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Reverse innovation in maternal health

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Abstract

Reverse innovation, defined as the flow of ideas from low- to high-income settings, is gaining traction in healthcare. With an increasing focus on value, investing in low-cost but effective and innovative solutions can be of mutual benefit to both high- and low-income countries. Reverse innovation has a role in addressing maternal health challenges in high-income countries by harnessing these innovative solutions for vulnerable populations especially in rural and remote regions. In this paper, we present three examples of 'reverse innovation' for maternal health: a low-cost, easy-to-use blood pressure device (CRADLE), a diagnostic algorithm (mini PIERS) and accompanying mobile app (PIERS on the Move), and a novel method for mapping maternal outcomes (MOM).

Keywords

Geographic information systems, global health, mobile technology, reverse innovation

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Introduction

Global health is often associated with the concept of risks flowing in one direction and philanthropy flowing back in the other direction.[1] However, this notion of global health fails to recognise the benefits of a bidirectional flow of ideas, in which those in well-resourced settings learn from those who have made more with less, and see the more severe end of the spectrum of maternal outcomes. Reverse innovation – the flow of ideas from lower to higher income settings – is gaining traction in health care as a way to generate innovative ideas.

Reverse innovation refers to the process of first identifying and/or fostering a successful innovation in a low- and middle-income country (LMIC) that addresses an unmet need in a high-income country (HIC), and then adapting and spreading the innovation from the LMIC to the HIC.[2] Reverse innovation allows for learning from and investing in poorer settings as one way to tackle problems in wealthier settings that require out-of-the-box solutions. These solutions often arise in LMICs because of an urgent, moral imperative to create effective, scalable solutions.[2] The five 'innovation gaps' of price, infrastructure, sustainability, regulations, and preferences drive innovation in LMICs by creating a favourable environment for new ideas to flourish.[2]

Once a problem has been identified and the innovation has spread across a LMIC, the idea must then cross-pollinate from lower to higher income settings. Spread across settings is more likely to move from LMIC early adopters to HIC innovators.[2] Once an idea has crossed over, the specifics of what constitutes the new process of intervention will likely require further modification to fit within the context of the HIC.[2]

The concept of 'doing more with less' or 'innovation by necessity' plays a prominent role in the health systems of HICs that are faced with the challenge of delivering high-quality care with limited financial resources.[3] In privatised service delivery, there is further incentive to innovate into the mainstream market.[3] Important lessons can be learned from emerging markets with less developed health systems that achieve positive patient outcomes with fewer resources.

Maternal health and reverse innovation

In 2015, the WHO introduced *Strategies toward Ending Preventable Maternal Mortality*, a framework that aims to catalyse global action to end preventable maternal and fetal/newborn deaths, and eliminate wide disparities in the rates of those deaths within a generation.[4] One of the priorities is to strengthen health systems to optimise the organisation and delivery of care, the workforce, and the commodities necessary to deliver high-quality care. Also, the framework highlights that research and development are needed to develop technologies that make birth safer.[4]

This framework is as applicable in LMICs as it in HICs, particularly for vulnerable women in rural and remote settings. For example, in the 2013 *Colour Outside the Lines: A Reverse Innovation Competition* held by the International Centre for Health Innovation at the Ivey Business School at Western University, Canada, a proposal described the use of mobile technology ('m-health') to transfer information to new mothers of late preterm infants to improve care following discharge from hospital.[3] This innovation was previously used in southern and southwestern Asia, Tanzania, Uganda, and Ghana, Serbia, Peru.

In this paper, we present three examples of maternal health innovations designed for LMICs that have the potential to be translated to high-income settings.

Microlife CRADLE Vital Signs Alert

More than half of all maternal deaths are caused by conditions that are associated with abnormalities in blood pressure (BP) and pulse (hypertensive disorders of pregnancy, obstetric haemorrhage, and sepsis).[5] Ninety nine percent of all deaths occur in LMICs, and the majority are preventable by simple interventions.[6] Early detection of abnormal vital signs allows early recognition of women who require urgent treatment or transfer to a higher level facility for definitive care. Accurate measurement of vital signs in pregnant/postpartum women is,

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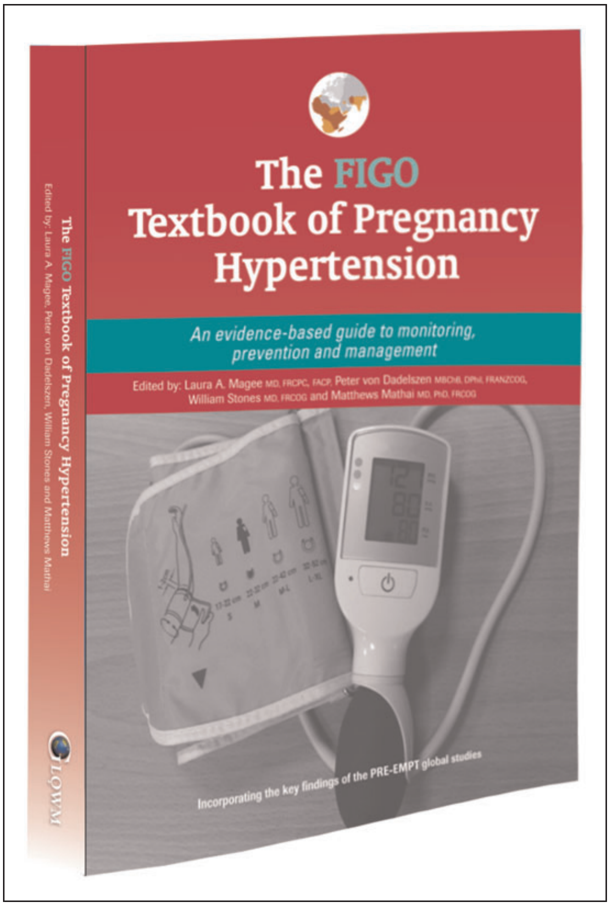

Figure 1. FIGO Textbook of Pregnancy Hypertension.

therefore, critical in the prevention of maternal mortality and morbidity, particularly for those women living in under-resourced settings. Unfortunately, access to accurate, easy-to-use, robust BP devices is most limited for those most in need.[7] Formal validation of BP devices prior to clinical use is crucial, particularly for devices used in pregnant women, as accuracy in non-pregnant populations does not guarantee accuracy in pregnancy; a problem most marked in women with pre-eclampsia. This is of such critical importance that the CRADLE device was put on the cover of the FIGO Textbook of Pregnancy Hypertension (Figure 1).

How the device works

The Microlife CRADLE (**C**ommunity blood pressure monitoring in **r**ural **A**frica and Asia: the **d**etection of under**l**ying pre-**e**clampsia and shock) Vital Signs Alert (VSA) is a hand-held, upper-arm, semi-automated device that measures BP and pulse. The device was developed by the CRADLE team at King's College London, UK. The device has been validated for use in pregnancy, including pre-eclampsia and hypotension in pregnancy, according to formal validation protocols.[8–10] In contrast, there are only a few other BP devices on the market that have been validated for use in pregnancy and pre-eclampsia, and none has been validated in hypotension.

Through funding by the Bill and Melinda Gates Foundation, the CRADLE VSA has been modified to ensure suitability (and meets the World Health Organization's requirements) for use by community health care workers in low-resource settings. It is affordable (less than USD$25), robust, easy to use, portable, requires infrequent calibration, has low power requirements (charging through a micro-USB port), and has dual auscultatory/oscillometric function.

The CRADLE team has also incorporated a 'traffic light' early warning system aiming to alert trained health care providers and untrained users to abnormalities in vital signs related to the hypertensive and hypotensive disorders of pregnancy (i.e. obstetric haemorrhage and sepsis). Pre-eclampsia, obstetric haemorrhage, and sepsis are the three leading causes of maternal mortality worldwide.[5] For pre-eclampsia, well-recognised thresholds for diagnosis of hypertension have been selected for the 'traffic lights', as follows:

- Green = systolic blood pressure (SBP) < 140 mmHg *and* diastolic blood pressure (DBP) < 90 mmHg
- Yellow = SBP 140–159 *and/or* DBP 90–109 mmHg (as long as neither is in the 'Red' light range)
- Red = SBP ≥ 160 mmHg *and/or* DBP ≥ 110 mmHg.

For shock from sepsis or haemorrhage, the thresholds for the various light colours have been set by their association with heart rate, through retrospective analysis of vital signs in datasets of women with postpartum haemorrhage.[11,12] The shock index, defined as the ratio of pulse to SBP, was shown to compare favourably with conventional vital sign assessment in predicting maternal intensive care unit admission. The shock index thresholds selected for the 'traffic light' colours were designed to maximise sensitivity (using yellow and red) and specificity (using red):

- Green = < 0.9
- Yellow = 0.9–1.69
- Red = ≥ 1.7.[11,12]

How the device is being used

The CRADLE device (with and without the VSA function) is being used to screen for hypertension in the community as part of the CLIP (Community Level Interventions for Pre-eclampsia) trials in Mozambique, India, Pakistan, and Nigeria (www.pre-empt.ubc.ca). Also, a one-year prospective validation of the CRADLE VSA's 'traffic light' thresholds is being carried out at three tertiary hospitals in South Africa. Both projects have been funded by the Bill and Melinda Gates Foundation.

The usability and feasibility of the device is being evaluated qualitatively by individual interviews and focus group discussions with pregnant women and stakeholders, as well as direct observations of community- and facility-level health care providers, across the CLIP and South Africa CRADLE sites.

The UK Medical Research Council-funded CRADLE trial is now underway. This is a stepped-wedge randomised controlled trial designed to determine whether implementation of the CRADLE VSA and a simple education package, into every level of routine maternity care, will reduce rates of maternal mortality and morbidity in 10 low-income countries (ISRCTN41244132).

How it can be translated to high-income settings

In the UK, the hypertensive disorders of pregnancy, obstetric haemorrhage, and sepsis contribute to more than one third of all direct maternal deaths.[13] The UK Confidential Enquiries into Maternal and Child Health (CEMACH) Report of 2003–2005 highlighted that a failure by health care professionals to immediately recognise and act on signs of life-threatening conditions, including pre-eclampsia, haemorrhage, and sepsis, contributes to avoidable maternal deaths.[14] This report recommended the use of Modified Early Obstetric Warning Score (MEOWS) charts for care of all pregnant and postpartum women to aid in more timely recognition of haemodynamic compromise.[14]

MEOWS charts are labour-intensive and require clinician interpretation and integration of changes in individual parameters, including vital signs but not limited to them. Despite their lack of validation with regards to clinical outcomes, these charts are in widespread use. However, the CRADLE VSA's traffic light system offers an alternative. It addresses concerns about MEOWS, and the thresholds have been developed in the UK.[15] The 'traffic light' is displayed immediately after taking the vital signs, aiding prompt decision-making based directly on accurate vital sign readings, rather than relying on the user to transfer vital signs to a paper MEOWS chart to determine the level of risk.

The Microlife CRADLE VSA is already in use clinically at a number of facilities throughout the world. Through successful device dissemination across settings, including a busy London maternity unit in the UK, it has become clear that the device is not only suitable for low-resource settings but also well-resourced settings, where delayed diagnosis of pregnancy complications still contributes to maternal mortality. The unique, evidence-based traffic early-warning system of the Microlife CRADLE VSA, although designed originally for use by untrained community health care workers, can be of benefit to trained health care workers in well-resourced settings.

miniPIERS (Pre-eclampsia Integrated Estimate of RiSk) and PIERS (Pre-eclampsia Integrated Estimate of RiSk) On the Move

Decision aids are tools used in medicine to support shared decision-making. They aim to provide clear information on the options available for treatment and make explicit the decision that is ultimately arrived at in high-resource settings. There is clear evidence that decision aids improve patient knowledge about options, improve the accuracy of risk perception, and improve provider–patient communication.[16] However, there is a lack of evidence about the use (or effectiveness) of decision aids in LMICs, despite the opportunity that these aids afford to improve patient engagement, health literacy, and health outcomes. Work in LMICs has focused on use of mobile technology for health education and 'push notifications' that alert the user through receipt of simple messages sent from central servers to their mobile devices using apps installed on those devices. These approaches have improved adherence to family planning practices and treatment regimens for communicable diseases, such as HIV and tuberculosis.[17]

A decision aid has been developed for care of women with pregnancy hypertension. The miniPIERS is a clinical risk prediction model that identifies hypertensive women who are at increased risk of maternal complications.[18]

How PIERS On the Move works

The miniPIERS model combines information on demographics (gestational age at assessment and parity), symptoms (chest pain and/or dyspnoea; headache and/or visual disturbances; and vaginal bleeding with abdominal pain), and signs (SBP and dipstick proteinuria) to determine an individual pregnant woman's likelihood of having an adverse maternal health outcome within the following 48 h.[18] The model was validated internally and externally and found to have good discriminatory performance (AUROC 0.731; 95% CI 0.698–0.764). Using a predicted probability of $\geq$25% to define a positive test, miniPIERS can accurately identify 85.5% of women who are at the highest risk.

The miniPIERS model includes only simple measures that can be assessed anywhere, including a woman's home, with minimal training or equipment. As such, the model can be used to provide effective care to pregnant women in traditionally hard-to-reach areas. The broader aim of this study was to create a model that can be used to improve access to care for women in low-resourced settings who are most adversely affected by the hypertensive disorders of pregnancy by providing an evidence-based method for making triage decisions.

The miniPIERS model has been converted into a simple mobile health (mHealth) decision aid for use by community health workers in low-resourced settings, called PIERS On the Move (POM).[19] The app guides a community health worker through an antenatal or postnatal assessment and provides recommendations for any required treatment or referral to facility, based on the results of the miniPIERS risk assessment (Figure 2). Throughout the app are pictorial aids, developed to support communication between the pregnant woman and the health worker regarding her risk status. Figure 1 shows that following login, the user performs an initial assessment to rule out the presence of a medical emergency or urgency that would require urgent transport to facility. Subsequently, the user collects information on pregnancy status, maternal signs of pre-eclampsia, maternal symptoms of pre-eclampsia, and oxygen saturation in the blood (by using a pulse oximeter placed on a finger and read by the mobile device). The user then receives recommendations about community-level treatment with antihypertensive therapy (methyldopa) or magnesium sulphate, as well as whether the woman should be seen at facility and with what urgency.

The decision algorithm used in the POM app was validated at Tygerberg Hospital, Cape Town, South Africa and Aga Khan University Hospitals, Karachi Pakistan. Validation involved two stages. First, end-user testing was undertaken to confirm that users thought that the app would be usefulness to them, and to confirm that they could learn how to use it. Second, the app was used in the care of a prospective cohort of women with pregnancy hypertension. The algorithm could identify women at high risk of an adverse maternal outcome, with a positive predictive value of 58.2% (95% CI 45.5–69.9) and negative predictive value of 89.9% (87.4–91.8).[20]

The POM app is being implemented as part of the CLIP cluster randomised controlled trials in Mozambique, Pakistan, and India to empower community health workers to care for women in their own communities, as pictured in India (Figure 3).[21] POM has also been evaluated in a related implementation study in Nigeria. Results from this trial are expected in early 2018.

How miniPIERS and POM can be translated to high-income settings

The miniPIERS app can improve access to antenatal care for underserviced poor or remote populations of pregnant women anywhere in the world. For example, there is significant potential for POM to have a positive impact if incorporated into rural maternity care services in Canada. Also, miniPIERS could be used in high-resourced settings where laboratory testing is not readily available, such as the clinic setting outside of facility.

Perhaps, the greatest potential will come from incorporating tools that adapt to what is available to the end-user. The miniPIERS study was actually a second step in the larger PIERS project that developed the fullPIERS model suitable for use in well-resourced settings.[22] The fullPIERS model includes maternal symptoms, signs, and laboratory tests designed to identify women at increased risk of adverse maternal outcome. The miniPIERS model was an adaptation of the fullPIERS one to settings where laboratory testing is not available. To make these models applicable to any health setting anywhere in the world, they have now been incorporated into a mHealth application that

Figure 2. PIERS on the Move mobile application.

Figure 3. Community health workers in India using the POM device.

will use either the mini- or full-PIERS model, based on resource availability at the time of assessment. This new app will facilitate evidence-based care and shared decision-making for women with suspected hypertensive disorders of pregnancy from the community to tertiary-level facilities. The miniPIERS could provide a first step in the triage process during regular antenatal assessments completed in an office, and this information could be linked to the app being used on the nearest referral facility, creating an integrated system of care.

Mapping Outcomes for Mothers

The new global strategy for improving maternal health has been expressed in the sustainable development goals (SDGs) set in Mozambique.[23] These cover medical, social, and geographic determinants of health, and they aim to put health into context.[23] Geographic information systems (GIS) have many potential health applications. For example, GIS can be used to model the physical barriers (e.g. severe weather) to care, when they occur, and the specific populations that are affected.[24,25] Also, GIS can be used to understand the location and movements of specific cultural groups so that culturally sensitive interventions can be targeted.

How Mapping Outcomes for Mothers works

The Mapping Outcomes for Mothers (MOM) project, set in Mozambique, implemented GIS to identify and measure the context-relevant determinants of maternal ill-health in the region.[26] MOM sought to identify the place-specific characteristics responsible for associations between social determinants and maternal health outcomes (both good and bad) and translate these into a mHealth application for use by minimally trained community health workers. The ultimate goal was to avert risk and build maternal resilience in the relevant communities.

The MOM mobile app incorporated community-specific determinants of health, as well as issues related to geographical access (Figure 4). A mixed-methods approach was used to characterise community perspectives on the factors that are associated with maternal risk. These views were gathered through focus group discussions with women, their spouses, and community leaders.[26] Factors explored included family support, distance from health facilities, and emergency transport options available. The data on adverse maternal outcomes and their potential determinants were used to generate spatial models that described community-level risk and resilience related to maternal health. A novel method for modelling geographical access to maternal health services was developed[25]; given that access to care is a known determinant of adverse maternal outcome[27,28] and in southern Mozambique, perennial floods are known to isolate communities from health facilities.[29] Spatio-temporal access was modelled by accounting for: (1) seasonal variation in access related to precipitation and floods, (2) daily transport options that characterise women journeys in the study area, and (3) the facility referral network that describes the realities of travel to health facilities from women's homes.

The prototype MOM mobile app runs on an android platform. Current work is ongoing related to external validation.

How it can be translated to high-income settings

Much of the innovation that characterises MOM can be transferred to high-income regions of the world that face similar challenges. Two areas for this reverse innovation include: (1) reaching isolated communities using location-sensitive mobile health services and (2) replicating the MOM process to elucidate the local character of the determinants of maternal health.

Reaching isolated communities through m-health

Incorporation of the above community-level intelligence into the design of mobile health apps will empower community health workers with some of the tools that they need to ensure that women deliver their babies safely. MOM (or other location-sensitive mhealth apps) in a typical HIC will aid delivery of near-real time data on the severity of weather, and how this may impede access to maternal care services in isolated regions. Canada is a logical place to test such implementation. There, First Nations communities have disproportionately higher maternal mortality and face challenges of poor access to maternal health services, related in part to geographic isolation and severe winter weather conditions.

Knowing and measuring the determinants of maternal health: A process innovation

It is likely that the key determinants that have been determined to matter in the MOM study region may not be generalisable to other regions of the high-income world. However, the process that has been undertaken in MOM is transferable – mixed-methods development by going into communities and understanding their perspectives of the determinants of maternal health, followed by quantifying the associations with maternal outcomes. This strategy could be of use for health authorities as part of creating culturally sensitive interventions that address the core concerns specific to the communities where they are implemented.

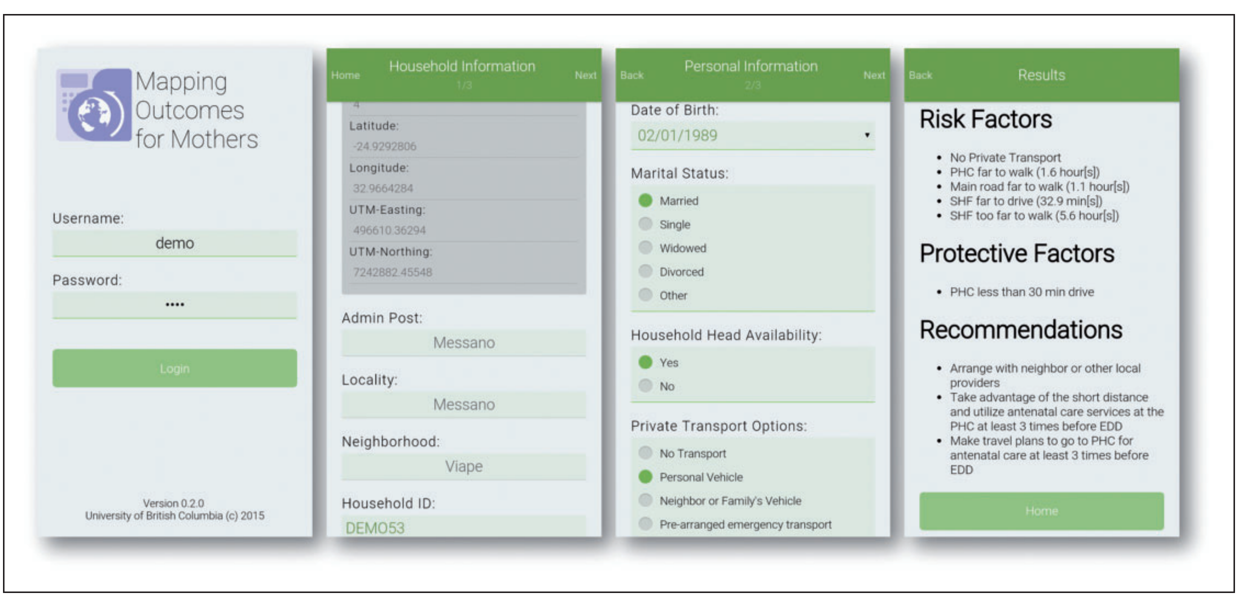

Figure 4. Mapping Outcomes for Mothers mobile application.

Future work will involve further developing the MOM app and integrating it with the other suite of clinical mobile tools like POM as part of a platform. This will result in a more holistic approach to delivering pregnancy care, accounting for clinical, social, and geographic determinants of health.

Conclusion

The 2030 SDG agenda is universal. SDG number 17, to 'strengthen the means of implementation and revitalise the global partnership for sustainable development' could not be more relevant for making global innovation flows real.[23] Reverse innovation is a way that countries from the global north and south can work together to address maternal health challenges faced by populations across the world. In fact, many intractable health care problems in HICs may be more readily solved than in LMICs.

In order to further promote and accelerate reverse innovation, four strategies have been recommended to engage health care policymakers, entrepreneurs, health system leaders, and researchers:[2]

1. Identify high-priority problems shared by lower and higher income countries.
2. Create opportunities for change, especially for LMIC innovators.
3. Bring LMIC early-adopters and high-income innovators closer together to promote exchange of ideas.
4. Measure reverse innovation activity globally.

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TF conceptualised the article. All authors contributed to writing of the manuscript.

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