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Resolution of exercise oscillatory ventilation with adaptive servoventilation in patients with chronic heart failure and Cheyne-Stokes respiration: preliminary study

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Abstract

Background: Exercise oscillatory ventilation (EOV) is a common pattern of breathing in heart failure (HF) patients, and indicates a poor prognosis.

Aim: To investigate the effects of adaptive servoventilation (ASV) on ventilatory response during exercise.

Methods: We studied 39 HF patients with left ventricular ejection fraction (LVEF) ≤ 45. Cardiorespiratory polygraphy, cardiopulmonary exercise testing (CPET), echocardiography, and measurement of N-terminal pro-brain natriuretic peptide (NT-proBNP) concentration were performed. Twenty patients with Cheyne-Stokes respiration and apnoea–hypopnoea index (AHI) ≥ 15/h were identified. Of these, 11 patients were successfully titrated on ASV and continued therapy. In the third month of ASV treatment, polygraphy, CPET, echocardiography, and measurement of NT-proBNP concentration were performed again.

Results: The EOV was detected at baseline in 12 (31%) HF patients, including eight (67%) who underwent ASV. The EOV was associated with significantly lower LVEF, peak oxygen uptake (VO_2), and ventilatory anaerobic threshold (VAT), and a significantly higher left ventricular diastolic diameter (LVDD), slope of ventilatory equivalent for carbon dioxide (VE/VCO_2), AHI, central AHI and NT-proBNP concentration. In seven patients with EOV, reversal of EOV in the third month of ASV therapy was observed; only in one patient did EOV persist ($p = 0.0156$).

Conclusions: The EOV can be reversed with ASV therapy. The EOV in association with central sleep apnoea and Cheyne-Stokes respiration (CSA/CSR) is prevalent in HF patients and correlates with severity of the disease.

Key words: exercise oscillatory ventilation, sleep-disordered breathing

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INTRODUCTION

Periodic breathing is a common ventilation pattern in heart failure (HF) patients. It has been observed both during sleep and exercise. The prevalence of central sleep apnoea associated with Cheyne-Stokes respiration (CSA/CSR) and exercise oscillatory ventilation (EOV) in HF patients has been reported to range from 28% to 40%, and from 7% to 35%, respectively [1–6]. Although EOV is present in only a minority of patients with CSA/CSR, almost all EOV patients have CSA/CSR [4]. Both CSA/CSR and EOV have been identified as strong predictors of mortality in HF patients, the latter being the most powerful one of all cardiopulmonary exercise testing-derived variables [4–9].

Adaptive servoventilation (ASV) is a novel effective therapeutic method for reducing CSA. The ASV provides low levels of background expiratory positive airway pressures to

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which a variable amount of inspiratory pressure support is added. The amount of ventilatory support depends on the actual breathing effort of the patient. It has been shown that by correcting periodic breathing, ASV may improve sleep quality and cardiovascular function [10–14]. Because CSA/CSR and EOV appear to have the same underlying pathophysiologic mechanism [4, 15], it seems reasonable to expect that correction of CSA/CSR may reverse EOV.

Therefore, the purpose of the present study was to investigate the effects of ASV on periodic breathing during exercise.

METHODS

Study population and design

We prospectively studied patients with systolic HF due to ischaemic or idiopathic dilated cardiomyopathy referred for sleep study and cardiopulmonary exercise testing (CPET) as part of comprehensive HF evaluation. Eligibility criteria were as follows: (1) echocardiographic left ventricular ejection fraction (LVEF) ≤ 45%; (2) New York Heart Association (NYHA) class I–III; (3) clinical stability with optimal medical treatment for at least one month; and (4) ability to perform CPET. Exclusion criteria were: (1) acute coronary syndrome within the last month; (2) patients with pacemakers, cardioverter-defibrillators or cardiac resynchronisation devices implanted within the last six months; (3) severe chronic obstructive pulmonary disease; and (4) history of stroke. All patients underwent polygraphy, CPET, echocardiography and determination of N-terminal pro-brain natriuretic peptide (NT-proBNP) concentration. The ASV therapy was offered to patients with moderate to severe CSA/CSR — apnoea-hypopnoea index (AHI) ≥ 15 and for whom there were no other conventional therapeutic options. In the third month of ASV therapy, polygraphy, CPET, echocardiography and measurement of NT-proBNP concentration were performed again.

Cardiopulmonary exercise testing

Symptom-limited CPET was performed on a cycle ergometer with a ramp protocol that was personalised with the aim of having each patient reach maximum exercise in 7 to 10 min. Breath-by-breath measurements of gas exchange were obtained by a metabolic cart (ZAN 680, ZAN Messgerate GmbH, Germany). Minute ventilation (VE), oxygen uptake and carbon dioxide output (VCO_2) were averaged over 10 s. Peak VO_2 was expressed as the mean value of VO_2 during the last 60 s of the exercise test. Ventilatory anaerobic threshold (VAT) was detected by the V-slope method. The VE/VCO_2 slope was calculated as a linear regression function using the data points from the whole exercise period. Peak oxygen pulse (O_2 pulse) was delineated as peak VO_2 divided by peak heart rate. The EOV was defined according to the following criteria: (1) three or more regular oscillations in VE; (2) a regular oscillation as defined by the standard deviation of three consecutive cycle lengths within 20% of the average; and (3) minimal average amplitude of ventilatory oscillation of 5 L [7].

Echocardiography

Standard M-mode and two-dimensional (2D) echocardiography and Doppler blood flow measurements were performed in all patients (Vivid 7 Dimension, GE Healthcare, USA). The LVEF was calculated according to Simpson's method from a 2D apical view.

Sleep study

All patients underwent in-hospital unattended polygraphy (Embletta™, Embla, The Netherlands) with recording of nasal air flow, chest and abdominal movement, pulse oximetry and body position. Analysis was performed automatically using standard software (Somnologica for Embletta™, Embla, The Netherlands) and subsequently reviewed and corrected by a sleep-disordered breathing specialist. Apnoea and hypopnoea were defined according to the American Academy of Sleep Medicine criteria [16]. Apnoeic events were detected when at least 10 s interval of the air flow signal dropped to ≤ 10% of baseline. Hypopnoeic events were detected when at least 10 s interval of the air flow signal dropped to ≤ 70% of baseline in combination with a ≥ 4% oxygen desaturation. Apnoea and hypopnoea were classified as either central or obstructive, depending on the absence or presence of thorax and abdominal movements. Cheyne-Stokes breathing was scored when there were at least three consecutive cycles of crescendo-decrescendo breathing amplitude with coexisting one of the following: (1) central AHI ≥ 5; (2) the cyclic crescendo-decrescendo change in breathing amplitude lasted for at least ten consecutive minutes. The CSA/CSR was classified as severe when AHI was at least 30, and moderate when the AHI was at least 15 and less than 30.

NT-proBNP

Blood samples were taken from all patients to determine NT-proBNP concentration (cobas e411, Roche, Switzerland).

Adaptive servoventilation

Servo-ventilation devices provide a mode of pressure support to treat obstructive and complex central sleep apnoea disorders. Dynamic bilevel pressure (BPAP) provides positive airway pressure support to sustain upper-airway patency. The expiratory pressure is set to eliminate obstructive apnoea/hypopnoea during sleep. The ASV device changes the inspiratory pressure above the expiratory pressure as required to normalise patients' ventilation. When the device detects normal breathing, dynamic BPAP acts like fixed continuous positive airway pressure (CPAP) by providing minimal pressure support; when the patient does not maintain the target peak inspiratory airflow, the device increases the pressure support above the expiratory pressure up to a maximum pressure, which can be set by the user. The device also provides automatic, timed, backup breaths during central apnoeas. The optimal backup rate is automatically determined by the device (based on the patient's sleep-disordered breathing presentation).

Table 1. Demographic and clinical data of the studied population

Variable	Total population (n = 39)	EOV patients (n = 12)	No-EOV patients (n = 27)	P*
Age [years]	61 ± 10	67 ± 8	59 ± 10	0.01
Male gender	39 (100%)	12 (100%)	27 (100%)	
Body mass index [kg/m^2]	30.0 ± 4.9	28.4 ± 4.8	30.7 ± 4.9	0.19
NYHA class	2.4 ± 0.6	2.6 ± 0.5	2.3 ± 0.7	0.24
Ischaemic aetiology	26 (67%)	9 (75%)	17 (63%)	0.71
Atrial fibrillation	8 (21%)	6 (50%)	2 (7%)	0.006
LVEF [%]	31 ± 7	28 ±6	33 ± 7	0.04
LVDD [cm]	6.6 ± 0.7	7.0 ±0.7	6.4 ± 0.6	0.02
Peak VO_2 [mL/kg/min]	13.8 ± 4.2	11.4 ±1.9	14.9 ± 4.4	0.001
VAT [mL/kg/min]	10.7 ± 2.9	9.5 ±1.4	11.1 ± 3.3	0.047
O_2 pulse [mL/beat/kg/100]	13.4 ± 3.4	12.0 ±3.3	14.0 ± 3.4	0.10
VE/VCO_2 slope	34.2 ± 8.6	41.1 ±7.3	31.2 ± 7.4	0.002
NT-proBNP [pg/mL]	839 (315; 3,101)	3,164 (855; 4,722)	375 (228; 1,143)	0.002
AHI [h^{-1}]	22.0 ± 16.6	31.1 ± 15.3	17.9 ± 15.7	0.01
AHI central [h^{-1}]	16.3 ± 16.1	28.2 ± 15.8	11.1 ± 13.4	0.004
Medications:				
ACE-I or ARB	38 (97%)	12 (100%)	26 (96%)	1.00
Beta-blockers	38 (97%)	12 (100%)	26 (96%)	1.00
Diuretics	36 (92%)	12 (100%)	18 (86%)	0.54
Spironolactone	32 (82%)	11 (92%)	21 (78%)	0.40

*EOV patients *vs* no-EOV patients; EOV — exercise oscillatory ventilation; NYHA — New York Heart Association; LVEF — left ventricular ejection fraction; LVDD — left ventricle diastolic diameter; VAT — ventilatory anaerobic threshold; VE/VCO_2 slope — slope of ventilatory equivalent for carbon dioxide; NT-proBNP — N-terminal pro-brain natriuretic peptide; AHI — apnoea-hypopnoea index; ACE-I — angiotensin-converting enzyme inhibitors; ARB — angiotensin-II receptor blocker

Therapeutic ASV was delivered from one of two devices (BIPAP AutoSV Advanced, Philips Respironics, Murrysville, PA, USA or AutoSet CS2, ResMed, Sydney, Australia) for three months. The therapy was initiated using the default settings and during the hospital stay was titrated with the aim of reducing the AHI to ≤ 10.

The study was approved by the Institutional Review Board of the Military Medical Chamber (IRB followed the Helsinki recommendations, approval number 38/07). All subjects provided informed consent.

Statistical analysis

Continuous data are expressed as mean ± SD or as median and first and third quartile in the case of skewed distributions (NT-proBNP). Characteristics of the study groups were compared by an unpaired Student t test or Mann-Whitney U test in case of non-normally distributed data. A Wilcoxon signed rank test or sign test were used for repeated measures (because of small sample size). For qualitative variables, the χ^2 test with Yates' correction and Fisher exact test, if necessary, was employed. Statistical differences with a p value < 0.05 were considered significant. All calculations were performed with statistical software (SAS 9.2, SAS Institute Inc., Cary, NC, USA).

RESULTS

Between January 2007 and September 2010, 39 patients met the inclusion criteria and were enrolled in this study. Demographic and clinical data for these patients are set out in Table 1.

Moderate to severe CSA/CSR was observed in 20 (51%) of the study sample. Ten (26%) of these presented a severe form (AHI ≥ 30) of sleep-disordered breathing. The EOV was detected in 12 (31%) subjects. Of all EOV patients, ten (83%) had AHI ≥ 15, while the other two (17%) patients had mild CSA/CSR. Compared to patients without EOV, patients with EOV had a significantly lower LVEF, peak VO_2, and VAT, and a significantly higher left ventricular diastolic diameter (LVDD), VE/VCO_2 slope, AHI, central AHI and NT-proBNP concentration (Table 1). Moreover, patients with EOV were significantly older and more frequently had permanent atrial fibrillation. There were no significant between-group differences in relation to other demographic and clinical characteristics, including NYHA functional class and O_2 pulse (Table 1).

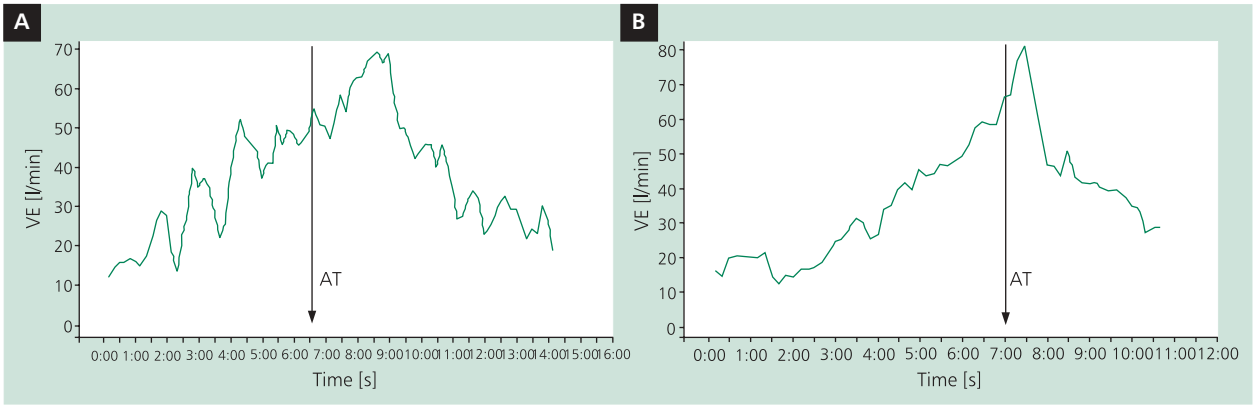

Figure 1. Representative example of exercise oscillatory ventilation (EOV) at baseline (**A**), and its resolution in the third month of adaptive servoventilation therapy (**B**); VE — minute ventilation; AT — anaerobic threshold

Of 20 patients with moderate to severe CSA/CSR, 14 patients were offered ASV therapy (the remaining six patients had other conventional therapeutic options such as cardioverter-defibrillator or cardiac resynchronisation device implantation). Two patients declined ASV therapy because of mask intolerance, and one subject for no specific reason. A total of 11 patients were successfully titrated on ASV, continued ASV therapy and underwent a follow-up visit in the third month of therapy. Medical treatment remained unchanged throughout the whole study period.

Resolution of exercise oscillatory ventilation

Eight patients out of 11 treated with ASV had EOV before therapy. The EOV was reversed in seven (86%) patients, and only in one patient did EOV persist ($p = 0.0156$). An example of the EOV pattern and its resolution is shown in Figure 1.

Sleep study

The AHI normalised during therapy, and resolution of Cheyne-Stokes breathing pattern was observed in all patients. There was a trend towards an improvement in mean nocturnal oxygen saturation, minimum nocturnal oxygen saturation and mean oxygen desaturation, but these did not reach statistical significance (Table 2).

Exercise response

Oxygen pulse increased significantly. There were trends towards an increase in peak oxygen uptake and VAT, but these did not reach statistical significance. The VE/VCO_2 slope did not change significantly (Table 2).

History, echocardiography and NT-proBNP

The LVEF increased significantly. The LVDD remained unchanged. There was a significant fall in the NT-proBNP concentration. There was a trend towards an improvement in NYHA functional class, but this did not reach statistical significance (Table 2).

DISCUSSION

Although periodic breathing during exercise in HF patients was described for the first time over 20 years ago [17], its clinical significance has only recently been appreciated. Recent reports have shown that EOV holds a high prognostic value in HF risk stratification. The EOV is superior to other conventional CPET-derived variables, including peak VO_2 and VE/VCO_2 slope, in predicting mortality and major cardiac events [4–9].

In this prospective study, we have demonstrated resolution of EOV with ASV therapy. Indeed, in all patients except for one treated with ASV, abnormal ventilatory pattern at baseline reversed in the third month of therapy.

The ASV is a novel method of treating patients with CSA/CSR. In our study, the effects of reverting EOV with ASV were accompanied by effective suppression of sleep-disordered breathing. The mechanisms responsible for resolution of EOV with ASV therapy are now a matter of speculation. It seems that periodic breathing both during sleep and exercise are coupled by the same pathophysiological mechanism [4, 15]. Both EOV and CSA/CSR are strictly associated with severity of HF. It has been demonstrated that different methods of therapy improving cardiac function, including medical treatment [18], cardiac surgery [19] and cardiac resynchronisation [20], may resolve sleep-disordered breathing. Only one study has reported reversal of abnormal ventilatory pattern during exercise in three patients treated with milrinone and two patients who underwent heart transplantation [17].

We observed EOV in 31% of patients and all patients with EOV had CSA/CSR. Our findings are similar to previously published data reporting the prevalence of EOV in HF patients of between 7% and 35%, and the coexistence of nocturnal with exertional periodic breathing [4–6]. Our results also confirmed a previously found correlation between EOV and severity of HF and impaired functional capacity [4–9, 21]. In the current study, patients with EOV compared to those without EOV had significantly lower LVEF, peak VO_2,

Table 2. Effects of ASV therapy in eight patients with EOV at baseline

Variable	Baseline	Follow-up	P
EOV	8 (100%)	1 (13%)	0.0156
AHI [h^{-1}]	30.0 ± 12.6	2.8 ± 3.4	0.008
AHI central [h^{-1}]	26.9 ± 13.2	0.0 ± 0.0	0.008
Mean SaO_2 [%]	91.1 ± 3.5	93.9 ± 2.0	0.063
Minimum SaO_2 [%]	70.3 ± 11.4	79.0 ± 15.0	0.22
Mean O_2 desaturation [%]	7.5 ± 1.7	5.4 ± 3.2	0.19
Peak VO_2 [mL/kg/min]	11.7 ± 2.2	14.6 ± 3.6	0.055
VAT [mL/kg/min]	9.9 ± 1.4	11.8 ± 2.1	0.094
O_2 pulse [mL/beat/kg/100]	13.1 ± 3.5	14.9 ± 4.2	0.047
VE/VCO_2 slope	42.5 ± 8.1	40.8 ± 11.0	0.74
LVEF [%]	27 ± 6	31 ± 7	0.008
LVDD [cm]	7.0 ± 0.6	7.0 ± 0.7	0.80
NT-proBNP [pg/mL]	3,164 (842; 4,513)	2,031 (915; 2,382)	0.039
NYHA class	2.5 ± 0.5	2.1 ± 0.6	0.25

SaO_2 — oxygen saturation; rest abbreviations as in Table 1 and Figure 1

and VAT, and significantly higher LVDD, VE/VCO_2 slope, AHI, central AHI and NT-proBNP concentration.

The ASV therapy not only reversed EOV and CSR, but also improved LVEF and decreased NT-proBNP concentration, which is in line with the findings of previous studies [10]. On the other hand, there was no significant improvement in NYHA functional class — which is probably a consequence of the short-term follow-up and small study group. Our results support the observation that ASV therapy does not change VE/VCO_2 slope [10].

Limitations of the study

The study was uncontrolled, the sample size was small, and the follow-up was short. The study showed that EOV could be reversed with ASV therapy, but the effects of EOV resolution on prognosis are unknown. Further studies are required to address this issue.

CONCLUSIONS

The present study provides original observation that periodic breathing during exercise could be reversed with ASV therapy. Because of the limitations of the study, further data is required.

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Conflict of interest: *none declared*

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Ustąpienie periodycznego oddychania w czasie wysiłku u pacjentów z przewlekłą niewydolnością serca i oddychaniem typu Cheyne-Stokesa leczonych adaptoserwowentylacją: doniesienie wstępne

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Streszczenie

Wstęp: Periodyczne oddychanie jest częstym zjawiskiem u pacjentów z przewlekłą niewydolnością serca (HF). Występuje ono nie tylko w czasie snu, ale i podczas wysiłku. Periodyczne oddychanie w czasie wysiłku (EOV) jest silnym predykatorem śmiertelności z przyczyn sercowych u pacjentów z HF. Adaptoserwowentylacja (ASV) jest nową metodą leczenia osób z oddychaniem typu Cheyne-Stokesa. Wykazano, że znacznie redukuje ona centralne bezdechy senne i normalizuje patologiczny tor oddychania w czasie snu.

Cel: Celem badania była ocena wpływu ASV na tor oddychania w czasie wysiłku.

Metody: Do badania włączono 39 pacjentów z przewlekłą HF, z frakcją wyrzutową lewej komory (LVEF) ≤ 45%. U wszystkich chorych wykonano badanie poligraficzne, ergospirometryczną próbę wysiłkową, badanie echokardiograficzne i oznaczono stężenie N-końcowego propeptydu natriuretycznego typu B (NT-proBNP). Oddychanie typu Cheyne-Stokesa i wskaźnik AHI (*apnea–hypopnea*) > 15/h stwierdzono u 20 (51%) pacjentów. U 11 spośród nich skutecznie wdrożono leczenie ASV. W 3. miesiącu terapii ponownie wykonano badanie poligraficzne, ergospirometryczną próbę wysiłkową, badanie echokardiograficzne i oznaczono stężenie NT-proBNP.

Wyniki: U 12 (31%) pacjentów z HF stwierdzono EOV, w tym u 8 (67%) leczonych ASV. Chorzy z EOV w porównaniu z osobami z prawidłowym torem oddychania w czasie wysiłku charakteryzowali się istotnie niższą LVEF, szczytowym pochłanianiem tlenu (VO_2), progiem beztlenowym oraz istotnie większym rozkurczowym wymiarem lewej komory, nachyleniem VE/VCO_2, AHI, centralnym AHI i stężeniem NT-proBNP. W 3. miesiącu terapii ASV stwierdzono ustąpienie EOV u 7 pacjentów, tylko u 1 osoby nie zaobserwowano poprawy w zakresie toru oddychania ($p = 0,0156$). Wśród pozostałych parametrów ergospirometrycznych tylko puls tlenowy istotnie wzrósł. Szczytowe pochłanianie tlenu i próg beztlenowy nieznacznie się poprawiły, ale różnice te nie osiągnęły istotności statystycznej. U wszystkich pacjentów leczonych ASV stwierdzono normalizację toru oddychania w czasie snu i zmniejszenie AHI do < 5/h. Ponadto w trakcie leczenia ASV zaobserwowano znamienne zwiększenie LVEF i istotną redukcję stężenia NT-proBNP.

Wnioski: Badanie pokazuje oryginalne zjawisko normalizacji toru oddychania w czasie wysiłku u pacjentów z centralnym bezdechem sennym leczonych ASV. Na podstawie powyższych danych nie można jednak wnioskować bezpośrednio o znaczeniu klinicznym tej obserwacji. Wpływ ustąpienia EOV w czasie leczenia ASV na rokowanie odległe wymaga przeprowadzenia dalszych badań. Również ze względu na ograniczenia tego badania (krótki okres obserwacji, mała grupa badana) jego wyniki wymagają potwierdzenia w kolejnych pracach.

Słowa kluczowe: oddychanie periodyczne w czasie wysiłku, zaburzenia oddychania w czasie snu

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