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CASE REPORT
Arrhythmias/Electrophysiology

Non-contact heart rate variability monitoring using Doppler radars located beneath bed mattress: a case report

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Background Heart rate variability (HRV) has been investigated previously in autonomic nervous system-related clinical settings. In these settings, HRV is determined by the time-series heartbeat peak-to-peak intervals using electrocardiography (ECG). To reduce patient discomfort, we designed a Doppler radar-based autonomic nervous activity monitoring system (ANMS) that allows cardiopulmonary monitoring without using ECG electrodes or spirometry monitoring.

Case summary Using our non-contact ANMS, we observed a bedridden 80-year-old female patient with terminal phase sepsis developed the daytime Cheyne-Stokes respiration (CSR) associated with the attenuation of the low frequency (LF) and high frequency (HF) of HRV components 20 days prior to her death. The patient developed a marked linear decrease in the LF and the HF of HRV components for over 3 days in a row. Furthermore, after the decrease both the LF and the HF showed low and linear values. Around the intersection of the two lines, the decreasing LF and HF lines and the constant LF and HF lines, the ANMS automatically detected the daytime CSR pathogenesis. The attenuation rate of HF (1340 ms^2/day) was higher than that of LF (956 ms^2/day). Heart rate increased by ~10 b.p.m. during these 3 days.

Discussion We detected CSR-associated LF and HF attenuation in a patient with terminal phase sepsis using our ANMS. The proposed system without lead appears promising for future applications in clinical settings, such as remote cardiac monitoring of patients with heart failure at home or in long-term acute care facilities.

Keywords Sepsis • Autonomic nervous activity • Heart rate variability • Cheyne-Stokes respiration • Non-contact monitoring • Case report

Learning points

- An 80-year-old female patient with sepsis developed the attenuation of the low frequency (LF) and high frequency (HF) of heart rate variability components associated with Cheyne-Stokes respiration (CSR).
- Around the intersection of the decreasing HF and LF line and the subsequent constant HF and LF line, CSR was observed.
- The present procedure could potentially enable the cardiopulmonary monitoring of hospitalized and home-care patients.

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Introduction

In this study, we present a non-contact monitoring case following the attenuation of the low-frequency (LF) and high-frequency (HF) components of heart rate variability (HRV) associated with Cheyne-Stokes respiration (CSR) in an 80-year-old female patient with terminal phase sepsis in a long-stay hospital, using only Doppler radars located beneath the bed mattress. In order to reduce patient discomfort, we designed a Doppler radar-based autonomic nervous activity monitoring system (ANMS) that allows cardiopulmonary monitoring without using electrocardiography (ECG) electrodes or spirometry monitoring. The patient died 20 days after the daytime CSR-associated LF and HF decrease. The frequency- and time-domain HRVs have already been investigated previously in autonomic nervous system (ANS)-related clinical settings,[1] while the correlation between the HRV and ANS remains to be elucidated.[2] The correlation between the LF (0.04–0.15 Hz) and baroreflex function was investigated by Rahman *et al.*[3] The HF (0.15–0.4 Hz) includes a normal respiratory frequency value (~0.25 Hz).[4] A decrease in HRV parameters has been reported mainly in neonatal sepsis.[5,6] In addition to HRV, ANMS automatically determines the pathogenesis of CSR.

Doppler radar-based ANMS does not require ECG electrodes and could be applied for contactless bedside cardiopulmonary monitoring. We have previously described how Doppler radar monitoring of cardiopulmonary indices could be applied for infection screening.[7–9] The frequency-domain HRV is calculated from the power spectrum densities determined from time-series heartbeat intervals.[1] This case report of a patient with terminal phase sepsis describes the non-contact monitoring of the CSR-related, coincidentally generated LF and HF attenuation, using only compact dual radars located beneath the bed mattress.

Timeline

Date	Events
24 October 2016	• Admitted to a long-stay hospital for Alzheimer's dementia • Developed myelodysplastic syndrome • Observed to have anaemia and thrombocytopenia • Difficulties in ingestion • Adopted nutritional support via central venous hyperalimentation
22 November 2016	• Suspected sepsis
22–28 November 2016	• Administered ampicillin sodium (1.5 g × 2)
29 November 2016	Administered meropenem hydrate (0.25 g × 2)
7 January 2017	• Developed attenuation of Cheyne-Stokes respiration-associated autonomic nervous system activation
20 January 2017	• Presented low systolic arterial pressure (49 mmHg)
27 January 2017	• Died of multiple organ dysfunction syndrome

Case presentation

An 80-year-old woman was admitted to a long-stay hospital for Alzheimer's dementia with previous history of chronic subdural haematoma, old cerebral infarction, dysphagia, and glaucoma on 24 October 2016. With an anxious expression on her face, physical examination revealed that she was 150 cm tall and body weight 30.1 kg with vital signs of body temperature 37.1°C, blood pressure 94/65 mmHg, heart rate 70 b.p.m. with ECG features of normal sinus rhythm, respiratory rate 20 breaths/minute, and transcutaneous arterial oxygen saturation 94%. White blood cell count (WBC) was 12 490 count/μL on admission and increased to 17 580 count/μL on 29 November. C-reactive protein also drastically increased from 1.31 mg/dL on admission to 2.20 mg/dL on 29 November. On admission, brimonidine tartrate drop was administered. After admission, she developed myelodysplastic syndrome (MDS) with anaemia and thrombocytopenia. MDS is a heterogeneous disorder related to haematopoietic abnormalities that are frequently found in elderly people. As ingestion intake was difficult, nutritional support via a central venous hyperalimentation route was adopted. She developed suspected sepsis and was treated with ampicillin sodium (3000 mg/day) on 22 November, with meropenem hydrate (500 mg/day) from 29 November, with ceftazidime hydrate (1000 mg/day) and gentamicin sulphate (80 mg/day) from 7 December, with ampicillin sodium (1500 mg/day) from 30 December, and with meropenem hydrate (250 mg/day) from 11 January 2017.

From 5 January to 7 January, ANMS monitoring showed a marked linear decrease in the LF and HF of HRV components. Furthermore, from 7 January to 12 January, both the LF and HF showed low and linear values (*Figure 1*). On 7 January, at 2:00 p.m., the ANMS automatically registered the CSR pathogenesis (*Figure 2*) around the intersection of two lines, that is, the decreasing LF line (from 5 January to 7 January) and the constant LF line (from 7 January to 12 January). The intersection of the LF lines overlapped with the intersection of the decreasing HF line (from 5 January to 7 January) and the constant HF line (from 7 January to 12 January). Our patient died from multiple organ dysfunction syndrome 20 days after the registration of daytime CSR pathogenesis.

The attenuation rate of HF (1340 ms^2/day) was higher than that of LF (956 ms^2/day). The heart rate increased by ~10 b.p.m. during these 3 days.

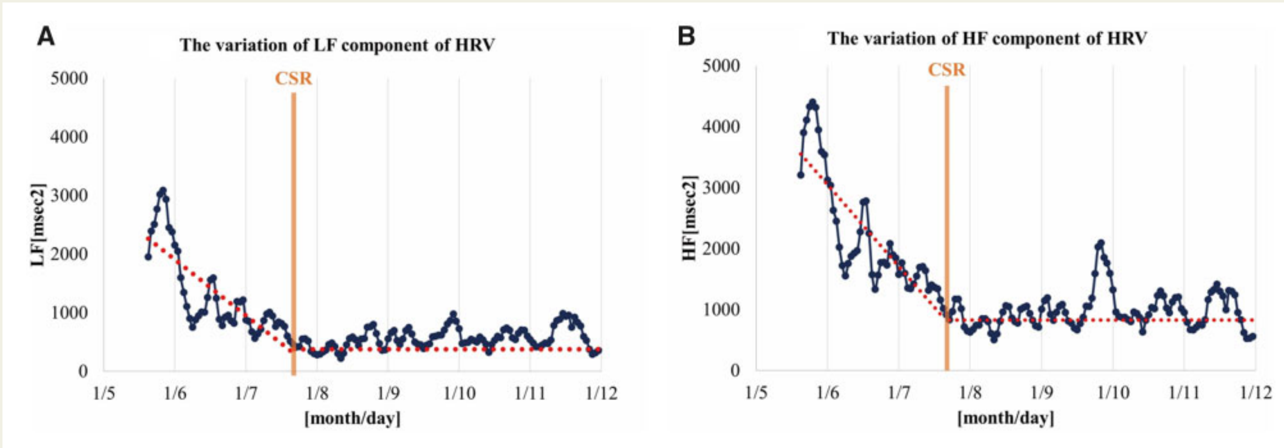

Figure 1 Data recorded from an 80-year-old patient with sepsis using Doppler radars located beneath the bed mattress. From 5 January to the 7 January, our non-contact system recorded a marked linear decrease in the low-frequency component (*A*) and the high-frequency component (*B*) of the heart rate variability. At the intersection of the two lines (7 January daytime), the novel autonomic nervous activity monitoring system automatically detected daytime Cheyne-Stokes respiration. CSR, Cheyne-Stokes respiration; HF, high frequency; HRV, heart rate variability; LF, low frequency.

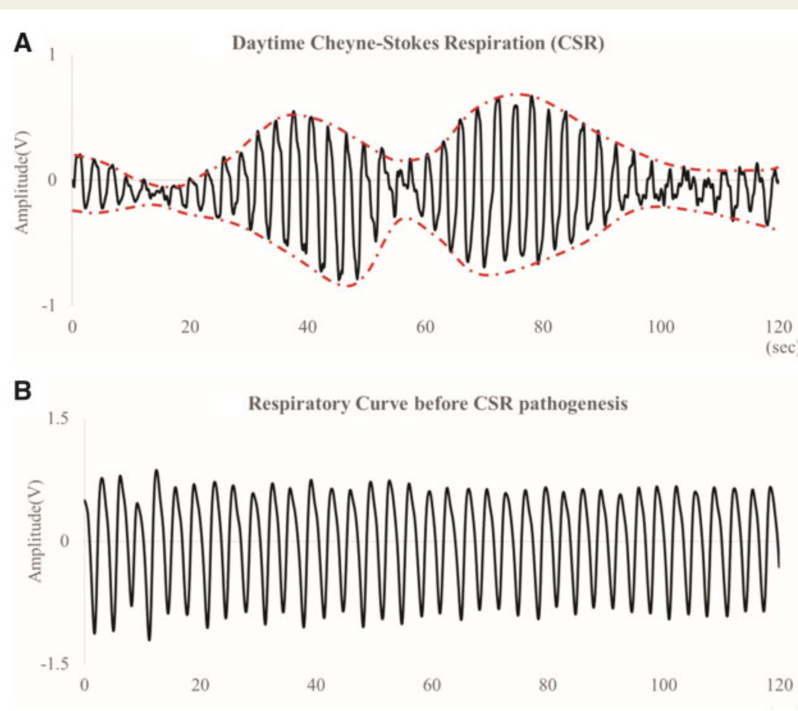

Figure 2 (*A*) Cheyne-Stokes respiration on 7 January. The novel autonomic nervous activity monitoring system automatically detected the Cheyne-Stokes respiration pathogenesis in the patient with sepsis who died 20 days later. (*B*) Respiratory curve before Cheyne-Stokes respiration pathogenesis. CSR, Cheyne-Stokes respiration.

Discussion

The feature of ANMS is that without using neither ECG nor a spirometer, it simultaneously monitors cardiac (e.g. heart rate and HRV) and respiratory parameters including abnormal ventilation patterns such as CSR in bedridden patients. The ANMS is composed of compact dual Doppler radars (24 GHz, 10 mW micro-output power) installed beneath the bed mattress. *Figure 3* shows a data-processing ANMS diagram. The radar records Wave 1, which contains a respiratory and a heartbeat component. First, the ANMS separates Wave 1 into Wave 2 (the respiratory component) and Wave 3 (the heartbeat component). Wave 2 is calculated using a

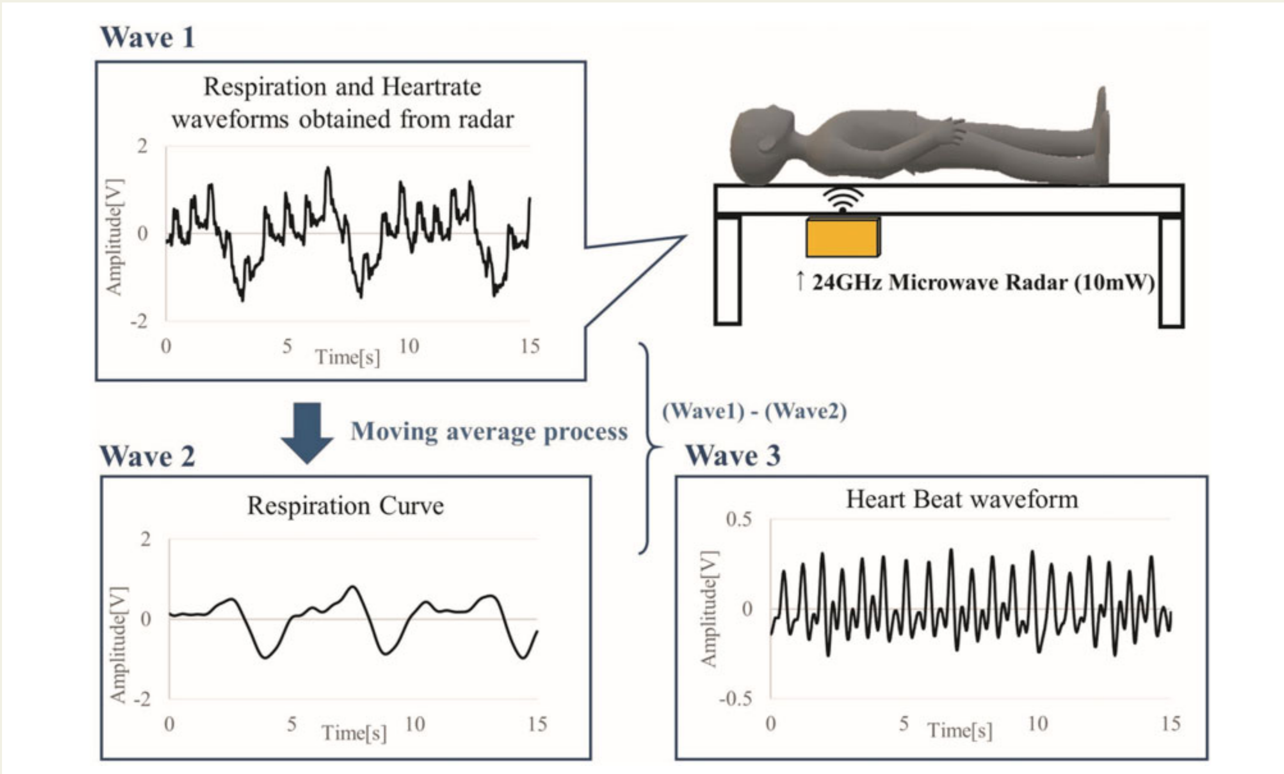

Figure 3 Our novel autonomic nervous activity monitoring system for monitoring heart rate variability and abnormal ventilation patterns. The autonomic nervous activity monitoring system measures respiratory and cardiac-origin skin surface micro-vibrations via dual Doppler radars located beneath the bed mattress, without requiring electrodes. Dual Doppler radars are placed beneath the bed mattress of the admitted patient to record Wave 1, which contains the respiratory component and the heartbeat component. The autonomic nervous activity monitoring system then separates Wave 1 into Wave 2 (the respiratory component) and Wave 3 (the heartbeat component) using a simple moving average. The ventilation is monitored from Wave 2. The cardiac parameters are then calculated from Wave 3, which is derived by subtracting Wave 2 from Wave 1. The heart rate variability is calculated from the time-series inter-beat intervals in Wave 3.

moving average filter to remove the heartbeat component from Wave 1. Wave 3 (e.g. an ECG waveform) is calculated as the difference between Wave 1 and Wave 2. Next, the ventilation is monitored from Wave 2, and the cardiac parameters are determined from Wave 3. The frequency of the time-series heartbeat peak-to-peak intervals is obtained from Wave 3. Finally, the LF (0.04–0.15 Hz) and the HF (0.15–0.4 Hz) components of the HRV are calculated by applying an autoregressive power spectrum density estimation.

In addition to the HRV, the ANMS enables automatic CSR detection. Specifically, the ANMS defines a sequence of respiratory curves as CSR when the respiratory curve envelope (dotted line in Fig. 2) indicates a CSR built-in oscillation (0.0083–0.04 Hz). In the present case, we detected CSR-associated LF and HF attenuation in an 80-year-old female patient with terminal phase sepsis using our non-contact ANMS. Specifically, this system intensively assessed changes in HRV and ventilation in patients with sepsis. We focused on LF, HF, and two-line intersections at the point when daytime CSR pathogenesis occurred 20 days before the patient died.

This study has a limitation in the physiological understanding of LF and HF decreases. While several studies have been conducted on the relationship between sympathetic nervous activities and LF,[10,11] intense exercise, which was expected to increase sympathetic nervous activity, resulted in a decrease in LF.[12] The correlation between HF and parasympathetic nervous activity was investigated under pharmacological autonomic block with atropine.[13] However, under high-dose atropine, not only HF but also LF disappeared.[14]

Another limitation of the ANMS is that the pulse wave determined is not electrophysiological. Thus, it is difficult to distinguish torsades de pointes from other types of extrasystoles. Nevertheless, the ANMS- and spirometry-derived respiratory curves were equivalent.

Traditional lead-based HRV has already been used to identify neuropathy-related illnesses in an intensive treatment unit.[15] The proposed system without lead appears promising for future applications in clinical settings, such as remote cardiac monitoring of patients with heart failure at home or in long-term acute care facilities.

Conclusion

We applied ANMS to an 80-year-old patient with sepsis. Without using ECG electrodes or a spirometer, this system detected the terminal phase of the illness 20 days prior to the death of the patient, indicated by CSR-associated HRV LF and HF attenuation.

The present procedure could potentially enable the cardiopulmonary monitoring of hospitalized and home-care patients.

Lead author biography

Yusuke Otake received the bachelor's and master's degrees in engineering from Tokyo Metropolitan University, Tokyo, Japan, in 2019 and 2021, respectively. He works in medical engineering, focusing on non-contact vital sign measurement, pneumonia screening system design, terminal phase patient monitoring system design, and biomedical signal processing.

Supplementary material

Supplementary material is available at *European Heart Journal - Case Reports* online.

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Slide sets: A fully edited slide set detailing this case and suitable for local presentation is available online as Supplementary data.

Consent: The authors confirm that written consent for submission and publication of this case report including images and associated text has been obtained from the patient in line with COPE guidance.

Conflict of interest: None declared.

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