

Post Discharge after Surgery Virtual Care with Remote Automated Monitoring Technology 3 (PVC-RAM-3) trial: Protocol for a Randomized Controlled Trial

Sandra Ofori, Michael H. McGillion, Flavia K. Borges, Carley Ouellette, Ameen Patel, David Conen, Maura Marcucci, Michael Ke Wang, Lily Jaeyoung Park, Conor Bell, Jennifer Lounsbury, Kanae Nagatani, Vikas Tandon, Trevor J. Wilkieson, Ahraaz Wyne, Valerie Harvey, Stephanie Harrison, Rahima Nenshi, Jessica Bogach, John Harlock, Margherita Cadeddu, Shawn Forbes, Shariq Haider, Reza D. Mirza, Sunita Narang, Clare J. Reade, Daniel M. Tushinski, Amit Raut, Samir Raza, Ted Scott, Anthony Adili, Jeremy Petch, PJ Devereaux

Submitted to: JMIR Research Protocols
on: February 15, 2025

Disclaimer: © The authors. All rights reserved. This is a privileged document currently under peer-review/community review. Authors have provided JMIR Publications with an exclusive license to publish this preprint on its website for review purposes only. While the final peer-reviewed paper may be licensed under a CC BY license on publication, at this stage authors and publisher expressly prohibit redistribution of this draft paper other than for review purposes.

Table of Contents

Original Manuscript..... 5

Supplementary Files..... 33

 Figures 34

 Figure 1..... 35

 Figure 2..... 36

 Multimedia Appendixes 37

 Multimedia Appendix 0..... 38

 Multimedia Appendix 1..... 38

Post Discharge after Surgery Virtual Care with Remote Automated Monitoring Technology 3 (PVC-RAM-3) trial: Protocol for a Randomized Controlled Trial

Sandra Ofori¹ MBBS, PhD; Michael H. McGillion¹ RN, PhD; Flavia K. Borges¹ MD, PhD; Carley Ouellette¹ RN, MSc; Ameen Patel¹ MD, FRCP; David Conen¹ MD, MPH; Maura Marcucci¹ MD, MSc; Michael Ke Wang¹ MD; Lily Jaeyoung Park¹ MD, MSc; Conor Bell¹ MBBCh, BA; Jennifer Lounsbury² RN; Kanae Nagatani² RN; Vikas Tandon¹ MD; Trevor J. Wilkieson¹ MD, MSc; Ahraaz Wyne¹ MD; Valerie Harvey³ BSc; Stephanie Harrison³ BHA; Rahima Nenshi¹ MD; Jessica Bogach¹ MD; John Harlock¹ MD, MSc; Margherita Cadeddu¹ MD; Shawn Forbes¹ MD, MSc; Shariq Haider¹ MD, FRCP; Reza D. Mirza¹ MD, MSc; Sunita Narang¹ MD, MPH; Clare J. Reade¹ MD, MSc; Daniel M. Tushinski¹ MD, MSc; Amit Raut¹ MDCM, FRCP; Samir Raza¹ MD; Ted Scott² PhD; Anthony Adili¹ MD, FRCS; Jeremy Petch¹ PhD; PJ Devereaux¹ MD, PhD

¹ McMaster University Hamilton CA

² Hamilton Health Sciences Hamilton CA

³ Population Health Research Institute Hamilton CA

Corresponding Author:

Sandra Ofori MBBS, PhD

McMaster University
1280 Main St W
Hamilton
CA

Abstract

Background: A substantial proportion of patients require acute hospital care after hospital discharge post-surgery, and many regions and countries have surgical backlogs.

Objective: The post-discharge after surgery Virtual Care with Remote Automated Monitoring technology-3 (PVC-RAM-3) trial tests the hypothesis that informing surgeons and patients of virtual care with remote automated monitoring (VCRAM) assignment will promote earlier discharge, thereby reducing the index length of hospital stay, and that post-discharge VCRAM will reduce acute hospital care.

Methods: The PVC-RAM-3 trial is a randomized controlled trial that compares VCRAM to standard post-discharge care among 2500 adults undergoing elective non-cardiac surgery in three Canadian hospitals. Following the randomization of patients prior to surgery, surgeons and patients are immediately notified whether the patient has been allocated to the VCRAM or control group. Outcome adjudicators remain blinded to each participant's group assignment.

Patients in the intervention arm learn to use a Health Canada approved cellular modem-enabled tablet computer and Bluetooth-enabled RAM technology from Cloud Dx to take daily wound photos for 7 days, and measure daily vital signs (i.e., blood pressure, heart rate, oxygen saturation, temperature, and weight) three times daily on days 1-7 and twice daily on days 8-14 post-discharge, along with completing a brief recovery survey. Nurses review these data and conduct scheduled virtual visits (days 1, 3, 7, and 14). Nurses will escalate care to a pre-assigned and available perioperative care physician if predetermined vital sign thresholds are exceeded, concerning symptoms arise, or a medication error is detected. These physicians manage the issues and add or modify treatments as needed.

The standard care group will receive post discharge care as per the standard of care at the hospital where they undergo surgery. The co-primary outcomes are acute hospital care and the index hospital length of stay within the first 30 days after randomization.

Results: Study recruitment and follow up is completed and analysis of the study results is underway.

Conclusions: This trial will offer insights into the role of VCRAM in reducing acute hospital care and index length of hospital

stay among adults undergoing elective surgery. Clinical Trial: ClinicalTrials.gov, no. NCT05171569

(JMIR Preprints 15/02/2025:72672)

DOI: <https://doi.org/10.2196/preprints.72672>

Preprint Settings

1) Would you like to publish your submitted manuscript as preprint?

✓ **Please make my preprint PDF available to anyone at any time (recommended).**

Please make my preprint PDF available only to logged-in users; I understand that my title and abstract will remain visible to all users.

Only make the preprint title and abstract visible.

No, I do not wish to publish my submitted manuscript as a preprint.

2) If accepted for publication in a JMIR journal, would you like the PDF to be visible to the public?

✓ **Yes, please make my accepted manuscript PDF available to anyone at any time (Recommended).**

Yes, but please make my accepted manuscript PDF available only to logged-in users; I understand that the title and abstract will remain visible.

Yes, but only make the title and abstract visible (see Important note, above). I understand that if I later pay to participate in <https://preprints.jmir.org/preprint/72672>

No. Please do not make my accepted manuscript PDF available to anyone. I understand that if I later pay to participate in <https://preprints.jmir.org/preprint/72672>

Original Manuscript

Post Discharge after Surgery Virtual Care with Remote Automated Monitoring Technology 3 (PVC-RAM-3) trial: Protocol for a Randomized Controlled Trial

Sandra Ofori, MBBS, PhD^{1,2} Michael H. McGillion, RN, PhD,^{1,3} Flavia K. Borges, MD, PhD,^{1,2,4} Carley Ouellette, RN, MSc,³ Ameen Patel, MD, FRCP,^{2,4} David Conen, MD, MPH,^{1,2} Maura Marcucci, MD, MSc,^{1,2} Michael K. Wang, MD,^{1,2} Lily Jaeyoung Park, MD, MSc,^{1,5} Conor Bell, MB, BCh, BAO,² Jennifer Lounsbury, RN,⁹ Kanae Nagatani, RN,⁹ Vikas Tandon, MD,² Trevor J. Wilkieson, MD, MSc,⁶ Ahraaz Wyne, MD,² Valerie Harvey, BSc,¹ Stephanie Harrison, BHA¹ Rahima Nenshi, MD,⁵ Jessica Bogach, MD,⁵ John A. Harlock, MD, MSc,^{5,7} Margherita Cadeddu, MD,⁵ Shawn Forbes, MD, MSc,⁵ Shariq Haider, MD, FRCPC,² Reza D. Mirza, MD, MSc,² Sunita Narang, MD, MPH² Clare J. Reade, MD, MSc,⁸ Daniel M. Tushinski, MD, MSc,^{9,10} Amit Raut, MDCM, FRCPC,² Samir Raza, MD,² Ted Scott, PhD,⁹ Anthony Adili, MD, FRCSC,^{5,9} Jeremy Petch, PhD,^{1,2} PJ Devereaux, MD, PhD.^{1,2,4}

Running title: PVC-RAM-3 Trial: Rationale and Design

Corresponding author: Sandra Ofori. Department of Medicine, McMaster University, Canada; Email: oforis@mcmaster.ca; tel: 19052965770

Word count: Abstract 345; Main text 4359.

Funding statement: This trial was funded by the Virtual Care and remote auTomated monitoring TechnOlogy Research (VICTOR) Program at the Population Health Research Institute and Hamilton Health Sciences. The funder had no role in the collection, management, analysis, and interpretation of data; writing of the report; and the decision to submit the report for publication.

¹ Population Health Research Institute

² Department of Medicine, McMaster University, Hamilton, Ontario, Canada

³ Department of Nursing, McMaster University, Hamilton, Ontario, Canada

⁴ Dept. of Health, Research Methods, Evidence, and Impact, McMaster University, Hamilton, Ontario, Canada

⁵ Department of Surgery, McMaster University, Hamilton, Ontario, Canada

⁶ Department of Anesthesia, McMaster University, Hamilton, Ontario, Canada

⁷ Division of Vascular Surgery, Hamilton Health Sciences, Ontario, Canada

⁸ Department of Obstetrics and Gynecology, Division of Gynecologic Oncology, McMaster University, Hamilton, Ontario, Canada

⁹ Hamilton Health Sciences, Ontario, Canada

¹⁰ St Joseph's Healthcare, Hamilton, Ontario, Canada

Abstract

Background: A substantial proportion of patients require acute hospital care after hospital discharge post-surgery, and many regions and countries have surgical backlogs.

Objective: The post-discharge after surgery Virtual Care with Remote Automated Monitoring technology-3 (PVC-RAM-3) trial tests the hypothesis that informing surgeons and patients of virtual care with remote automated monitoring (VCRAM) assignment will promote earlier discharge, thereby reducing the index length of hospital stay, and that post-discharge VCRAM will reduce acute hospital care.

Methods: The PVC-RAM-3 trial is a randomized controlled trial that compares VCRAM to standard post-discharge care among 2500 adults undergoing elective non-cardiac surgery in three Canadian hospitals. Following the randomization of patients prior to surgery, surgeons and patients are immediately notified whether the patient has been allocated to the VCRAM or control group. Outcome adjudicators remain blinded to each participant's group assignment. Patients in the intervention arm learn to use a Health Canada approved cellular modem-enabled tablet computer and Bluetooth-enabled RAM technology from Cloud Dx to take daily wound photos for 7 days, and measure daily vital signs (i.e., blood pressure, heart rate, oxygen saturation, temperature, and weight) three times daily on days 1-7 and twice daily on days 8-14 post-discharge, along with completing a brief recovery survey. Nurses review these data and conduct scheduled virtual visits (days 1, 3, 7, and 14). Nurses will escalate care to a pre-assigned and available perioperative care physician if predetermined vital sign thresholds are exceeded, concerning symptoms arise, or a medication error is detected. These physicians manage the issues and add or modify treatments as needed. The standard care group will receive post discharge care as per the standard of care at the hospital where they undergo surgery.

The co-primary outcomes are acute hospital care and the index hospital length of stay within the first 30 days after randomization.

Results: Study recruitment and follow up is completed and analysis of the study results is underway.

Conclusions: This trial will offer insights into the role of VCRAM in reducing acute hospital care and index length of hospital stay among adults undergoing elective surgery.

Trial registration: ClinicalTrials.gov, no. NCT05171569

Keywords: Elective surgery, Virtual Care, Remote Automated Monitoring, Index length of Stay, Acute hospital care, Randomized controlled trial

Strengths and limitations

- This is a large RCT that evaluates the impact of knowledge of assignment to receive VCRAM on index length of stay and VCRAM on post-discharge acute hospital care.
- The intervention builds on our prior VCRAM studies and is optimized for efficiency by shortening the intervention period from 30 to 14 days, reducing wound photo duration to 7 days, and strictly enforcing vital signs' escalation thresholds across all centers.
- Findings may not generalize to cardiac surgery populations or health systems outside Ontario, Canada.

Introduction

Each year, more than 100 million adults (including >500,000 Canadians) aged 45 and older undergo major surgery; of these, 29% develop prognostically important complications, 7.5% require hospital readmission, and >1.5% die within 30 days [1, 2]. A Canadian Institutes of Health Information study

analyzing 2.1 million acute hospitalizations found that surgical patients (both inpatient and same-day procedures) accounted for 31% of cases. Among the surgical cases, 7% had an unplanned 30-day readmission (costing CAD 9,700 per readmission), and 19% returned to the emergency department within 30 days [3]. Overall, 20–25% of adults discharged after elective surgery require acute hospital care within 30 days. With rising surgical volumes outpacing the growth of hospital bed capacity, surgical backlogs continue to grow [4, 5]. Addressing these challenges requires innovative strategies to both shorten hospital length of stay (LOS) and reduce readmissions after surgery.

Virtual care with remote automated monitoring (VCRAM) has emerged as a promising approach to improve post-surgical transitions to home [6, 7]. Virtual care encompasses all the ways that healthcare providers remotely interact (e.g., telephone, tablet computer) with their patients. Remote automated monitoring (RAM) refers to the use of technology to remotely obtain data regarding patients' biophysical parameters (e.g., blood pressure) [6].

In our previous Post discharge after surgery Virtual Care with Remote Automated Monitoring technology-1 (PVC-RAM-1) trial, 905 patients who had undergone non-elective surgery were randomized to VCRAM for 30 days or standard care [8]. Patients in the experimental group used a cellular-enabled tablet and RAM technology that collected biophysical data, took wound photographs, and engaged in scheduled and when needed, unscheduled virtual visits with nurses and physicians. There were threshold-based alerts that immediately triggered nurse-physician interventions, to ensure timely detection and management of abnormalities. We found a signal for reduction in acute-hospital care (22.0% in the virtual care group versus 27.3% in the standard-care group; relative risk, 0.80; 95% confidence interval [CI], 0.64-1.01), brief acute hospital care (13.7% versus 18.1%; relative risk, 0.75; 95% CI, 0.56-1.02), hospital re-admission (9.5% versus 12.8%; relative risk, 0.77; 95% CI, 0.53-1.11), and emergency department visits (19.7% versus 24.4%; relative risk, 0.81; 95% CI, 0.64-1.04) [8].

It is only credible to expect VCRAM to impact outcomes if identified problems lead to change in management. In PVC-RAM-1, centres could adjust the threshold parameters for care escalation. Post-hoc analyses demonstrated that in the centres with the highest escalations of care (i.e., centres where nurses identified, and physicians rapidly addressed abnormalities based on adherence to the predetermined vital sign thresholds) substantial absolute reductions in these outcomes were realized: acute-hospital care 14.1% (95% CI, 5.2-23.0); brief acute-hospital care 11.0% (95% CI, 3.6-18.4); and emergency department visits 14.2% (95% CI: 5.4-23.0). However, these findings were post-hoc and hypothesis-generating, requiring confirmation through an adequately powered trial. Additionally, the impact of advance knowledge that a patient will receive VCRAM on discharge timing and subsequent outcomes remains unclear.

The use of VC-RAM for patients discharged home after surgery can help identify and manage early post-operative complications. We hypothesize that this approach will reduce the need for acute hospital care, which includes hospital readmissions or emergency department visits after discharge. Additionally, we believe that if surgeons and patients know that post-discharge virtual care and RAM are available, they may be more inclined to opt for earlier discharges, potentially decreasing the length of the index hospital stay. To test these hypotheses, we are evaluating the impact of our VC-RAM intervention compared to standard post-discharge care on two co-primary outcomes: the rate of acute hospital care post-discharge, and the index length of hospital stay.

By evaluating both acute hospital care and index length of stay (LOS), this trial aims to build on lessons from PVC-RAM-1, extending to elective surgeries and providing evidence on integrating VCRAM into routine post-surgical care. The goal is to optimize safe discharge and patient outcomes while addressing significant systemic challenges like bed capacity and surgical backlogs.

Methods

Design and setting

The PVC-RAM-3 trial is a multicentre, parallel-group superiority randomized controlled trial (RCT) involving 2,500 patients undergoing elective non-cardiac surgery at three Canadian hospitals: Hamilton General Hospital, Juravinski Hospital and Cancer Centre, and St. Joseph's Healthcare Hamilton. The trial evaluates the effects of virtual care with remote automated monitoring (VCRAM) compared to standard care post-discharge. A study flow diagram is provided in Figure 1 and the Standard Protocol Items: Recommendations for Interventional Trials (SPIRIT) checklist is provided as a supplemental file.

Trial population

Patients included in the trial are 18 years of age or older, undergoing inpatient elective non-cardiac surgery with an expected hospital stay of ≤ 3 days after surgery, and provide informed consent. Exclusion criteria include inability to communicate with research staff, complete study surveys, or undertake an interview using a tablet computer due to language barrier or a cognitive, visual or hearing impairment. Patients residing in areas without cellular network coverage are also excluded.

Patient recruitment

Study personnel use efficient recruitment strategies we previously developed in our perioperative trials including identifying eligible patients through daily screening of surgical lists [8–10]. Surgeons with appropriate surgical populations (i.e., surgeries with an anticipated length of stay of 3 or fewer days) are contacted prior to any recruitment of their patients and asked to confirm their willingness to have their patients participate. Research personnel approach eligible patients during the preoperative period to obtain written informed consent (appendix 1).

Randomization

Randomization occurs before surgery after eligibility is confirmed and informed consent is obtained. We randomize as close to the time of surgery as possible, to minimize the risk of surgery

postponement. Patients are randomized using an Interactive Web Randomization System (IWRS), a 24-hour computerized system maintained by the coordinating centre at the Population Health Research Institute (PHRI), a joint institute of Hamilton Health Sciences and McMaster University in Hamilton, Ontario, Canada.

The randomization process uses block randomization with varying block sizes stratified by site, ensuring that study personnel and investigators remain unaware of block sizes. Patients are randomized in a 1:1 ratio to receive VCRAM or standard care. Following randomization, research personnel notify the patient's surgeon and the patient of the treatment allocation. Patients, healthcare providers, and data collectors are aware of treatment assignments, while outcome adjudicators remain blinded to treatment allocation.

Trial interventions

Patients are randomized to receive virtual care with RAM technology (VCRAM) or standard care. Participating surgeons receive information on the trial protocol, objectives, and the intervention model through rounds, in-service education, and discussions with trial researchers. This ensures that early discharge decisions for their patients are guided by their clinical judgment and understanding of the intervention care model (i.e., when patients are assigned to the VCRAM group the patient will go home with VCRAM to facilitate virtual care and vital sign monitoring).

The Cloud DX tablet is equipped with a camera and Bluetooth-enabled, Health Canada-licensed RAM technology (Figure 2). The Cloud DX Connected Health mobile application, hosted on the tablet, serves as the primary interface for the virtual care intervention and complies with the Personal Information Protection and Electronic Documents Act (PIPEDA) and the Personal Health Information Protection Act (PHIPA). This system has undergone extensive validation and user testing and was used in our previous PVC-RAM-1 trial [8, 11]. The intervention begins the day after discharge and lasts 14 days or until 30 days post-randomization, whichever comes first. The 14-day timeframe is based on a period where major perioperative complications occur and from our previous

PVC-RAM-1 trial findings, where we determined that 30 days of monitoring often exceeds the needs of most patients [1, 2, 8]. Nurses establish contact and set up the system with patients as soon as possible after discharge, ensuring patients know how to seek help if they experience symptoms or issues arise.

Research staff teach patients (with family members participating where possible) in the VC-RAM group to use the automated Bluetooth-enabled monitoring devices paired with a preprogrammed, cellular modem-enabled tablet computer to measure their biophysical parameters, including blood pressure, heart rate, oxygen saturation, and temperature, three times daily on days 1–7 and twice daily on days 8–14. They measure their weight daily. They also complete a recovery survey developed for the trial, consisting of questions related to infection, bleeding, pain, dehydration, and cardiovascular and respiratory complications, daily. Patients photograph their wounds daily for the first 7 days, unless otherwise directed. The biophysical parameters automatically upload via Bluetooth to the tablet, except for temperature, which is entered manually. These results are immediately wirelessly forwarded to the VC nursing team, and nurses actively review these results daily. If nurses do not receive a patient's measurements, they will contact the patient at the earliest opportunity to understand the reasons behind the missing data. These vital signs, recovery survey, and wound photos are parameters typically monitored in hospital or during clinic visits, which we are now extending into the home setting.

Nurses conduct scheduled video visits on days 1, 3, 7, and 14 to assess symptoms, review wound photographs, reinforce recovery principles, and assess pain. They perform medication reconciliation on days 1, 7, and 14. Unscheduled video visits are arranged if biophysical measurements or survey responses exceed thresholds or if other health concerns are identified. Nurses escalate care to a pre-assigned physician when necessary, such as when RAM measurements exceed predetermined thresholds (examples in Appendix 2), patients report specific symptoms (e.g., shortness of breath),

drug errors are identified, or concerns arise that require physician intervention. Physicians adjust treatments, order outpatient laboratory and diagnostic testing, liaise with surgeons, patients' family physicians or other healthcare providers, and arrange in-person clinic care when required.

Perioperative physicians hold scheduled video visits with patients on days 1 and 14 to assess patients, ensure proper medication use (by reviewing medication indication and proper dosing), and address medical needs. For patients who have a history of atherosclerotic disease, or are current smokers, an additional video call occurs on day 7 to optimize cardiovascular secondary prevention and smoking cessation therapy by ensuring that where indicated, patients were receiving secondary prevention medications (aspirin, statin, Angiotensin-Converting Enzyme Inhibitors/Angiotensin II Receptor Blockers) and smoking cessation medications respectively. These mechanisms ensure patients have 24/7 access to virtual nurses or physicians for urgent issues via secure video (appendix 3).

In both groups, discharge occurs when the most responsible surgeon deems it fit to discharge the patient. In the standard care group, patients receive post-discharge management according to the standard of care at the hospital where they underwent surgery. No changes to surgeons' standard of care regarding post discharge management occur for patients randomized to either group, as a result of the trial. In Canada, standard post-surgery care typically involves follow-up with a healthcare provider within 30 days of discharge. Before this appointment, patients are responsible for contacting their surgeon or family physician with any concerns.

Trial outcomes

The PVC-RAM-1 trial provided encouraging data that virtual care with RAM may reduce acute hospital care [8]. In PVC-RAM-3, we wanted to inform the impact on acute hospital care and the index length of hospital stay. Initial sample size calculation assumptions suggested index length of hospital stay would require a larger sample size than acute hospital care. To avoid being

underpowered for these outcomes, we made index length of hospital stay the primary outcome. At the time of the final interim analysis, blinded overall data on the length of stay and acute hospital care indicated there was adequate power to split the alpha and evaluate two co-primary outcomes (i.e., acute hospital care and length of hospital stay). Consequently, we revised the primary outcome to include both index length of stay and post-discharge acute hospital care as co-primary outcomes, making this change without any knowledge of the trial results.

The primary objective of this trial is to determine whether VCRAM compared with standard care after elective surgery and informing surgeons and patients of VCRAM allocation reduces the occurrence of the co-primary outcomes within 30 days of randomization. The first co-primary outcome is post-discharge acute hospital care (defined as hospital readmission or emergency department visit) within 30 days after randomization. The second co-primary outcome is index hospital length of stay (i.e., time from the end of surgery to index hospital discharge).

Secondary outcomes during the first 30 days after randomization include: 1) hospital re-admission; 2) emergency department visit; 3) medication error detection; 4) medication error correction; 5) surgical site infection; and 6) days in hospital; 7) pain of any severity, and moderate-to-severe pain assessed at 15 and 30 days after randomization; 8) proportion of patients with atherosclerotic disease taking classes of efficacious medications at 30 days, [i.e., an antiplatelet or anticoagulant drug; an angiotensin-converting enzyme inhibitor or angiotensin-receptor blocker; and a statin]; and 9) the proportion of active smokers before surgery receiving pharmacological smoking cessation interventions at 30 days after randomization. Outcome definitions are presented in Appendix 4.

Tertiary outcomes include: 1) infection; 2) re-operation; 3) composite of myocardial infarction, acute heart failure, and arrhythmia that results in acute hospital care; 4) death; 5) health-related quality of life (HRQoL); and 6) health services utilization-related costs.

We hypothesize that VCRAM will reduce all primary, secondary, and tertiary outcomes, except for identifying more medication errors in the intervention group compared to the standard care group, which would reflect improved care through increased detection.

Follow up

The day of randomization is day 1 of the trial, and all patients undergo 30 days of follow-up. Study personnel contact patients at day 30 to collect data on acute hospital care, secondary and tertiary outcomes, medication error detection and corrections, and current medications. The EQ-5D-5L is administered at baseline and day 30, and the Brief Pain Inventory-Short Form (BPI-SF) is administered on days 15 and 30. In the virtual care group, virtual nurses collect data on medication error detection and corrections throughout the intervention period.

If a patient reports an event, study personnel obtain source documentation from hospital or family physician records. If patients cannot be contacted directly, study personnel reach out to a designated relative, friend or the primary care physician. Study personnel and virtual nurses record all data in case report forms that are then entered into an electronic data capture system (Trial Master).

Sample size calculations

Post-discharge acute hospital care and index hospital length of stay are co-primary outcomes with a shared alpha. We allocate $\alpha=0.04$ for acute hospital care and $\alpha=0.01$ for index hospital length of stay (details in appendix 5).

Table 1a presents the trial power for acute hospital care based on a Log-rank test with 2-sided $\alpha=0.04$ using SAS software. Assuming a 14% event rate in the control group, with an overall sample of size 2500 subjects (1250 in the control group and 1250 in the treatment group) we will achieve 88.7% power to detect a relative risk reduction of at least 0.70 (30% relative risk reduction). Table 1b presents the trial power for index length of stay based on a Two sample Wilcoxon Test assuming equal variance with 2-sided $\alpha=0.01$. We expect patients in the standard care group to have a mean

index hospital length of stay of 2.5 days. If knowledge that patients in the intervention group will receive virtual care with RAM after hospital discharge results in 35% of patients having their index hospital length of stay reduced by 1.0 day, we will require a sample size of 2500 to have more than 80% power to detect this difference, with a 2-sided alpha of 0.01.

Table 1a: Power to detect a Relative Risk of (RR= 0.65 or 0.70 or 0.75) based on Log-rank test with a two-sided alpha=0.04 assuming control group event rates 12%, 14%, 16%, 18% for a given total sample of size 2500, 2800, 3000, or 3200.

Sample size per group	RR 0.65 (35% reduction)			RR 0.70 (30% reduction)			RR 0.75 (25% reduction)		
	Assumed Control Event Rate	Treatment P	Power	Assumed Control Event Rate	Treatment P	Power	Assumed Control Event Rate	Treatment P	Power
1250	12%	7.8%	93.3 %	12%	8.4%	82.5 %	12%	9.0%	65.5 %
1400			95.6 %			86.7 %			70.6 %
1500			96.7 %			89.0 %			73.7 %
1600			97.6 %			90.1 %			76.5 %
1250	14%	9.1%	96.6 %	14%	9.8%	88.7 %	14%	10.5%	73.4 %
1400			98.0 %			92.0 %			78.3 %
1500			98.6 %			93.6 %			81.1 %
1600			99.0 %			95.0 %			83.6 %
1250	16%	10.4%	98.4 %	16%	11.2%	93.0 %	16%	12%	80.0 %
1400			99.1 %			95.4 %			84.4 %
1500			99.4 %			96.5 %			86.8 %
1600			99.6 %			97.4 %			88.9 %
1250	18%	11.7%	99.3 %	18%	12.6%	95.8 %	18%	13.5%	85.3 %
1400									
1500									
1600									

1400			99.7 %			97.4 %			89.1 %
1500			99.8 %			98.2 %			91.1 %
1600			99.9 %			98.7 %			92.8 %

Table 1b: Power Calculation based on Two-Sample Wilcoxon Tests Assuming Equal Variance in Length of Stay with 2-sided $\alpha=0.01$.

Standard care group expected index hospital LOS (days)	Intervention group expected impact on index hospital LOS	Sample size		
		80% power	85% power	90% power
3	40% of patients have their LOS reduced by 1.5 days	1078	1216	1400
3	35% of patients have their LOS reduced by 1.5 days	1450	1634	1882
3	30% of patients have their LOS reduced by 1.5 days	2030	2288	2634
3	40% of patients have their LOS reduced by 1.0 days	2618	2950	3396
3	35% of patients have their LOS reduced by 1.0 days	3482	3924	4518
3	30% of patients have their LOS reduced by 1.0 days	4826	5438	6260
2.5	40% of patients have their LOS reduced by 1.5 days	714	806	928
2.5	35% of patients have their LOS reduced by 1.5 days	968	1090	1256
2.5	30% of patients have their LOS reduced by 1.5 days	1362	1536	1768

	reduced by 1.5 days			
2.5	40% of patients have their LOS reduced by 1.0 days	1764	1988	2290
2.5	35% of patients have their LOS reduced by 1.0 days	2356	2656	3058
2.5	30% of patients have their LOS reduced by 1.0 days	3280	3696	4254
2	40% of patients have their LOS reduced by 1.5 days	424	478	552
2	35% of patients have their LOS reduced by 1.5 days	582	656	754
2	30% of patients have their LOS reduced by 1.5 days	828	932	1074
2	40% of patients have their LOS reduced by 1.0 days	1078	1216	1400
2	35% of patients have their LOS reduced by 1.0 days	1450	1634	1882
2	30% of patients have their LOS reduced by 1.0 days	2030	2288	2634

Statistical analyses

We will analyze all data according to a pre-specified statistical analysis plan developed and finalized before any investigator is unblinded.

Following the intention-to-treat principle, we will analyze patients in the treatment groups to which they were randomized. For both co-primary outcomes, we will compare all patients allocated to the PVC-RAM-3 intervention to all patients allocated to standard care.

For co-primary 1 (composite of hospital readmission or emergency department visit), we will compute the time to event from discharge date and plot the cumulative incidence curves between the two treatment groups. We will use a Cox regression model to obtain HRs and 95% CIs. Any acute hospital care event that occurs before patients undergo their index surgery, in cases where surgery is postponed, will not be included in this outcome.

For co-primary 2 (index hospital length of stay), we will calculate the hospital LOS for both groups and compare them with a two sample Wilcoxon Rank Sum Test. Given the large sample size, the two-sample Wilcoxon Rank Sum Test will produce results that will be similar to the two-sample t-test.

For the co-primary outcome analyses, we will censor patients whose surgeries were canceled and not rescheduled within 30-days of randomization.

VCRAM will be considered effective if either of the 2 co-primary efficacy analyses is significant. We will use a gatekeeping with fallback procedure to analyze their statistical significance [12]. We will start with an overall alpha of 0.05, split between the two outcomes with a computed 2-sided p value less than an α of 0.04 for post-discharge acute hospital care and

less than an α of 0.01 for index length of hospital stay. If the first co-primary outcome achieves significance at an alpha level of <0.04 , the alpha from this test will be added to the second co-primary outcome's alpha (i.e., the alpha will be 0.05). However, if the first co-primary outcome is not significant, the second co-primary outcome will be tested at an alpha level of <0.01 .

For secondary and tertiary outcomes, we will use the chi-square test for binary or categorical variables and the two-sample t-test for continuous variables. We will assess the effect of VCRAM using log-binomial regression models and report the corresponding relative risks and 95% confidence intervals (CIs). For continuous outcomes, we will evaluate the intervention effect using analysis of covariance regression models to obtain effect estimates and their 95% CIs. Depending on the frequency of time-to-event outcomes, we may use the log-rank test to assess differences between groups. The alpha level for all secondary and tertiary outcomes will be set at 0.05. For the secondary and tertiary outcomes, we will not adjust for multiple testing as we will be evaluating the consistency of effect, number of outcomes, and size of the effect to offer insights into the reliability of any statistically positive secondary or tertiary outcomes. Economic analysis (appendix 6) will be done in a separate protocol and publication.

Sub-group analyses

We will analyze subgroups based on weekday of randomization: Mondays and Tuesdays versus Wednesdays, Thursdays, and Fridays. We hypothesize that the treatment effect will be less among patients randomized mid-to-late week as they may have longer stay because their post-surgical recovery is more likely to overlap with weekends where there may be operational delays in discharge, such as the absence of physiotherapists, that cannot be influenced by knowledge of VCRAM allocation. To examine this, we will include interaction terms between group assignment and weekday of randomization into the Cox regression model, with significant

interaction inferred at a p value of <0.05 .

Interim analyses

Two interim efficacy analyses based on the primary outcome occurred when 50% and 75% of the patients had been followed for 30 days. The Data Monitoring Committee (DMC) employed the modified Haybittle-Peto rule of 4 standard deviations (SDs) ($\alpha = 0.0000633$) for analyses in the first half of the trial (including the first planned interim analysis) and 3.5 SDs ($\alpha = 0.0004653$) for all analyses in the second half. For a finding of the treatment to be considered significant, these predefined boundaries had to have been exceeded in at least 2 consecutive analyses, 2 or more weeks apart. The interim analyses were conducted under protocol version 1.0 dated 2021-12-22, and therefore did not take into consideration the changes made to the primary outcome in protocol version 2.0 dated 2025-01-25.

Ethics

This trial is conducted in compliance with the protocol, the principles outlined in the Declaration of Helsinki, and Good Clinical Practice (GCP). The Hamilton Integrated Research Ethics Board (HiREB) provided their approval for the protocol and consent form (Project ID 14365) before initiating the study. Research personnel obtain informed consent for each patient before randomization.

All patient information is stored in a high-security computer system and kept strictly confidential. Subject confidentiality is further ensured by using identification code numbers to correspond with treatment data in computerized files. Medical information obtained during the trial is considered confidential and is not disclosed to third parties. However, this information may be shared with the patient's personal physician or other appropriate medical personnel responsible for the patient's care.

Trial organization

The Population Health Research Institute (PHRI) is the sponsor and coordinating centre for this trial, overseeing trial organization, randomization scheme development, study database creation, data consistency checks, data analysis, and study centre coordination. The trial structure includes a project office, operations committee, steering committee, data monitoring committee (DMC), site principal investigators, co-investigators, and adjudication committee. The Co-Principal Investigators, Project Officers, Program Manager, and Research Coordinator are responsible for the activities of the Project Office. If safety concerns arise during the trial, the DMC Chair convenes a formal committee meeting. The DMC reviews all available data and relevant external studies before making recommendations to the Project Office Operations Committee. If termination is considered, the committee explores all alternatives before a decision is made. A detailed charter governs the DMC's activities.

Results

The first patient was randomized on December 29, 2021, and recruitment of the target 2,500 patients was completed on October 25, 2024. The Data Monitoring Committee (DMC) conducted the first and second scheduled interim analyses and recommended continuing the trial. The final version of the study protocol was submitted prior to unblinding of the trial investigators. Some protocol amendments were implemented during the trial, with the most recent version finalized near the end of the study period. This paper is based on the most recent version of the study protocol (v2.0 2025-01-25).

The data will be analysed, and the study results will be published in a separate manuscript.

Discussion

Reducing post-discharge acute hospital care and index length of hospital stay remains a critical

unmet need for surgical patients. We hypothesize that VCRAM holds significant potential to address these challenges by lowering the incidence of these key outcomes. Building on the lessons learned from the PVC-RAM-1 trial, which established a scalable and effective model for VCRAM, the PVC-RAM-3 trial adapts the intervention for elective surgical populations and examines how pre-surgical knowledge of VCRAM allocation influences discharge decisions.

Throughout the last decade, there have been substantial changes in the duration of hospital admission for some surgical interventions. The relationship between the length of hospital stays and readmission rates is unclear, as some research indicates that shorter hospital stays are associated with higher readmission rates, while other studies suggest that longer stays may lead to more readmissions [2, 13]. To the extent that shorter hospital stays may result in the need for more acute hospital care post-discharge, this identifies a greater need for interventions to decrease acute hospital care post-discharge, an objective that our VC-RAM intervention seeks to address. Our inclusion of patients undergoing elective surgery with an expected length of stay of ≤ 3 days in this trial, focuses on a lower-risk population, where hospital discharge is less likely to be delayed by competing comorbidities. This targeted approach allows for a meaningful evaluation of VCRAM's ability to safely shorten hospital stays and optimize post-discharge care. Previous evidence has not identified significant safety risks associated with VCRAM [8], supporting its feasibility for broader implementation.

With our VC-RAM intervention, when escalation triggers are met, nurses promptly escalate care to the perioperative physicians. These physicians can then take several actions depending on the patient's needs, including continuing remote monitoring, conducting a video visit, referring the patient to an outpatient diagnostic facility, initiating or altering medications, or arranging follow-ups with themselves or non-study doctors, such as the surgeon or family physician. These

measures are designed to manage complications within the community or through virtual care, thereby reducing the necessity for acute hospital visits.

PVC-RAM-3 trial is powered to detect a 30% relative risk reduction in acute hospital care and a 1-day reduction in index length of stay in at least 35% of patients. With estimated baseline rates of 20-25% for acute hospital care and an average hospital stay of 2.5 days [7], a 30% reduction could prevent 6–7.5 acute care visits per 100 patients. Post-pandemic elective surgery volumes for those meeting PVC-RAM-3 inclusion criteria is approximately 4,500 surgeries per year. If we reduce length of stay by a day for 30% of these elective surgeries, we could free up hospital beds and increase surgical volume by an additional 1,350 cases per year to address surgical backlogs. This has the potential to generate substantial cost savings for the healthcare system.

Our previous trial demonstrated the potential of VCRAM to improve other patient important outcomes, such as the identification and correction of drug errors, pain management, and the medical optimization of patients, including those with atherosclerotic disease, for whom proven secondary prevention therapies exist, and those who smoke tobacco [8]. However, significant opportunities remain to further optimize pharmacological therapy to enhance long-term health outcomes, and these are evaluated in PVC-RAM-3.

A potential limitation of our study is the burden of frequent monitoring and patient contacts, as well as the possibility that the resources required to deliver the intervention may offset in-hospital cost savings in settings outside our health system, thereby limiting generalizability. However, a separate economic evaluation is planned to address this issue.

Dissemination

We will disseminate findings through presentations at national and international conferences,

publications in high-impact peer-reviewed journals, and posts on the "Reducing Global Perioperative Risk" Resource Centre, a global multimedia platform linked to Elsevier's online readership.

Conclusion

The results of the PVC-RAM-3 trial will provide critical insights into the role of VCRAM in addressing current health system pressures and enhancing perioperative care globally.

Authors' contributions: All authors planned the conceptualization and design of the study and the protocol. All authors contributed to critical revisions of the manuscript and approved the final version to be published. All authors agreed to be accountable for all aspects of this work

Competing interests: MM undertook training sessions for study nurses with CloudDX regarding how to use their technology. Outside the present work, he has received patient monitors from Philips Healthcare. MW is supported by the CIHR Canada Graduate Scholarships Doctoral Research Award. DC reports Grants from CIHR, Speaker fees from Servier, and Consulting fees from Trimedics all outside of the current work. DT is a Stryker consultant but is not relevant to this study. All the other authors declare no competing interests. No investigator has a financial relationship with CloudDX. The devices in the Connected Health kit used in the PVC-RAM-3 trial are licensed and approved for use by Health Canada, independent of any involvement from the investigators or PHRI. Based on fee for service, participating sites engaged Cloud Diagnostics Canada for trial devices, patient management software, data plans, participant onboarding to the system, and technical support. In addition, Cloud Diagnostics Canada provided training sessions for virtual nurses and perioperative physicians and surgeons on how to use their technology. Cloud Diagnostics Canada did not fund the trial and was not directly involved in

protocol development, trial management, or data analyses.

Data Sharing Statement: The Population Health Research Institute (PHRI) is the sponsor of this trial. The PHRI believes the dissemination of clinical research results is vital and sharing of data is important. PHRI prioritises access to data analyses to researchers who have worked on the trial for a significant duration, have played substantial roles, and have participated in raising the funds to conduct the trial. PHRI balances the length of the research study and the intellectual and financial investments that made it possible with the need to allow wider access to the data collected. Data will be disclosed only upon request and approval of the proposed use of the data by a review committee. Data requests from other non-PVC-RAM-3 investigators will not be considered until 5 years after the close of the trial. All data requests should be made to the corresponding author.

References

- [1] Jessica Spence, Yannick LeManach, Matthew T.V. Chan, C.Y. Wang, Alben Sigamani, Denis Xavier, Rupert Pearce, Pablo Alonso-Coello, Ignacio Garutti, Sadeesh K Srinathan, Emmanuelle Duceppe PJD on behalf of the VI. Association Between Postoperative Troponin Levels and 30-Day Mortality Among Patients Undergoing Noncardiac Surgery. *JAMA* 2012; 307: 2295–2304.
- [2] McGillion MH, Borges FK, Conen D, et al. Risk Factors for Hospital Readmission Following Noncardiac Surgery: International Cohort Study. *Annals of Surgery Open*; 5, https://journals.lww.com/aosopen/fulltext/2024/06000/risk_factors_for_hospital_readmission_following.13.aspx (2024).
- [3] Canadian Institute for Health Information. All-Cause Readmission to Acute Care and Return to the Emergency Department Health System Performance. *Health System Performance* 2012; 64.
- [4] Gauvin FP, Wilson MG, Lavis JN WK. *Panel summary: Taking a step towards achieving worry-free surgery in Ontario*. Hamilton, Canada, 2017.
- [5] Feinberg AE, Porter J, Saskin R, et al. Regional variation in the use of surgery in Ontario. *CMAJ Open* 2015; 3: E310 LP-E316.
- [6] McGillion MH, Duceppe E, Allan K, et al. Postoperative Remote Automated Monitoring: Need for and State of the Science. *Can J Cardiol* 2018; 34: 850–862.
- [7] Ontario Health. A Measured Approach to Planning for Surgeries and Procedures During the COVID-19 Pandemic [https://www.ontariohealth.ca/sites/ontariohealth/files/2020-05/A Measured Approach to Planning for Surgeries and Procedures During the COVID-19 Pandemic.pdf](https://www.ontariohealth.ca/sites/ontariohealth/files/2020-05/A%20Measured%20Approach%20to%20Planning%20for%20Surgeries%20and%20Procedures%20During%20the%20COVID-19%20Pandemic.pdf) (2015).
- [8] McGillion MH, Parlow J, Borges FK, et al. Post-discharge after surgery Virtual Care with

Remote Automated Monitoring-1 (PVC-RAM-1) technology versus standard care: randomised controlled trial. *BMJ* 2021; 374: n2209.

- [9] Devereaux PJ, Marcucci M, Painter TW, et al. Tranexamic Acid in Patients Undergoing Noncardiac Surgery. *N Engl J Med* 2022; 1–12.
- [10] Borges FK, Bhandari M, Guerra-Farfan E, et al. Accelerated surgery versus standard care in hip fracture (HIP ATTACK): an international, randomised, controlled trial. *The Lancet*; 0. Epub ahead of print February 2020. DOI: 10.1016/S0140-6736(20)30058-1.
- [11] McGillion M, Marcucci M, Borges F, et al. Detection of Postoperative Vital Signs Abnormalities on a Surgical Ward using Conventional and Remote Automated Monitoring. *Canadian Journal of General Internal Medicine* 2022; 17: 17–27.
- [12] Wiens BL, Dmitrienko A. The fallback procedure for evaluating a single family of hypotheses. *J Biopharm Stat* 2005; 15: 929–942.
- [13] Li RD, Joung RH-S, Chung JW, et al. Divergent Trends in Postoperative Length of Stay and Postdischarge Complications over Time. *Jt Comm J Qual Patient Saf* 2024; 50: 630–637.

Patient screening and recruitment

Patients undergoing elective surgery are eligible if they meet ALL the following criteria:

- ≥ 18 years of age at the time of enrolment, undergoing inpatient elective noncardiac surgery with an expected length of hospital stay ≤ 3 days after surgery medication, and provide informed consent to participate
- No exclusion criteria

Informed Consent

Randomization

Virtual care with RAM
versus
Standard post discharge care

VCRAM intervention

- Give remote monitoring kit to patient
- Patient takes wound photos daily for 7 days, measures vitals every day on days 1-7 and every other day on days 8-14, and complete recovery survey every day
- Nurses conduct virtual video visits on days 1, 3, 7, 14 post discharge
- Physicians conduct virtual video visits on days 1 and 14 post discharge with an optional day 7

Standard care

- Per participating hospital and surgical team

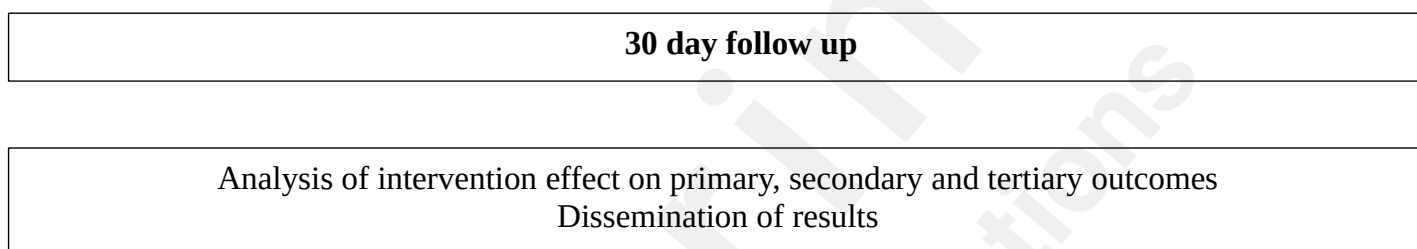


Figure 1. Trial Flow diagram



Figure 2. Cloud DX Connected Health kit

Cloud DX Connected Health Kit, including Bluetooth-enabled Pulsewave wrist cuff blood pressure monitor, body weight scale, wireless oximeter and temperature probe, paired with Android health tablet. Reproduced with permission from Cloud DX

Preprint
JMIR Publications

Supplementary Files

Figures

Trial flow diagram.

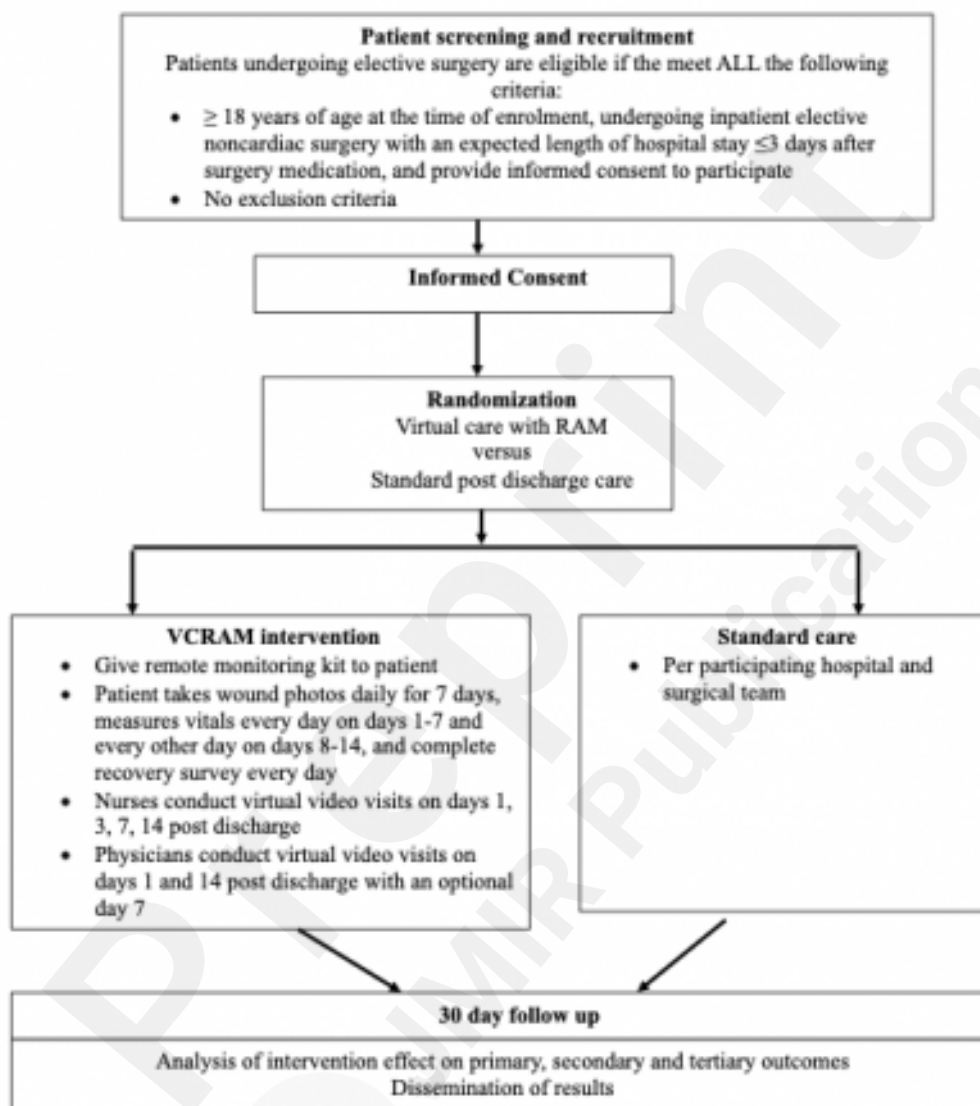


Figure 1. Trial Flow diagram

Cloud dx connected health kit.



Figure 2. Cloud DX Connected Health kit

Cloud DX Connected Health Kit, including Bluetooth-enabled Pulsewave wrist cuff blood pressure monitor, body weight scale, wireless oximeter and temperature probe, paired with Android health tablet. Reproduced with permission from Cloud DX

Multimedia Appendixes

Untitled.

URL: <http://asset.jmir.pub/assets/f56dbca5ed2dcb9957b9e2f7374f8faf.docx>

Supplementary Material.

URL: <http://asset.jmir.pub/assets/45197aa8bc15b7a20cc5328014ca0ebe.docx>

