

**Supplementary material****Design and development of a clinical decision support system for community health workers to support early detection and management of non-communicable disease***Authors*

Sojib Bin Zaman<sup>1</sup>, Nisal De Silva<sup>2</sup>, Tian Yu Goh<sup>2</sup>, Roger G Evans<sup>3,4</sup>, Rajkumari Singh<sup>5</sup>, Rajesh Singh<sup>5</sup>, Akash Singh<sup>5</sup>, Parul Singh<sup>5</sup>, Amanda G Thrift<sup>1</sup>

*Affiliation*

<sup>1</sup>Department of Medicine, School of Clinical Sciences at Monash Health, Monash University, Melbourne, Victoria, Australia

<sup>2</sup>Faculty of Information Technology, Department of Human Centred Computing, Monash University, Melbourne, Victoria, Australia

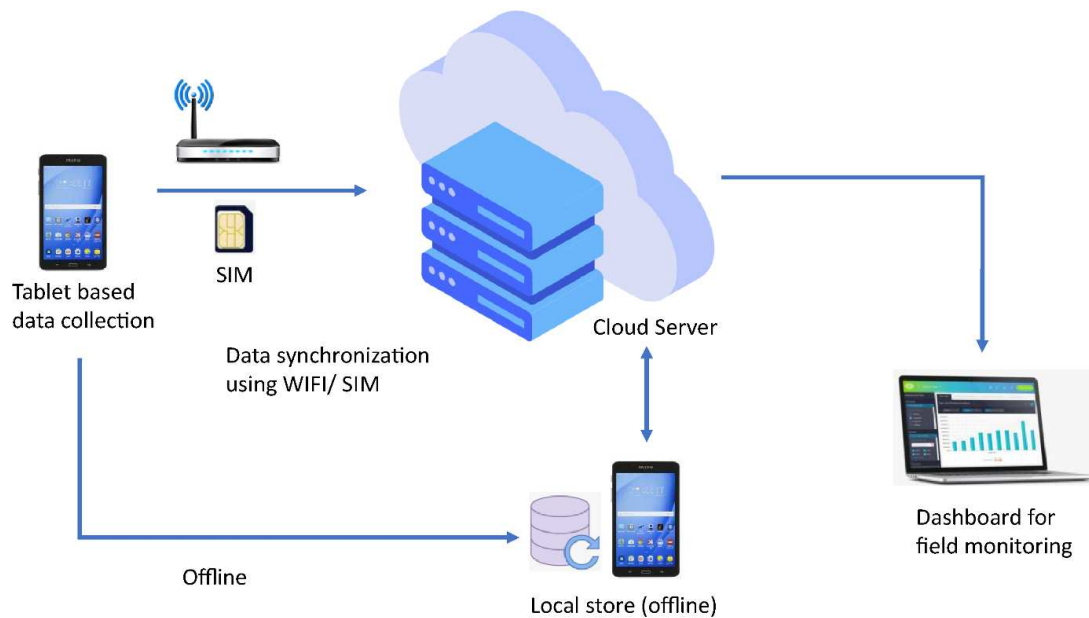
<sup>3</sup>Cardiovascular Disease Program, Biomedicine Discovery Institute and Department of Physiology, Monash University, Melbourne, Victoria, Australia

<sup>4</sup>Pre-clinical Critical Care Unit, Florey Institute for Neuroscience and Mental Health, University of Melbourne, Melbourne, Victoria, Australia

<sup>5</sup>Garhwal Community Development and Welfare Society, Chamba, Tehri Garhwal, Uttarakhand, India

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**Supplementary Figure 1.** Architecture and data flow structure.

Once community health workers are able to complete the various sections of the Arogya Sahyog app, they can upload data to the server with an internet data connection. Until then, data are stored locally in the app and can be accessed even when the device is offline. Once uploaded, data are available for tracking or monitoring using a dashboard and can be downloaded from the server.

**Supplementary Table 1.** Requirements for the Arogya Sahyog app.

Criteria	Specific requirements
• System requirement	Android-based tablet software (Version 4.1 or above) (Google, USA).
• Size of tablet	7 inches (preferred).
• Language	English and Hindi.
• Interface	User-friendly (large icon and colourful display).
• Offline data collection ability	Data are stored locally in the device during the interview when there is unlikely to be internet connectivity. Data collectors can upload data to the server through the internet manually.
• Special feature	Real-time data synchronisation.
• Server requirements	For storing the data, cloud storage in Google Firebase was used. Although the data are initially stored inside the device, whenever the device is connected to the internet the newly generated data can be transferred to the server in order to have a central storage. The server is used to store both the user data and patient data in JSON format. For storing larger data, we have used No-SQL server such as Google Firebase. It can support up to 100 simultaneous connections. This is useful when multiple devices are used to gather data. It also has a storage of 1 GB which is sufficient to store the data necessary for most purposes.
• Validation and built-in checks	Data validation is the process of ensuring that a program maximises the fidelity of data entry. Maximum validation rules were set in the Arogya Sahyog app to prevent errors during data collection.
• Data management (database)	We used the No-SQL database/server (Google Firebase) which is free and allows convenient export of the data to other formats (e.g., MS Excel, STATA) for analysis.
• Data Security	User-specific passwords are required for entering and exploring data.
• Time restrictions	Certain time restrictions are applied in the app to increase the likelihood that users adhere to guidelines. For example, for detecting hypertension, there should be a 7-day period between the first and second set of measurements.
• Contents of the app and clinical algorithm	The contents of the app were designed and a clinical algorithm was developed after consultation with the app development team.
• Network coverage	Best internet network coverage is used among the available internet providers

JSON, JavaScript Object Notation; SQL, Structured Query Language; NoSQL: Not only SQL

**Supplementary Table 2.** Types of various checklists and questionnaires used in the app.

Checklist/ questionnaire	Details
<ul style="list-style-type: none"> <li>Community-based assessment checklist</li> </ul>	<p>This checklist is used by the for the early detection of hypertension and diabetes. A score &gt; 4 indicates that the person may be at risk of developing an event of non-communicable disease (NCD) and should be prioritised for attending the weekly NCD day in the nearest sub-centre for further diagnosis and management [1].</p>
<ul style="list-style-type: none"> <li>Standard clinical/ laboratory assessments</li> </ul>	<p>Standardised clinical and laboratory tests are used to identify people with hypertension and other co-morbidities.</p> <ul style="list-style-type: none"> <li>Hypertension: Systolic blood pressure 140 mmHg or diastolic blood pressure BP<math>\geq</math> 90mmHg or history of taking antihypertensive medication.</li> <li>Diabetes: Random blood glucose (RBG)&gt; 200mg/dl or high glycated heamoglobin (HbA1c <math>\geq</math>6.5%)</li> <li>Pre-diabetes: RBG 140-200mg/dl or HbA1c <math>\geq</math>6.5%</li> <li>Anaemia: Hemoglobin level if &lt;130 g/l for male or &lt;120g/l for female</li> <li>Hyperlipidemia: High total cholesterol (<math>\geq</math>240 mg/dL) or high LDL cholesterol (<math>\geq</math>160 mg/dL) or high triglycerides (<math>\geq</math>200 mg/dL)</li> </ul>
<ul style="list-style-type: none"> <li>Existing validated questionnaire-based assessments</li> </ul>	<p>An existing validated questionnaire is deployed in the app to assess socio-demographic and lifestyle factors, quality of life, utilisation of health services, barriers to diagnosis and management, and knowledge of hypertension, diabetes, and their consequences [2].</p>

**Supplementary Table 3:** Self-rated knowledge of the participants on Information and Communication Technology (ICT) who took part in initial testing and field testing of the app.

Contents	Testing of the initial version of the app (5 dummy participants, Australia)	Field testing of the stable version of the app (4 participants*, India)
I know how to start and close down a computer	✓	✓
I know how to distinguish between basic computer components, such as software applications, hardware and operating systems	✓	✓
I know how to navigate the Internet with a browser	✓	✓
I know how to download and save content (e.g. pdf files)	✓	✓
I know how to use an email management tool (Microsoft Outlook)	✓	✓
I know how to use a word processor (Microsoft Office Word) application	✓	✓
I know how to use spreadsheets (Microsoft Office Excel)	✓	✓
I know how to use a visual and graphical application (Microsoft Office PowerPoint)	✓	✓
I know how to switch on, navigate and switch off a tablet or smartphone	✓	✓
Do you have an email address?	✓	✓

MS, Microsoft; UI, User experiences

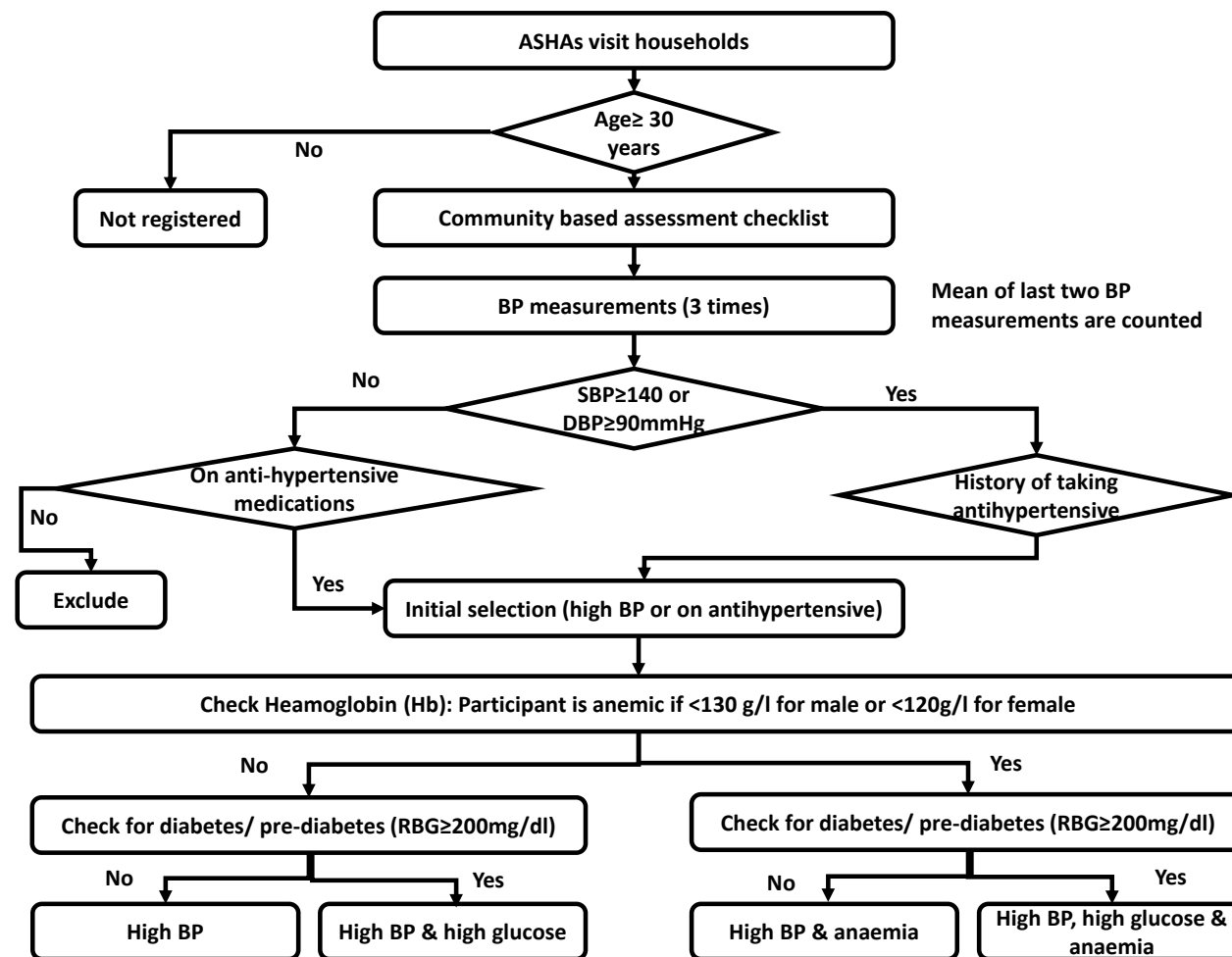
✓ represents 100% here

\*Members of the App Field Testing Team

**Supplementary Table 4.** The various features of the Arogya Sahyog app.

Functions	Details
Reminder	A traffic light system is used for identifying people at risk of NCDs. Red means urgent attention; yellow means at risk (i.e., the value of a test is outside the normal range); and green means the value is within the normal range. This approach was suggested by the ASHAs.
Advisor	Specific age- and sex-specific advice on preventive measures are provided to ASHAs regarding the actions to take for people whose blood pressure or blood glucose level is not controlled. Notification is provided for emergency cases so that urgent referrals can be initiated. This function was included on the suggestion of the ASHAs.
Guide	The ASHAs, who were interviewed, found it difficult to recall the clinical decision based on patient history and laboratory values. They expressed a desire to use the app as an educational platform to provide them with intervention-specific information. For example, in the case of diabetes or dyslipidaemia, management-specific information appears on the tablet to guide the ASHAs in the delivery of health education.
Visual display	ASHAs were particularly interested in having an in-built dashboard in the app so that they can observe all clinical and medical information for an individual patient. In addition, we came to know that clinicians and researchers want a web-based dashboard so that they can track of daily enrolment and progress of ongoing data collection easily. Therefore, both of these functions were included in the app.

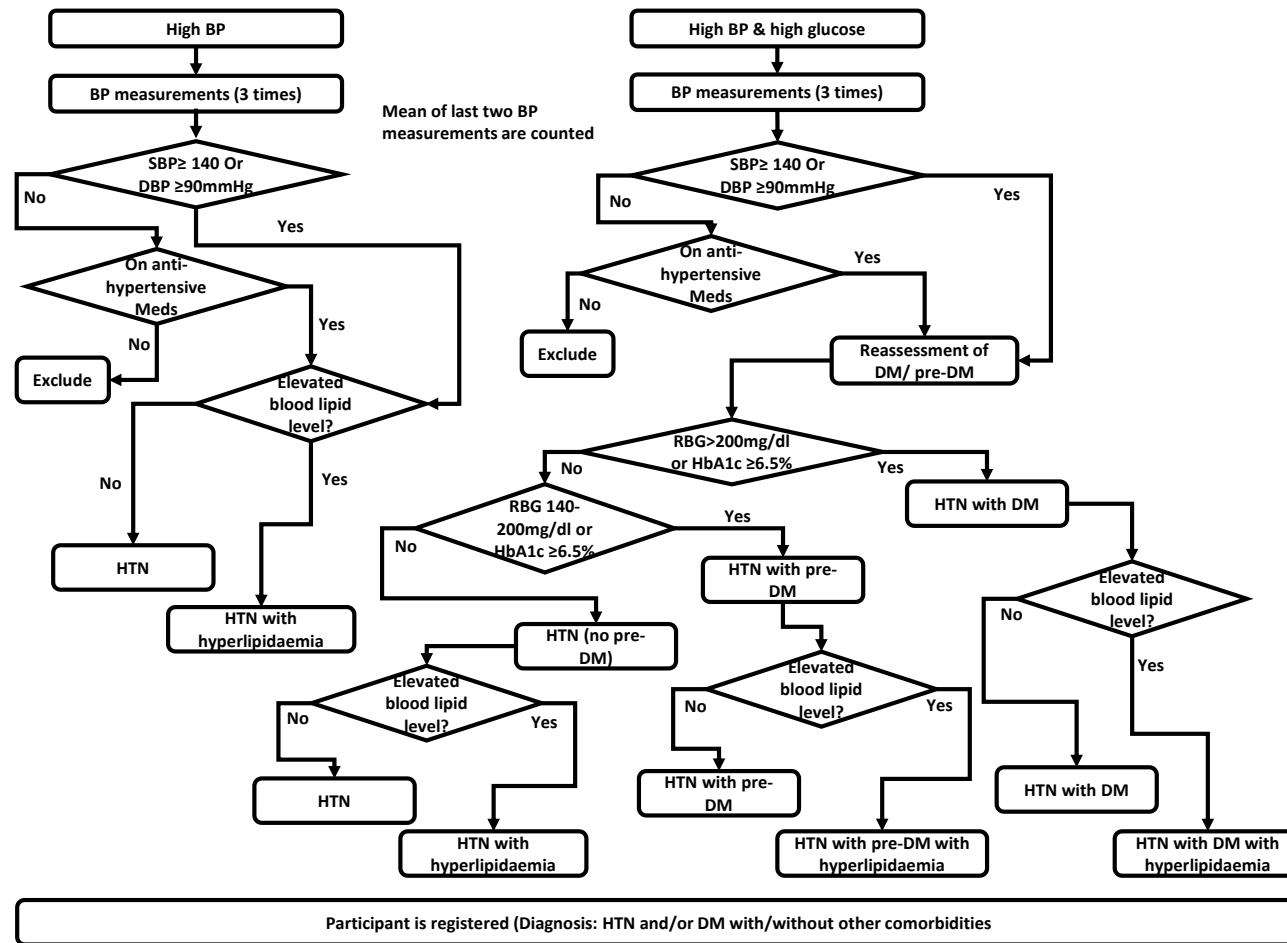
NCD: non-communicable disease; ASHAs: Accredited Social Health Activists  
Arogya Sahyog, is a Hindi phrase for 'health assistant'

**Supplementary Figure 2.** Flow chart and decision tree showing the process of initial selection of patients.



ASHAs, Accredited Social Health Activists; BP, blood pressure; SBP, systolic blood pressure; DBP, diastolic blood pressure; Hb, Haemoglobin; This section includes information that is required for the initial selection of a patient as having hypertension. ASHAs assess blood pressure three times for each patient and the average of last two BP measurements is considered. ASHAs also ask patients about their history of taking antihypertensive medication(s). If patients are detected with either having high blood pressure or taking antihypertensive medications, the ASHAs are advised to also check the patient's blood haemoglobin and glucose levels.

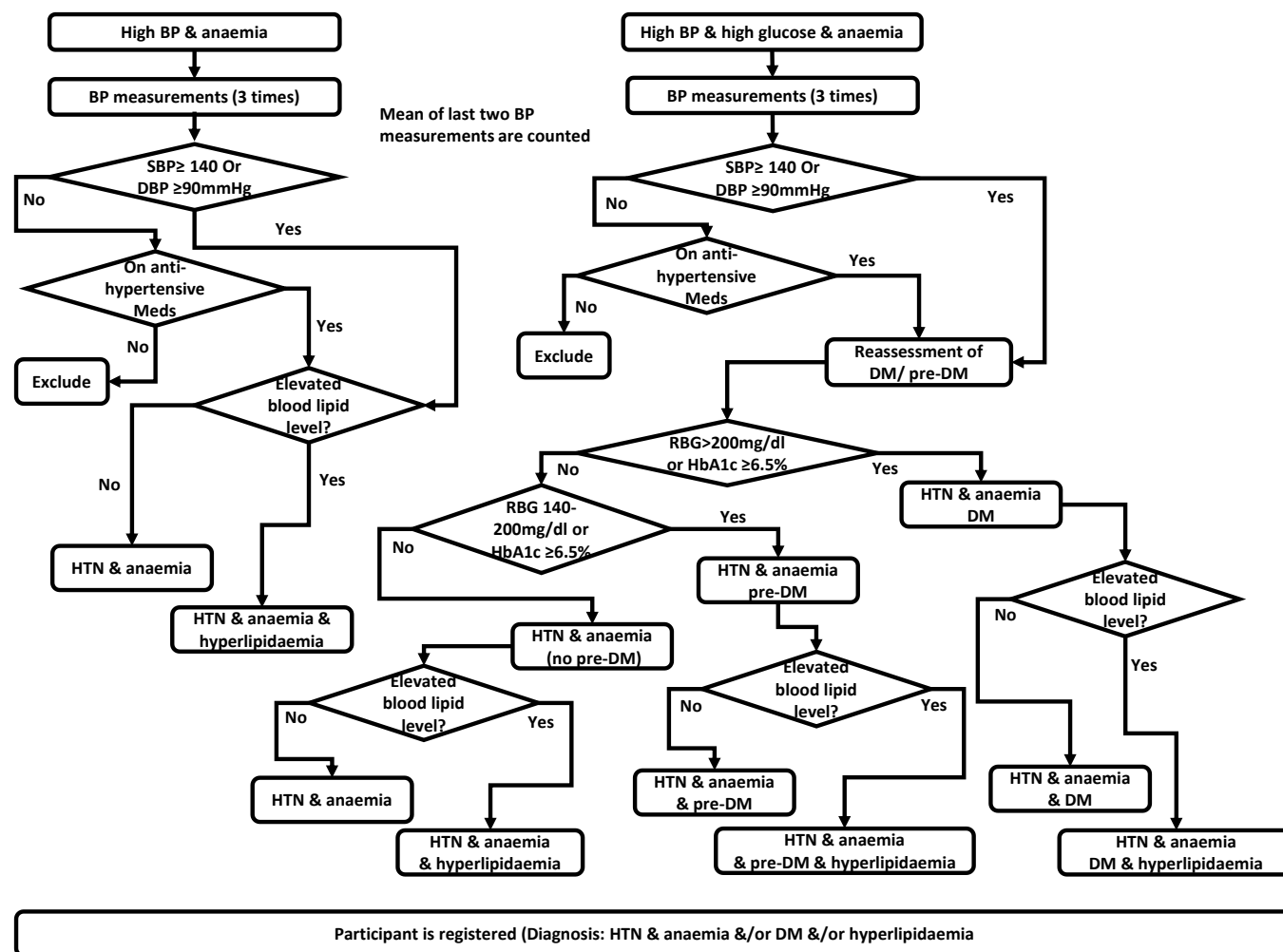
**Supplementary Figure 3a.** Flow chart showing how the system can be used to diagnose people with hypertension and other morbidities.



BP, blood pressure; Meds, medicine; DM, diabetes mellitus; HbA1c, glycated haemoglobin; RBS, random blood glucose; SBP, systolic blood pressure; DBP, diastolic blood pressure; HTN, hypertension

This section is applicable for those who had high BP for the first time that BP was measured. Patients are advised to return after 7-14 days for another check of their BP, to determine whether they are hypertensive. Only patients who are assessed as being hypertensive are assessed for their blood sugar and lipid profile by point of care devices (by ASHAs).

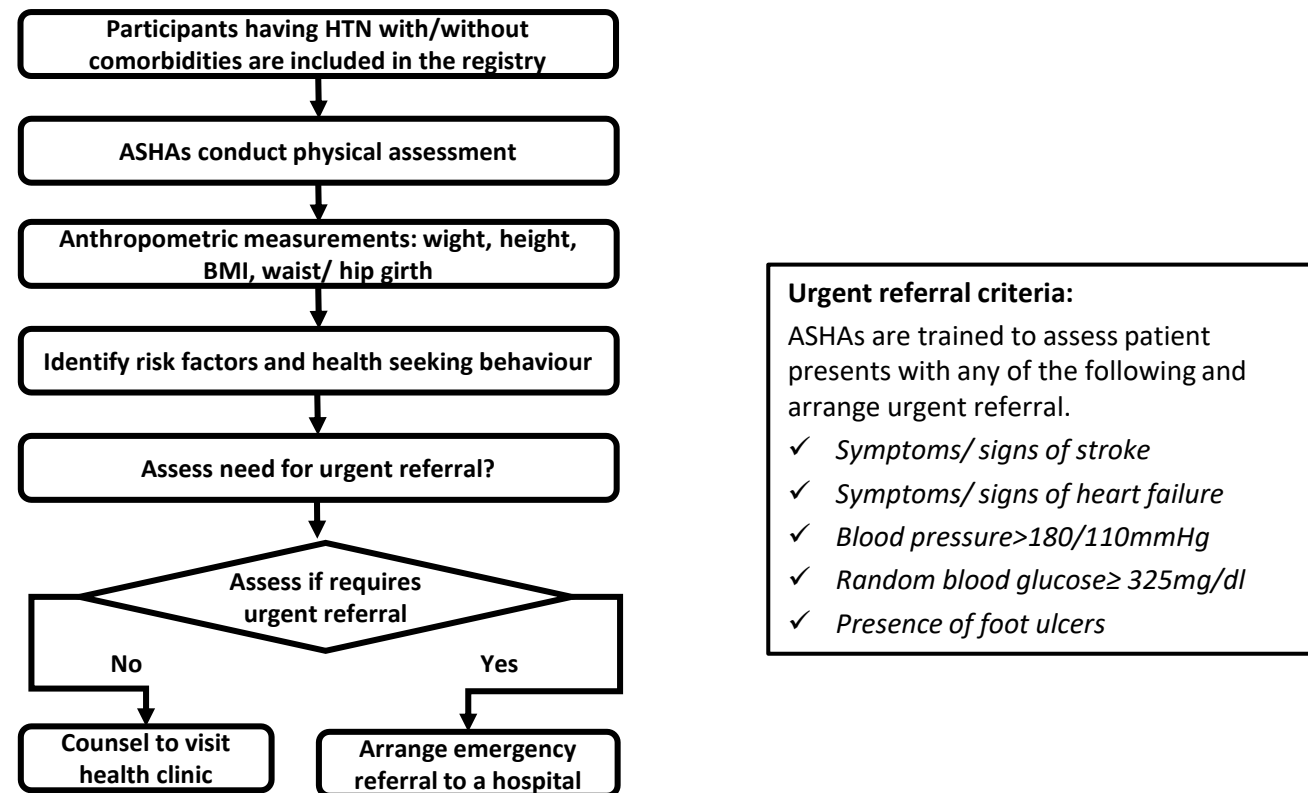
**Supplementary Figure 3b.** Flow chart showing how the system can be used to diagnose hypertension and other morbidities for people presenting with anaemia.



BP, blood pressure; Meds, medicine; DM, diabetes mellitus; HbA1c, glycated haemoglobin; RBS, random blood glucose; SBP, systolic blood pressure; DBP, diastolic blood pressure; HTN, hypertension

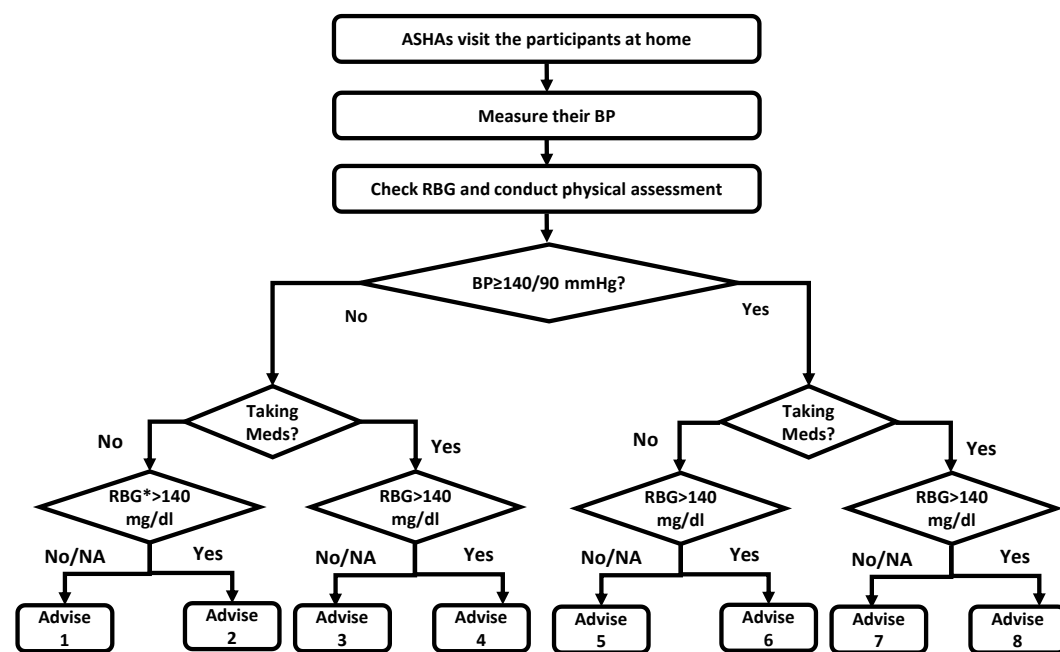
This section is applicable for those who had high BP and anaemia detected for the first time of BP measurement.

**Supplementary Figure 3c.** Flow chart showing how the system can be used to assess whether a patient needs urgent referral to a hospital.



BP, blood pressure; HTN, hypertension; BMI, body mass index;

Only patients who are assessed as being hypertensive are assessed for their anthropometric measurements (by ASHAs). Based on the measurement data, the app guides ASHAs to determine whether a patient is critical and requires urgent referral to a hospital.

**Supplementary Figure 4.** Flow chart showing how advice is displayed based on baseline information.

\*RBG is applicable for hypertensive patient with diabetes or pre-diabetes  
Specific advise appears in the Arogya Sahyog app based on this algorithm

**Advise 1:** Check lifestyle & weight. Motivate to continue or reduce weight if required.

**Advise 2:** Check lifestyle & weight. Motivate to reduce weight & increase physical activities, if required. **Refer to health centre.**

**Advise 3:** Check lifestyle & weight. Motivate to continue Meds as this is helping to control BP, motivate to reduce weight & increase physical activity if required.

**Advise 4:** Check lifestyle & weight. Motivate to continue BP Meds as this is helping to control BP, motivate to reduce weight & increase physical activity if required. **Refer to health centre.**

**Advise 5:** Check lifestyle & weight. **Refer to health centre to check BP & consider taking BP Meds.** Motivate to reduce weight & increase physical activity if required.

**Advise 6:** Check lifestyle & weight. **Refer to health centre to check BP and diabetes.** Suggest they ask doctor about taking Meds to BP & diabetes. Motivate to reduce weight & increase physical activity if required.

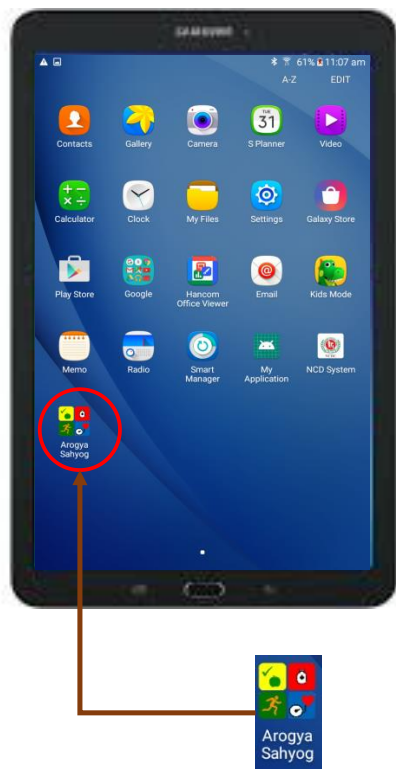
**Advise 7:** Check lifestyle & weight. Motivate to take BP Meds regularly. **Refer to health centre.** Motivate to reduce weight & increase physical activity if required.

**Advise 8:** Check lifestyle & weight. Motivate to take Meds for BP (& diabetes) regularly. **Refer to health centre.** Motivate to reduce weight & increase physical activity if required.

BP, blood pressure; RBG, random blood glucose; MEDS, medication; NA, not applicable;

This section is applicable for patients who are hypertensive. ASHAs visit these patients at their home to check their BP, RBG and adherence to medication. Based on data entered by the ASHAs, the app can display various advice in the screen for ASHAs to use to facilitate actions by the patients.

**Supplementary Figure 5.** Logo of the Arogya Sahyog app shown with the app installed on a device.





Supplementary Figure 6: Screenshots of the Arogya Sahyog app.



Figure 6a

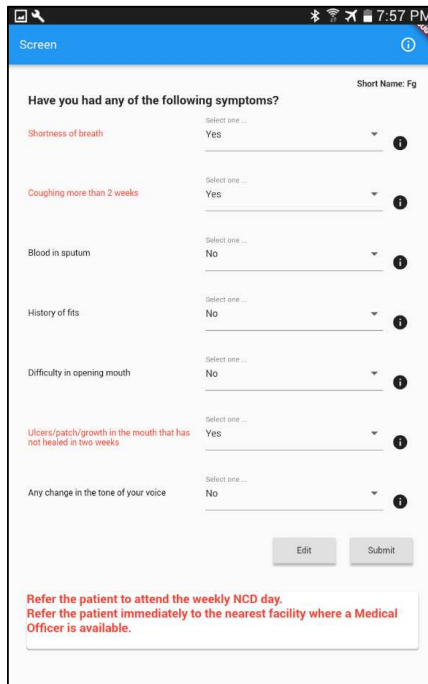


Figure 6b

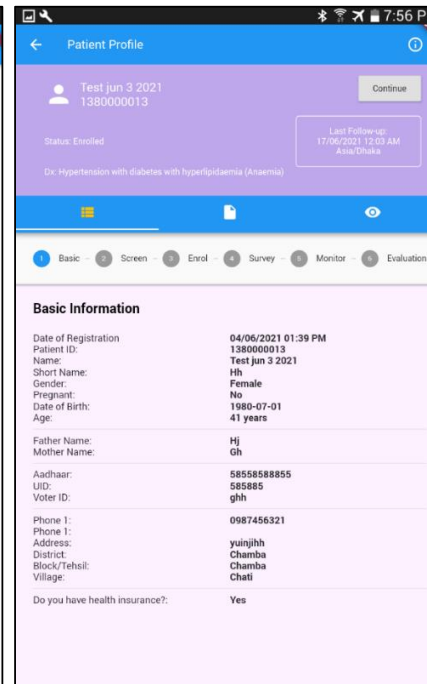


Figure 6c

The figure shows the dashboard (6a), the online version of part of community assessment checklist, along with specific instruction based on standard guidelines (6b) and the profile of an individual patient with various components (basic, screen, enrol, survey, monitor, and evaluation) at 6c. The displayed names in this figure are not from real people.

Basic: This section contains registration information of the patient.

Screen: This section includes information related to the measurement of blood pressure (BP).

Enrol: This section includes details of the measurement of blood pressure for the patient.

Supplementary Figure 7. Screenshot of the web-based Arogya Sahyog dashboard.

Filtering options:

ASHA ID: ASHA ID

Village name: Village name

Date From mm/dd/yyyy To mm/dd/yyyy

Refresh Clear Filters

ID	Asha Name	Asha Phone	Asha Group	Patient ID	Name	Age	Sex	Phone	Block	Village	Screen Date	BP Screen	Initial Selection	Reassessment Date	BP	Enrolled	Diagnosis
116		0	Usual care?	1160000001	test 01	1598-07-01	Female	0159888880	N/A	N/A	2019-07-22	100/140	No	2019-06-22	100/140	No	No
116		0	Usual care?	1160000002	test 02	1598-07-01	Female	0159888880	N/A	N/A	2019-07-22	100/135	No	2019-06-22	120/250	No	No
116		0	Usual care?	1160000003	test 00	1598-07-01	Male	0888888888	N/A	N/A	2019-07-22	120/140	No	2019-06-22	122.5/140	No	No
116		0	Usual care?	1160000004	test 02	1598-07-01	Female	0888888888	N/A	N/A	2019-07-22	120/140	No	2019-06-22	147/156	No	No
116		0	Usual care?	1160000005	test 04	1598-07-01	Female	0888888888	N/A	N/A	2019-07-22	130/141	No	2019-06-22	125/140	No	No
122	surovi	0470490809	Usual care?	1220000001	test01	1598-07-01	Male	0159808888	N/A	N/A	2019-07-23	100/228.5	sBE	2019-08-23	100/159	sHD0	sHD
122	surovi	0470490809	Usual care?	1220000002	dbdhehe	1985-07-01	Male	0159888888	N/A	N/A	2019-07-23	100/279.5	sBE	2019-08-23	100/279.5	No	No
122	surovi	0470490809	Usual care?	1220000003	giggh	1598-07-01	Male	0159880000	N/A	N/A	N/A	N/A	No	N/A	N/A	No	No
122	surovi	0470490809	Usual care?	1220000004	yh	1598-07-01	Male	0255555555	N/A	N/A	2019-07-24	100/159	sCE	2019-08-24	100/159	No	sHHA
122	surovi	0470490809	Usual care?	1220000005	fhg	1598-07-01	Male	0222222228	Jakhidhar	Chopadyali	N/A	N/A	No	N/A	N/A	No	No
122	surovi	0470490809	Usual care?	1220000006	ge	1598-07-01	Female	0111111111	Bhlangana	Bada syuta	2019-07-25	124.5/150	sOE	2019-08-25	145.5/154	sHD0	sHDHA
122	surovi	0470490809	Usual care?	1220000007	ts	1598-07-01	Female	0129888888	N/A	Chopadyali	N/A	N/A	No	N/A	N/A	No	No
122	surovi	0470490809	Usual care?	1220000008	oaz	1598-07-01	Female	0159800000	N/A	Bueggi	N/A	N/A	No	N/A	N/A	No	No
122	surovi	0470490809	Usual care?	1220000009	rgh	1598-07-01	Female	0155555558	N/A	Chopadyali	N/A	N/A	No	N/A	N/A	No	No
122	surovi	0470490809	Usual care?	1220000010	test000	1598-07-01	Female	0129800000	N/A	Chopadyali	2019-08-2	120/147	sOE	2019-07-2	120/148	sHD0	sHDA

This screenshot shows overall structure and components of the dashboard. The displayed names and all information in this figure are not from real people.

**Supplementary Table 5.** Percent of reported error by the research team members

Name	Error (%) in Case study 1	Error (%) in Case study 2	Error (%) in Case study 3	Error (%) in Case study 4	Average (%) errors
Participant A	0.5	0.1	0.0	0.7	0.3
Participant B	0.3	0.2	0.1	0.1	0.2
Participant C	0.0	0.0	0.0	0.0	0.0
Participant D	0.2	0.1	0.2	0.4	0.1

A, B, C, D are anonymous participants.

There are 176 entries in case study 1

There are 151 entries in case study 2

There are 163 entries in case study 3

There are 144 entries in case study 4

Data were entered using the app, downloaded from the server, and matched with the 'hard copies' of set-answers for four case studies. Then, we calculated the average error rates matching the uploaded data in the server with the original data in hard copy.

**Supplementary Table 6:** Cost analysis for development of the Arogya Sahyog app.

Stage 1: We assessed the breakdown of cost for the Arogya Sahyog app by development stages. The total app cost depended on several elements. First, during the developmental stages, we considered the estimated amount of time taken to conduct the activities required for development of the app. Second, we assessed the percentage of the budget spent for each developmental stage.

Development stages	Activities/ elements to be considered	Costing
App development (app strategy) planning	<ul style="list-style-type: none"> <li>Identifying requirements</li> <li>Choosing app features &amp; structure (wireframing)</li> <li>Choosing the appropriate set of technologies (e.g., programming languages, platforms, a database, front-end tools, and back-end tools for app development)</li> <li>Work plan</li> <li>Budget</li> </ul>	Time required: ~35 hours (10% of total budget)
User experience design (UX) design	<ul style="list-style-type: none"> <li>Establish behaviours, needs and motivations of the users</li> <li>Establish how users think and design information in a logical way (information architecture)</li> <li>App navigation</li> <li>Wireframing</li> </ul>	Time required: ~40 hours (11.4% of total budget)
User Interface (UI) design	<ul style="list-style-type: none"> <li>Brand styles - logos, icons, colours</li> <li>App interface - visuals, content</li> <li>Rendered design for the app</li> <li>Final design/ prototype</li> <li>Selection of application programming interfaces (APIs)</li> </ul>	Time required: ~50 hours (14.3% of total budget)
Developing simple app user features	<ul style="list-style-type: none"> <li>Login</li> <li>User profile (make &amp; edit)</li> <li>File uploading</li> <li>Dashboard</li> <li>Search options (basic and advanced)</li> <li>Native device features</li> <li>Customisation</li> <li>Sync across all devices</li> <li>Multi-language support</li> </ul>	Time required: ~70 hours (20% of total budget)
Developing simple administration features	<ul style="list-style-type: none"> <li>Content management system</li> <li>User management</li> <li>Feedback system</li> <li>Push notifications</li> <li>Reminder system</li> <li>Data collection &amp; analytics</li> </ul>	Time required: ~40 hours (11.5% of total budget)
Developing system/ app infrastructure	<ul style="list-style-type: none"> <li>Database/ server setup</li> <li>Data storage solutions</li> <li>API integrations</li> <li>Data encryption &amp; app security</li> </ul>	Time required: ~80 hours (23.0% of total budget)

App testing	<ul style="list-style-type: none"> <li>• Quality assurance</li> <li>• User experience testing</li> <li>• Device and platform testing</li> <li>• Performance testing</li> <li>• Security testing</li> </ul>	Time required: ~30 hours (8.6% of total budget)
App deployment and publishing	<ul style="list-style-type: none"> <li>• Upload app to a repository</li> <li>• Configure the server</li> </ul>	Time required: ~5 hours (1.4% of total budget)
Total cost: ~350 hours x AUD 60 = ~AUD 21,000		

The content of this table was adapted from the GoodFirms website [3].

Stage 2: In addition to the cost of development of the app, we incurred costs associated with the purchase equipment, as well as storage maintenance of the app. We also estimated the cost of developing a simple dashboard web application. However, we did not include the procurement, dashboard web development, and maintenance costs in the analysis of the design and development phase of the app. These are presented below.

Line items	Costing
Equipment, storage and app maintenance cost (continuous bug fixing; app stability; code optimisation; emergency maintenance; and updating the app for the latest OS versions).	A total of four android tablet devices were procured to test the app. For storing the data, cloud storage in Google Firebase was used. This provided storage of 1 GB without cost. There are also yearly expenditure items related to app maintenance and support. This would be ~10% of the development cost per year for this app.
Cost of developing a simple dashboard web application.	In addition to the app cost, it also took about 40 hours of investment to develop a simple dashboard web application (AUD ~2400). We paid the Apple Developer Program annual fee (AUD ~130). As these two are optional, we did not add them to the app development cost.

## References

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