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Vibration-based Microphones as a Solution for Non-invasive Ventilation Related Communication Impairment

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Abstract

The incidence of acute respiratory failure (ARF) has dramatically increased in the past few decades in the United States. From 2002 to 2017, there was a 197% increase in the annual incidence of ARF, and in response, a 437% increase in the use of noninvasive mechanical ventilation (NIV). Multiple studies have demonstrated that use of NIV frequently causes communication impairment (CI), which is strongly associated with anxiety and can in turn contribute to NIV intolerance and failure, and ultimately, mortality.⁸⁻¹⁰ CI also prevents accurate evaluation of patients by providers, which can contribute to worse clinical outcomes¹¹. Recently, Lee et al at Pohang University, South Korea, published their development of a flexible, wearable vibration sensor that can amplify speech while minimizing ambient noise. Although this device is intended for use in portable devices such as cell phones, it also poses as a viable solution for NIV-related communication impairment. Use of this vibration-based microphone can help address NIV-related CI and significantly improve clinical outcomes in patients with acute respiratory failure.

Acute respiratory failure (ARF) is an increasingly common and pressing issue in the United States, especially in the hospital setting. From 2002-2017, there was a 197% increase in annual incidence of ARF, from 429 to 1,275 cases per 100,000 adults, with a 57% decrease in hospital mortality from 28% to 12%. In the same period, there was a 437% increase in use of noninvasive mechanical ventilation (NIV), from 41 to 220 cases per 100,000 adults, with a 38% decrease in hospital mortality from 16% to 10%.¹ Respiratory failure arises not only from a primary respiratory insult such as pneumonia, COPD exacerbation, or anaphylaxis, but also secondary to anesthesia in hospital procedures or as sequelae to another primary health issue. Stefan et. al. state that ARF related hospitalization rates increased across all age groups from 2001 to 2009 and can only partially be explained by the growth and aging of the US population. They demonstrate that the increased in ARF incidence is “mainly driven by a surge in cases of sepsis and pneumonia”, as well as acute renal failure, conditions that predispose patients to development of ARF.²

NIV modalities, such as BIPAP and CPAP, have gradually replaced more invasive methods, such as mechanical ventilation via intubation, as first-line treatment. In France, Demoule et al showed the rate of first-line NIV use for ARF increased from 16% in 1997 to 37% in 2011.³ Similarly, Toft-Petersen et al in Denmark found that NIV made up just 36% of assisted ventilation in 2004 compared to 67% in 2011.⁴ This is most likely due to the less invasive nature of NIV; intubation bypasses the vocal cords to directly supply air to the lungs, therefore impairing speech production, whereas NIV provides air flow across the vocal cords and allows for phonation. Furthermore, NIV masks can be intermittently removed, allowing for more effective communication.⁵

In most patients, NIV is implemented using an oronasal (full-face) mask, which covers the mouth and nose. Obstructing the mouth, coupled with the ambient noise produced by BIPAP/CPAP devices, contributes to the difficulty in communication for patients. Although NIV masks can be temporarily removed for communication, many patients are unable

to tolerate removal due to rapid reduction in oxygenation and possibly lung derecruitment. Furthermore, many patients with respiratory dysfunction have, at baseline, decreased speech volume and thus cannot be heard over the ambient noise. This poses a need for maintenance of communication in patients on NIV without removal of respiratory support and potential respiratory decompensation.

Communication impairment (CI) can be severely detrimental to patient care. Multiple studies have demonstrated that CI contributes to fear, anger, and distress in patients and is the most remembered experience associated with NIV.^{6,7} Patients are often apologetic for their inability to communicate with their providers or refrain from even attempting to communicate due to their inability to be understood. Studies have also shown that CI is strongly associated with anxiety, which can in turn contribute to NIV intolerance and failure, and ultimately mortality.^{8,9,10} CI also prevents accurate evaluation of patients by providers, which can contribute to worse clinical outcomes.¹¹

Several teams have been looking for ways to improve communication for patients on NIV. A clinical trial started in 2019 at Emory University is testing the efficacy of the F2S Communication System, a communication aid that lets patients choose words or phrases to be read aloud.¹² A review paper by Wong et al. discusses further solutions for NIV associated communication deficits inspired by similar circumstances, such as in astronauts, scuba divers, and fighter jet pilots.⁶ Although communication tools such as communication boards (devices that display photos, symbols, or illustrations to which users can gesture or point), have been utilized historically, they are limited in vocabulary and lack the ability to fully express users' thoughts. Writing or typing are also viable options but are more time-consuming and less fluent than speech, limiting the rate of communication. Furthermore, many patients receiving NIV treatment tend to be physically constrained, limiting their ability to write or type. Wong et al identified three major categories of microphone solutions: intraoral, peri-pharyngeal, and within the mask. One such device is the SPEAX by Ataia Medical, which

imbeds a microphone directly into the CPAP mask.¹³ However, intraoral and intra-mask microphones require sterilization between uses, are exposed to moisture, and are vulnerable to ambient noise. Therefore, microphones placed peripherally around the neck area pose the most viable option for communication enhancement in NIV.

Also in 2019, Lee et al at Pohang University of Science and Technology (POSTECH), South Korea, announced that they have developed a flexible, wearable vibration sensor that can be applied to the throat and amplify speech while minimizing ambient noise.¹⁴ The project's primary goal was to replace cellphone microphones, which are often inaccurate and pick up ambient sound from the environment. However, their device has also great potential to be applied in the setting of communication enhancement in noninvasive ventilation. Since their device directly measures vibrations produced by the patient and does not depend on acoustic transmission of sounds through air, their microphone can be used to minimize the noise produced by NIV equipment.

Notably, there have been previous implementations of vibration sensor-based microphones used in other applications. Tanaka et al in 2015, for example, have previously developed wearable tactile sensors incorporating vibration sensors¹⁵ Zhou et al in 2017 also discussed the use of vibration sensors in documentation of seismic data in unattended ground sensors (UGS).¹⁶ However, the POSTECH team is the first to utilize vibration sensors to record speech.

The cost of producing electronics such as microphones has dramatically decreased in recent years, primarily with the advent of micro-electrical mechanical systems (MEMS). The implementation of MEMS, in which the functionality of electronic systems such as microphones can be scaled down to micron-scale sizes, as well as the development of novel materials, have greatly reduced the cost of producing these devices.¹⁷ Soon, it will be possible to mass produce wearable and disposable vibration-based microphones, similar to electrodes placed for cardiac telemetry, greatly increasing viability of this technology for use in healthcare.

The ever-increasing prevalence of ARF globally, along with a gradual shift away from invasive mechanical ventilation towards NIV modalities, have made it exceedingly critical that CI associated with NIV use be addressed. Multiple studies have demonstrated that the masks used in NIV such as CPAP or BiPAP severely limit the users' abilities to communicate, and the resulting detriment in patient satisfaction and clinical outcomes. Vibration-based wearable microphone technology demonstrates a clear advantage over current communication tools for NIV-associated CI and can be implemented in the hospital setting in order to address this increasingly pressing healthcare pitfall. Further work should be done to develop vibration-based microphones for the purpose of communication-impairment in the hospital setting, as well as implementation and evaluation in the hospital setting to gauge feasibility of widespread use.

POTENTIAL CONFLICTS OF INTEREST:

None.

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