Overdose detection among high-risk opioid users via a wearable chest sensor in a Supervised Injecting Facility: Study protocol for an observational study.

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Abstract

Background: Opioid overdose is a global health crisis, affecting over 27 million individuals worldwide, with more than 100,000 drug overdose deaths in the USA in 2022-2023. This protocol outlines the development and validation of the PneumoWave DC chest biosensor, a wearable device designed to detect respiratory depression in real-time through chest motion measurement, intending to enhance early intervention and thereby reduce fatalities.

Objective: The study aims to: 1) differentiate opioid-induced respiratory depression (OIRD) from non-fatal opioid use patterns to develop and refine an overdose detection algorithm; 2) examine acceptability of the chest biosensor to participants.

Methods: The study adopts an observational design over a six-month period. The biosensor, a small device, will be worn by consenting participants during injecting events to capture chest motion data. Safe Injecting Facilities (SIF) in Sydney (Site 1) and Melbourne (Site 2), which are legally-sanctioned space where individuals can use pre-obtained illicit drugs under medical supervision. Each site is anticipated to recruit up to 100 participants who inject opioids and attend the SIF. Participants will wear the biosensor during supervised injecting events at both sites. The biosensor will capture data on an anticipated 40 adverse drug events. The biosensor's ability to detect OIRD will be compared to the staff-identified events that use standard protocols for managing overdoses. Measurements will include: 1) chest wall movement measured by the biosensor, securely streamed to a cloud, and analysed to refine an overdose detection algorithm; 2) acute events/potential overdose identified by site staff.

Results: As of January 2024, 47 participants have been enrolled and data from 1,145 injecting events have already been collected, including 10 overdose events. The study is expected to be finalised by early March 2024.

Conclusions: This protocol establishes a foundation for advancing wearable technology in opioid overdose prevention within SIFs. The study will provide chest wall movement data and associated overdose data that will be used to train an algorithm that allows biosensor to detect an overdose. The study will contribute crucial insights into OIRD, emphasising the biosensor's potential step forward in real-time intervention strategies.

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Overdose detection among high-risk opioid users via a wearable chest sensor in a Supervised Injecting Facility: Study protocol for an observational study.

Wearable overdose detection study protocol

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Abstract

Background: Opioid overdose is a global health crisis, affecting over 27 million individuals worldwide, with more than 100,000 drug overdose deaths in the USA in 2022-2023. This protocol outlines the development of the PneumoWave chest biosensor, a wearable device designed to detect respiratory depression in real-time through chest motion measurement, intending to enhance early intervention and thereby reduce fatalities.

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Results: As of April 2024, 47 participants have been enrolled and data from 1,145 injecting events have already been collected, including 10 overdose events. This consists of 17 female and 30 male with an average age of 45 years. Data analysis is ongoing.

Conclusions: This protocol establishes a foundation for advancing wearable technology in opioid overdose prevention within SIFs. The study will provide chest wall movement data and associated overdose data that will be used to train an algorithm that allows the biosensor to detect an overdose. The study will contribute crucial insights into OIRD, emphasising the biosensor's potential step forward in real-time intervention strategies.

Keywords: wearable sensor; overdose; opioid-related deaths; injecting opioid use; Medically Supervised Injection Centre, Opioid Induced Respiratory Depression

Background & Rationale

World-wide, more than 27 million people have an opioid use disorder (OUD) and more than 150,000 people die each year from opioid overdose [1], [2]. In the USA, in 2022-23, there are estimated to be more than 100,000 drug overdose deaths [3]. Naloxone is an opioid antagonist and an antidote to opioid overdose. Effective interventions, such as take-home naloxone are available [4], [5] but coverage is incomplete and they are not suited to many overdose situations people may be alone or the onset of their overdose goes unnoticed [6], [7], [8]. In such situations, intervention requires detection of the overdose to signal the need for a response.

Recently, technological developments in wireless 'wearable' devices have enabled real-world, real-time measurement of physiological functioning and these devices have grown hugely in popularity [9], [10], [11]. Devices in relation to overdose could capture a wide range of different parameters but it is important that these are sensitive, accurate and reliable. Opioids affect the control of breathing and can cause fatal overdoses, usually by respiratory failure. Respiratory depression, referring to the characteristic effect of opioid drugs, is slowed and shallow breathing (or reduced chest movement) which can sometimes lead to changes in levels of blood gasses and a suppression of the usual responses to these changes. This can lead to hypoxia, respiratory failure and death. However, currently available wearable devices lack the ability to analyse and interpret respiratory depression data in real time and with sufficient accuracy to achieve medical device regulatory clearance. They are also not practical or economically viable for individual use in the community [12]. A chest sensor that reliably detects the overdose breathing signature, in real time, could alert family or friends to help or could directly alert emergency service. This could save lives, when fully developed and used in the community.

The PneumoWave chest biosensor is a small device (Figure 1) (40mm diameter 14mm height) that sticks onto the chest using a small plastic patch (an ECG sticker) and measures chest motion. Consequently, it is able to detect change in breathing patterns as well as detect reduced chest movement. However, to be relevant to detection of overdoses in the community, research is required on people at high risk of opioid-induced respiratory depression (OIRD) to capture chest motion during an injecting event, where absence or presence of overdose can be externally verified. This will then be used to develop and refine sensitive and specific OIRD detection algorithms that can interpret chest movement data in real time on a smart phone or tablet without the need for live clinician analysis and interpretation.

Those who inject opioids die at a much higher rate than other drug-using groups [13]. A Safe Injecting Facility (SIF), also known as Medically Supervised Injecting Centre or Room/drug consumption room/safe consumption room/overdose prevention centre, is a legally sanctioned space where people can bring their own pre-obtained illegal or illicit drugs, and either inject or inhale them using sterile equipment under the supervision of nurses or other medical professionals. The main objective of a SIF is to improve survival and increase social integration [14]. However, overdoses, whilst at a lower rate than the general using population, still occur at SIFs [15]. This also provides an important opportunity for study [16].

In this study, as participants wear the biosensor whilst they are injecting their opioids,
the objectives of the study are: 1) to capture chest motion data using the PneumoWave biosensor, and staff-measured outcomes as the clinical reference (including clinical identification of an acute event), during instances of opioid injection and potential opioid overdose by attendees at a SIF, to develop and refine the overdose detection algorithm; 2) to examine acceptability to SIF attendees of the chest

biosensor.

Methods

Ethical Considerations

This paper is based on version 1.1, 05 April 2023, of the study protocol. Ethics was approved by the Alfred Hospital Ethics Committee (reference number: 92786). This study adheres to SPIRIT checklist (Appendix I).
In order to obtained informed consent, the site research personnel will explain study methodology to the potential participant, the individual will be given time to read the Participant Information Sheet (PIS) and consider participation, and if they agree to participate, informed consent will be obtained. Study explanation can occur before or after using the SIF, depending on preference of the client and aligning with capacity to consent. Study enrolment and first recording injecting event can therefore occur on different days.
Data will be recorded pseudo-anonymously (i.e. pseudonyms will be used; no personally identifiable information will be stored alongside chest motion data) and streamed to a secure cloud. Participants who consent to take part will be assigned a numerical study ID number that will be linked to subsequent visits that they make to the MSIC/MSIR. All electronic data will be anonymous and stored on secure, password protected devices/servers, accessible only by approved study personnel. All paper-based consent forms containing participant names will be kept on-site at the MSIC/MSIR following completion and will not be removed from the site.
To reimburse participants for their time and inconvenience, participants will be reimbursed $50AUD following initial screening and study enrollment. Participants will then receive a weekly reimbursement of $20AUD on the basis they have attended the MSIC/MSIR to inject opioids (either alone or in combination with other drugs) whilst wearing the biosensor device at least once during the week.

Objectives

The objectives of the study are: 1. To capture chest motion data using the PneumoWave biosensor, and staff-measured outcomes as the clinical reference (including clinical identification of an acute event), during instances of opioid injection and potential opioid overdose by attendees at a SIF, to develop and refine the overdose detection algorithm; 2. To examine acceptability to SIF attendees of the chest biosensor.

Study Design

This is an observational pilot study. Over six months, this study aims to capture approximately 40 overdose events which occur for consenting participants who are wearing the chest sensor during visits to inject at the SIF. Participants who consent to take part will be assigned an anonymous, numerical study ID number that will be linked to subsequent visits that they make to the SIF.

Chest motion data will be collected on the device securely and pseudo-anonymously (i.e. pseudonyms will be used; no personally identifiable information will be stored alongside chest motion data) and streamed to a secure cloud. A SIF is designed to respond to a broad spectrum of adverse drug reactions, recognising that not all incidents may escalate to an opioid overdose (thus any event that is attended to and requires prompting by staff is termed ‘acute event’). The data collected here will be used to test and further develop chest wall movement ‘signatures’ to accurately

detect an ‘acute’ drug event or potential overdose, as diagnosed by the current clinical observations in the SIFs. Wearing the device will not alter the services participants receive at the SIF and the sites will manage each acute event as per their standard protocols.

PneumoWave biosensor and data collection platform

The study will utilise the PneumoWave biosensor and data collection platform which includes a wearable biosensor that attaches to the press-stud on a supplied and approved ECG electrode. The biosensor can be placed in a number of locations on the chest and diaphragm area, and automatically connects to a Data Hub via Bluetooth (Fig. 1). In this study the Hub will be a router type device or a mobile computing platform (application running on a tablet or phone).

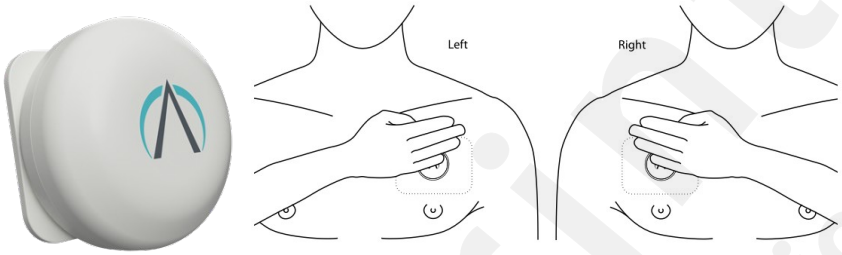

Figure 1: Image of Pneumowave chest sensor and location of placement on the body

Once consented and enrolled in the study, participants will be asked to wear the biosensor each time they attend their relevant SIF to take opioids, to an unlimited number of times. There will be no pre-defined number of visits that each participant should adhere to, though reimbursement will be predicated on attendance to the SIF and wearing of the biosensor at least weekly.

We will now highlight inclusion and exclusion criteria applicable to the study.

Eligibility Criteria

Inclusion Criteria

Participants will be recruited from the SIFs via advertisement and direct approach by site personnel and must meet the following criteria:

1. Adult (18 years or over);
2. Current Injecting opioid user (note: participant may be using other substances as well)
3. Regular client of the SIF (minimum of 4 visits in the past month)
4. Willingness to wear biosensor device whilst injecting at the facility

Exclusion criteria

1. Inability to provide informed consent
2. Under 18 years of age
3. Not currently injecting opioids

4. Skin sensitivity to ECG electrodes
5. Broken skin over chest area
6. Implanted pacemaker device in-situ
7. In the clinical opinion of the investigator would not be suitable to participate

Sample Size

Participants will be recruited via purposive selection – SIF staff will identify individuals who frequently attend the SIF and inject opioids – and via site advertisements, with individuals approaching site research personnel about potential participation.

During a study period of 6 months, we estimate that approximately 100 participants will be recruited at each participating SIF to meet the desired targets of approximately 2000 opioid injecting visits (a total of 4000 visits), leading to approximately 40 recorded acute/overdose events. This is based on an estimated overdose event rate (the proportion of injections that result in an overdose event) to be 1.2%, from previous data from the Medically Supervised Injecting Centre in Sydney, Australia [15], [17]). An estimated 1,200 opioid injecting visits occur per month per site, with an estimated 70 unique individuals attending for opioid injecting per month, per site.

Outcome Measures

We will initially separate outcome measures into categories of primary outcome measures (chest motion measures and acceptability) and SIF-determined measures. The latter will then be separated into intervention measures and acute event measures.

Primary Outcome measures:

Capture of chest motion of participants include chest wall measurements via PneumoWave biosensor of people before and after injection of opioids in a SIF, compared by: 1) those experiencing hypoxia and meeting defined criteria for an acute/opioid overdose (SIF-determined outcome measure/acute event) and, 2) those not experiencing symptoms of hypoxia or acute/opioid overdose (i.e. safe injecting event).

SIF-determined outcome measures:

The following data will be collected for each opioid injecting event in the SIF:

- Participant Study ID
- Time/date of client presentation to SIF
- Substances reported by participant as intended for injecting (confirmation that opioids are being injected)
- Time of opioid use
- Any apnoea and prompts to breathe

The following outcome data will be recorded for any intervention by SIF clinical staff (including acute event response):

- Precise timing of the first clinical indication of acute event,
- Unique ID number of clinician initially assessing the event to be an opioid overdose
- Opioid overdose criteria being met (based on site specific training materials / opioid overdose reference criteria). These are based on the measures that are described below.

The following outcome measures will be collected for each acute event (including prompts), as applicable:

1. Response to audio, physical and painful stimuli,
2. Level of consciousness –timepoints as per standard of care, recorded (using Alert Verbal Pain Unresponsive (AVPU) scale – see Appendix II) at intervals indicated by clinical concern,
3. Respiratory rate recorded at least every five minutes (though in practice, likely more often) after first clinical indication of opioid overdose,
4. Heart rate – timepoints as per standard of care,
5. SpO_2% via pulse oximetry, where measured – timepoints as per standard of care, recorded at intervals indicated by clinical concern,
6. Administration of oxygen,
7. Administration of manual resuscitation/ventilate (Bag-Valve-Mask (BVM) ventilation),
8. Administration of airway adjunct (nasopharyngeal/ oropharyngeal airway),
9. Administration of naloxone (yes/no),
10. CPR
11. Ambulance called.

Acceptability

Acceptability measures incorporate a participant feedback/satisfaction survey (see Appendix III). During study participation, each participant will be asked at least once if they wish to provide feedback on their experience of attaching or wearing the biosensor during injecting drug use. Participants may complete the feedback questionnaire more than once to record fluctuating levels of acceptability. For any feedback provided, the site will collate responses and provide it as an anonymised table listing (see Appendix III). There will also be a subset of participants who will be interviewed and surveyed in more depth.

Participant Timeline & Study Visits

The process of the investigation is more clearly understood though examination of the Schedule of Events below (Visits 1 and then subsequent visits).

Baseline Procedures

After participant has consented, completion of participant basic, baseline (e.g. demographics, drug use characteristics, etc.) questionnaire will be conducted using a stand-alone data collection tool using an electronic tablet. Each participant's height and weight will be recorded at the site at baseline and changes in their height and weight will be recorded every 4 weeks.

The following Schedule of Events will be followed for Visit 1 and then Visit 2 (until withdrawal or final self-injecting event).

Visit 1 Procedures (performed by site research personnel, Table 1):

Initially, research personnel will confirm injection of opioids (either alone or in combination with other drugs) and then provide instructions on the use and wearing of the biosensor. The biosensor will then be issued to the participant and the biosensor number will be recorded with the participant ID number. The researcher will verify that the biosensor has been correctly attached to the chest wall and provide further guidance to the participant, as required.

Research personnel will record basic information (day/time, drug reported for injection) for each participant SIF attendance. Site research personnel will record time of self-injecting by monitoring participant from a distance and estimating time of drug injection (this may include multiple injections within a single episode). If this is not possible to record, the site personnel will document that it could not be collected. Site research personnel will also record event interventions for an acute / overdose event (as applicable) including start time, end time and event assessment / level of intervention, clinicians unique ID, and overdose criteria. A record of 'no acute event' will also be maintained if the self-injecting visit occurred without any requirement for site personnel intervention. Any adverse events will also be recorded and, if necessary, an early withdrawal form will be completed if the participant did not progress to utilise the biosensor at Visit 1 and declined further participation.

Table 1. Visit 1 (Baseline and 1st study specific self-injecting visit).

	Enrolment / Baseline	Prior to Injecting Event	Acute / overdose event[d]	Post Injecting Event	Early Withdrawal [c]
Informed Consent[a]	X				
Eligibility Criteria	X				
Complete baseline questionnaire	X				

Instructions (Use of biosensor)		X			
Issue Chest Sensor		X			
Attach to Chest Wall		X			
Record of Event[b]			X		
Adverse events		X	X	X	X
Return of Biosensor				X	
Early Withdrawal Form					X

[a] Consent and eligibility review. Performed at a time most suitable to site personnel and participant during their visit.

[b] Event start time, event stop time, assessment of event, event outcome, if an applicable acute event occurs

[c] If participant withdraws after providing consent and prior to any use of the sensor

[d] If a self-injecting event occurred without the need for intervention the event should be recorded to reference the time of the device was attached and returned and that no interventions were required.

Visit 2 through to withdrawal or final self-injecting visit (performed by site research personnel, Table 2):

At Visit 2 and subsequent visits until withdrawal or final self-injecting visit, research personnel will verify informed consent remains valid for the participant to continue on the study. They will also confirm injection of opioids (either alone or in combination with other drugs) and provide a reminder instruction on the use and wearing of the biosensor. They will then issue the biosensor to the participant and record biosensor number used with participant ID. They will verify that the biosensor has been attached to chest wall correctly and provide further guidance to the participant, as required.

Site research personnel will record basic information (day/time, drug reported for injection) for each participant SIF attendance and will record time of self-injecting by monitoring participant from a distance and estimating time of drug injection (may include multiple injections within a single episode). If this is not possible to record, the site personnel will document that it could not be collected. Site research personnel will also record event interventions for an acute / overdose event (as applicable) including start time, end time and event assessment / level of intervention, clinicians unique ID, and overdose criteria. A record of ‘no acute event’ will also be maintained if the self-injecting visit occurred without any requirement for site personnel intervention. Any adverse events

will also be recorded and, if necessary, a withdrawal form will be completed if the participant did not progress to utilise the biosensor and declined further participation.

Table 2. Visit 2 through to final Self-Injecting visit

	Prior to Injecting Event	Acute/ overdose [c,d] Event	Post-Injecting Event	Withdrawal [b]
Verify informed consent remains valid	X			
Instructions (Use of Sensor) (as required)	X			
Issue Chest biosensor	X			
Attach to Chest Wall	X			
Record of Event[a]		X		
Adverse events		X	X	X
Return of Biosensor			X	
User Experience survey	During enrolment period / prior to withdrawal / final self-injecting visit			
Withdrawal Form[b]				X

[a] Event start time, event stop time, assessment of event, event outcome, if an applicable acute event occurs

[b] For all withdrawals from visit 2 onwards

[c] If a self-injecting event occurred without any need for intervention the event should be recorded to reference the time the device was attached and returned and that no interventions were required.

[d] If a self-injecting event occurred without the need for intervention the event should be recorded to reference the time of the device was attached and returned and that no interventions were required

Example study schedule:

The number of visits and injection events per participant will differ. The following range of frequency of attendees at the SIF may be anticipated: frequent attendee: 2 visits per day; mid-level attendee: 5 visits per week; low-level attendee: 1 visit per week.

[15], [17]

Data Management

All data will be captured using a dedicated web-based data system accessible only to site research personnel. Following completion of any given data form, data will be uploaded to a secure, password-protected server managed by the sponsor and located in Canada. It will be the Contract Research Organisation's (CRO) responsibility to manage data security. Following project completion, the CRO will lock the data system from further changes and securely transfer data to Pneumowave, where data will be securely stored. Site-specific datasets will also be provided to the SIF. All data will be anonymous, using only study IDs.

PneumoWave Managed Biosensor Data

As soon as the biosensor chest placement has been carried out, chest movement data will commence being captured. Data from the biosensor will be uploaded securely and automatically to a Data Hub stored in a small container, located within the SIF.

The data storage platform (supplied by Galen Data) complies with Health Insurance Portability and Accountability Act (HIPAA) requirements as set forth in the Galen Cloud HIPAA Compliance Matrix (004-0020), General Data Protection Regulation (GDPR) requirements as set forth in the Galen Cloud GDPR Compliance Matrix (004-0021), and California Consumer Privacy Act (CCPA) requirements. Additionally, Galen Cloud deployed on AWS is HITRUST certified.

PneumoWave will review both chest movement data stored within the Galen cloud and study data, including baseline questionnaire, injecting event, acute event and satisfaction questionnaire data.

Early Withdrawal

Participants may request to withdraw from the study at any stage for any reason without prejudice. Participants will need to complete an early withdrawal form. Participants may also request deletion of all study data collected about them up until the point of their withdrawal.

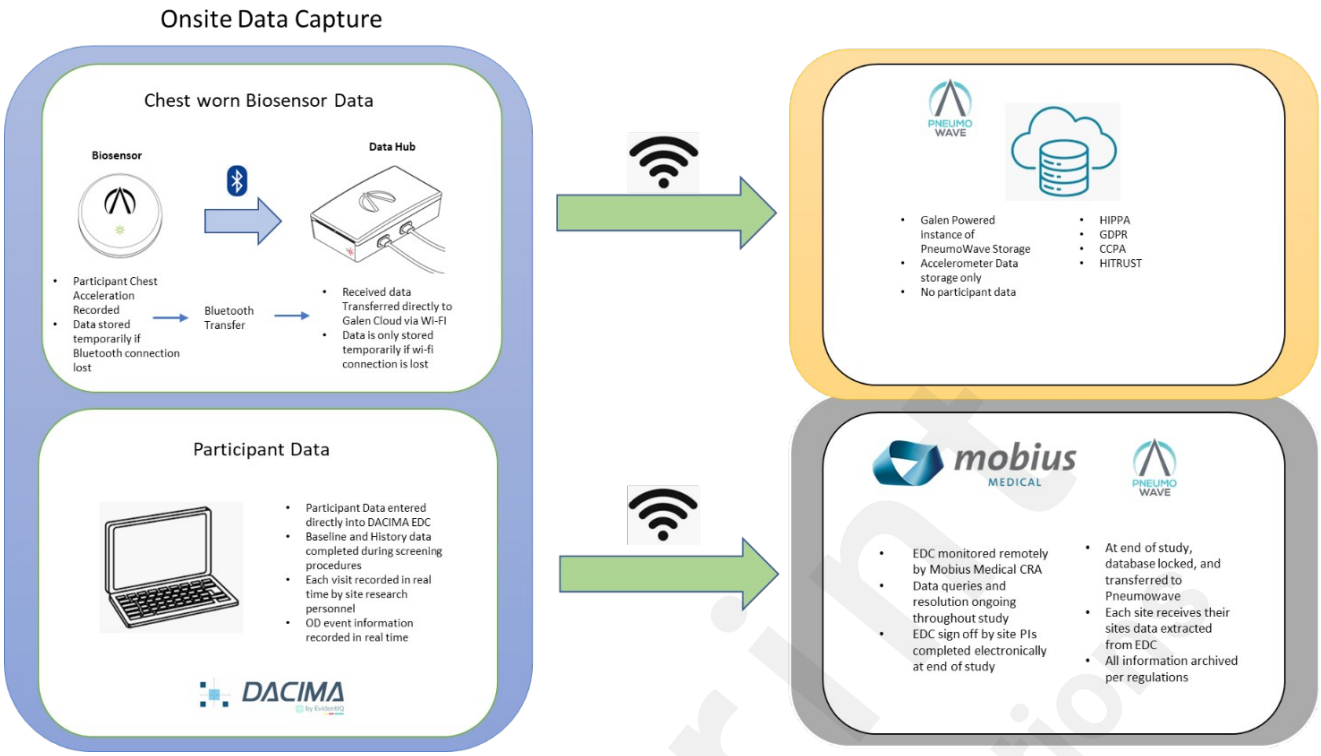

Figure 2. Data management flow

Study procedure risks and benefits

It is understood there may be the occasional loss of a biosensor with the key issue being the potential for a participant to leave the facility prior to removal of the biosensor. While site personnel will aim to minimise this risk it does remain a factor for device accountability / traceability records. The safety risk relating to a biosensor being taken off-site is assessed to be minimal. Anticipated risks are expected to be very minimal and with a low chance of occurrence. This is a non-interventional, observational study with retrospective analysis of the biosensor data and no protocol specified procedures impacting standard of care. Even so, potential study risks include data breach. However, all electronic data will be anonymous and stored on secure, password protected devices/servers, accessible only by approved study personnel. Numerical study IDs will be used in place of participant names. All paper-based consent forms containing participant names will be kept on-site at the SIF following completion and will not be removed from the site. ECG electrodes used in the study are designed to be worn for up to 3 days continuously. The average duration of wear is expected to be less than 1 hour, however, there is a low risk of mild skin irritation.

Given the preliminary, small-scale nature of this research, it is not anticipated that there will be any direct benefits to participants. This work aims to advance the development of future devices that may identify and intervene during opioid overdose, however, such devices may not eventuate for a number of years. The absence of immediate benefit will be outlined to participants during the consent process.

Safety

The capture of safety events will be solely related to Adverse Device Effects (ADE) and will only be captured for an event relating to the use or wearing of the device. All ADEs and/or Serious ADEs (SADE) will be recorded by site research personnel and will be assessed for severity (mild, moderate or severe) by the study team.

All ADEs and SADEs will be recorded from the time a participant is enrolled and until the participant's last study visit as per the time periods outlined. Participants who have enrolled but then withdrawn prior to wearing the biosensor for the first time will not have adverse events captured.

Only unanticipated effects will be captured as reportable adverse device effects.

Analyses

Statistical Analysis

For the SIF-determined outcome measures (e.g. demographic data) and satisfaction survey, descriptive statistics will be reported using means and standard deviation for continuous data. Absolute numbers and percentages will be reported for categorical data. Any statistical software can be used.

Biosensor analyses

Reference Event

Staff-identified events are any event that has required an intervention by staff in the facility. Interventions can range from a simple audio stimulus, up to and including requesting an ambulance to attend. These events include those where overdose may not have occurred, but the response will have been managed in the same way according to the sites SOPs. These incidences will be recorded as an 'acute event.' Where an overdose has been clearly identified using the tools mentioned previously, these incidences will be identified as 'overdose event.' Analysis will incorporate both types of 'reference' events.

Algorithm Under Test

The PneumoWave Hub receives transmits Biosensor data to a Cloud Storage facility. The stored data is then processed in the cloud using experimental algorithms for the presence of reduced chest movement events in adults.

The performance of the Algorithm (Under Test, AUT) will be compared to the reference events at the SIF in terms of the AUT's sensitivity and false alarm rate.

If the target numbers for sample size, injecting visits and acute events are not reached, analysis will still be possible and feasible.

Results

Funding was granted in July 2023 and dates for data collection are August 2023 to February 2024. As of April 2024, we have enrolled 47 participants, consisting of 17 female and 30 male with an average age of 45 years. Heroin was the preferred drug for most participants (n=40/47) and then methadone or an Opioid Agonist Treatment (n=6/47), with the largest proportion injecting two to five times daily (BD-5D – n-23), and then once daily (14/47). The majority had experienced an overdose in the past (29/47). Among all the participants, a total of 1,145 injecting events were recorded whilst participants wore the sensor, with 10 overdose events being observed. Data analysis of the outcome measures is ongoing.

Discussion

There has been a recent surge of interest in mobile health and wearable devices to treat opioid use disorders [18], [19] and specifically to detect and respond to opioid overdoses. However, there is limited research on detecting true overdose (which requires intervention) and on the effectiveness of these devices to detect overdose in the community has not yet been adequately evaluated. A chest sensor that reliably detects the overdose breathing signature could alert the emergency services and save lives, when fully developed and used in the community.

This observational study aims to capture chest motion data while participants wear a small chest-worn biosensor within Medically Supervised Injecting Centres in Australia. The data collected here will be used to test and develop respiratory ‘signatures’ to accurately detect an acute or potential opioid overdose. Testing will allow for the differentiation of patterns that occur following opioid use but do not result in an overdose.

It is anticipated that this study will capture chest motion data from the sensor whilst participants inject opioids and it is likely that some instances of potential overdose will also be captured by the sensor. It is uncertain how much chest motion data will be corroborated with staff-measured outcomes. It is anticipated that the sensor will be considered positively overall among participants.

Findings of this study will be compared to a previous study of this chest sensor among participants who wear the sensor at home and are on Opioid Agonist Treatment (manuscript in preparation) as well as other studies on wearable devices that have been examined acceptability and feasibility of varied technologies to combat the overdose crisis [20], [21], [22], [23], [24], [25]. The potential effectiveness and acceptability among these studies is varied. Generally, there is limited but expanding research in this area with studies focussed on products or technologies that are relatively new or in early development [12]. There is no published work on a remote chest sensor that can reliably detect chest wall movement in the context of an opioid overdose.

The strengths of this study are that it examines the effectiveness of the chest sensor among people who are injecting opioids in a relatively controlled but real drug using environment. Research within a SIF is a unique opportunity to address external validity as participants will be those who the sensor is eventually intended for.

However, the study is likely to be limited in a few different ways. Firstly, it is likely that participants will be polydrug users, and it may not be possible to examine the effect of opioids alone. Additionally, the number of prompt or acute events are likely to be lower than other drug-using environments as participants will be users who are using in a safe setting that is aimed at reducing

harms and mortality around injecting drug use. This may mean target number of acute events will be negatively impacted. Other potential limitations could include physical movement of individuals whilst using the device interfering with the data capture, or data quality. The more still the participant, the better quality the data will be.

Future development of this work will involve conducting a randomised clinical investigation of a medical device (CIMD) to determine its effectiveness in detecting OIRD. It will also be important to test the device among people's personal environments, e.g. in their home.

Conflicts of Interest: BT is supported by National Institute for Health & Care Research (NIHR) Biomedical Research Centre for Mental Health at South London and Maudsley NHS Foundation Trust, King's College London and part funded by the Maudsley Charity.

JS is a researcher and clinician who has worked with a range of governmental and non-governmental organisations, and with pharmaceutical companies to seek to identify new or improved treatments from whom he and his employer (King's College London) have received honoraria, research grants and/or consultancy payments: this includes, last 3 years, MundiPharma, Camurus, Accord/Molteni, Pneumowave. For a fuller account, see at http://www.kcl.ac.uk/ioppn/depts/addictions/people/hod.aspx. JS's research is supported by the National Institute for Health & Care Research (NIHR) Biomedical Research Centre for Mental Health at South London and Maudsley NHS Foundation Trust and King's College London.
PD, DO'K, MJ, MB, NC, BH, CC, OM: none declared.

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The study is funded by PneumoWave (who are developing a chest sensor for the detection of opioid-induced respiratory depression and will submit relevant parts of these findings for further approvals of the device). PneumoWave will have the ultimate decision on submission of the final report to regulatory authorities with close discussions with King's College London. PneumoWave are Sponsor of the study.

Author contributions: This study design was conceived and proposed by JS, BT & WL and all authors contributed to the write-up of the protocol.

Abbreviations

ADE: Adverse Device Event
AVPU: Alert, Voice, Pain, Unresponsive
CRO: Contract Research Organisation
ECG: Electrocardiogram
OUD: Opioid Use Disorder
PIS: Participant Information Sheet
SADE: Serious Adverse Device Event

SIF: Safe Injecting Facility
SpO2%: pulse oximetry

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Appendices

Appendix I – SPIRIT Checklist

Appendix II – Alert, Voice, Pain, Unresponsive (AVPU) Scale

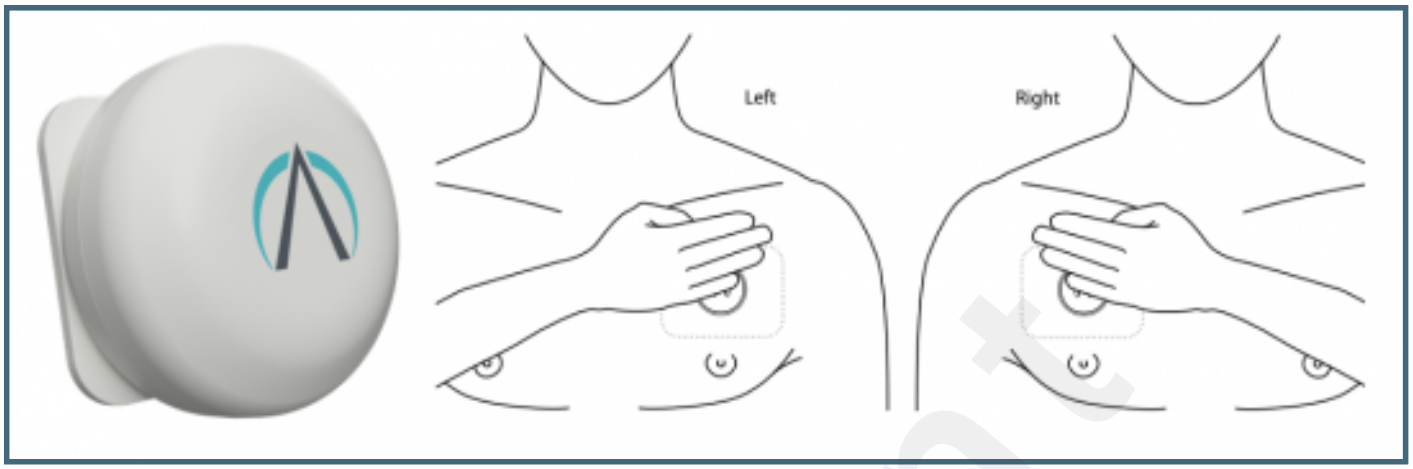
Appendix III – Participant Satisfaction Survey

Appendix IV - Model participant consent form

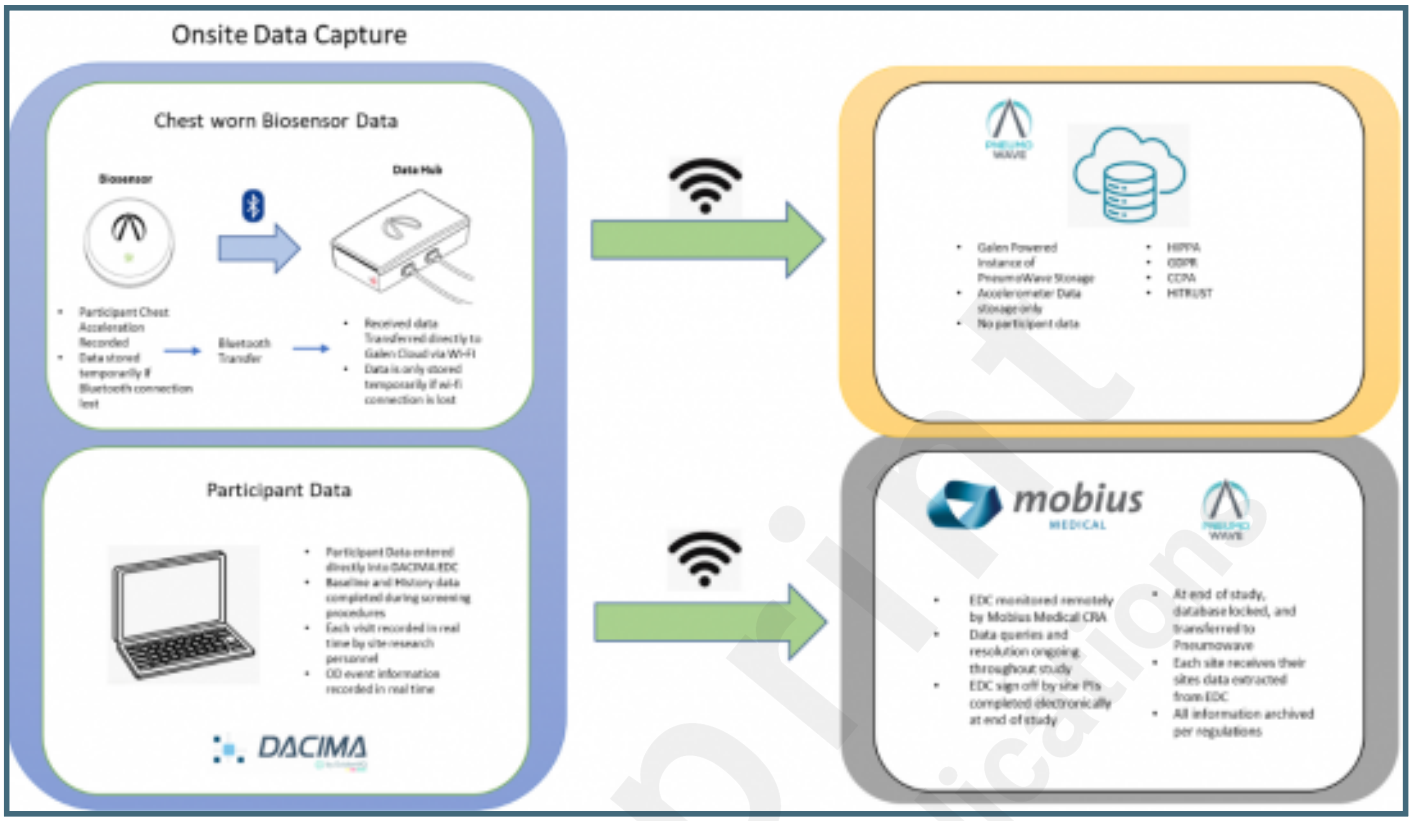
Supplementary Files

Figures

Image of Pneumowave chest sensor and location of placement on the body.



Data management flow.



Multimedia Appendixes

SPIRIT guidelines.
URL: http://asset.jmir.pub/assets/b66d85de10d166063261b4acb1125dc1.pdf

AVPU scale.
URL: http://asset.jmir.pub/assets/6da5fac950efb7f6a56af7869a772e83.pdf

Participant satisfaction survey.
URL: http://asset.jmir.pub/assets/9491208fdb4413834596961445af6217.pdf

Consent form.
URL: http://asset.jmir.pub/assets/0a295554127c660364259ff44851dc2a.pdf