Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Journal of Infection 81 (2020) e142–e144

Contents lists available at ScienceDirect

Journal of Infection

journal homepage: www.elsevier.com/locate/jinf

A Pneumonia Screening System based on Parasympathetic Activity Monitoring in Non-contact Way using Compact Radars Beneath the Bed Mattress.

Dear Editor,

We previously reported in the *Journal of Infection* infection-screening systems based on vital signs.[1–6] The World Health Organization (WHO) has reported that lower respiratory tract infections, including pneumonia, were the fourth leading cause of death in 2016[7]. COVID-19 pneumonia, as well as conventional pneumonia, induces a systemic inflammatory response,[8] which is associated with elevated respiratory rate (RR) and heart rate (HR). Increases in HR are frequently associated with attenuation of parasympathetic nervous function. Here, we propose a novel pneumonia screening system (PSS) to monitor changes in parasympathetic nervous function and vital signs induced by pneumonia pathogenesis.[9–10] The PSS monitors pneumonia pathogenesis in a non-contact manner (*i.e.*, without using any electrodes) while the patient is lying in a bed.

This PSS is composed of a pair of compact Doppler radars (24 GHz, 10 mW micro-output power) installed beneath the bed mattress and pneumonia-screening algorithms (Fig. 1). The PSS does not adopt thermography for body temperature measurement, since such individual monitoring over 24 h may raise privacy concerns.

The PSS monitors parasympathetic nervous system activation, by means of the high-frequency (HF) component of the heart rate variability (HRV), as well as the HR and RR. The HF is modulated by the vagal tone, which is frequently attenuated as the HR increases. The Mahalanobis' squared distance (MSD), a non-Euclidean distance representing the extent of separation between two groups, is then determined from the three-dimensional distributions of the RR, HR, and HF before and after pneumonia onset[6]. The results shown in Fig. 2 indicate that the MSD drastically increases at the moment of pneumonia pathogenesis.

Because the vital signs of elderly patients vary between individuals more than among young adults and middle-aged people, we adopted the MSD to determine the optimal screening conditions for elderly patients. The vital signs recorded in 8-hour period are classified into two groups (anterior half 4 hours (before pathogenesis) and latter half 4 hours (after pathogenesis)) to determine the MSD from the RR, HR, and HF values.

The PSS algorithms utilize a linear discriminant (LD) function to detect pneumonia pathogenesis from the maximum MSD value and the corresponding RR, HR, and HF of each patient. The Z value of the LD function is expressed as follows:

$$Z = a \cdot MSD + b \cdot \Delta RR/\Delta t + c \cdot \Delta HR/\Delta t + d \cdot \Delta HF/\Delta t + e,$$

where $\Delta RR/\Delta t$, $\Delta HR/\Delta t$, and $\Delta HF/\Delta t$ are the rates of change in the parameters over the past 8 hours.

We conducted a clinical test of the PSS with 19 chronically ill, bedridden patients without pneumonia (12 females and 7 males aged 42–90 years) for five consecutive days. The participants were recruited at Genkikai Yokohama Hospital. During the clinical testing period, two patients developed pneumonia, as diagnosed by chest X-ray and based on sputum examination.

Fig. 1 shows a schematic of the PSS. The system does not require any electrodes to be attached to the patient. Two Doppler radar sensors were installed beneath the bed mattress to record Wave 1, which contains a respiratory component and heartbeat component. One Doppler radar with higher signal-to-noise ratio output signal is automatically selected depending on the situation. The PSS then separates Wave 1 into Wave 2 (the respiratory component) and Wave 3 (the heartbeat component). To isolate the respiratory component (Wave 2) from the heartbeat component, a simple moving average (SMA) is calculated from Wave 1 at 0.5 s intervals. The heartbeat component (Wave 3) is calculated as the difference between Wave 1 and Wave 2. Then, the RR is determined from Wave 2, and the HR is calculated from Wave 3. In addition, the PSS evaluates the time-series heartbeat peak-to-peak (PP) intervals from Wave 3, then the HF component (0.15–0.4 Hz) of the HRV, corresponding to parasympathetic nervous system activity, is obtained by applying an autoregressive (AR) power spectrum density estimation. The system displays the HR and RR of a patient on a monitor at the nurses' station. The PSS system also calculates the Z value of the LD function as follows:

$$Z = 0.18 \cdot MSD + 0.15 \cdot \Delta RR/\Delta t + 0.12 \cdot \Delta HR/\Delta t + 0.001 \cdot \Delta HF/\Delta t - 3.$$

When Z is greater than 0, the PSS indicates that pneumonia is suspected.

Fig. 2 shows the RR, HR, and HF of a patient before and after pneumonia pathogenesis as three-dimensional plots. The left plot depicts the changes before and after pneumonia pathogenesis, and the right plot shows the moment PSS measured upon pneumonia pathogenesis (shadowed area), during the period for this patient. The data show that the RR and HR increase, while HF decreases, indicating attenuation of parasympathetic nervous activity.

The most important indices for pneumonia screening, the sensitivity and negative predictive value (NPV), were both 100% for this PSS. Based on these findings, the PSS appears promising for future pneumonia screening, potentially in patients with COVID-19, in hospitals or at home. This system offers unique benefits in healthcare as it does not require the use of electrodes and imposes minimal inconvenience to the examinee.

https://doi.org/10.1016/j.jinf.2020.06.002

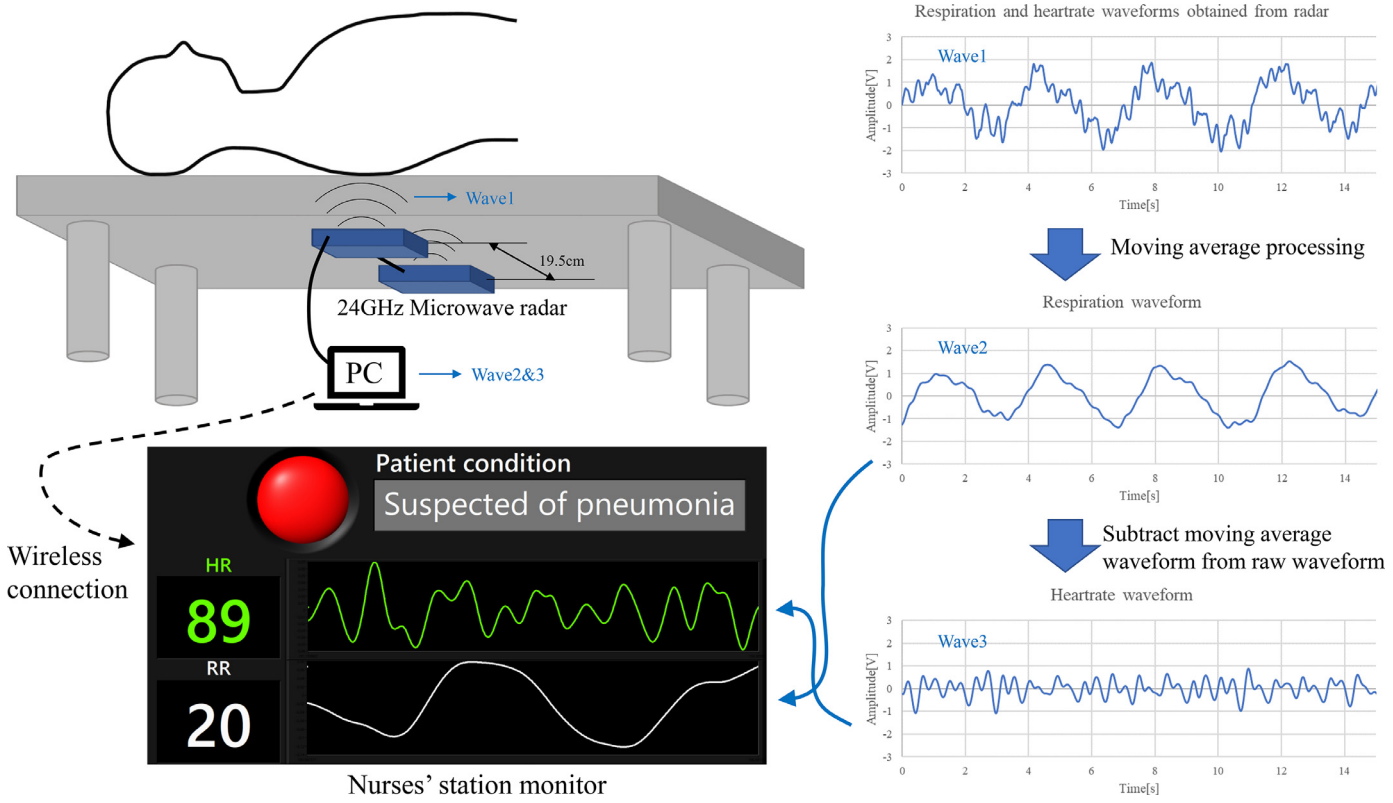

Fig. 1. Pneumonia screening system (PSS) composed of two compact Doppler radars (24 GHz, 10 mW micro-output power) installed beneath the bed mattress and pneumonia screening algorithms. Using this system, the PSS monitors the heart rate (HR) and respiratory rate (RR) of a bedridden patient without using any electrodes and displays them at the nurses' station. When $Z > 0$ (where $Z = 0.18 \blacksquare MSD + 0.15 \blacksquare RR/\Delta t + 0.12 \blacksquare \Delta HR/\Delta t + 0.001 \blacksquare \Delta HF/\Delta t - 3$), the PSS indicates that the patient is "suspected of pneumonia". The dual radars of the PSS installed beneath the bed mattress monitor Wave 1, which contains both the respiratory component and the heartbeat component. The PSS then separates Wave 1 into Wave 2 (the respiratory component) and Wave 3 (the heartbeat component). The RR is determined from Wave 2, and the HR and HF of the heart rate variability (HRV) are calculated from Wave 3.

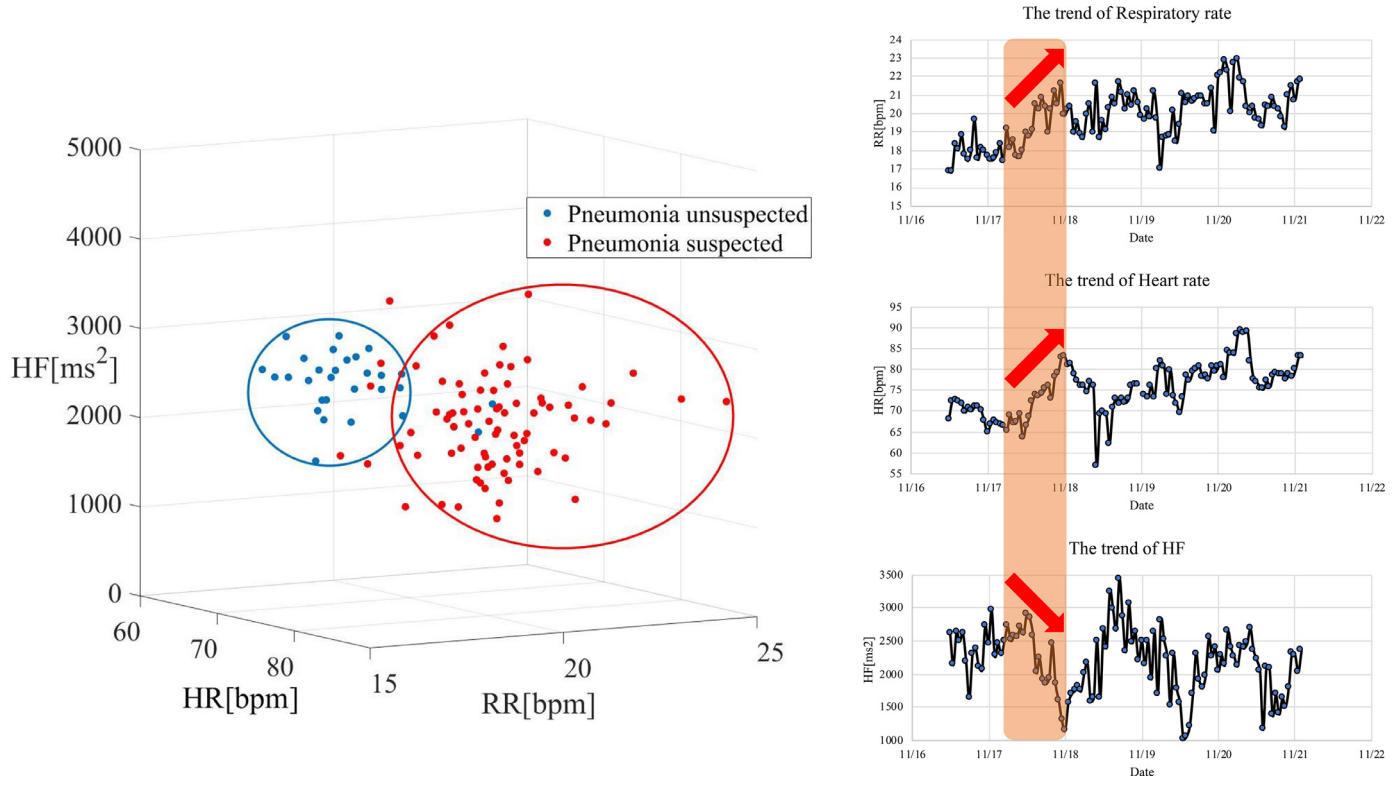

Fig. 2. Left: Three-dimensional plots of heart rate (HR), respiratory rate (RR), and HF (representing parasympathetic nervous activity) before and after pneumonia pathogenesis (*i.e.*, pneumonia unsuspected and suspected, respectively). Right: The moment of pneumonia pathogenesis in a patient (shadowed area) identified by the PSS; at this point, the RR and HR increase, and the parasympathetic nervous activity decreases (represented by an increase in the HR).

Conflicts of interest

The authors declare that they have no conflicts of interest.

Ethical Approval

The present study was approved by the ethics committees of Genkikai Yokohama Hospital, Tokyo Metropolitan University, Hino Campus and Konica Minolta, Inc.

Acknowledgements

The author sincerely thanks Ms. Saeko Nozawa for her contributions to manuscript preparation and revision and Ms. Yoko Kato for her support in drawing figures. We thank Stephanie Knowlton, PhD, from Edanz Group (https://en-author-services.edanzgroup.com/) for editing a draft of this manuscript.

References

1. Dagdanpurev S, Abe S, Sun G, Nishimura H, Choimaa L, Hakozaki Y, Matsui T. A novel machine-learning-based infection screening system via 2013-2017 seasonal influenza patients' vital-signss as training datasets. *J Infect.* 2019;**78**(5):409–21.
2. Sun G, Trung NV, Matsui T, Ishibashi K, Kirimoto T, Furukawa H, Hoi LT, Huyen NN, Nguyen Q, Abe S, Hakozaki Y, Kinh NV. Field evaluation of an infectious disease/fever screening radar system during the 2017 dengue fever outbreak in Hanoi. *Vietnam: a preliminary report. J Infect.* 2017;**75**(6):593–5.
3. Sun G, Akanuma M, Matsui T. Clinical evaluation of the newly developed infectious disease/fever screening radar system using the neural network and fuzzy grouping method for travellers with suspected infectious diseases at Narita International Airport Clinic. *J Infect.* 2016;**72**(1):121–3.
4. Sun G, Matsui T, Hakozaki Y, Abe S. An infectious disease/fever screening radar system which stratifies higher-risk patients within ten seconds using a neural network and the fuzzy grouping method. *J Infect.* 2015;**70**(3):230–6.
5. Sun G, Hakozaki Y, Abe S, Vinh NQ, Matsui T. A novel infection screening method using a neural network and k-means clustering algorithm which can be applied for screening of unknown or unexpected infectious diseases. *J Infect.* 2012;**65**(6):591–2.
6. Matsui T, Hakozaki Y, Suzuki S, Usui T, Kato T, Hasegawa K, Sugiyama Y, Sugamata M, Abe S. A novel screening method for influenza patients using a newly developed non-contact screening system. *J Infect.* 2010;**60**(4):271–7.
7. Global Health Estimates 2016: Disease burden by Cause, Age, Sex, by Country and by Region, 2000-2016. https://www.who.int/healthinfo/global_burden_disease/estimates/en/index1.html.
8. Arnaldez FI, O'Da b SJ, Drake CG, Fox BA, Fu B, Urba WJ, Montesarchio V, Weber JS, Wei H, Wigginton JM, Ascierto PA. The Society for Immunotherapy of Cancer perspective on regulation of interleukin-6 signaling in COVID-19-related systemic inflammatory response. *J Immunother Cancer.* 2020;**8**(1) pii: e000930.
9. YANG X. A novel regulator of lung inflammation and immunity: pulmonary parasympathetic inflammatory reflex. *QJ Med* 2014;**107**:789–92.
10. Matsui T, Yoshida Y, Kagawa M, Kubota M, Kurita A. Development of a practicable non-contact bedside autonomic activation monitoring system using microwave radars and its clinical application in elderly people. *J Clin Monit Comput.* 2013;**27**(3):351–6.

Takemi Matsui*
Graduate School of System Design, Tokyo Metropolitan University, Tokyo 191-0065, Japan

Tsuyoshi Kobayashi
KONICA MINOLTA, INC., Tokyo 192-8505, Japan

Masaya Hirano
Graduate School of System Design, Tokyo Metropolitan University, Tokyo 191-0065, Japan

Masahiro Kanda
Graduate School of System Design, Tokyo Metropolitan University, Tokyo 191-0065, Japan

Guanghao Sun
Graduate school of Informatics and Engineering, University of Electro-Communications, Tokyo 182-8585, Japan

Yusuke Otake
Graduate School of System Design, Tokyo Metropolitan University, Tokyo 191-0065, Japan

Masakazu Okada
KONICA MINOLTA, INC., Osaka 569-8503, Japan

Sadao Watanabe
Vital Lab Ltd., Tokyo 191-0065, Japan

Yuikiya Hakozaki
Genkikai Yokohama Hospital, Yokohama 226-0013, Japan

*Corresponding author
E-mail address: matsui@tmu.ac.jp (T. Matsui)