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Novel Ramp Test to Optimize Pressure Setting of Adaptive Servo-Ventilation Using Non-Invasive Lung Fluid Level Quantification

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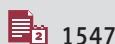
Patient: Male, 83-year-old
Final Diagnosis: Congestive heart failure
Symptoms: Dyspnea
Medication: —
Clinical Procedure: —
Specialty: Cardiology

Objective: Unusual clinical course

Background: Optimal patient selection and device pressure settings are key to successful adaptive servo-ventilation therapy, but there is no established strategy thus far. Adaptive servo-ventilation therapy at an inappropriately high pressure setting for those without pulmonary congestion decreases cardiac output and worsens clinical outcomes. The remote dielectric sensing system (ReDS) is a novel noninvasive tool to estimate the lung fluid amount. The ReDS might be a promising tool for successful adaptive servo-ventilation therapy if appropriately utilized for optimal patient selection and device pressure setting.

Case Report: An 83-year-old woman was admitted to our hospital to treat acute decompensated heart failure with preserved ejection fraction that was refractory to conventional medical therapy. Following the confirmation that she had significant pulmonary congestion with 47% of the ReDS value (normal range, 20-35%), we performed a “ramp test” to optimize device pressure, by measuring ReDS values and noninvasively estimating the cardiac output and stroke volume at each pressure setting. The device pressure setting was finally determined to minimize pulmonary congestion and maximize cardiac output. Following the continuous adaptive servo-ventilation therapy with the optimized pressure setting, the patient’s hospitalization was uneventful and she was discharged.

Conclusions: We propose performing a ramp test to optimize the pressure setting of adaptive servo-ventilation by utilizing ReDS technology for each patient, instead of using a default or inappropriately higher pressure setting. However, further studies including large patient populations are warranted to validate the prognostic implication of this customized ramp test protocol.

Keywords: Heart Failure • Hemodynamics • Pulmonary EdemaFull-text PDF: <https://www.amjcaserep.com/abstract/index/idArt/935086>

Background

Adaptive servo-ventilation is noninvasive positive pressure ventilation that improves morbidity and mortality in patients with congestive heart failure by reducing cardiac unloading and venous return, suppressing sympathetic nerve activity owing to respiratory stabilization, improving cardiac output, and facilitating cardiac reverse remodeling [1]. However, adaptive servo-ventilation therapy performed at relatively high pressure settings to aggressively treat sleep disorders has aggravated clinical outcomes in patients with heart failure [2]. Therefore, creating optimal patient selection by identifying the existence of pulmonary congestion, which should be a therapeutic target, as well as the optimal adjustment of the pressure setting to maintain or increase cardiac output, should be required for successful adaptive servo-ventilation therapy [1].

Our team previously proposed a novel protocol to optimize the device pressure setting by performing a “ramp test”, during which hemodynamics were invasively measured at incremental device pressure settings [3]. A critical limitation of this test was the requirement of invasive right heart catheterization.

Recently, a remote dielectric sensing system (ReDS, Sensible Medical Innovations Ltd, Netanya, Israel), which is a noninvasive wearable device to estimate the lung fluid amount, has been introduced and has become available internationally (Figure 1) [4]. Our hospital was the first to use this device in Japan, before it was used commercially.

We hypothesized that a novel ramp test using the ReDS system might be a noninvasive and promising protocol to optimize device pressure settings and improve clinical outcomes in patients with congestive heart failure receiving adaptive servo-ventilation.

Case Report

Before Referral

Two years prior to referral to our institution, an 83-year-old woman with a history of type 2 diabetes mellitus, hypertension, and paroxysmal atrial fibrillation was admitted to a former hospital to treat congestive heart failure, which was treated with diuretics. Following discharge, her symptoms remained relatively stable on 10 mg/day of furosemide.

On Referral

The patient was admitted to our hospital with concerns of having dyspnea at rest. Her height was 150 cm, weight was 42.7 kg, blood pressure was 177/113 mmHg, heart rate was 130 beats per min, and oxygen saturation was 90% under 10 L/min oxygen supply via facial mask. Her plasma B-type natriuretic peptide level was 389 pg/mL.

Chest X-ray showed cardiomegaly and bilateral pulmonary congestion (Figure 2A). An electrocardiogram showed sinus



Figure 1. The remote dielectric sensing system: (A) a monitor (B) and a sensor.

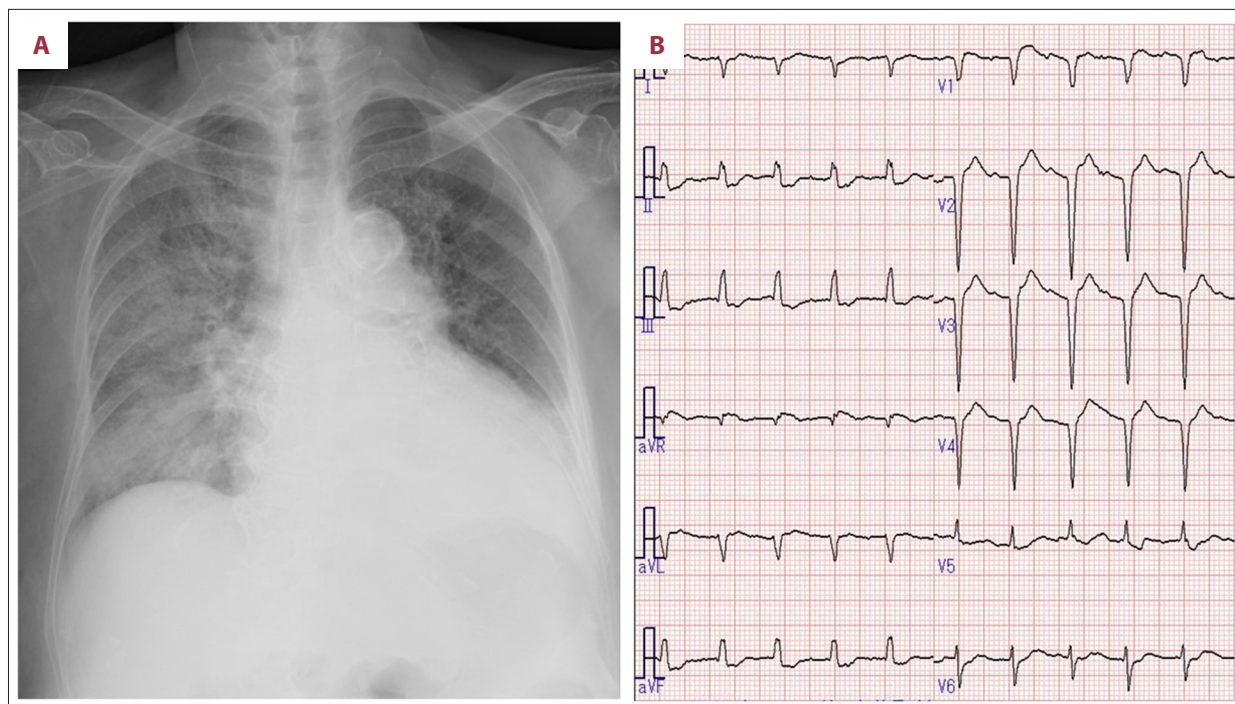


Figure 2. (A) Chest X-ray and (B) electrocardiogram on admission.

tachycardia and poor R progression in V1-4 (**Figure 2B**). In transthoracic echocardiography, the left ventricular diastolic diameter was 46 mm and left ventricular ejection fraction was 64%, accompanying mild mitral regurgitation and mild tricuspid regurgitation, as well as preserved respiratory change in the inferior vena cava diameter. The patient's ReDS value on admission was 55% (normal range, 20-35%).

In-Hospital Course

We initiated the intravenous administration of cilnidipine and biphasic positive airway pressure therapy to unload the left ventricle, reduce venous return, and improve systemic oxygenation (**Figure 3A**). Intravenous furosemide and oral tolvaptan were administered for persistent pulmonary congestion. Biphasic positive airway pressure was weaned off on day 3 but was initiated again for worsening pulmonary congestion on day 4. We initiated adaptive servo-ventilation on day 10 to continue respiratory therapy out of the Intensive Care Unit. The patient's ReDS value before the initiation of adaptive servo-ventilation therapy was 47% (**Figure 3B**).

Ramp Test

We performed a ramp test using adaptive servo-ventilation (AirCurve 10 CS-A TJ, ResMed) with a full-face mask (AirFit F20, ResMed) to optimize the pressure setting (**Figure 4**). The device was set to deliver appropriate minimum and maximum inspiratory support between 3 and 10 cmH₂O. A default setting

of end-expiratory pressure was 5 cmH₂O, which was adjusted according to the ramp test.

During the ramp test, (1) the ReDS value, which indicated lung fluid amount [4], and (2) stroke volume, which was estimated noninvasively by using the AESCULON mini [5], were measured at incremental end-expiratory pressure (**Figure 4**). The patient was made to sit at rest for 3 min at each pressure setting.

The ReDS value was highest at baseline and gradually decreased at incremental pressure settings (from 35% to 27%). The stroke volume was highest at 3 to 4 cmH₂O of end-expiratory pressure setting and gradually decreased at further incremental pressure settings. The patient expressed discomfort at pressure settings above 6 cmH₂O. Therefore, we set the end-expiratory pressure at 4 cmH₂O.

Post-Ramp Test Course

Following the initiation of adaptive servo-ventilation therapy at 4 cmH₂O of end-expiratory pressure, the serum creatinine level transiently increased but then decreased to the baseline level. The plasma B-type natriuretic peptide level also decreased to around 100 to 300 pg/mL. The dose of furosemide was decreased from 40 mg/day to 20 mg/day. The ReDS value further decreased to 27% following the 5-day adaptive servo-ventilation therapy (on day 15, **Figure 3C**). The patient underwent a pacemaker implantation for symptomatic bradycardia on day 19. She also received percutaneous coronary interventions to

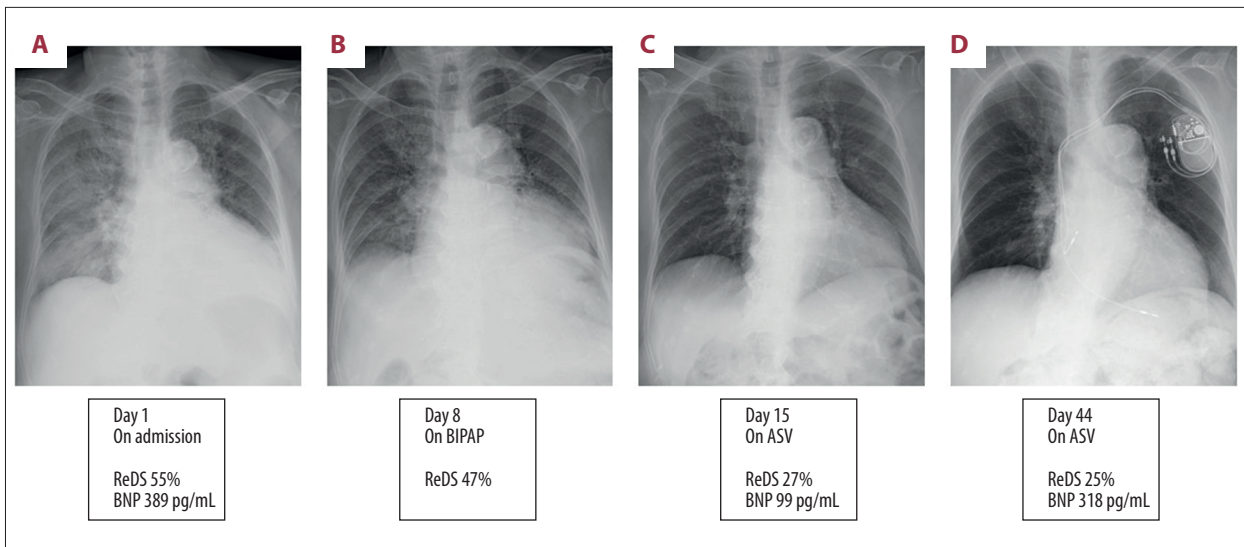


Figure 3. (A-D) Time course of chest X-ray and ReDS values. ReDS – remote dielectric sensing; BNP – B-type natriuretic peptide; ASV – adaptive servo-ventilation.

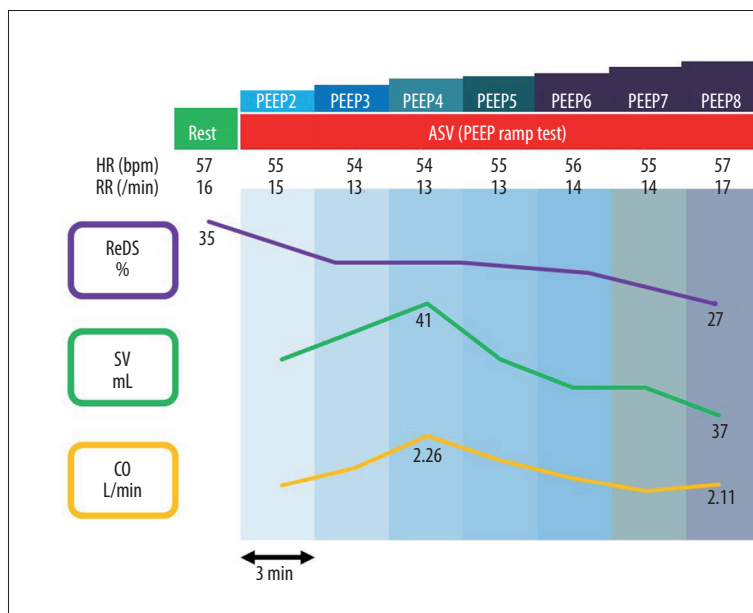


Figure 4. The ramp test. The ReDS value decreased at incremental pressure settings, whereas the SV had a peak at PEEP 4 cmH₂O. HR – heart rate; RR – respiratory rate; ReDS – remote dielectric sensing; SV – stroke volume; CO – cardiac output; PEEP – positive end-expiratory pressure.

the right coronary artery and left anterior interventricular artery on day 26 and day 33, respectively. She finally received percutaneous left atrial appendix closure on day 41.

She was discharged on day 44 following the confirmation that the ReDS value was 25% (Figure 3D). The plasma B-type natriuretic peptide level was 318 pg/mL. The New York Heart Association functional class was II. She continued adaptive servo-ventilation therapy following the index discharge until 1 month later, when congestion was well controlled.

Discussion

Optimal Patient Selection

Given the conflicting findings of adaptive servo-ventilation therapy between Japan and other nations (ie, positive outcomes in Japan and negative outcomes elsewhere), optimal patient selection should be one of the keys to successful adaptive servo-ventilation therapy [1]. A key target of this therapy is pulmonary congestion, and the existence of pulmonary congestion is essential for safe and effective adaptive servo-ventilation therapy.

However, there have been no established methodologies to accurately quantify the degree of pulmonary congestion. Chest X-ray and computed tomography are conventional tools, but these require expert techniques to assess, and the assessment is quantitative. Plasma B-type natriuretic peptide levels can be referenced, but there are several challenges in interpreting the value, including age, obesity, and renal function [6]. Right heart catheterization and CardioMEMS can directly measure intracardiac pressure. However, these procedures are invasive. We should also understand the difference between volume and pressure [7]. Patients with advanced heart failure sometimes have elevated intracardiac pressure without pulmonary congestion.

The ReDS is a novel device that can estimate lung fluid amounts noninvasively, quickly, and easily by an operator without extended experience [4]. It was found that the ReDS value had a considerable correlation with the amount of pulmonary congestion estimated by computed tomography using a specific software [8]. Our patient had an ReDS value of 47%, which was beyond the upper limit of the manufacturer-recommended normal range of 35% [4]. This is the reason we adopted adaptive servo-ventilation therapy on this patient. We highly encourage clinicians to measure ReDS values to confirm the presence of pulmonary congestion before performing adaptive servo-ventilation therapy.

Optimal Device Pressure Setting

The findings of the SERVE-HF trial showed that a relatively high end-expiratory pressure setting may not be recommended or rather should be avoided to prevent low cardiac output during adaptive servo-ventilation therapy [2]. However, the methodology to optimize pressure settings remains unknown. The conventional way has been to avoid extensive pressure that patients find uncomfortable.

We recommend performing a ramp test to optimize the device's pressure settings. During the ramp test, we measure pulmonary congestion and cardiac output at an incremental pressure setting. As we presented here, pulmonary congestion improved at incremental pressure settings, whereas cardiac output decreased at an extremely high-pressure setting,

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probably due to considerable reduction in preload. The respiratory rate was relatively high at baseline but stabilized with the appropriate pressure setting. Too much device pressure increased the respiratory rate, indicating the patient's discomfort. We will decide the final pressure setting at which the pulmonary congestion and cardiac output are ameliorated together. This is a proof-of-concept study, given it is a single case report, and clinical trials including cohorts with a large sample sizes are warranted to validate the implication of our novel test.

There are several limitations to this report. We should state that the patient received adaptive servo-ventilation-incorporated combination therapy. Percutaneous coronary intervention would have improved myocardial ischemia and relieved ischemic injury. Pacemaker therapy would have increased cardiac output and improved systemic perfusion. Both therapies would also have affected her heart failure improvement, together with adaptive servo-ventilation therapy. During the ramp test, we waited for 3 min at each pressure setting, according to the previous report [9], but the appropriate wait time remains uncertain. Hemodynamics and congestion status might vary during the long-term follow-up period. Repeated ramp tests and re-adjustment of the pressure setting might be recommended if necessary. Improvement in each parameter during the ramp test might be trivial. Their prognostic impact should be validated in the next study. The patient had preserved ejection fraction, as did patients in previous studies [10], but the applicability of our ramp test should be validated in a variety of clinical scenario.

Conclusions

We propose using the ramp test to optimize the pressure setting for successful adaptive servo-ventilation therapy using the ReDS system, although further studies including large samples of patients are warranted.

Declaration of Figures' Authenticity

All figures submitted have been created by the authors who confirm that the images are original with no duplication and have not been previously published in whole or in part.

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