheter was evaluated via:

- Doppler and bidimensional echocardiograms (Toshiba, Sono-layer SSH 65-A), with the patient in supine decubitus position and receiving the oxygen flow, as previously determined through transtracheal catheter. The right-side catheterization data was obtained and a right ventricle free wall stress (RVFWS) index was determined according to the formula:

$$RVFWS = \frac{RVFWT \times PAPd}{RV \text{ diastolic diameter}}$$

where RVFWT is the right ventricle free wall thickness (mm); PAPd is the diastolic pulmonary arterial pressure, which is the pressure of the right ventricle at the end of the isometric contraction period (mm Hg); and RV is the right ventricle.

- Isotopic ventriculography with oxygen administered via transtracheal catheter at rest and exercise to determine the RVEF, LVEF and ventricular volumes. Once the end-diastolic volume (EDV) and EF were known, the beat volume (BV) could be calculated ($BV = EF \times EDV$). The end-systolic volume can

be obtained by subtracting the BV from the EDV.

- Right heart catheterization was performed through the subclavian vein with a Swan-Ganz catheter, using the Seldinger technique, after administering subcutaneous lidocaine anesthetic. The distal end position of the floating catheter in the pulmonary artery was continuously controlled by monitoring the pressure curve in a Space Lab 701 monitor (Edwards). Cardiac output was obtained by thermodilution. We carried out at least 5 measurements, discarding the 2 end measurements, and calculated an average with the remaining 3, provided there was no more than a 10% variation between the 3 measurements. The pressure waves of right atrium (RA), right ventricle (RV), pulmonary artery and pulmonary capillary wedge pressure (PCWP) were recorded on the same graph paper that the initial study measurements were recorded. During the initial hemodynamic study, a radial artery catheter was inserted, which permitted the monitoring of the systolic and diastolic blood pressure, and series determinations of arterial gasometry. During the final hemodynamic study, blood pressure was measured by a sphyngomanometer and an arterial gasometry was performed by puncture after lidocaine local anesthetic. Patients were monitored through digital oximetry at all times.

Step 7. Statistical evaluation was carried out with Pearson's correlation, and Student's *t* test for paired data (with Bonferroni correction) and two-way analysis of variance. A *P* value of less

Table 1. Hemodynamic Response to the Three Different Oxygen Delivery Devices Evaluated With a Radionuclide Ventriculography (Mean \pm SD).

	mRVEF		mLVEF	
	Rest	Exercise	Rest	Exercise
Nasal Prongs (T0)	38 \pm 9.7	42 \pm 11.2	2.9 \pm 9.4	61.5 \pm 11.1
Oxymizer (T0)	39.6 \pm 12.8	37.4 \pm 7.5*	54.1 \pm 7.4	56.2 \pm 9.5 [†]
Transtracheal (T0) catheter	38.1 \pm 12.2	42.6 \pm 9.5	54.0 \pm 11.5	59.8 \pm 15
(T1)	37.6 \pm 9.8	44.4 \pm 7.1	57.0 \pm 7.46	58.7 \pm 10.6

*RVEF slightly decreased during exercise ($P=0.06$)
[†]LVEF increased less markedly during exercise with oxymizer than with nasal prongs or transtracheal catheters ($P<0.05$).
 MRVEF indicates mean right ventricle ejection fraction (%); mLVEF, mean left ventricle ejection fraction (%); T0, beginning of the study; and T1, end of the study.

Table 2. Pulmonary Function Tests at the Beginning and at the End of the Study (Mean \pm SD).

	T0	T1
FVC (L)	1.68 \pm 0.64	1.56 \pm 0.65
FEV ₁ (L)*	0.78 \pm 0.32	0.62 \pm 0.22
FEV ₁ /FVC (%)*	47 \pm 9.9	34.7 \pm 9.5
RV (L)	4.68 \pm 1.61	4.55 \pm 1.71
TLC (L)	6.15 \pm 3.02	6.84 \pm 2.26
SGaw (S ⁻¹ .cm.H ₂ O ⁻¹)	0.044 \pm 0.039	0.037 \pm 0.025
DICO (%)*	59.8 \pm 28	51.2 \pm 24
KCO (%)	73.4 \pm 39.2	68.2 \pm 29.5
MVV (L/min)	33.8 \pm 12.7	32.8 \pm 14.1

* $P<0.05$
 T0 indicates beginning of the study; T1, end of the study; FVC, forced vital capacity; FEV₁, forced expiratory volume in the first second; FEV₁/FVC; RV, residual volume; TLC, total lung capacity; DICO, diffusing lung capacity for carbon monoxide; KCO, DLCO/alveolar volume; MVV, maximal voluntary ventilation; and Sgaw, specific airways conductance.

than 0.05 was considered significant.

Step 8. The protocol was approved by the ethical committee of the Germans Trias i Pujol Hospital and written informed consent was obtained from all patients.

RESULTS

Nocturnal pulse-oximetries were performed in 14 patients, but the right heart catheterization in only 10. Of these 10 patients, isotopic ventriculography was performed in 9, but ventricular volumes

could be obtained in only 5 of them. The population studied included 9 males and 1 female, average age 61.2 \pm 5.6 years, weight 61.68 \pm 8.7 kg, and height 162.8 \pm 6.6 cm. The follow-up time was 11.4 \pm 3.8 months. As observed elsewhere,⁸ transtracheal catheter insertion did not present any difficulties.^{13,15}

The oxygen flows required to maintain oxygen saturation levels above 88% during 95% of the night, and the percentages of oxygen savings are shown in Figures 1A and 1B.¹⁴

Table 3. Comparison of the hemodynamic data obtained after right heart catheterization at the beginning of the study and after 1 year of oxygenation 24 hours a day with liquid oxygen via transtracheal catheter (Mean \pm SD).

	T0	T1
mPAP	28.6 \pm 7	27.1 \pm 8.3
PVR	427 \pm 120	390 \pm 138
PAVR *	331 \pm 108	268 \pm 92
PCWP	6.0 \pm 3.2	9.39 \pm 3.5
CO	5.6 \pm 0.9	5.67 \pm 0.7
CI	3.35 \pm 0.68	3.38 \pm 0.49
SVRI	2111 \pm 581	2138 \pm 418
CW	9404 \pm 1353	9559 \pm 1435
RVFWSI *	54.2 \pm 29	40.6 \pm 19

* $P < 0.05$
T0 indicates beginning of the study; T1, end of the study; mPAP, mean pulmonary arterial pressure (mm Hg); PAVR, pulmonary arteriolar vascular resistances (din/s/cm-5); PVR, pulmonary vascular resistances (din/s/cm-5); PCWP, pulmonary capillary wedge pressure (mm Hg); CO, cardiac output (L/min); CI, cardiac index (L/min/m²); SVRI, systemic vascular resistances index (din/s/cm-5); CW, cardiac work (calculated as: systolic blood pressure x cardiac rate) (mm Hg/BPM); RVFWSI, and right ventricle free wall stress index (mm Hg).

The isotopic studies performed at the beginning of the study, comparing the changes of the right and left ejection fractions (EF) at rest and during maximal exercise with the patients oxygenated via nasal prongs, oxymizer, and transtracheal catheter, demonstrated that the LVEF and RVEF values during rest were similar in all 3 methods. However, during maximal exercise, the EF increments of both ventricles were significantly higher with nasal prongs or transtracheal catheter. In other words, at maximal exercise the LVEF increases less markedly and the RVEF decreases slightly with oxymizer than with nasal prongs or transtracheal catheter (Table 1 and Figure 2).

The follow-up study showed that hemoglobin values decreased from 15.21 \pm 2.09 g/dL to 12.91 \pm 1.48 g/dL ($P < 0.05$), the decrease being uniform (Figure 3A). The Pao₂ at the beginning and at the end of the study with the patients oxygenated via transtracheal catheter at the preset oxygen flow are shown in Figure 3B; an increase in Pao₂

values was observed.

The initial PFTs are shown in Table 2. Only the FEV₁, the FEV₁/FVC quotient and DLCO (diffusing lung capacity for carbon monoxide) but not the KCO (DLCO/alveolar volume) deteriorated statistically significantly (Figure 3C).

The 6-minute walking test did not deteriorate at the end of the follow-up (325 \pm 134 m versus 327 \pm 112 m, $P =$ NS, Figure 4) and there were no differences between the cardiac rate values (94 \pm 11 versus 99 \pm 11 BPM) and the VAS score (3.5 \pm 2.6 versus 3.8 \pm 2.14). The only significant differences occurred between heart rate and VAS value, at the beginning and at the end of each test, which indicates that patients made a considerable effort, causing an increase in heart rate, as well as a feeling of dyspnea. No correlation was found with any of the hemodynamic parameters previously mentioned.

The anamnesis, performed routinely, showed that all the patients usually spent more than 4 hours away from

their homes, and 3 of them restarted work. The oximetric monitoring ruled out an inaccurate oxygen delivery, as is sometimes the case with some portable liquid oxygen devices.¹⁷

A comparison of the RVEF and LVEF, after 1 year of oxygenation via transtracheal catheter and liquid oxygen 24 hours a day, showed no deterioration (Table 1). Reliable results of ventricular volumes were obtained in 5 patients. They results showed that effort did not alter either RV or LV volumes, however, at rest, the end-systolic volume ($P = 0.05$) and the end-diastolic volume ($P = 0.06$) of the right ventricle showed a tendency to decrease (Figures 5A and 5B).

Data referring to right heart catheterization are shown in Table 3 and Figures 5C and 5D. A sustained PAVR improvement was observed at the end of the follow-up. Pulmonary arterial pressure, PVR, and cardiac output did not vary; pulmonary capillary wedge pressure (PCWP) was always within normal limits. Similarly, the cardiac work observed did not vary (9559 ± 1435 vs 9955 ± 1710 mm Hg BPM).

The echocardiography evaluation showed that there was slight tricuspid regurgitation (TR) in 6 patients and moderate in 2 at the beginning and at the end of the follow-up. No differences were detected in the end-diastolic left ventricle diameter (41.7 ± 9 mm), in the RV free wall (RVFW) thickness (8.6 ± 1.8 mm), or in the septum thickness (11.1 ± 1.16 mm). The end-diastolic right ventricle diameter showed a non-significant tendency to decrease (31.6 ± 8 versus 27.5 ± 4.5 mm) (Figure 6A). We also calculated a proportional RVFWS index, which showed a decrease of the post-load (54.2 ± 29 versus 40.6 ± 19 mm Hg; $P < 0.05$) (Figure 6B).

DISCUSSION

In this study, we contrasted the hemody-

namic responses to 3 different oxygen delivery devices in a group of patients suffering from very severe COPD, who had previously been receiving oxygen through nasal prongs 18 hours a day. Patients who were reliable followers of instructions, as was demonstrated by the continuous anamneses carried out with them and with their relatives, and the hemoglobin levels were in the normal upper range despite their baseline hypoxemia. Patients were in a stable situation since none had suffered a respiratory infection or a c. pulmonale decompensation during the 3 months previous to the beginning of the study, and the PFTs did not improve at the end of the study when compared to those at the beginning. Finally, cardiac output measured by thermodilution and average EF by isotopic ventriculography (both performed with oxygen) was within normal limits, and the PCWP ruled out the possibility of hyperhydration or left cardiac failure. Clinical data, anthropometric data and the morphology of desaturations ruled out the possibility of obstructive sleep apnea syndrome, which could otherwise have been relieved with the insertion of a transtracheal catheter. Clinical tolerance to transtracheal catheter was good, in keeping with the literature on the subject.^{18,19} The level of oxygen saving was as expected, with patients at rest (including sleep) or exercising.¹⁴

The evaluation of the acute response to the 3 different oxygen delivery devices tested revealed that with the patient at rest, the 3 methods are useful and that oxymizer and transtracheal catheter save almost 50% of the oxygen consumption needed compared with nasal prongs. When patients performed maximal exercise, despite the fact they could reach the same level of cardiac work, the hemodynamic response of the right ventricle of the patients differed

markedly depending on the oxygen device used. The clinical application of this observation is that the oxymizer is a good method for oxygenating these patients at rest (including sleep) and that allows a 50% oxygen saving. In those patients who are keen to restart physical activity, the oxymizer is not the best oxygen saving device. Transtracheal catheter, while maintaining the preset percentage of oxygen saving, allows a hemodynamic response as satisfactory as nasal prongs.

It may be that this different hemodynamic response could have been demonstrated by determining the $SaO_2\%$ changes with a pulse-oximeter during a 6 minute walking test or a treadmill test. Although pulse-oximetry is generally accepted as an excellent method to evaluate the $SaO_2\%$,²⁰ in some cases (patients with dark skin or increased levels of bilirubin), the procedure is less reliable.²¹ During effort, the changes in $SaO_2\%$ seem to be reliable but their correspondence with the Pao_2 is less so.²² Moreover, light and motion artifacts cannot be completely avoided.²³ Finally, after observing that despite the different hemodynamic response to the different oxygen devices the patients reached the same level of cardiac work, we believe that the more reliable methods for the evaluation of the hemodynamic response are those tests that directly assess the hemodynamic function of the cardiac pump.

Since the oxymizer was not thought to be a good oxygenation device for patients undertaking considerable levels of physical activity, we performed a long-term evaluation only of patients oxygenated via transtracheal catheter and liquid oxygen 24 hours a day. Oxygenation in these patients improved, as demonstrated by the decrease in hemoglobin values, also noted by Christopher.¹⁹ Attention should be drawn to the improvement observed in

PaO_2 at the end of follow-up, although the PFTs did not improve.¹² This finding has also been pointed out by O'Donohue,²⁴ who attributes it to the benefits of oxygen therapy.

The PFTs of our patients not only failed to improve, but some parameters, such as the FEV_1 worsened, thus ruling out the hypothesis that cardiopulmonary hemodynamic improvement might be due to an improvement in PFTs.¹³ Christopher²⁵ suggested the possibility that the continuous oxygen flow may have a positive end-expiratory pressure effect. Couser and Make,²⁶ demonstrated that transtracheal catheter-delivered oxygen lowered the inspired minute-volume and that this was one of the mechanisms that improved the patients' clinical state.

VAS, 6 minute walking test, and maximum voluntary ventilation did not worsen, possibly for the reasons stated in the theory of Couser and Make,²⁶ as much as the improvement in Pao_2 , but it is obvious that it was not due to PFT changes. Weitzemblem²⁷ observed that although oxygen delivered via nasal prongs could partially reverse pulmonary arterial hypertension, it could not improve patients' spirometry; nor could it be expected, therefore, to improve the spirometry of our group. Continuous oxygen delivered by transtracheal catheter can slow down the deterioration in exercise capacity, but it does not improve static or dynamic PFT.²⁸ We could not relate 6-WT to any other hemodynamic parameter. Nevertheless, hemodynamic parameters are frequently not correlated to the patient's exercise capacity.

The echocardiography evaluation showed that the incidence of TR at the beginning and at the end of this study was practically identical, and never severe. Cardiac output calculated by thermodilution is therefore reliable.²⁹ Only the RV diameter showed a ten-

endency to decrease although it did not reach a statistical significance.

According to some authors,³⁰ EF is a good non-invasive method to evaluate the function of both ventricles. MacKnee et al.³¹ studied the repercussion that oxygen administration could have on the ventricular function of patients with COPD, without signs of c. pulmonale, and on patients with decompensated c. pulmonale. He concluded that the RV and LV functions are normal in patients suffering from COPD without clinical signs of c. pulmonale, but they are diminished in patients with decompensated c. pulmonale. He also observed that mean pulmonary arterial pressure was not significantly different in the 2 groups, which led him to the conclusion that the lowering of contractility in patients with decompensated c. pulmonale was not due to a post-load increase. In other words, the worsening of pulmonary hypertension could not be the cause of right heart failure. Our results show that the RVEF is slightly lower in this group of patients than in the normal population and although, RVEF and LVEF at rest were maintained, the response to exercise showed a deficit. Moreover, Weitzemblem et al.³² have recently observed in a longitudinal study that a hemodynamic worsening is observed in patients with COPD exhibiting both edema and an exacerbation of respiratory failure and could explain the development of right heart failure. Thus, the lack of mean pulmonary arterial pressure increase observed by Macnee et al. could be due to the inability of the RV, in their patients, to generate a greater pressure and therefore to increase the EF or the cardiac output.

We observed a slight decrease in mean pulmonary arterial pressure at the end of the 1-year follow-up as well as a sustained increase in pulmonary arteriolar vasodilation. There was no deteriora-

tion in the EF of either ventricle; RV dilation tended to decrease when evaluated with 2 different techniques (isotopic ventriculography and echocardiogram), and there was also a fall of the proportional index of the RV wall stress. By oxygenating our patients in a more rational manner (reflected by a decrease in the hemoglobin values), we have achieved a long-term decrease in PAVR. This could possibly be attributed to several factors, such as decreasing blood viscosity secondary to a lower hematocrit and/or continuous capillary recruitment of the pulmonary vasculature. The long-term repercussion of this is demonstrated in the involution of RV dilation.

To summarize, we have shown that oxymizer and transtracheal catheter are excellent methods for home oxygen therapy and that they allow a 50% oxygen saving, which is especially important when patients require high oxygen flows. In these cases, the oxygen-saving devices make the oxygen therapy more tolerable, allow the use of concentrators, and increase the autonomy of liquid oxygen strollers. If the patients intend to restart work or perform outdoor physical activity for very long, we believe that continuous 24-hour a day oxygenation with liquid oxygen via transtracheal catheter improves the hemodynamic situation of patients suffering from severe COPD and chronic hypoxemia although they were previously correctly oxygenated via nasal prongs 18 hours a day. Continuous oxygenation with transtracheal catheter allows them to maintain the same exercise capacity and improve the arterial blood gases. Therefore, this confirms Flenley's point of view⁵ that the more hours O₂ is received by a patient the better, and it is obvious that, nowadays, the best method to achieve a 24-hour oxygenation is via transtracheal catheter. We have also been able to demonstrate that it is possible to intervene

in the evolution of chronic c. pulmonale. Likewise, we should note that several studies carried out to date have evaluated patients applying only 1 technique, a situation that did not reliably reflect the effect that oxygen may have on pulmonary hemodynamics. In contrast, we have studied a series of patients by applying 3 different techniques simultaneously. Moreover, we have studied a number of parameters that have not been well studied in the literature published to date (PAVR, wall stress, ventricular volumes), and which may give a better reflection of the real evolution of chronic c. pulmonale treated by long-term oxygen therapy. Finally, our data confirm empirically clinical observations demonstrating the advantages of transtracheal catheter-delivered oxygen, such as better tolerance to exercise,²⁸ improvement of c. pulmonale, and a lowering of the hematocrit.¹⁹

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