



RESEARCH

INFORMATION

Digital biomarkers and continuous physiological monitoring to improve prediction of pregnancy and childbirth risk



AIMS

Every year nearly 3 million babies are stillborn in the third trimester of pregnancy, when if we had known that they were struggling we could have intervened to deliver them. Our existing tools for monitoring babies are limited to things that can be checked every few weeks in an antenatal clinic appointment and don't take account of variation between people, or the massive changes a pregnant body goes through. This means that we often miss babies with problems – in the UK today around 50% of small babies are not identified before birth, despite increasing usage of ultrasound and other tests. We also recommend interventions like induction of labour or Caesarean section to women who are thought to be at risk, even though we know the majority do not benefit from them.

This project used new technologies to improve identification of women and babies at risk of complications in pregnancy and childbirth, to help pick up struggling babies earlier and to avoid medical interventions in healthy pregnancies. We did this by developing **digital phenotyping** approaches: that is, using patterns derived from personal digital devices, wearable sensors and medical imaging to build a picture of how an individual's health changes over time. We linked



these **longitudinal digital data** (data collected repeatedly over the course of pregnancy) with clinical information to better characterise trajectories of risk.

The project had three interconnected strands:

- 1. Born in Scotland (BiS):** Building a representative, linked birth cohort to study the factors that affect health outcomes for mothers and babies in Scotland.
- 2. iTest (retinal imaging):** Testing whether changes in photographs of the back of the eye (the retina) during pregnancy can predict serious complications such as pre-eclampsia (a dangerous rise in blood pressure) and stillbirth.
- 3. IMPALA (intrapartum monitoring):** Testing continuous wireless monitoring of mother and baby during labour to detect deterioration earlier than current methods allow.



KEY FINDINGS

Across three projects, we have consistently found that trajectories of change are useful in the prediction of long-term outcomes of pregnancy. We have also shown that new technologies allow the collection of continuous data that allow us to identify these trajectories at home, in outpatient clinics, in hospital and via linkage of existing electronic health records. We have also found that combining data from multiple sensors gives more information than the sum of its parts – this is a subject of ongoing exploratory research in the IMPALA studies.

- Born in Scotland:** We have developed and piloted a secure, data protection (GDPR)-compliant digital platform capable of collecting data from personal devices (such as mobile phones) and linking these to NHS health records and stored blood samples. Our opt-out recruitment model — where all eligible women are included unless they actively choose to leave — produces a cohort that genuinely reflects the diversity of the Scottish population, including those from more deprived communities. <https://edinburgh-pregnancy-research.ed.ac.uk/current-studies/born-in-scotland>



- **Retinal imaging (iTest):** Photographs of the small blood vessels at the back of the eye, taken at 10–23 and again at around 36 weeks of pregnancy, reveal changes that predict serious complications. Women whose retinal vessel patterns changed in a characteristic way were at greater risk of pre-eclampsia, stillbirth and fetal distress. This simple, inexpensive test — which can be done with a handheld camera or smartphone — outperforms any currently available clinical measurement. <https://edinburgh-pregnancy-research.ed.ac.uk/current-studies/itest>
- **Wireless continuous monitoring during labour (IMPALA):** Simultaneous continuous monitoring of both the mother and baby (the mother-baby pair) using wireless wearable sensors allowed earlier detection of signs of deterioration in labour. Combining information from multiple sensors together gives more warning than any single measurement in isolation. <https://www.globalsurgeryunit.org/impala/>



WHAT DID THE STUDY INVOLVE?

The aim of this fellowship was to use new technologies to find better ways of identifying when mothers and babies are becoming unwell during pregnancy, including the period immediately before birth.

Our original plan included measuring environmental exposures such as air pollution using location tracking on our app platform, but this was not technically feasible with the systems available. We adapted our approach and tested four alternative monitoring methods:

- **Retinal imaging (iTest):** Camera photographs of the back of the eye, taken with a low-cost handheld device or smartphone.
- **Wrist-worn wearables:** Consumer-grade devices similar to a smartwatch, worn continuously during pregnancy.
- **Under-mattress sensors:** Non-invasive devices placed beneath the mattress to track maternal heart rate and movement during sleep.

- **Wireless labour monitors (IMPALA):** Hospital-grade wearable sensors worn during labour and birth, simultaneously monitoring mother and baby.

In each case, we were particularly interested in whether tracking how an individual changes over time — rather than comparing their measurements to general population averages — could give us earlier and more accurate warning that they were becoming unwell.

We recruited 400 women to the retinal imaging study (iTest), 200 to the under-mattress sensor study, and 417 to the wireless continuous labour monitoring study (IMPALA 1). In the Born in Scotland cohort, which uses routinely collected NHS data with an opt-out model, we have been able to study a large, representative sample of all births in Lothian.



WHAT WERE THE RESULTS AND WHAT DO THEY MEAN?

Born in Scotland (BiS)

Born in Scotland is a birth cohort study: a study that follows a large group of babies born in Lothian and the Borders to learn about the factors that affect their health and the health of their mothers over time. We tested two models of including people in the study. For the 'opt in' model participants were asked to navigate to a website and complete a consent form to join the study. In the 'opt out' model all eligible women are automatically included unless they choose to leave the study (opt out). This approach ensures that the cohort reflects the full range of Scottish society — including families from more deprived backgrounds who are often under-represented in research, but who are frequently those most affected by poor pregnancy outcomes.

The table below compares key characteristics of the cohort during the opt-in and opt-out periods. Monthly enrolment refers to the average number of new participants joining each month. The Scottish Index of Multiple Deprivation (SIMD) is a measure of socioeconomic deprivation based on postcode: decile 1 represents the most deprived 10% of areas in Scotland; 'high deprivation' in this table refers to women living in the most deprived 20% of areas (SIMD deciles 1–2). 'First-time mother' refers to a woman pregnant for the first time.



Table 1 shows that the opt-out cohort includes a significantly higher proportion of women from more deprived areas, confirming that this approach achieves greater representativeness than opt-in recruitment.

VARIABLE	Complete Cohort n = 1560	Opt In n = 904 (29 months)	Opt Out n = 656 (2 months)	Difference p Value
Monthly Enrolment	-	31	328	-
Mean Age	33.41 ± 4.91	34.46 ± 4.24	31.95 ± 5.37	< 0.001
Age equal or over 30	1284 (82.31%)	815 (90.15%)	469 (71.49%)	< 0.001
Mean BMI	26.2 ± 5.84	25.78 ± 5.60	26.77 ± 6.11	0.002
Obese	270 (17.31%)	143 (15.82%)	127 (19.36%)	0.079
Mean SIMD Decile	6.68 ± 2.73	7.05 ± 2.62	6.16 ± 2.80	< 0.001
High Deprivation	120 (7.69%)	49 (5.42%)	71 (10.82%)	< 0.001
White Ethnicity	1296 (83.07%)	777 (85.95%)	519 (79.11%)	< 0.001
Non-White Ethnicity	179 (11.47%)	62 (6.86%)	117 (17.84%)	< 0.001
Smoker	70 (4.49%)	16 (1.77%)	54 (8.23%)	< 0.001
Depression	118 (7.76%)	63 (6.79%)	55 (8.38%)	0.344
Domestic Abuse	59 (3.78%)	28 (3.10%)	31 (4.73%)	0.126
Primigravid	842 (53.97%)	494 (54.65%)	348 (53.05%)	0.566

Table 1. BIS cohort summary statistics. Means include the standard deviation after “±”. Counts include the percentage between parenthesis. The p value for the difference between Opt in and Opt out periods was obtained through t-tests (means) and two proportions z-test (proportions). High Deprivation is defined as Scottish Index of Multiple Deprivation 2020 ⁴ (SIMD) Decile 1 or 2. Depression status is derived from the Whooley questionnaire.

Retinal imaging (iTest)

In the iTest study we looked at changes in the small vessels of the retina during the pregnancy using a simple photo that can be taken with a cheap and sustainable hand held camera, or even a smartphone.

In the iTest study, we took retinal photographs (photographs of the blood vessels at the back of the eye) at two time points during pregnancy: early (12–20 weeks) and late (~36 weeks). We then



calculated how the characteristics of these blood vessels changed between the two visits. We observed that retinal features change during pregnancy in all women. These changes are also correlated with common blood tests that have been used to identify women with pre-eclampsia. Lastly, we observed that these changes are exaggerated in women who go on to develop pre-eclampsia.

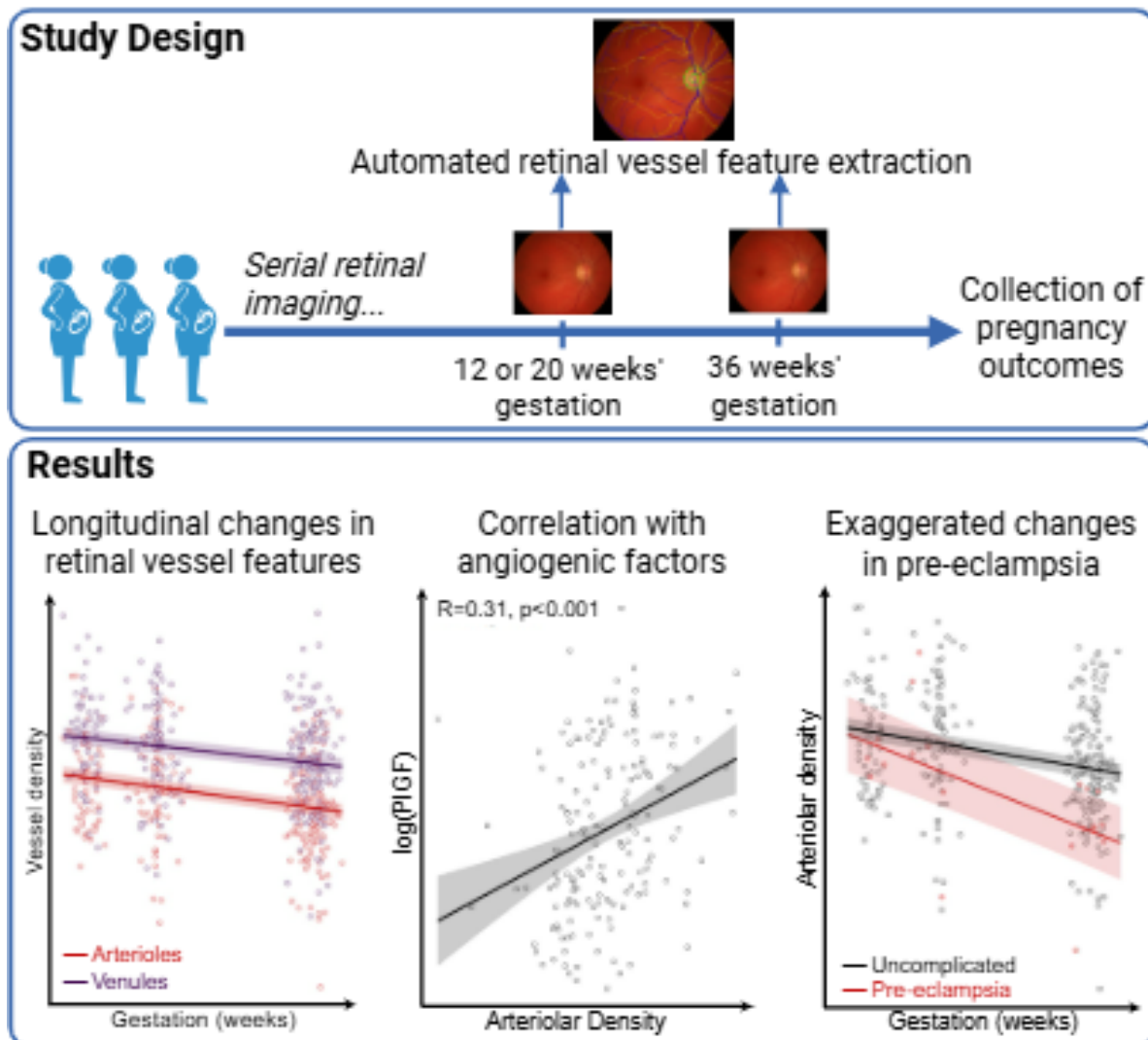


Figure 1 below shows that the change (delta, Δ) in retinal vessel measurements between the two visits helps predict which women will develop pre-eclampsia. In simplified terms: the graph shows that combining retinal vessel measurements with standard clinical information (blood pressure and routine checks) gives much better prediction than any single test alone, represented by the area under the curve (AUROC) moving closer to 1.0 (perfect prediction). Of all the measures available to us in the antenatal clinic, the change in retinal blood vessels was the most informative single



indicator of pre-eclampsia risk, and when combined with other clinical information improved our ability to predict risk of pre-eclampsia.

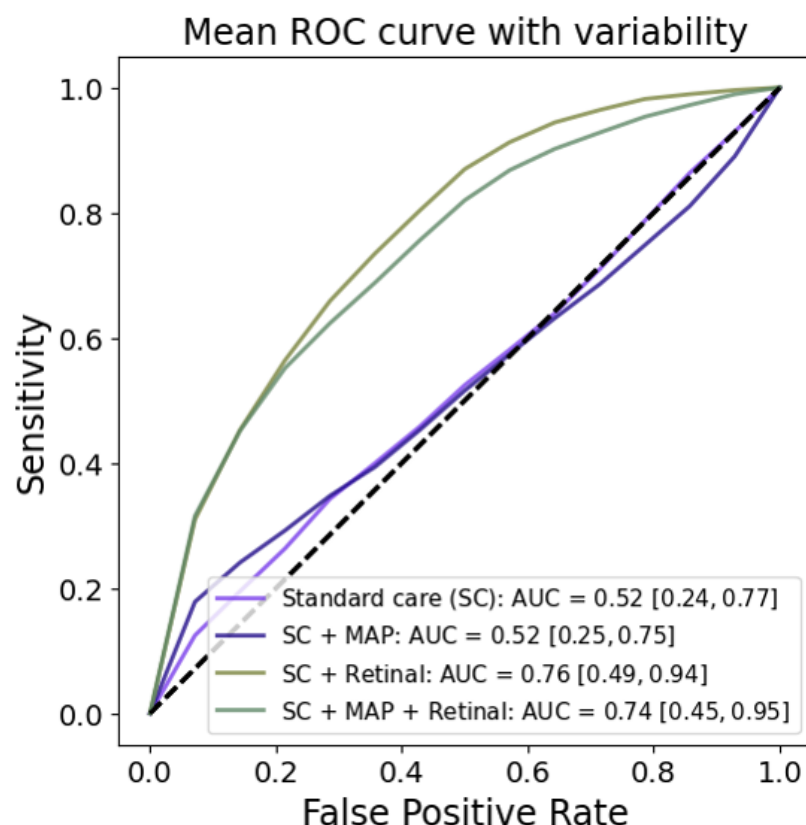


Figure 1: Delta (Δ) retinal vascular features derived from colour fundus imaging at 10–23 and ~36 weeks of gestation improve classification and prediction of term pre-eclampsia.

Control $n=84$, pre-eclampsia $n=9$. AUROC for the four logistic regression models, integrating demographic, clinical and retinal covariates, presented as the mean (95% confidence interval) averaged across 1000 resampled bootstrap iterations. AUROC = area under receiver operating characteristic curve, SC = standard care, MAP = mean arterial blood pressure

Wireless continuous labour monitoring (IMPALA)

In IMPALA 1, women giving birth were offered wireless wearable sensors to monitor their vital signs continuously throughout labour. This allows freedom of movement and comfort while collecting high-quality continuous data. The monitoring trace shown in the original report captures data from a single participant: the top line shows the mother's heart rate, which rises in the period just before delivery as she pushes to give birth. The vertical blue line marks the moment of birth. We are using machine learning methods to identify subtle patterns in these continuous signals — for example, changes in the natural variation (variability) of both the maternal and fetal heartbeats — that provide earlier warning of problems than monitoring the headline numbers alone.

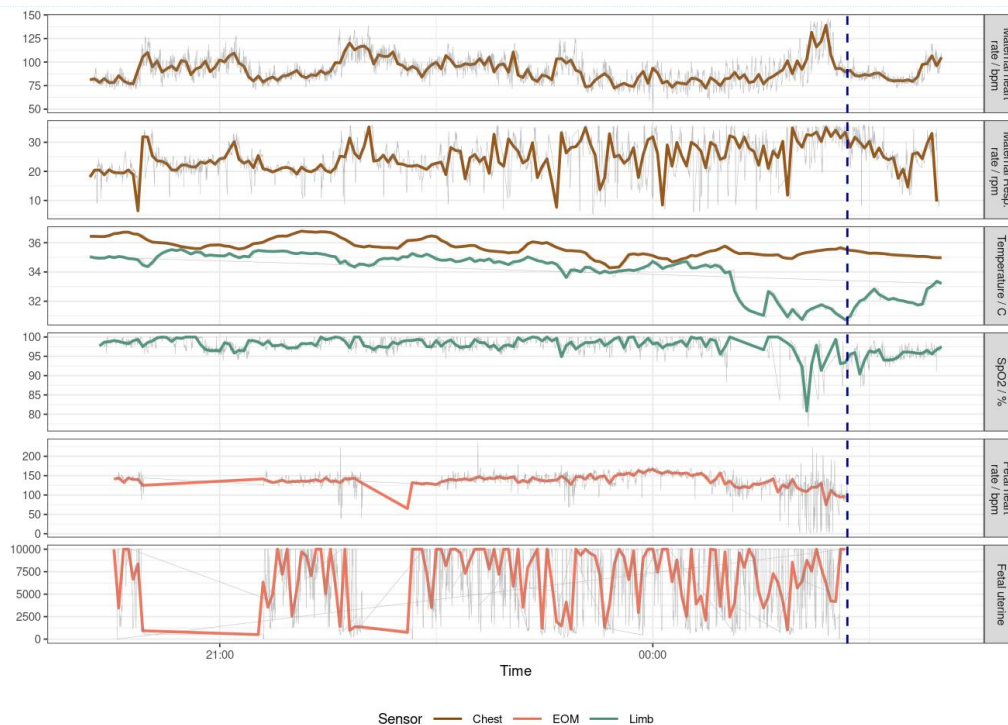


Figure 2. Multi channel continuous sensor data from a woman giving birth, showing the changes in maternal and fetal physiology in that time.

We are exploring combining data from each of these separate continuous wave forms, each of which tells us something different about the mother and the baby. We have shown in pilot work that adding continuous information that draws on trajectory changes helps us to identify better women who are well and can anticipate a normal birth, and conversely those who may be developing complications that require intervention.

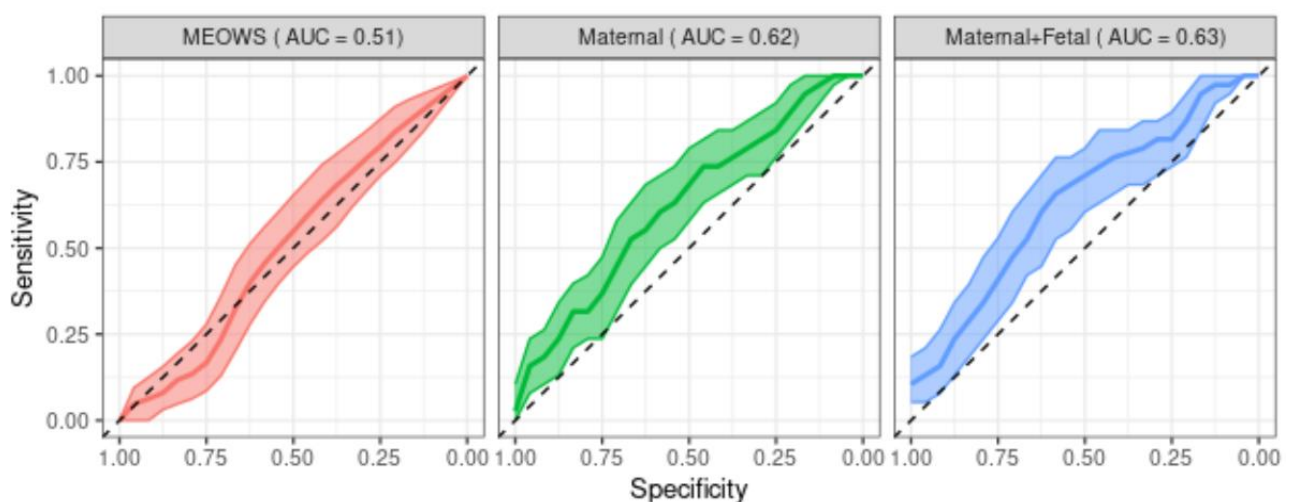
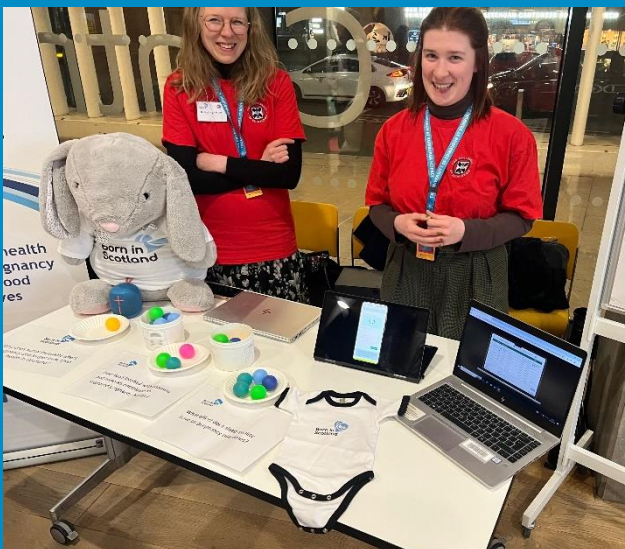


Figure 3. Three models were tested for their ability to predict normal birth with a healthy mother and baby. The addition of continuous data (first maternal, and then fetal) improved the predictive ability of the model. This represents early pilot work that will be further refined with the addition of new derived variables and additional clinical data.



WHAT IMPACT COULD THE FINDINGS HAVE?

- **Patients:** We will be able to offer new ways of tracking pregnancy health and more personalised recommendations around prevention of hypertensive disease and timing of birth. We will also be better placed to help people optimise their own health and their babies' health after pregnancy, using the unique information we have about their individual health trajectory during pregnancy.
- **Policy:** Our representative birth cohort will help drive health policy recommendations relevant for all of Scotland and support a healthier future for the Born in Scotland generation.
- **Practice:** Current antenatal care involves women travelling to hospital for measurements taken at fixed time points — which may not coincide with when problems first arise. Our work supports a shift towards minimally intrusive, highly sensitive tools that can track wellbeing at home in daily life, identifying those who need to be seen sooner rather than waiting for a scheduled appointment.



Some of our research team representing Born in Scotland at the Science Festival in 2024. (Dr Kathryn Hunt and Dr Jazz Kirkwood)



HOW WILL THE OUTCOMES BE DISSEMINATED?

We have already published several papers relating to these projects and have five more in preparation. We also regularly present our work at academic conferences, including invited speaker roles, and engage in public events to discuss our research.

We have hosted a session at the Edinburgh Science Festival every year for the last three years (2023: 'Our Planet, Our Health'; 2024: 'Healthy Pregnancies, Healthy Lives'; 2025: 'Eye eye, Doctor!'). In 2025, I performed in the Edinburgh Fringe as part of the University of Edinburgh showcase 'The Provocateurs', with a show entitled 'Life as a Fetus'.



CONCLUSION

Changes in the way a woman's body functions across the duration of pregnancy are important for understanding health and disease in both the mother and baby. Tracking these changes helps us identify who is most at risk of complications, but also supports planning for healthy lives for both mother and baby after the birth.

New technologies, including retinal imaging, wearable sensors and continuous wireless monitoring, allow this kind of personalised monitoring to be offered non-invasively and even at home. Learning from individual trajectories of change may also help us understand when and why complications begin, opening the possibility of developing new treatments to prevent them altogether in the future.



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