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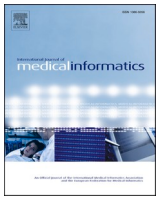

Clinicians' perspectives on wearable sensor technology as an alternative bedside monitoring tool in two West African countries

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ABSTRACT

Objective: Healthcare facilities in low- and middle-income countries (LMICs), especially in Africa, suffer from a lack of continuous bedside monitoring capability, adversely affecting timely detection of hemodynamic deterioration and the opportunity for life-saving intervention. Wearable device technologies can overcome many of the challenges of conventional bedside monitors and could be viable alternatives. We assessed clinicians' perspectives on the use of a novel experimental wearable device ("biosensor") to improve bedside monitoring of pediatric patients in two West African LMICs.

Methods: Focus groups were conducted in 3 hospitals (2 in Ghana and 1 in Liberia), in both urban and rural settings and of variable size, to elucidate clinicians' attitudes about the biosensor and to identify potential implementation needs. The focus group sessions were coded using a constant comparative method. Deductive thematic analysis was applied to pair themes with Consolidated Framework for Implementation Research (CFIR) contextual factors and domains.

Results: Four focus groups were conducted in October 2019, and included 9 physicians, 20 nurses, and 20 community health workers. Fifty-two codes in four thematic areas were linked to 3 CFIR contextual factors and 9 domains. Key themes were durability and cost of the biosensor, hospital setting, and staffing concerns, which were related to the "Inner Setting" and "Characteristics of the Intervention" CFIR contextual factors. Participants, who recognized the limitations of current vital sign monitoring systems, further identified 21 clinical settings in which a biosensor could potentially be useful and expressed willingness to implement the biosensor.

Conclusion: Clinicians who provide care to pediatric patients in two West African LMICs suggested multiple uses of a novel experimental wearable biosensor and expressed willingness to use it for continuous bedside vital sign monitoring. They identified device design (e.g., durability, cost), hospital setting (rural vs urban), and staffing as important factors to consider during further development and implementation.

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1. Introduction

Vital signs (heart rate, blood pressure, respiratory rate, and temperature) are the main physiological measurements used to assess the hemodynamic status of a patient. [1] Accurate and timely measurement of patients' vital signs is crucial to detecting hemodynamic deterioration and, thus, clinical complications. However, since continuous bedside monitors are expensive, susceptible to high humidity, and require reliable electric power, and often require disposable supplies (e.g., single use chest pads) and repair capabilities, hospitals in many low- and middle-income countries (LMICs), especially in Africa, have little available continuous patient monitoring.[2–4] In fact, medical device failure and lack of durability in tropical environments, such as in African countries is a chronic problem.[5] As a result, manual vital sign monitoring remains the standard of care in most LMICs. [6,7] However, with limited personnel available to assess patients' vital signs and frequently non-functional equipment, timely assessment of deterioration and appropriate intervention is often fatally delayed in LMICs. [8] Therefore, vital sign monitoring solutions that are cost-effective and address the multiple logistical and operational challenges in LMICs are needed.

Wearable sensor devices, which generate continuous, accurate, real-time vital signs data in adults and children, may be a viable alternative to the current manual vital sign monitoring standard of care.[9,10] Most wearable devices are airtight, wirelessly rechargeable, reusable, and relatively low cost. [11,12] such sensors have the potential to significantly improve critical care in LMICs by providing more affordable and reliable assessment of hemodynamic stability. [9] Wearable sensor devices have been shown to be an effective vital sign monitoring method in a wide variety of patient populations, including in adult patients with stroke, Parkinson's disease, and heart failure, [13,14] as well as, in neonates [15] and children with sepsis and pneumonia. [7,16] Because children are often not able to communicate their symptoms as clearly as adults, objective data from a wearable device may be particularly useful in detecting hemodynamic instability. However, less is known about the use of wearable sensor devices for vital sign monitoring of pediatric patients in LMICs.

The Consolidated Framework for Implementation Research (CFIR) is an established framework that defines implementation domains. Qualitative methods, such as focus groups, are conducted to determine the implementation needs within such domains—See methods for further details.[17–19] In this study, we conducted focus groups with clinicians in diverse healthcare settings in two West African countries to harness their perspectives about the usefulness of a novel experimental wearable vital sign sensor ("biosensor") for vital sign monitoring of pediatric patients.

The biosensor, developed at Northwestern University, potentially addresses key challenges to optimal vital signs monitoring in African countries.[20] It is a reusable, wirelessly rechargeable device that is capable of reliably capturing heart rate, respiratory rate, and temperature (Fig. 1). It is a Band-Aid-like device that is flexible and can be affixed to a variety of locations on a patient's body using a dermatology-tested adhesive. [11,12,21,22] Because it is airtight, the device is immune to high humidity that can cause malfunctioning as in conventional bedside monitors. The cost of the biosensor is 0.05–0.07 USD/patient/day, and data are transmitted wirelessly to any Bluetooth-enabled platform, such as a smartphone. [12,23].

2. Methods

In October 2019, focus groups were conducted in two West African countries, Ghana and Liberia, with clinicians who care for pediatric patients to gather their perspectives on the use of the novel biosensor device for vital sign monitoring. The audio-tapes of the focus groups were transcribed, coded, and themes were mapped to key aspects of implementation, as described by the Consolidated Framework for Implementation Research (CFIR). [17–19].

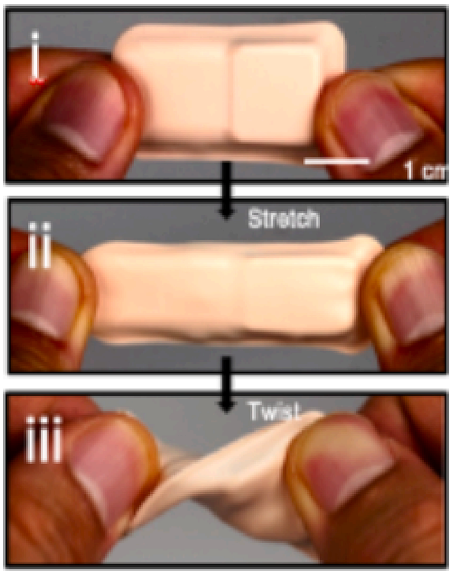

Fig. 1. The Biosensor and its size, shape, and conformal design.

2.1. Data collection procedures

In Ghana, focus groups were conducted at the Ahmadiyya Hospital in Agona Swedru, a 75-bed, district level hospital and at the Korle Bu Teaching Hospital in Accra, a prestigious, 2,000 bed, teaching hospital. In Liberia, a focus group was conducted at the Phebe Hospital and Nursing Center in Phebe, a 75-bed, regional referral center.

Clinicians who measure and/or use vital signs to assess the hemodynamic status of pediatric patients were recruited as participants. An initial informational email was sent to the leaders of the Departments of Pediatrics, Surgery, and Emergency Medicine at each hospital. They were asked to disseminate the information and ask for voluntary participation in the focus groups. No pre-specified minimum or maximum number of participants was required for a focus group. All clinicians who participated in a focus group session were included. Participants provided consent, using a Lurie Children's Hospital IRB-approved informed consent. The focus groups were conducted in English, which most clinicians in Ghana and Liberia speak fluently, and were facilitated by authors BM and HG. Each focus group lasted approximately 1 h (minimum 45 min maximum 1.5 h) and was audio recorded.

A standardized focus group guide was used. The guide consisted of a PowerPoint presentation with photographs of the novel biosensor wearable device, followed by examples, drawn from the relevant literature, of uses of a wearable device in clinical care, and a series of standardized open-ended questions (Table 2). Questions were designed to gather clinicians' perspectives about current vital sign monitoring systems, current practices for gathering vital sign measurements, potential barriers to implementation of the biosensor for vital sign monitoring, and attitudes towards potential implementation.

The audio recording of each focus group was transcribed. The first author (BM) performed quality assurance by listening to the recording, verifying the transcript, and removing identifying information. Using a multiple coding method, two co-authors (BM and AA), independently coded one focus group transcript, compared their codes, and reached consensus on any codes or coded segments that differed. A third coder (HG) reviewed and settled any differences in coding that could not be resolved through consensus. Multiple coding allows for new insights to emerge through discussion and is a valid means for coding. [16] The consensus-derived codes from the first transcript were used to create a codebook. The remaining transcripts were then coded using the codebook.

2.2. Thematic analysis

A deductive analytic approach, using CFIR, was used to identify *a priori* themes and codes, related to pre-established hypotheses. [24] CFIR was chosen as the framework for the deductive analysis because it includes a comprehensive taxonomy of contextual factors related to implementation of an intervention, including factors such as characteristics of the intervention (design, adaptability), inner setting (structural, cultural context), outer setting (economic, political context), individuals involved (people with agency who influence implementation), and the implementation process (interrelated processes occurring at multiple levels). Each contextual factor is associated with a number of domains. [17–19] For example, the CFIR contextual factor "Characteristics of the Intervention" includes domains such as relative advantage, adaptability, trialability, complexity, design quality, and cost. Additional focus group comments describing clinicians' perspectives beyond the *a priori* codes and themes were analyzed, using an inductive analytic approach, specifically related to clinical applications.

3. Results

3.1. Focus groups and focus group Participants

Four focus groups were conducted and included 9 physicians, 20 nurses, and 20 community health workers, who all self-identified as measuring and/or using vital signs to assess the hemodynamic status of pediatric patients. Table 1 shows the composition of participants by focus group.

3.2. Codes and themes

The final codebook consisted of 52 codes in four deductive analytic thematic areas, including, "implementation issues", "barriers to optimal monitoring in LMICs", "dissatisfaction with current monitoring systems" and "clinical applications." All focus groups contributed codes to each of the four themes. Nurses provided more insight into the "barriers to optimal monitoring" and "dissatisfaction with current monitoring systems" themes. Surgeons commented more often on "implementation issues" and "barriers to optimal monitoring". Nine CFIR domains were linked to codes, with most codes being related to the CFIR contextual factors of "Inner Setting" and "Characteristics of the Intervention." A complete list of codes linked to the CFIR contextual factors with verbatim quotations, are reported in Table 3.

3.2.1. Inner setting

The CFIR "Inner Setting" contextual factor refers to "the social architecture, age, maturity, and size of an organization". Focus group participants frequently commented on "Inner Setting" domains related to "structural characteristics", "networks and communications", "culture", and "implementation climate." For example, comments related to "structural characteristics" included consideration about rural versus urban health care settings; hospital units in which the biosensor would be useful (babies ward, postoperative anesthesia unit, emergency centre), and specific environmental concerns, such as the "humidity in Ghana," and "staffing issues". Comments related to "networks and communications" focused on the availability of wireless internet and Bluetooth. Comments related to "culture" highlighted the role of the government in prioritizing purchases of new equipment and the limited resources for biomedical equipment repair. Finally, comments related to "implementation climate" revealed willingness to implement a novel monitoring device, like the biosensor.

Table 1
Focus Group Location and Participants.

1. Swedru Ahmadiyya Hospital, Agona Swedru, Ghana
1 General Surgeon
10 Community Health Workers
2. Korle Bu Teaching Hospital, Accra, Ghana
(2 Focus Groups, total participants listed)
4 Pediatric Surgeons
20 Pediatric Nurses
10 Community Health Workers
3. Phebe Hospital and Nursing Center
3 General Surgeons
1 Anesthesiologist
1 OBGYN

Table 2
Standardized Focus Group Questions.

1. For what clinical conditions or procedures would Biosensor data be useful to you?
2. For which patients (e.g., age group, co-morbidities) would real-time monitoring be helpful?
3. For which clinical settings would Biosensor data be most useful to you?
4. How would you prefer to receive "real time" data (e.g., tablet, phone)?
5. How often do you think you would want to receive updated data?
6. If the data suggest a problem, who do think should be notified first?
7. Do you have any other questions or concerns about the Biosensor?

3.2.2. Characteristics of the Intervention

Comments related to "Characteristics of the Intervention" were specific to the CFIR domains of "relative advantage", "adaptability", "design quality", and "cost." Comments related to "relative advantage" of the biosensor highlighted the labor-intensive nature of current monitoring systems, a shortage of batteries for manual cuffs making manual vital signs monitoring difficult, and limited access to real-time patient monitoring systems. Comments related to "adaptability" (Table 4) highlighted numerous clinical conditions and patient scenarios wherein the biosensor was perceived as being potentially useful. Participants described multiple clinical scenarios related to traumatic injury including "road traffic accidents", "crush injuries", "falls from tree during mango season", and during "triage." Participants suggested that use of the biosensor in the Accident Centre/Emergency Department would be helpful and acknowledged acceptability of the biosensor for use in injured children, including for children with "crush injuries" from "road traffic accidents." Participants also suggested that the biosensor could be deployed in the Babies Ward for routine monitoring after injury. Other examples of potential scenarios for use of the sensor included "to monitor shock", "sepsis", "asthmatics", "after invasive procedures", "ruptured appendicitis", and "patients who present after illegal abortions". Comments related to "design quality" were almost exclusively expressed in terms of concern about biosensor battery life, biosensor sanitation for multiple uses, privacy concerns with respect to formatting of data, and questions regarding the storage (duration, format) of patient data. Participants also voiced concern regarding biosensor cost, with most participants feeling that the biosensor was too costly.

4. Discussion

In this study, we assessed clinicians' perspectives about a novel experimental wearable sensor device, the biosensor, for vital signs monitoring of pediatric patients in two West African LMICs. Participants recognized many shortcomings of current monitoring systems and expressed a willingness to implement the new biosensor as an alternative vital signs monitoring system. Participants noted that the biosensor was superior to the current standard of manual vital sign measurement, which is labor-intensive, requires supplies such as batteries, and is not conducive to real-time patient monitoring. More than 20 clinical applications of the biosensor were suggested, demonstrating the potential for novel wearable monitoring systems in a variety of settings. Participants underscored the need to further reduce cost, produce a high-quality device with limited need for repair, and highlighted important differences in implementation needs, based on related to the location

Table 3
Consolidated Framework for Implementation Research (CFIR) Domains.

CFIR Contextual Factors	Deductive Codes	Examples from Transcript
Characteristics of the Intervention		
Relative advantage	Labor intensive nature of current monitoring system Shortage of batteries for manual cuffs Limited real-time monitoring	"We are happy in the Intensive Care Unit. But the ward and the OB, we are not happy." "You can see that most the equipment we have it's not enough."
Adaptability	Numerous clinical conditions and patient scenarios proposed for trial	See Table 4
Design Quality	Concern around battery life Concern around sanitizing after use Concern around frequency of data Concern around format of data Concern around storage and access of data Concern around durability	"What happens if supposedly, if the device is connected and the battery goes off, so the back record that was there is it stored or is it just vanished?" "Can you go backward to see yesterday day before yesterday at a specific time for what the temperature was?" "How safe is the information? Can someone use his or her mobile phone to destroy this information?" "How do you store it? For instance, after using it on a client how can you store it for the next one?" "I want to ask if it has a life span. Like maybe 1 year or 2 years or maybe 6 months. Like how many years, like how many years can we use it. "I have a worry, but is it sticky?"
Cost	Concerns about cost	"The cloud will not be affordable for them because they won't have access to the cloud. So, if this can be in your consideration." "So how many of these can be affordable?" "Very, very expensive."
Inner Setting		
Structural Characteristics	Accident Centre Babies Ward Postoperative Anesthesia Care Unit Intensive Care Unit Rural setting Urban setting At home Humidity and Weather Outdated equipment Limited quantity of equipment Inconsistent staffing	"Then again, this device is only for big cities and big cities that are really enjoying their facilities. Because so we see the remote areas. Let's suppose somebody does not have a mobile phone but the device is like that, then we could transmit data to the television screen anywhere." "Some of the machines are faulty, they do not move even." "You can't monitor to know how well the child is receiving oxygen, if the child can be weaned off, whether you can reduce the fluids and the oxygen. You cannot do anything because the saturation monitor is not working."
Networks and Communications	Availability of WIFI Availability of Bluetooth Availability of smart phones	"Another question, how will you see the device where we don't have the network?" "If I understand what you said, that means, you have to use the internet to call and access."
Culture	Limited resources (expertise) for device repair Government drives change Early warning systems do not exist	"We have only one biomedical engineer in the country" "So, this device if it could come, we'll say roughly on Ghana level, if the government could give millions of dollars…"
Implementation climate	Willingness to implement Excitement for new technology Recognition of potential to improve	"So in said cases you would have wished that you have device like this or if possible be on the monitor for you to begin getting vitals." "Just imagine you are set up having this small device placed on patient gives you all information. That one you like, or you want to go with conventional tush, tush, tush, tush, tush [sound of manual blood pressure cuff]"
Outer Setting		
External policies and incentives	Ministry of Health involvement in purchasing equipment	"The Ministry of Health purchases equipment"

Table 4
Clinical Applications and Patient Scenarios Proposed for the Biosensor.

Acute kidney injury
Unconscious patients
Injured patients
Patients with fluctuating clinical status
During Triage
To detect apnea
Monitor sepsis
Cardiac patients
Preterm babies
Asthmatics
Patients in shock
Newborns after birth
Pneumonia
After invasive procedures
Malnourished patients
Hemorrhage
Patients who present after illegal abortions
Ruptured appendicitis
Road Traffic Accidents
Crush injuries
Falls from tree during mango season

(rural vs urban).

Participants' comments were primarily related to the CFIR contextual factors of "Inner Setting" and "Characteristics of the Intervention". Concerns about "Inner Setting" seemed to be based on knowledge of the culture and organizational structure of their hospitals that may hamper implementation of a novel device like the biosensor. In LMICs, certain characteristics of the health systems can make implementation and diffusion of healthcare innovation more challenging, namely a lack of resources and less efficient governance structures. [25] Due to limited

resources, innovations in LMICs are generally driven by a desire to fill a specific need, like improved monitoring, rather than to improve outcomes or profit, which are primary drivers in high income settings. [26] Additionally, a persistent challenge of implementation of a healthcare innovation in LMICs involves a concern that a novel technology might increase scrutiny of the healthcare system, thus, revealing other dysfunction. [27] Further investigation with small pilot studies, involving senior leadership of hospitals could provide additional important information about how wearable monitoring technology could be successfully deployed in West African LMIC hospitals.

Comments related to the CFIR contextual factor "Characteristics of the Intervention" centered on biosensor design, complexity, effectiveness, cost, and adaptability. Participant comments about the design of the device can help to improve and adapt it to the local setting. Suggestions for further refinement of device robustness, including tougher exterior and increased stabilization of the internal accelerometer components, may benefit eventual implementation. Educational efforts about the biosensor are a critical next step for successful implementation and will be important to clinicians' understanding of the uses and limitations of the device.

Participants highlighted that the biosensor cost of 0.05–0.07 USD/patient/day was high. [23] These comments may be anchored by the country-specific average worker earnings (Ghana: average daily income USD $2; Liberia: average daily income less than USD$0.78).[28] The biosensor may be also perceived as more expensive than existing manual vital sign monitoring because the actual costs of labor, supplies, and repair are not born or known by participating clinicians. Finally, concern about cost may also be related to negative personal experiences with buying and paying to maintain equipment. In LMICs, the cost of maintaining equipment sometimes falls directly on patients and their families. While these are legitimate concerns, further studies investigating the cost effectiveness of the device in these settings from provider and health system perspectives, as well as, input of biomedical engineering teams (responsible for equipment maintenance at the hospitals), are needed.

Focus group participants described the need for better monitoring in both rural and urban settings but suggested that the needs of the two settings are very different. In any setting, wearable data could help to predict which patients are at highest risk of hemodynamic deterioration prior to evaluation by a skilled clinician. [29] In urban settings, participants suggested that wearables can be used to improve monitoring in the Emergency Department and inpatient units. The device could reduce time spent manually measuring vital signs with a significantly lower cost burden than continuous bedside monitors. [6,7,23] In rural settings, focus group participants suggested that there is a need for vital signs monitoring of patients "in the field". Continuous assessment of vitals by a wearable biosensor would allow for more rapid recognition of hemodynamically unstable patients, targeted selection of patients in need to transfer, and more transfer to the appropriate level of care.

This study has several limitations. First, while clinicians from the two African countries were well represented, the coding team was from a high-income country, and implicit biases of our experiences must be acknowledged. Future work should include representatives from LMICs in both the research design and data analysis. Second, the biosensor is experimental in nature and, as such, focus group participants could not preview a fully functional device and monitoring system. In addition, participants may have had limited prior knowledge of biosensor technologies, thereby potentially biasing their responses to new technology. A baseline assessment of biosensor knowledge would have strengthened the present work. However, smart phone use was widespread by study participants, which represents an integral part of the proposed platform. Participants could not predict all important considerations, both benefits and challenges, if full scale implementation were to take place. Although we recruited a diverse sample of participants, the study is limited to two West African nations and the results may not be generalizable to all LMICs, especially in other continents. Nonetheless, the sites (a prestigious teaching hospital, a regional referral center, and a rural district level hospital) represent a representative cross-section of health care facilities in West Africa. Additionally, this study highlights the unique concerns of clinicians working in LMICs, regarding device implementation, perspectives which are often underrepresented in the literature.

5. Conclusion

Clinicians who care for pediatric patients in two West African countries expressed significant enthusiasm for a novel biosensor device that can provide real-time continuous vital signs data. Participants suggested numerous clinical situations where use of the biosensor would be beneficial. However, they also highlighted important considerations related to device design, specifically durability and cost. Efforts to implement novel wearable device technology in LMICs must engage local clinicians, biomedical engineers, and health system leaders, with attention to governance structure, in order be successful.

Summary table

What is already known on this topic

- Healthcare facilities in low- and middle-income countries (LMICs) suffer from a lack of continuous bedside monitoring capabilities, adversely affecting timely detection of hemodynamic deterioration and the opportunity for life-saving intervention.
- Wearable sensor devices generate continuous, accurate, real-time vital signs data in adults and children. Most wearable devices require little infrastructure, are airtight, wirelessly rechargeable, reusable, and relatively low cost.
- These sensors have the potential to significantly improve critical care systems in LMICs by providing more affordable and reliable assessment of hemodynamic stability.
- Previous studies have shown wearables to be an effective vital sign monitoring method in a wide variety of patient populations including adult patients with strokes, Parkinson's disease, and heart failure as well as neonates and children with sepsis and pneumonia.

What this study adds

- This study is the first to assess clinicians' perspectives on the use of a novel wearable device ("biosensor") to improve bedside monitoring of pediatric patients in two West African LMICs.
- Clinicians who provide care to pediatric patients in two West African LMICs suggested multiple uses of a novel wearable biosensor and expressed willingness to use it to for continuous bedside vital sign monitoring.
- The clinicians identified device design (e.g., durability, cost), hospital setting (rural vs urban), and staffing as important factors to address during implementation.

Informed consent was obtained for all individuals in this study.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] J.B. Holcomb, et al., Manual vital signs reliably predict need for life-saving interventions in trauma patients, J Trauma 59 (4) (2005), pp. 821–8; discussion 828–9.
[2] M.T. Shah, et al., Assessment of the Availability of Technology for Trauma Care in India, World J. Surg. 39 (2) (2015) 363–372.

[3] T.P. Hanche-Olsen, et al., Trauma Care in Africa: A Status Report From Botswana, Guided by the World Health Organization's "Guidelines for Essential Trauma Care", World J. Surg. 36 (10) (2012) 2371–2383.
[4] L. Chokotho, et al., Improving hospital-based trauma care for road traffic injuries in Malawi, World J Emerg Med 8 (2) (2017) 85–90.
[5] A.R. Zubair, Biomedical instruments: safety, quality control, maintenance, prospects and benefits of African technology, Afr J Med Med Sci 39 (Suppl) (2010) 35–40.
[6] S.B. Asiimwe, S. Okello, C.C. Moore, Frequency of vital signs monitoring and its association with mortality among adults with severe sepsis admitted to a general medical ward in Uganda, PLoS One 9 (2) (2014) e89879.
[7] S.C. Garbern, et al., Validation of a wearable biosensor device for vital sign monitoring in septic emergency department patients in Rwanda, Digital health 5 (2019), 2055207619879349.
[8] WHO Guidelines Approved by the Guidelines Review Committee, in World Report on Child Injury Prevention, M. Peden, et al., (Eds.), 2008, World Health Organization Copyright (c) World Health Organization 2008.: Geneva.
[9] H.C. Turner, et al., Achieving affordable critical care in low-income and middle-income countries, BMJ Glob. Health 4 (3) (2019) e001675.
[10] D. Ryu, et al., Comprehensive pregnancy monitoring with a network of wireless, soft, and flexible sensors in high- and low-resource health settings, Proc Natl Acad Sci U S A 118 (20) (2021).
[11] H.U. Chung, et al., Binodal, wireless epidermal electronic systems with in-sensor analytics for neonatal intensive care, Science 363 (6430) (2019) eaau0780.
[12] J. Kim, et al., Miniaturized Battery-Free Wireless Systems for Wearable Pulse Oximetry, Adv. Funct. Mater. 27 (1) (2017) 1604373.
[13] D. Johansson, K. Malmgren, M. Alt Murphy, Wearable sensors for clinical applications in epilepsy, Parkinson's disease, and stroke: a mixed-methods systematic review, J Neurol 265 (8) (2018) 1740–1752.
[14] J. Stehlik, et al., Continuous Wearable Monitoring Analytics Predict Heart Failure Hospitalization: The LINK-HF Multicenter Study, Circ Heart Fail 13 (3) (2020) e006513.
[15] H.U. Chung, et al., Binodal, wireless epidermal electronic systems with in-sensor analytics for neonatal intensive care, Science (American Association for the Advancement of Science) 363 (6430) (2019) 947.
[16] K. Mala, et al., A wearable diagnostic device to combat children's pneumonia, 2016, pp. 54-659.
[17] L.J. Damschroder, et al., Fostering implementation of health services research findings into practice: a consolidated framework for advancing implementation science, Implement Sci 4 (2009) 50.
[18] L.J. Damschroder, et al., The updated Consolidated Framework for Implementation Research based on user feedback, Implement Sci 17 (1) (2022) 75.
[19] A.R. Means, et al., Evaluating and optimizing the consolidated framework for implementation research (CFIR) for use in low- and middle-income countries: a systematic review, Implement Sci 15 (1) (2020) 17.
[20] M.J. Cummings, et al., A complex intervention to improve implementation of World Health Organization guidelines for diagnosis of severe illness in low-income settings: a quasi-experimental study from Uganda, Implement Sci 12 (1) (2017) 126.
[21] S.P. Lee, et al., Highly flexible, wearable, and disposable cardiac biosensors for remote and ambulatory monitoring, npj Digital Med. 1 (1) (2018) 2.
[22] Y.K. Lee, et al., Chemical Sensing Systems that Utilize Soft Electronics on Thin Elastomeric Substrates with Open Cellular Designs, Adv. Funct. Mater. 9 (3) (2017) 1605476.
[23] Personal Communication, Dr. John Rogers, 2019.
[24] S. Elo, H. Kyngas, The qualitative content analysis process, J Adv Nurs 62 (1) (2008) 107–115.
[25] T.A. Shuvo, et al., eHealth innovations in LMICs of Africa and Asia: a literature review exploring factors affecting implementation, scale-up, and sustainability, Innovat. Entrepreneur. Health 20152 (2015) 95–106.
[26] F.C. Oppong, Innovation in income-poor environments, Br J Surg 102 (2) (2015) e102–e107.
[27] A.B. Labrique, et al., Best practices in scaling digital health in low and middle income countries, Glob. Health 14 (1) (2018) 103.
[28] W. Bank, The World by Income and Region. 2023 [cited 2023 1/31/2023]; Available from: https://datatopics.worldbank.org/world-development-indicators/the-world-by-income-and-region.html.
[29] E. Kańtoch, Recognition of Sedentary Behavior by Machine Learning Analysis of Wearable Sensors during Activities of Daily Living for Telemedical Assessment of Cardiovascular Risk, Sensors (Basel, Switzerland) 18 (10) (2018) 3219.